Bartlett school of graduate studies

Renewable Energy for Sustainable Communities:

Case Study Dongtan, China

by

Jue Chen

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CONTENTS

Jue Chen **MSc EDE**

Abstract

This paper concentrates on the study of Dongtan Eco-city in Shanghai, aiming to put forward improvement suggestions about the renewable electricity application system.

The study includes the calculation of the total energy consumption from the buildings, and the amount of energy generated from potential renewable energy technologies that might be applied in the near future.

For the calculation of the total energy consumption, the assumption of a typical 3-storey attached dwelling with the total area of 102 m^2 is made. TAS simulation software is applied to estimate the heating and cooling load of the dwelling. All of the 27,000 dwellings in the city have the total load of 4560.7 MWh/year. Based on the monitoring results of BedZED project, the total energy demand in all types of buildings of 236 GWh is figured out.

Generally, it is suggested that renewable energy contributes to generating 291 GWh based on the proposed design. The total area of 1,452,600 m^2 thin-film BIPV using new technology with high efficiency of 20% creates solar energy of 70,995 MWh, covering 30.1% of the energy demand; the twenty-four 1.5 MW wind turbines produce wind energy of 36,792 MWh which offsets **14.5% of the demand and a biomass–CHP** plant with the peak load of 30 MW heat energy and 8 MW electricity generate heat energy of 147,000 MWh and the electricity of 39,200 MWh, covering 55.4% of the demand in total, and meanwhile selling the remaining 55,500 MWh of energy to the national grid, providing the benefits of £3,330,000.

Carbon Savings is one of the benefits from using renewable energy. Solar energy, wind energy and biomass energy contributes to reducing 32,658 tCO_2, 17,007 tCO_2, and 62,132 tCO_2 per year respectively.

1. Introduction

1.1 Climate Change and the Change of Ecosystems

In March 2005, the report named "Millennium Ecosystem Assessment, Ecosystems and Human Well-being: Opportunities and Challenges for Business and Industry" was released by the United Nations Environment Program, which claimed that two thirds of ecosystems in the world now are severely damaged.(UNEP, 2005) It was stated that:

"In the last 50 years humans have changed ecosystems more rapidly and extensively than in any comparable time in human history, largely to meet rapidly growing demands for food, fresh water, timber, fibre and fuel. This has resulted in a substantial and irreversible loss in the diversity of life on Earth."

According to IPCC (2007), the green house gas emissions in the last 100 years contribute to a significant increase in global temperature. Global warming, the higher sea levels, and the glacier melting are all due to the emissions of green house gases, which is the consequence of the increasing use of fossil fuels. (Haughton G. 2003) Obviously, the energy use in the daily life contributes a lot to the total carbon dioxide emissions, such as the heating of the house, the traffic, and the other aspects of the life.

In order to reduce the carbon emissions during the daily life, living in a sustainable way is important to everyone, including living with a healthy lifestyle and the construction of sustainable community. Nowadays, countries all over the world have explored the way how people could live harmoniously with the earth and how to make the best benefit from the earth.

1.2 Sustainable Development and Sustainable Community

According to Smith (2005), sustainable development will not be implemented successfully without focusing on sustainable urban development. Global urban growth is changing the conditions of humanity and the face of the earth. Half of the world's people now live in cities, with most of the other half depending on them for their economic survival. Fossil fuel technology has been powering modern urbanization. But according to Smith(2005), 40% of **the world's people live within 40 miles of** the sea, and in the coming decades, if current practices are maintained, many cities will be threatened by the rising tides of climate change.

According to Peter Hall (Zhao, 2005), modern cities are not only the largest structures we have made, but they also **use the bulk of the world's resources. On just 2% of the world's land surface**, and with half its population, cities consume over 75% of its resources of which the key resource, fossil fuels, and non-renewable energy. A huge demand for energy defines modern cities more than any other factors for operating their internal and external transportation systems, and for operating their buildings most of which could not function without air conditioning and without lifts ceaselessly going up and down.

What is a sustainable community? **According to the book of "sustainable cities", the definition of it** could be found: (Haughton G. 2003)

A sustainable city is one in which its people and businesses continuously endeavor to improve their natural, built and cultural environments at neighborhood and regional levels, whilst working in ways which always support the goal of global sustainable development.

Within a sustainable community, natural systems could be integrated well with the cities and facilities. According to the Herbert (2005), the communities have to use the re-using resources efficiently and eliminating waste not compatible with natural systems, which means that there will be no waste in the community. Every output by an ecosystem contributes to the continuous renewal of the whole living environment. However, because the community is not a true ecosystem, a certain part of the raw materials put into the city system will end up with waste, which would be the pollution into the environment such as the sewage into rivers and solid waste in the landfill which is hardly decomposed. To create a sustainable community, the city system should be similar to ecosystems, which means that the raw materials could be either renewable or recyclable. In addition, as a matter of great urgency, the waste emissions to the nature should be reduced as much as possible, without destroying the comfortable life of the city residents. The emission of carbon dioxide should be given priority over other matters due to the climate change issues.

1.3 Research Aim and Structure

In order to develop a sustainable community, renewable technologies and the whole efficient city system help to contribute a lot towards the healthy living environment and creative life style. The application of renewable energy is another key point to show substantial economic and environmental benefits, which helps to reduce the burning of fossil fuels, so as to control the carbon emissions. There are several forms of renewable energy that could be utilized by humans, such as solar, wind, biomass and recyclable waste. However, due to the technology limitation and the economic reason, renewable energy has not been applied in the society as the primary fuel in most of the cities all over the world.

In addition to the application of renewable energy, the rebuilt of urban production and consumption systems make the city operate efficiently. As far as it is concerned, the recycling and remanufacturing of the waste materials are worth being considered. For instant, the organic materials should be composted, by which they are returned from the "city system" to natural system, which is know as "biomass". Especially, the plant nutrients which are returned back into the farmland contribute to the maintaining of the high carbon content in the soil. On the other hand, the recycling system within the community is taken into consideration, including the collection of the used products which could be reproduced. (Birkeland J, 2002)

In this matter, developed countries lead the steps towards the sustainable communities, especially the European countries. However, some developing countries are more and more aware of the energy issues, such as China. Several projects are under construction now, and an impressive project has been used for the Beijing Olympic Games. In Shanghai, Dongtan Eco-City is a hugely important project which will demonstrate that it is possible to create a form of urban development that is environmentally sustainable while also offering a solid economic base for its inhabitants.

Governments nowadays are full of enthusiasm about sustainable cities. Many countries are seeking for the efficient ways to make the city more environmental friendly. Meanwhile, the reduction of energy consumption is another critical issue for the government. Therefore, Dongtan Eco-city has a target with "zero carbon" emission in 2050, and with all of the buildings use renewable energy in 2020.

As to the design and operation of the eco-city, almost every single aspect in our daily life should be taken into account. The factors are related to each other, such as the waste combustion and ordinary landfill make contribution to the air pollution. As a result, the aim of this research is to study the different aspects towards the "zero carbon" and "zero waste" targets. Basically, the study of Dongtan Eno-city initial plan will be implemented after exploring the case studies of other successful projects and related literature review.

Based on the initial design of the Dongtan Eco-city and the targets set by Shanghai Government, the calculations of energy consumption make it possible to estimate the whole city consumption, by which the energy saving capacity would be clearer. A dynamic building simulation software TAS model of a typical dwelling utilizing different sustainable strategies in Dongtan is simulated under the Shanghai weather condition. (EDSL) Based on the heating and cooling load of the dwelling, further attempt of utilizing different renewable energy will be made, in order to offset the energy consumption in buildings. Building Integrated PV systems, wind farms, biomass and CHP plants, as well as waste management systems will be carefully examined. Furthermore, the report will focus on the study of the carbon savings of different strategies, with consideration about the efficiency and economic parts. The comparison together with some suggestions will be put forward.

Besides, the factors that would be highly related to the energy producing process, such as efficiency, the pollution problems and the lifecycle analysis will be discussed. Other aspects in terms of the daily life such as water recycling and the energy efficient lights will be focused in the sensitivity study. Conclusion will be drawn to summarize the whole report and highlight the key findings and problems existed in the research.

1.4 Research Questions

The main research questions and other concerns about the application of renewable energy in Dongtan Eco-city are listed as follows:

1.4.1 Main Question

How much energy could be drawn from the renewable source, such as solar, wind, biomass and waste? How much contribution the each form could make to the reduction of carbon dioxide?

1.4.2 Subsidiary Questions

1) How much energy consumed in well-designed sustainable dwelling?

What is the percentage of heating load and cooling load in such a dwelling?

How to integrate a dwelling in a community?

How much renewable energy can be applied in the dwelling?

2) How to integrate the renewable energy technology with a dwelling?

How much is the cost of installing a PV system in a dwelling?

Whether or not can wind energy be used?

3) What factors will limit the use of renewable energy?

What factors will influence the efficiency of wind electricity producing process?

What factors will influence the biomass and CHP plant?

Why district energy system is suitable in Dongtan?

What factors will influence the heat efficiency in the district energy system?

4) What other aspects will lead to the reduction of energy consumption in a district?

2. Background Information and Case studies

2.1 Related Policies

There are several policies related to the sustainable living in the world.

2.1.1. One planet living strategy

As a global initiative, One Plant Living is developed to encourage the countries in the whole world, especially the developed countries, to find solutions of reducing their ecological footprint. Globally, the resources are consumed at a faster rate than the replenishing rate of our planet. It is estimated that if everyone in the world consumed as much of the natural resources as the average citizens in each typical countries such as UK, the USA, and China, the increased number of the planets would be needed to survive the people. (One Planet Living Report ,2008)

In order to measure the natural resource consumption rate, Ecological Footprint has been put forward to relate it to the planet biological capacity, which includes the ability to replenish resources and to absorb greenhouse gases such as carbon dioxide. Ecological footprinting is a rapidly emerging methodology which is measured by comparing the planet biological capacity to the consumption of each country in the world, which is the World Ecological Footprint. (WWF, 2006)

As can be seen in Figure 2.1, (WWF, 2004), after 1985, the World ecological footprint started to exceed the available capacity, which means that the natural source in the planet could not afford the current living style. Within different regions in the whole world, the ecological footprints differ from the economical and social developing levels.

According to the same report, Figure 2.2 shows that the ecological footprint is influenced by the energy consumption ability within each region, but not by the population. There is a tendency that the people having high income cost more ecological footprint than those having low income. This is in part because the energy consumption by humans is limited primarily by consumer's ability to pay.

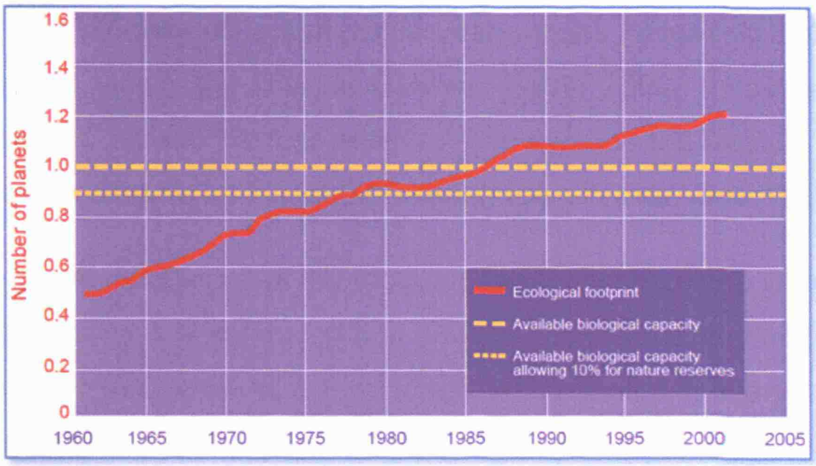


Figure 2.1 The trend of the number of planets needed (WWF, 2004)

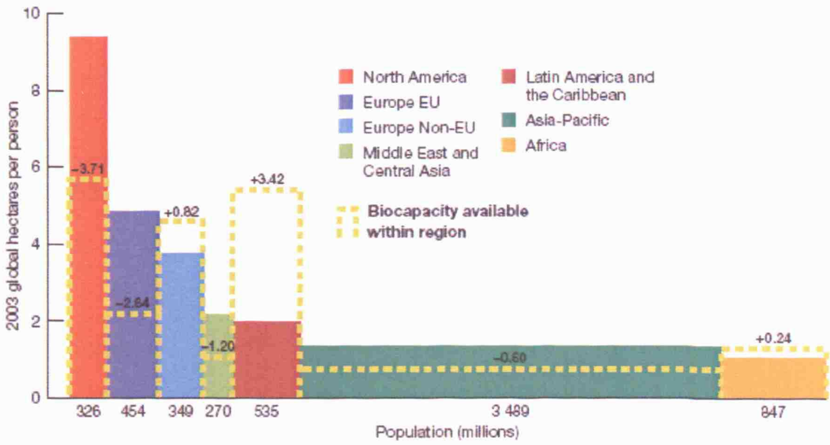


Figure 2.2 Ecological Footprint and Biocapacity by region (WWF, 2006)

Various ecological footprint studies for the UK have been carried out. Part of the ecological footprint is attributable to carbon dioxide. Pulling together data from various sources, the average person in the UK has a carbon footprint in the region of 12 tonnes of carbon dioxide per annum. According to the report of One Planet Living in the Thames Gateway (WWF 2006), it has been estimated where carbon impacts arise from an average UK lifestyle for a person living in a home built to 2002 Building Regulations. (see Table 2.1)

According to the calculation of the footprint and the comparison with the ecological capacity, it is estimated that several planets are needed to support the residents on the earth. As is now widely being quoted, if everyone on Earth consumed as much as the average person in the UK, three planets would be needed to support. As far as it is concerned, a world-wide network of One Planet Living Communities and other exemplary projects are being built. (One Planet Living London Project, 2008)

Table 2.1 Carbon impacts of average person in the UK

Category	UK Average % of total CO2 impact
Space heating in the home	4%
Hot Water	4%
Appliances in the home	3%
Personal transport	18%
Embodied energy in home infrastructure	3%
Waste and consumer items	13%
Food	23%

Category	UK Average % of total CO_2 impact
Shared services (total energy for running schools, hospitals, financial services .etc)	12%
Shared infrastructure (embodied energy in constructing schools, hospitals, roads, airports .etc)	20%
Total	100%

One planet living is based on ten principles of sustainability as shown in Figure 2.3. Every aspect represents a significant part in our life. Every aspect is important to the energy consumption in the whole society, which should be focused on in order to minimize the waste and the energy. They are suitable to all countries, either developed or developing.

Figure 2.3 Ten Principles of One Planet Living

(One Planet Living London Project, 2008)

2.1.2 The Code for Sustainable Homes – the environmental assessments of new dwellings

Building is a significant part in the community and the city. The successfully sustainable design of the buildings is a key issue to fulfill the goal for the eco-city. According to the introduction of *The Code for Sustainable Home*, (CSH, 2007), in April 2007 the Code for Sustainable Homes replaced Ecohomes for the assessment of new housing in England. The Code is an environmental assessment method for new homes based upon BRE's Ecohomes, which aims to protect the environment by providing guidance on the construction of high performance homes built with sustainability in mind.(CSH,2007)

The Code for sustainable homes covers nine categories of sustainable design, for which performance measures reducing impacts can be objectively assessed, evaluated and delivered in a practical and cost effective way by the construction industry, including:

- Energy and CO2 Emissions
- Water
- Materials
- Surface Water Run-off
- Waste
- Pollution
- Heath and Wellbeing
- Management
- Ecology.

For every category, credits are used to demonstrate the performance of the sustainability of the buildings. There are six levels of the improvements, among which the Level 6 is set as “Zero Carbon” requirement.(see Table 2.2)

Table 2.2 Level 6 for improvement of the building performance (CSH,2007)

Issue ID	Description	Credits	Aim
Wat 1	Indoor water use	5	To reduce the consumption of potable water in the home from all sources
Wat 2	External Water use	1	Encourage the recycling of rainwater

It could be concluded that in order to reduce the energy consumption, the recycling use of the waste, including the water resource is an important aspect in the whole building.

2.2 Literature Review

In order to successfully build a sustainable community, the application of renewable energy and the use of energy-efficient building services are both important. In the whole world, there are some successful sustainable communities and some are under construction. Furthermore, for different strategies, the effects of the applications are different.

2.2.1 District Heating System

According to Mark (Mark F., 2008), in order to reach the highest possible levels of energy-efficiency, the revolution and increasing application of renewable energy technology are needed to make the “future-proofing” of our urban energy systems come true. The sustainable cities of the future will need to be powered by wind, solar and biomass energy. Already 20% of the electricity supply to some major European cities, such as Copenhagen, is from wind power.

Based on Poul's paper, (Alberg,2006) Denmark has the world's highest penetration of grid connected wind power in electricity generation with a share of 15.0% of total domestic demand in 2002. In London, it is stated that the "London Array" built in the Thames estuary, which will include up to 270 wind turbines, will help supply 25% of the domestic electricity demand of 7.5 million Londoners. Besides, the integration of wind power and other forms of energy could combine together to result in higher fuel-efficiency.

The other form of distributed generation in Denmark is the extensive cogeneration of heat and power(CHP) plants for district heating. The possibilities for integrating more wind power into the electricity grid by using new power balancing strategies that exploit the possibilities given by the existence of CHP plants as well as the potential impact of heat pumps used for district heating and installed for integration purposes are analyzed in Poul's paper.(Alberg. 2006) Two approaches to power balancing are described in the Figure 2.4.

According to the research by Çomakli (Çomakli,2004), more thick the pipe is, the more heat loss will create. Heat loss due to the network is about 8.62% of the energy provided by heating plant. However, increasing the thickness of 20cm will reduce the heat loss by 25% instead of 8 cm in pipes.

Table 2. Heat and exergy losses of pipes (k_e=1 W/mK, k_c=2.5 W/mK, k_i=0.065 W/mK (150 °C), hc=1.2 m)

Pipe diameter (mm)	Pipe length (m)	Heat loss (kJ) × 10^9	Exergy loss (kJ) × 10^9
250	3227	11.032	3.067
200	1870	5.825	1.619
150	984	2.701	0.751
125	2759	7.008	1.948
100	1495	3.457	0.961
80	1393	3.092	0.859
65	260	0.528	0.147
Total		33.643	9.352

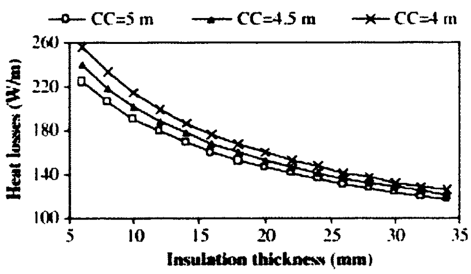


Figure 2.4 Heat and exergy losses of pipes

In addition, the increase of water temperature will cause more heat loss. It is suggested that the heat losses could be kept at a minimum by lowering the supply temperature and meanwhile increasing the insulation in pipes.

However, due to the comfort issue of customers, the supply and return water should be within a reasonable range.

2.2.2 Wind Energy Application

According to the location of on-site wind turbines, there are different kinds of them. The one is roof mounted, and the other is mast mounted.(Ettoumi F., 2008) Larger systems in the region of 2.5 kW to 6 kW would cost between £11,000 and £19,000 to install.

Turbines can have a life of up to 22.5 years but require service checks every few years to ensure they work efficiently. For battery storage systems, typical battery life is around 6-10 years, depending on the type, so batteries may have to be replaced at some point in the system's life.

According to the study by the British Wind Energy Association (BWEA), it is issued that onshore wind in the UK already generates electricity at prices competitive with new conventional generation technologies, including nuclear, while offshore wind, initially more expensive, is starting to fall, with the general consensus that prices will reduce dramatically by 2020. (BWEA,2006)

The BWEA also showed that current prices for onshore wind of 3.1 p/kWh would drop to 2.7p/kWh by 2010. The same research also found that current costs for offshore wind are 5.5p/kWh, predicted to fall to 4.4p/kWh by 2010 and further falling to 3.7p/kWh by 2020.

2.2.3 Solar Energy Application

Besides from wind energy, solar energy is also a renewable energy which is widely used nowadays in many countries. Many countries all over the world are dedicated to encourage the PV market growth.

Government support programs in Japan, Europe and China now give households and companies substantial financial incentives to install PV cells on their buildings. (Zahedi A. ,2005)

Solar electricity is still much more expensive than conventional electricity, but its cost is now coming down rapidly. It was forecasted by European Commission that by 2030, PV generation costs will be low enough to compete with conventional electricity market and other renewable ways, approximately down to 0.05-0.12 €/kWh.(European Commission, 2005) In 2030, the yearly generation and maintenance cost of PV systems will occupy 0.5-1% of the investment costs. Grid-connected PV electricity which will gain a competitive advantage over conventional retail electricity, will be used in large parts of Europe by 2015. As can be seen in Figure 2.4, currently the generation costs of PV electricity from grid-connected systems are in the range of 0.25-0.65 €/kWh in Europe, depending on local solar irradiation. By 2010-2015 these will have been halved, while in 2030 generation costs will be in the 0.05-0.12 €/kWh range.

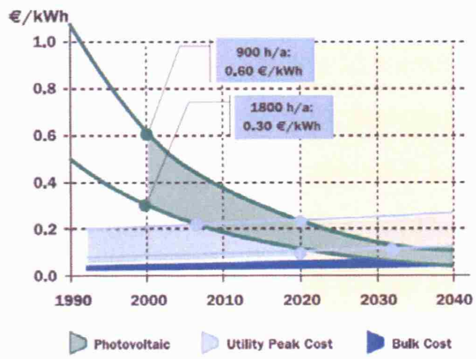


Figure 2.4 Generation costs of PV electricity

According to Figure 2.5, among all ways of generating electricity, PV technology is predicted as one of the most popular ways by 2040.

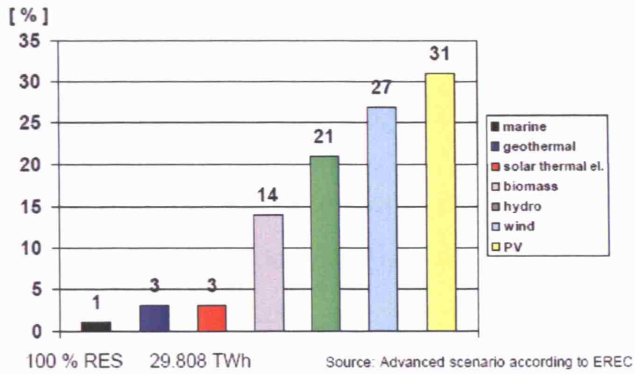


Figure 2.5 The contribution of different ways to the electricity (European Commision, 2006)

Fuel cell technology is another important component of the future sustainable city, converting hydrogen straight into electricity without combustion, using an electro-chemical process. Fuel cell-powered buses, trucks, cars and boats are expected to be mass-produced within a decade or so. One important advantage they have for cities is the tendency to minimize CO_2 emission because fossil fuels are not needed. Fuel cells are also power buildings or whole urban districts. In various cities in Europe and America, fuel cell power stations make highly efficient use of natural gas, methanol or pure hydrogen. to generate electricity for the whole area. Due to the advantages, they must have a bright future(Gustavo O., 2007)

2.2.4 Biomass

Other than solar and wind energy, the other form of renewable energy which is biomass has also been utilized for a long time. In China, biomass has been used for a quite long time, especially in rural area. The traditional way of combusting biomass has the heat efficiency of only 10%.(Pengmei,2008)

Nowadays, new technologies in biomass converting systems help increase the heat efficiency and hence produce electricity or use for heating. Particularly, biomass is introduced into combined heat and power systems (CHP). Through the direct combustion in boilers, the energy in biomass is converted into power by steam turbines.

In the system, the gas extraction technologies make contribution to the higher conversion efficiency. The heat generated from the gas engine can be reused by the steam turbines, to produce the gas which can be directly combusted.

There are mainly three gas extraction technologies. The first one is low energy fuel producing air blown process, the power produced by which is between 3.5 and 7 MJ/m^3. The second one is oxygen-rich air gasification process, the power produced by which is from 7 MJ/m^3 to 15 MJ/m^3. The last one is medium energy fuel producing heat transforming process, offering the power from 15 MJ/m^3 to 25 MJ/m^3.

The energy produced from the biomass and CHP systems is not only affected by the gas extraction technologies, but also related to the density of biomass. According to the study by Bakos (2008), the biomass in Crete has the possibility of producing the total electricity power of 630 MW, with the density of biomass about 4.5 t/km^2 per year. The installation of 63 CHP plants with a unit power of 10 MW each is suggested. It also indicates in the paper that the area with high agricultural density is suitable for large power plants with 50MW installed power capacity, while in the area with lower biomass density, smaller CHP power plant with the installed power capacity from 1 to 2 MW.

According to Chinese Agriculture Yearbook(2004), the three main biomass residue resources are rice, corn and wheat. The quantity of main agricultural product yields in China in 2003 is listed in the Table 2.3. It reveals that rice has the largest production value, especially in the Yangzi River district.

Table 2.3 The quantity of main agricultural product yields in China

	Product (10^4t)	Residue Source
Rice	16065.5	Straw
Wheat	8648.8	Straw
Corn	11583.0	Stalks

The cost of the biomass CHP system is necessary to calculate. Table 2.4 shows the general cost of the biomass CHP system (Pengmei, 2008). It indicated that the cost of the system is higher compared to the wind turbines and PVs. However, according to Pengmei, the investment cost of the CHP system is £262.8 / KW, which is half of the value of the steam turbine system.

According to the research by Talanta (2008), the gas extractor with a pressurized air-free process which produces approximately between 16.7 MJ/m^3 and 18.6 MJ/m^3 has a high converting efficiency and heating value, which allows the gas directly to come into the gas turbine engines after cooling and scrubbing without introducing other greenhouse gases. The process of the gas extractor developed by Future Energy Research Corporation is shown in Figure 2.6.

Table 2.4 General Cost of the Biomass CHP system

Capital	Gasifier	20,000	Depreciation period: 10y
	Gas Scrubbing	3,333	
	Construction expenditure	13,333	
	Total	36,666	
Operation Cost (£/y)	Electricity	10,266	
	Labor Cost	1,333	10 persons
	Feed	25,600	£13.3 /t, including collection and processing
Maintenance	5% of utilities	7867	
Other	1% of capital Cost	1733.3	

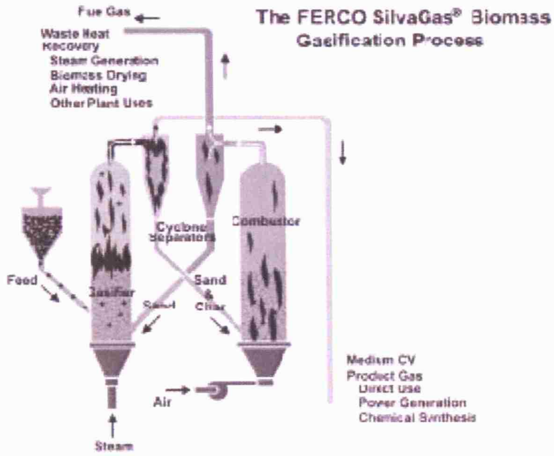


Figure 2.6 Diagram of FERCO synthetic gas process

The other benefits of the FERCO gas process is that the high temperature exhaust gas of around 560℃ is introduced to a waste heat boiler. At the meantime, the steam is then recycled into the steam turbine to be applied again, contributing to an overall cycle efficiency of over 38%, much higher than conventional biomass systems with a maximum efficiency of 25%. Heat from the turbine is recovered by a condenser. The electricity producing efficiency is 21%,

Furthermore, the combined cycle of gas and steam turbines help to maximize the overall thermal efficiency. The heat to electricity ratio is reduced to 1.5:1 from around 8:1. The recovery heat is used as a district heating source in winter, while in summer, it is a part of the heat is stored in hot water system.

According to the case study design in Australia, another high-efficient project is here, where there is a 2 MW biomass gasification plant constructed in 2004. It is the first plant in Australia by implementing of a new fluidized bed combustion process. The gas production reactor was recognized b FICFB-gasification system (fast internally circulation fluidized bed gasifier). The advantage of the system is to gain the product gas without nitrogen. Additional air is introduced into the combustion section alongside the bed material, separately streamed off with gas flows in combustion section. Finally, a product gas almost without nitrogen with heat values of over 12,000 Kj/Nm^3(dry) is emitted. Figure 2.7 shows the principal of this gasification process. (European Commision, 2004)

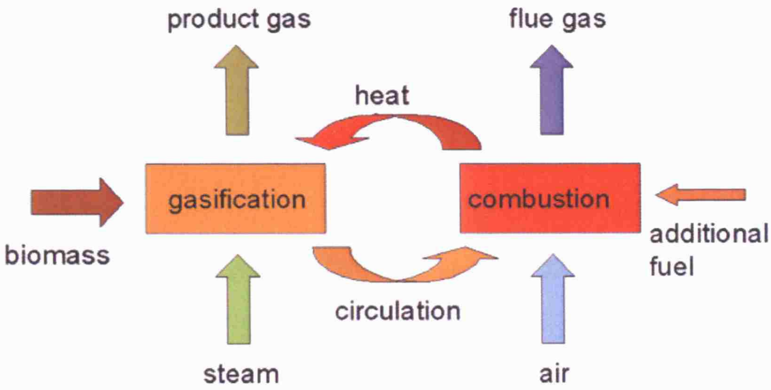


Figure 2.7 Principles of the gasification process

Due to the compact construction and high fixed-in tariffs for green electricity in Australia, the plant is operating quite well, with the energy efficiency of 81.3% in total.

2.3 Cases Study

Generally speaking, sustainable community is a region with the energy balance, where people could live harmoniously with the environment and at the meantime consume the minimum energy. As a result, the "planning" of the energy is the key issue in the design of the eco-city. It is encouraged to conduct case studies of some successful projects.

There are several successful projects in Europe and China. This section will focus on the Beddington Zero Fossil Energy Development (BedZED) eco-village in the London Borough of Sutton, which is one of the famous One Planet Living programs, the Vauban district in the city of Freiburg im Breisgau, the Hamburg sustainable community in Germany, the Singapore-Tianjin Eco-city and Beijing Olympic Village.

2.3.1 Renewable Energy Application

2.3.1.1 Solar Energy

Solar energy is widely used in the world. In the projects in BedZED, German, France, China, the photovoltaics are installed on the roof and the south façade of the buildings. The application of these PV panels could not only convert solar energy into electricity, but also provide the shading to the buildings.

As shown in Figure 2.8, at BedZED, the photovoltaics are installed on the roof of the sunspaces and the south façade of the building. There are 1138 PV panels in total, the highest power of which could reach 109 kW. They could provide the electricity of 88,000 kWh. Figure 2.9 displays the PV panels installed in the south façade of a house. Currently the payback period for PVs to displace fossil-fuel use in building is around 73 years. However, the energy produced by the PVs could be used for transport, which could reduce the payback time greatly. A109 kW peak solar-electric (photovoltaic) panel installation provides enough electricity to operate forty small electric cars, each running 13,700 km/year. (Nicole, 2007)

Figure 2.8 PVs on the roof

Figure 2.9 PVs on Windows

In addition, in Beijing Olympic City, solar energy is also used in LED and street light. The most interesting facility is the application of light pipes. For example, the 148 light pipes with the length of 8 m are installed in the stadium in the Beijing Technology University. It is shown that 80% of the solar energy could be introduced by the light pipes into the stadium. Figure 2.10 shows the solar powered street light. Figure 2.11 displays the layout pf the light pipes in Beijing Stadium. (One world One dream, 2008)

Figure 2.10 Solar Powered Street Light (One Wold One Dream, 2008)

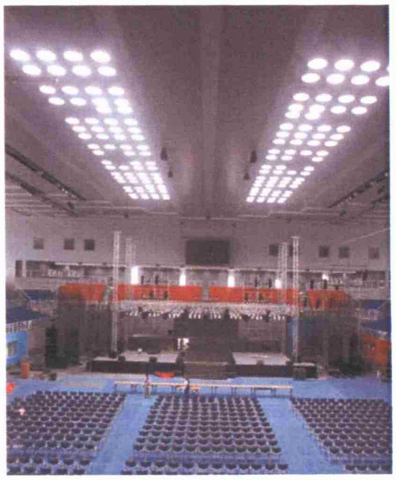


Figure 2.11 Light Pipes in Beijing Studium(One Wold One Dream, 2008)

2.3.1.2 Wind Energy

The application of wind energy is more and more popular all over the world. However, the efficiency varies from the site location and the wind speed. The output power fluctuate greatly in some circumstances.

At BedZED, wind-driven passive ventilation system is good.(Nicole, 2007) In summer, natural ventilation is the main measure to prevent overheating. In addition, enough windows are open to turn each glass sunspace into an open-air balcony as shown in Figure 2.12, avoiding the need for expensive external shades. On the roofs of the houses there stand a lot of wind-driven ventilation cowls. As can be seen in Figure 2.13, a wind-driven passive ventilation system provides around 50% to 70% efficient heat recovery with no electrical energy consumption, completely driven by wind.

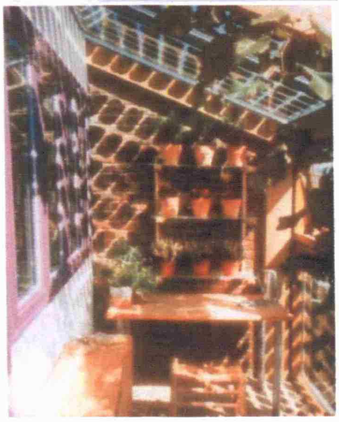


Figure 2.12 Open Air Balcony in Sunspace

Figure 2.13 Wind-driven passive ventilation system

The most significant strategy in the Olympic City is the application of the wind energy. It is the first attempt for Beijing to make use of the wind energy. Beijing Guanting wind energy power station is in the "upstream" of the wind direction, which is located in the south part of Beijing. It is estimated that 100 GWh green electricity could be produced annually from here. It will provide 300 MWh electricity to the national grid, which meets the demand of 100,000 families. In the Olympic city, 20% of the energy load will be provided by the wind energy. Figure 2.14 shows the wind turbines in the Olympic city.

Figure 2.14 Wind Turbines in Beijing Olympic City

2.3.1.3 Biomass-Combined Heat and Power Use

CHP in the sustainable community makes use of the waste heat from the electricity generation process.

At BedZED. all of the heat and the electricity are provided by the combined heat and power plants within the community. The fuel of CHP is the remains of the leaves and plants nearby rather than fossil fuel. A 135 kW electricity out combined CHP runs off 850 tonnes of woodchip per year at 30 % moisture content, which requires an area of short-rotation coppice woodland of around 70ha, with around 24 ha of coppice being cut annually to meet the community's fuel demand. At BedZED the woodchip is being sourced from BioRegional urban tree station, which takes urban tree waste from the London Boroughs of Sutton and Croydon that would otherwise go to landfill. (Nicole L. ,2007)

According to the initial study by BioRegional, the embodied energy of the CHP plant itself is around 145 MWh, displacing approximately 326t CO_2 annually from the national grid electricity production. (BioRegional, 2006)

2.3.2 Carbon Savings

Lately, in order to figure out the carbon savings achieved by achieved at the BedZED, BioRegional have conducted an analysis based on the monitored energy consumption figures and residents questionnaires. Table 2.1 shows the estimated energy saving in every aspects of the daily life for the average residents at BedZED compared to the average carbon consumption in the UK..

It was indicated from the results in Table 2.5 that the largest savings are coming from the green transport in addition to the wood-fired CHP, which faced some problems in installation. While the passive solar strategies and photovoltaic panels contribute much less to the savings. Although low embodied energy materials were used, a greater volume of heavy-weight material was needed to create the thermal mass for the particular energy efficient design taken at BedZED. Besides, it is worth realizing that the carbon savings could accrue from food and waste so that there would be a great potential to improve in such areas. (Nicole L. ,2007)

Table 2.5 Carbon Savings for Each Aspect

	Tonnes CO_2 saved per resident per year	% contribution to reducing CO_2 impact over UK average
Wood-fired CHP	1.94	16%
Green Transport Plan/Car club	1.30	11%
Food (assuming increase in local seasonal and organic produce and 10% lower animal protein diet)	0.48	4%
Waste and recycling (assuming 30% increase in recycling)	0.36	3%
	Tonnes CO_2 saved per resident per year	% contribution to reducing CO_2 impact over UK average
Super-insulation	0.32	3%
Passive solar gain via south-facing conservatories	0.16	1%
Water efficient appliances reducing hot water use	0.17	1%

Energy efficient appliances	0.17	1%
Photovoltaics	0.17	1%
Low embodied energy materials	0	0%
Total Saving	5.07	41%

3 Research Methodology

3.1 Scope of Methodology

The study focuses on the design of the Dongtan Project in Shanghai, with the target by 2020. The calculation of the energy produced by several types of renewable energy in Dongtan will be made. The project aims to figure out the proportion of the energy produced by each type of renewable energy, and compare the carbon savings by different types of source.

The Simulation tool used in this project is TAS thermal simulation software. Local climate and a simulation model of a typical dwelling in Dongtan will be discussed first, followed by the calculation of the heating load and cooling load in the residential area, in order to compare the amount of the electricity produced with the energy demand.

Carbon savings of the renewable energy are calculated out by simple calculation method. The technical data of the renewable energy generating machine is indirectly taken from manufacture. For the solar energy calculation, the simulation results of the dwelling are output as surface solar gain, and only the exposed window area of the target zone was selected. So the data would be the solar radiation received by the PVs installed on the windows. Life cycle and economic analysis will be conducted in the discussion..

3.2 Projects Review

3.2.1 Dongtan Eco-city Plans Review

Dongtan eco-city incorporates many traditional Chinese design features and combines them with a sustainable approach to modern living, within which the residents will be familiar with the surroundings and live harmoniously with the environment, creating a lifestyle of "zero-carbon" emissions. .

According to Arup Report, (2007) The plan of the Dongtan eco-city has three phases. At the first stage, it aims to create a city with the population of 5,000 people by 2010, when is the time for World Expo in Shanghai. Later, by 2020, the city will grow into an area which can accommodate 80,000 people. For the last phase by 2050, the population is designed up to 500,000

The project will increase bio-diversity on Chongming Island, and will create a city that runs entirely on renewable energy for its buildings, its infrastructure and its transport needs. Dongtan will recover, recycle and reuse 90% of all waste from the area, with the eventual aim of becoming a zero waste city.

Ultimately, Dongtan eco-city aims to have: (Arup Report, 2007)

60% smaller ecological footprint

66% reduction in energy demand

40% energy from bio-energy

100% renewable energy for in-use buildings & on-site transport

Waste to landfill down by 83%

Almost no carbon emissions

In order to accomplish the targets, the design of the pattern of renewable energy use in the city is important. According to the site and the weather, with reference to the other successful eco-city plans, for each stage, different area and the percentage of renewable energy applied among the total energy consumption are set. The capacity and the number of renewable energy electricity plants will increase based on the amount results.

According to the Arup Report 2007, the detailed targets of the design of the Dongtan Eco-city are listed in Table 3.1. (Arup Report 2007)

The location which will be developed by 2020 is shown in Figure 3.1. The area of 634 ha is in the south-west of the eco-city, where is 3.2 km from the wetland part. It will accommodate 80,000 people. An eco-farm is located to the north-east of the area. As can be seen in Figure 3.1, the wetland park acts as the buffer zone. The eco-farm could offer renewable electricity to the town.

Table 3.1 Plan Details of Dongtan Eco-city by 2020 (Arup Report 2007)

634 Ha	Land Developed
57%	Development Area / 43% Open Space, Water and Major Roads
27,000	Dwellings
5.1 M square meter	Gross floor area
55%	Residential as proportion of GFA
24%	Commercial, retail and light industrial
16%	Culture, tourism, leisure and hotel
5%	Education and Social Infrastructure

Figure 3.2 reveals the three villages in the town, which are separated by two rivers. The form of the villages is compact, which would minimize energy consumption especially in the buildings and transport. Three villages meet to form a city centre, separated by two water routes rooted from the lake in the center.

Figure 3.3 shows the walking and cycling routes within the town. It indicates that access into the town center from the three villages is convenient, and any point in each town is within 800m (ten-minute walk) from the village center. Besides, the continuous network of walking and cycle routes is connected to green parks and canals, which make the residents a easier and healthier life. It is estimated by Arup that the improved accessibility in Dongtan will reduce travel distances by 1.9 million kilometers, reducing CO_2 emissions by 400,000 tonnes per year. (Arup Report, 2007)

Figure 3.1 The Location of the area developed by 2020

Figure 3.2 Town planning of the city containing three villages

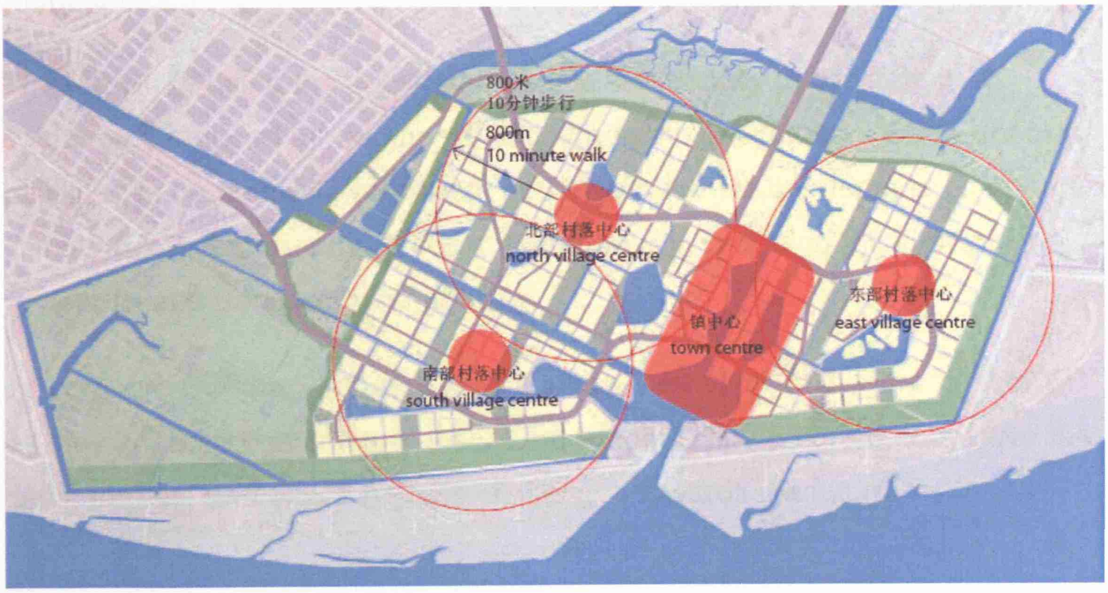


Figure 3.3 The Walking and Cycling Routes within the town

As can be seen in Figure 3.4, it is a compact city, with dwellings attached together. The reason of attaching the houses is to reduce the exposed wall area so as to reduce the heat loss. As mentioned before, the three villages meet in the center lake, where is also the town center. Water taxis is the most interesting public transport mean in the town. Canals provide another new option for transport. In addition to Water taxis, buses and the convenient cycle-paths and pedestrian routes help to prevent the motorized transport, which will produce greenhouse gases.

Furthermore, the town center is designed as pedestrian friendly environments, which is served by public transport. There are well mixed facilities within the walking distance of residential areas, which reduces the possibility of long-distance walking. As a result, it is probably not necessary to travel by car or other private motorized vehicles in daily life, which helps to reduce the air and noise pollution.

As to the view of the town center, the lake and canals in it create a beautiful and peaceful environment. The large green area near the city center also has the benefits of making fresh air and absorbing CO_2 which results in the heat-island effect.

The reason of using the public transport is that usually public transport contributes reduced air and noise pollution to the environment which enables buildings to be naturally ventilated, and in turn reduce the demand on energy. Canals, lakes and marinas will permeate the city, providing a variety of recreation and transport opportunities.

To compare Dongtan with BedZED, it is in a very similar category to BedZED as they are both constructed under One Planet Living program, they have the same targets, and also the same challenges towards the future.

Figure 3.4 The View of the Town Center

3.2.2 Demonstration of The Dwelling Model

The design in this paper attributes to achieve the targets of 2020, which aims to accommodate up to 80,000 people in the area of 674 ha. .

The model of the flats in the city is simulated to predict the energy consumption of all the buildings. The compact city makes it possible to have 3-storey attached house using innovation and green technologies to reduce the energy demand in it. As far as is concerned, there is no need to use lifts in such flat buildings, which represents the sustainable way of living in the urban area.

Based on the design targets, the calculation of the dwelling area is made in Table 3.2. It is assumed that all of the buildings have four floors. Due to the One-child Policy in China, the number of people in each family is assumed to be three. In terms of the average GFA of a 3-people family, 103.9 m^2 is suitable to live in the city. In addition, 27,000 dwellings could accommodate the population of 81,000, which meets the target of 2020.

Table 3.2 Calculation of the Gross Floor area and Ground Floor Area in Each Dwelling

The Developed area = 6,740,000 m^2 x 57% = 3,841,800 m^2
The Residential Gross Floor Area = 5,100,000 m^2 x 55% = 2,805,000 m^2
The Number of Dwellings = 27,000 (Assume 3-storey dwelling)
The Gross Floor Area of each Dwelling = 2,805,000 / 27,000 = 103.9 m^2
The Ground Floor Area of each Dwelling = 2,805,000 m^2/ 3 / 27,000 = 34.6 m^2 /floor
The proportion of the Ground Area of All dwellings = 34.6 m^2 x 27,000 /3,841,800 = 24%

Figure 3.5 shows the dwellings along side the river in the village. Most of the dwellings are low-rise, high density compact forms as shown in the Figure. As a result, the attached house with three or four floors represents the dwelling type in Dongtan Eco-city, which is used as building the simulation model.

Figure 3.5 Photo from Dongtan Eco-city (Arup Report 2007)

In order to estimate the heating, cooling loads and energy consumption, Thermal Analysis Simulation model of a typical dwelling is made in the next section. Based on the data of dwellings, the energy condition in other type of buildings could be estimated.

3.3 The TAS modeling and Simulation Assumption

3.3.1 The weather condition in Dongtan Eco-city

Weather condition plays a significant role in the design of Dongtan Eco-city. In order to make the best use of the weather features in Shanghai, temperature, solar radiation, wind speed and direction are studied in the following chapter.

3.3.1.1 Air Temperature

Air temperature is one of the primary thermal comfort conditions in buildings and the surroundings. According to the Chinese Weather Statistics Profile, Shanghai is located in the latitude of 31.13 (N) and longitude of 121.58, with the temperature from the lowest -5.2℃ to the highest 37.7℃. Generally, Shanghai has cold winter and hot summer. According to the monthly temperature profile as shown in the Table 3.3, it indicates that the temperature differences between the seasons are moderate, while the difference between daytime and nighttime is small.

Table 3.3 The Average Monthly Shanghai Temperature

Average Data	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Average High (deg.C)	8	9	13	19	24	28	32	32	28	23	17	11
Average Low (deg.C)	0	1	5	10	15	20	24	24	20	14	9	3

According to the fluctuating temperature throughout the whole year, it is necessary to use heating and cooling strategies in summer and winter respectively.

3.3.1.2 Wind Speed and Direction

Chongmin is located in the mouth of the Yangze River, which suggests that the wind speed is higher than inner area. Figure 3.6 indicates the wind speed frequency in Shanghai. Nearly 86% of the time, the wind speed is higher than 2 m/s. However, because it is the average data of Shanghai City, the data might not present the condition in Chongming Island, especially the Dongtan area. Figure 3.7 shows the prevailing wind direction in Shanghai.

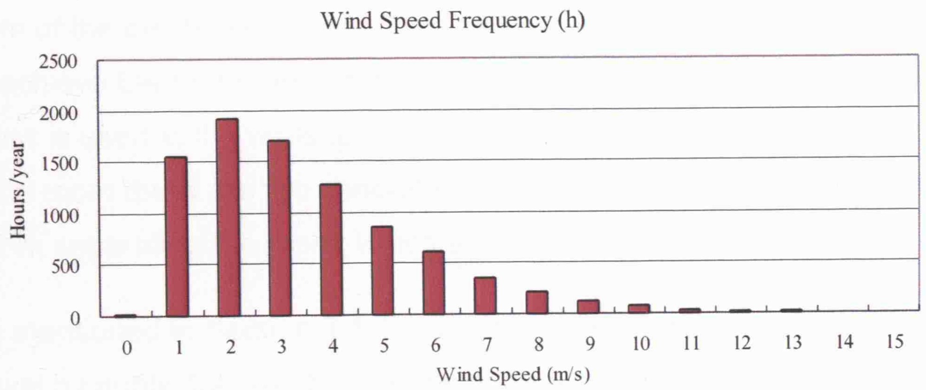


Figure 3.6 Wind Speed Frequency in a year in Shanghai

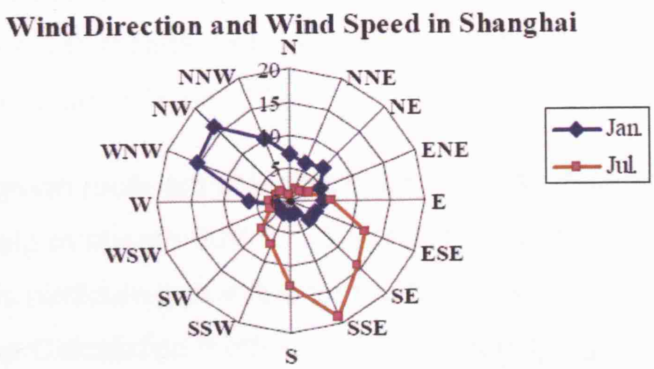


Figure 3.7 Prevailing Wind Direction in Shanghai

Wind direction in Shanghai is influenced by the ocean and Yangzi River. Generally, the prevailing wind direction changes with the seasons, according to the Shanghai Statistics, the prevailing wind direction in July is south east, coming from the ocean. However, in January, the wind direction changes to northwest. The highest wind speed reaches more than 15m/s in winter and nearly 20 m/s in summer.

3.3.2 Build the TAS Model

TAS model is built based on the calculations in Section 3.2. The model is 3-storery building with mix-mode ventilation. There are five dwellings attached together, each one with the dimension of 4m x 8.5m. The floor height is 2.2 m. Front façade is facing south-east, with reference to the layout of the town. The form of the building is compact, so as to minimize the exposed area. In order to achieve the better performance towards the sustainability, the thermal mass is used in the walls to store the heat inside during the cold winter. Inside each room there are two concrete internal walls with the dimension of 1.24m x 2.2 m separating the room, which are used as thermal mass.

As mentioned in Section 3.1, because residents are encouraged to walk or travel by public transport, there might be less noise and air pollution in the town. Natural ventilation can be used in the building. However, due to the hot summer, the mix-mode ventilation should be used when the temperature is above 25℃. In addition, in order to introduce the maximum sunlight into the room, the huge south façade glazing is used, with the dimension of 3.2m x 1.8m, as can be seen in Figure 3.8.

In the design, green roofs are selected to be used. As discussed in previous section, they help to absorb 90% to 50% of rainwater depending on how much it rains, which is particularly suitable for the humid weather in Shanghai. According to the Calculation method of the U-value, the green roof is estimated to have a U-value of 0.86 W/m^2℃ (Brian Anderson, 2006)

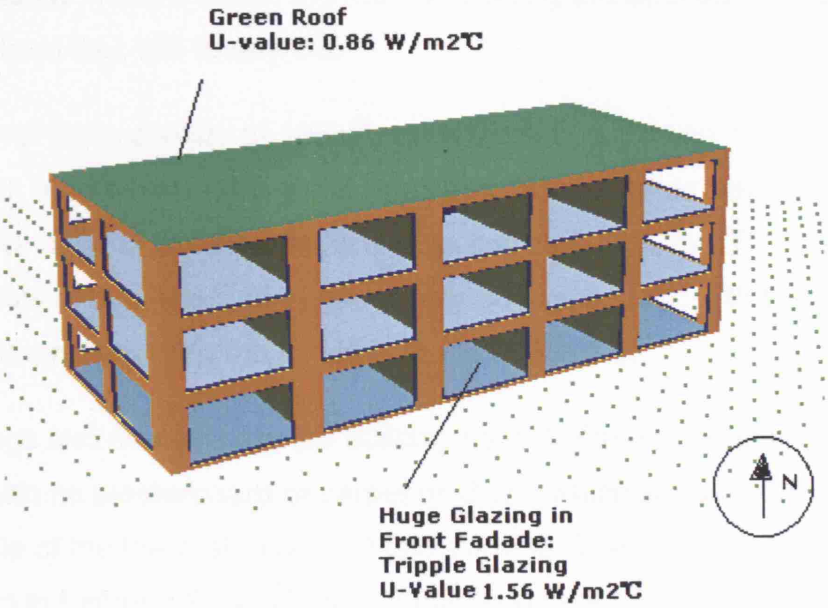


Figure 3.8 Green Roof and the Front Glazing of the Building

Windows are formed of low-e coated triple glazing with the U-value of 1.56 W/m^2℃. **In the south façade**, the larger area of 5.76 m^2 (3.2m x 1.8m) windows enables the rooms to receive a lot of solar gain during the winter. The inner part of the triple glazing allows the solar irradiation through the window, and meanwhile keeps the heat inside the room. It significantly reduces the unwanted heat transfer between inside and outside of the building, and hence reduces the heating load in the winter. Another benefit of the large windows is to maximize the daylight during the day, reducing the light energy consumption in the dwelling.

In the back façade, there are one small window with the dimension of 2m x 1m, and a wood door with the dimension of 1.2m x 1.9m. The windows can be functionally controlled, which allows the building performed in a mix-mode ventilation system. When the zone temperature is below 20℃, the window would be shut down; while when the zone temperature is higher than 28℃, the windows would be shut down automatically to allow the cooling system to work efficiently. What's more, the feature shading are applied during the summer, from day 150 to day 240.

The external wall consists of 105mm brick block outside and 100mm brick inside, with 55mm thick fibre glass insulation and 50mm air between them. The total U-value of the external wall is as low as 0.381W/m^2℃. The internal wall consists of two layers of 75mm clinker concrete block with 50mm air between them, providing the U-value of 1.862 W/m^2℃.

The ceilings and floors inside the building have 150mm concrete facing the interior, with no plasterboard or carpet on them, which act as thermal mass. The U-vale of the thermal mass is 0.609 W/m^2℃. The internal thermal walls are shown in Figure 3.9, which are 150mm concrete walls, standing in the center of the room, which are also used to separate the space.

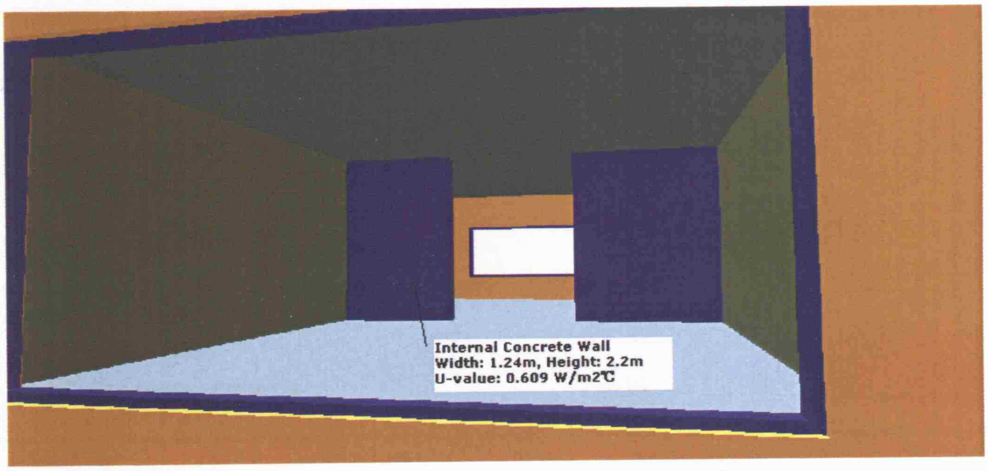


Figure 3.9 Internal Concrete Walls inside the Room

Creating the suitable internal conditions is important.

Owing to the cold winter and hot summer, the use of heating and air conditioning systems is necessary in the community. Furthermore, thermostat is also taken into account in order to automatically control the air-conditioning system, and at the meantime keep the temperature within the comfort zone, which is set to operate heating and cooling system between 20℃ and 24℃. In terms of the worst case scenario, the houses would be occupied throughout the whole year at all of the time. Figuring out the most heating load and cooling load makes it possible to keep the energy reduction zero at all of the time by means of the sustainable design of the community.

The internal gains from 3-people flat and the other internal conditions such as metabolic rate, ventilation rate and infiltration rate are listed in Table 3.4.

Table 3.4 Internal Gains and related conditions in the building model

Building Type	Mix-mode Homes
Infiltration rate(ach)	0.3
Ventilation rate(ach)	3
When windows are open for natural ventilation	
Lighting Gain (W/m^2)	12
Occupancy Gain (W/m^2)	Sensible 8 and Latent 4
Equipment Gain (W/m^2)	Sensible 15
Metabolic Rate (W/m^2)	75.66

In order to simulate the average heating and cooling load of the dwellings in the town, the attached one should be the target of the project. The whole buildings are set for two zones. The temperature and the loads of the dwelling in the middle are set as Zone 1, and the other dwellings are set as Zone 2.

As can be seen in the Figure 3.10, Zone 1 is the target zone to simulate, which represent a attached dwelling. The indoor air temperature, heating and cooling loads are examined in this model, in order to estimate the electricity used to keep the temperature within the comfort zone. The temperature of Zone 1 is calculated in the following sections.

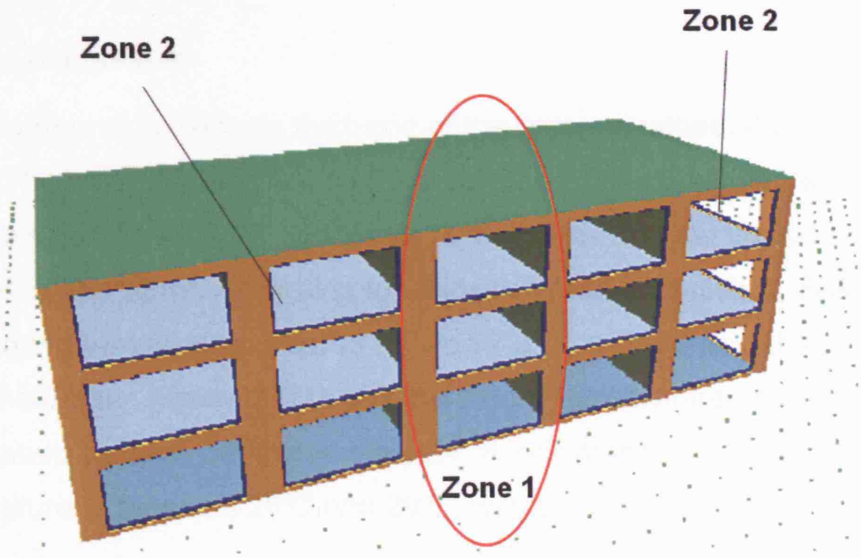


Figure 3.10 Target Zone in the Model

Zone 1 represents a typical dwelling in the Dongtan eco-city with two walls facing outside, while other two sharing with the neighbor. However, there are some stand-alone dwellings and the ones semi-detached. Owing to the relatively large number of attached dwellings, the energy consumption in them approximately equals to the average value.

The simulation results are shown in the next section. Based on the heat load and cooling load, the form and the amount of renewable energy electricity will be figured out. In addition, the suggested locations of the electricity plants will be selected.

4. Results

4.1 Results from TAS Model

4.1.1 Air Temperature

Indoor temperature reflects the trend of the external temperature to some extent. The most important role of the buildings is to make the interior conditions comfortable for occupants to stay, reducing the fluctuation of the external temperature. According to Chinese Weather statistics, Shanghai has a fluctuating temperature from -3.5℃ to 37.3℃, representing the cold winter and hot summer. Figure 3.9 shows the indoor temperature and external temperature through out the whole year. It indicates that the indoor temperature is between 20℃ and 29℃, with the average value 23.76℃.

According to Figure 4.1, during summer and autumn, the indoor temperature is a little higher than that in spring and winter. The temperature range is larger than the comfort zone we set from 20℃ to 24℃. One of the reasons might be the natural ventilation strategy used in the building as long as the temperature is between 20℃ and 28℃, which will bring unwanted heat gain from outside during hot days.

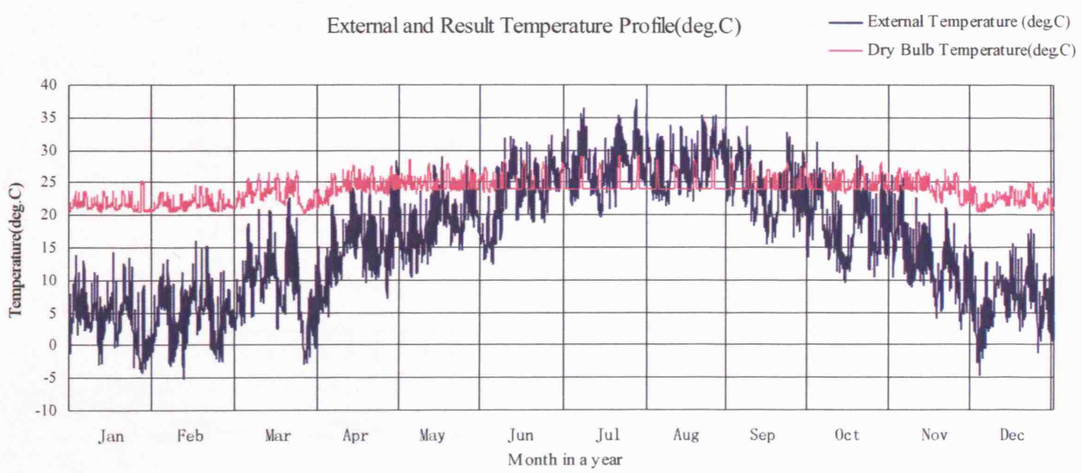


Figure 4.1 Temperature Results of Zone 1 throughout the whole year

4.1.2 Heating and Cooling Loads

Besides the temperature profile, the heating loads and cooling loads show the greatest importance in terms of the energy consumption of the heating and cooling systems.

The external temperature fluctuates from -5.2℃ to 37.7 ℃. Air-condition system and heating system will be used, which will contribute to cooling load and heating load. However, natural ventilation strategies are applied in the buildings, as well as the other sustainable strategies, the heating loads and the cooling load will be offset.

The calculation of the heating and cooling load of the target zone is made in this section. The total floor area of Zone 1 equals to 102 m^2.

Figure 4.2 shows the day with the highest heating load (Day 38). Figure 4.3 demonstrates the day with highest cooling load in summer.(Day-209). It indicates that during winter, the peak load might reach 3 KW, while in summer, the peak load is above 2 KW. The electricity system and district heating system should take the peak load into consideration.

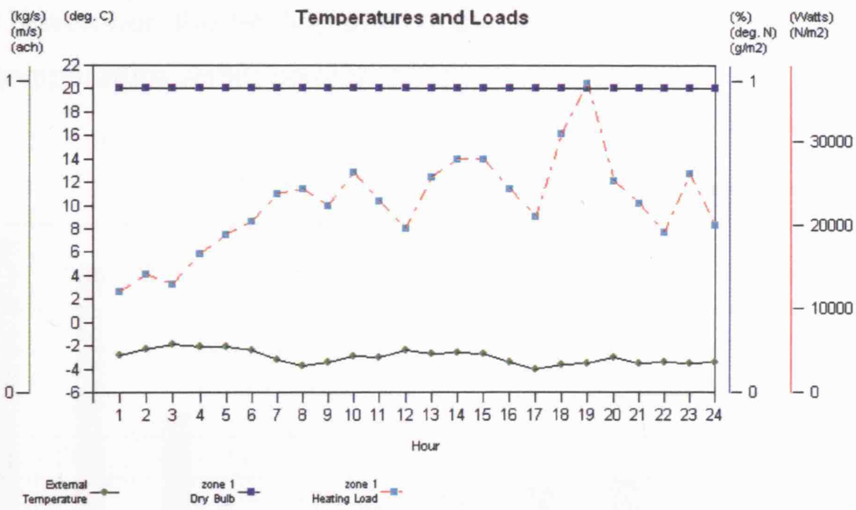


Figure 4.2 Heating Load in Typical Winter Day (Day-27)

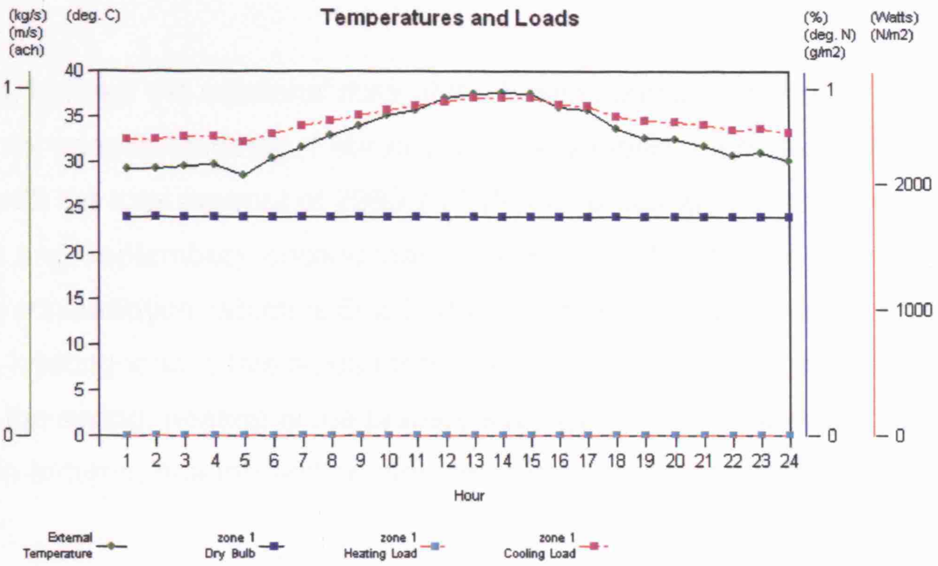


Figure 4.3 Cooling Load in Typical Summer Day (Day- 209)

Figure 4.4 shows the distribution of monthly heating loads and cooling loads in the whole year. The total heating loads and cooling loads throughout the whole year are 3724..4 KWh and 836.2 KWh/m^2. From the distribution of the heating and cooling loads, it indicates that in mid-season, such as March, April, and November, the heating and cooling systems are both necessary to keep the temperature within comfort zone.

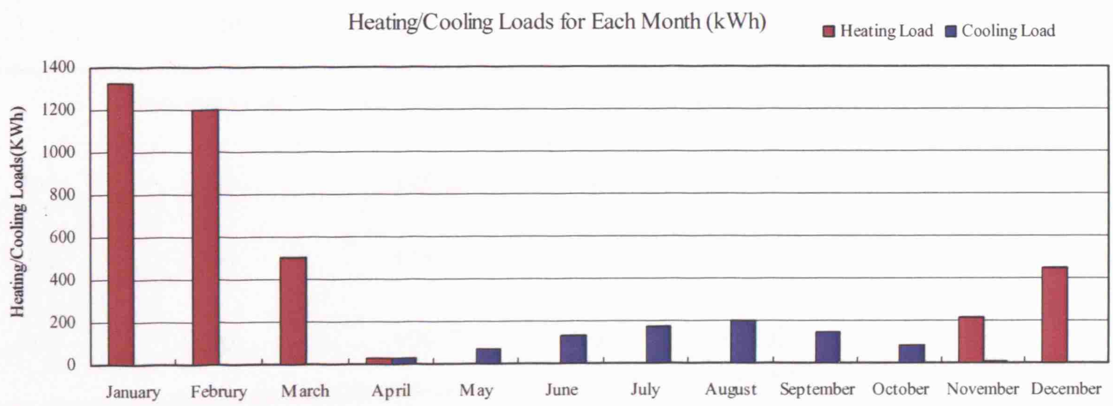


Figure 4.4 Monthly Distribution of Heating Load and Cooling Load

Table 4.1 shows the seasonal data of the heating and cooling loads. During the winter season (January, February, and December), there are only heating loads with the total amount of 2969.7 KWh. While during the hot season (July, August and September), cooling loads make the contribution to the total energy consumption, which is 502.9 KWh. With respect to mid-seasons, in spring, heating load is five times more than cooling load, which indicates that during the spring, heating is the primary strategy used in residential buildings. While in autumn, heating and cooling consumed almost the same amount of energy.

Table 4.1 Seasonal Data of Heating and Cooling Loads (KWh)

	Winter			Spring	
	Heating Load	Cooling Load		Heating Load	Cooling Load
Jan	1324.3	0.0	Mar	504.6	2.4
Feb	1196.4	0.0	Apr	31.0	27.6
Dec	449.0	0.0	May	0.6	72.2
Total	2969.7	0.0		1044.36	102.2
	Summer			**Autumn**	
	Heating Load	Cooling Load		Heating Load	Cooling Load
Jun	0.00	128.2	Sep	0.00	141.9
Jul	0.00	175.0	Oct	1.4	79.6
Aug	0.00	199.7	Nov	217.0	9.4
Total	0.00	502.9		425.45	231.0

In order to compare the heating/cooling loads in Dongtan project with index of Shanghai energy consumption, the calculation of the total energy consumption in Dongtan eco-city are shown in Table 4.2. It shows that the total heating and cooling consumption in Dongtan is 125,416 MWh.

Table 4.2 Summary of Annual Heating and Cooling loads Required in Dwellings

Gross Floor Area of Zone 1= 102 (m^2)		
Gross Floor Area in the town=2,805,000 (m^2)		
	Total Loads per dwelling (KWh)	Total Loads per square meter (KWh/ m^2)
Annual Heating Load	3724..4	36.5
Annual Cooling Load	836.3	6.2
Total Loads of the Dwelling	4560.7	44.7
Total Heating and Cooling consumption of the total residence buildings		
44.7 KWh/ m^2 x 2,805,000 m^2 = 125,416 MWh		

According to the BedZED Energy Report, (1999), in the worst case scenario, a three-bedroom flat will consume 5863 kWh/year, while in typical scenario, 2657 KWh/year is enough, and 1633 KWh/year for best ones. Assume the area of a 3-bedroom flat at BedZED is the same as in Shanghai, the total energy consumption per m2 at BedZED is from 16.63 KWh/m2 to 58.63 KWh/m2.

In the same report, it states that in buildings the heating load to total energy ratio is 0.70. Residential building accounts for only 63% of the total energy of the whole buildings. The related tables in BedZED Energy Report are in

Appendix A. Based on these figures, the energy consumption in all of the buildings in Dongtan is shown in Table 4.3.

Table 4.3 Calculations of Total Energy Consumption in All Bulidings

The Energy Consumption in Dongtan Dwelling per m^2 = 36.5 KWh / 0.7 = 53 KWh/ m^2
The Energy Consumption in one Dwelling = 53 KWh/ m^2 x 102 m^2 = 5406 KWh
The Energy Consumption in Residential Buildings in Dongtan= 53 KWh/m^2 x 2,805,000 m^2 = 148,665 MWh
The Total Energy Consumption in Dongtan = 148,665 MWh / 0.63 = 235,976 MWh

As a result, it was assumed that the energy consumption in all of the buildings might be 236 GWh. The average energy consumption per m^2 in dwellings in Dongtan is 53 KWh/m^2. Compared to BedZED projects, the dwelling in this paper is ranked as Typical building.

To conclude, in the buildings, a combination of traditional and innovative building technologies will reduce energy requirements of buildings. The integration of natural ventilation and air-conditioning system helps to control the air temperature as well as reduce the cooling load as much as possible. However, during the cold season, although the application of thermal mass and triple glazing plays significant parts in obtain and store solar gains, heating load is still unavoidable in the design. In addition to the building technology aspect, the high efficient lights, PVs and mini wind turbines will be discussed to reduce the energy requirement from outside in particular buildings.

4.1.3 Surface Solar Gain

Besides temperature, the surface solar gains of the buildings are important to measure in order to determine the numbers of PVs and the energy produced by them which could offset the energy demand in the buildings.

In Dongtan projects, the Building integrated photovoltaics are assumed to be installed on the windows of every facade, in order to maximize the renewable electricity. Only windows in Zone1 dwelling are selected when viewing the simulation results, because the external walls and windows have different solar absorption coefficient. In order to be accurate, the average solar radiation on the surface of the windows is examined. As a result, the surface solar gains in different months are measured as shown in Figure 3.12. Based on the Section 3.1, the total window area of Zone 1 is 23.28 m^2. It reveals that in June, the windows surface could absorb maximum solar radiation, while in January, minimum

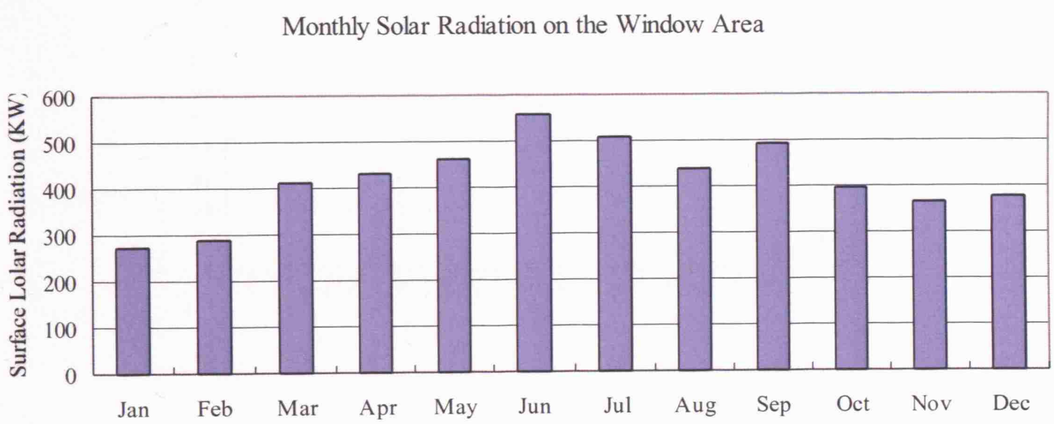
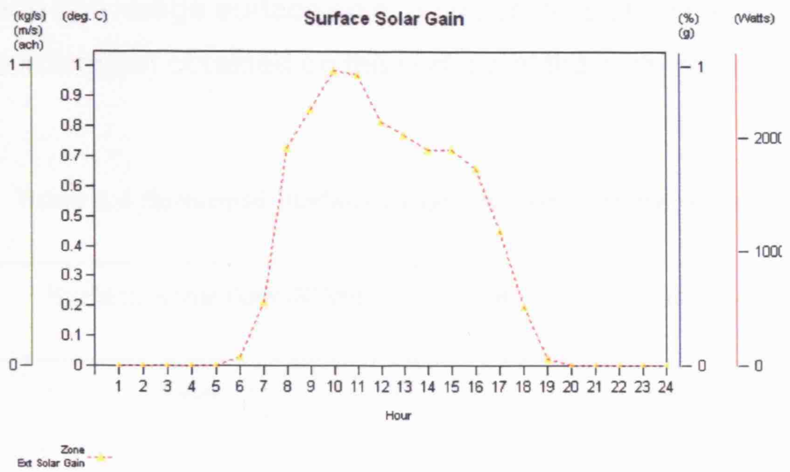
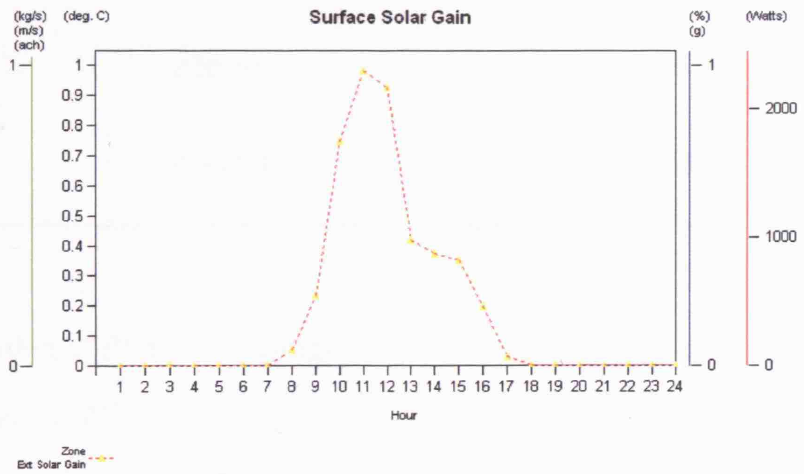


Figure 4.5 Monthly External Surface Solar Gain in Zone 1

Figure 4.6 shows the typical summer day of solar profile in Day-213 and typical winter day in day-353 in (a) and (b) respectively. Compared the two typical days in summer and winter, it indicates that the figures of solar radiation received on the surface of the windows are almost same. One of the reasons might be the feature shading applied during summer, which will stuck a certain amount of solar radiation.



(a) Typical Summer Day – Day 213



(b) Typical Winter Day – Day 353

Figure 4.6 Surface Soar Gain in Typical Days

Table 4.5 shows the seasonal surface solar gain on the windows. It indicates that the solar gains of Zone 1 from the façade surface are a little bit lower during the winter season, in December, January and February, which accounts for 938.30 KWh in total. While during the summer, the solar radiation is 1502.74 KWh in total. Throughout the whole year, the total surface solar gain is 4996.58 KWh.

The calculation of average surface solar gain per m^2 is shown in Table 4.4. The average solar gain obtained on the surface of the building will be 214.63 KWh/ m^2.

Table 4.4 Seasonal Surface Solar Gain per square meter

	Surface Solar Gain(KWh)	Surface Solar Gain per m^2(KWh/m^2)
Spring	1304.31	56.02
Summer	1502.74	64.55
Autumn	1251.23	53.75
Winter	938.30	40.31
Total	4996.58	214.63

4.2 Application of PVs in Dwellings

4.2.1 Selection of PVs

With reference to the BedZed project, Building Integrated Photovoltaics(BIPV) and the PVs in the facade of buildings are taken into consideration to reduce the energy demand from the grid. In addition, the semi-transparent PVs are also taken into consideration because the windows could be covered by PV panels with the effect of producing energy and introducing the light. As a result, the thin-film semitransparent ASITHRU-30-SG solar modules are chosen. Table shows the manufacturing data of it..

The calculations of the energy produced by the PV panels are shown in Table 4.5. According to the dimensions of the module (1000mm x 600mm), the numbers could be fit in each window varies from the size of the windows.

Table 4.5 Calculations of the number of PV panels

The area of the smaller window in north façade = 1m x 2m = 2 m^2
The area of the smaller windows = 2 m^2 x 3 = 6 m^2
The number of cells fit in one small window = 2
The number of cells fit in all small windows = 2 x 3 = 6
The area of the large window = 3.2m x 1.8m = 5.76 m^2
The area of the larger windows = 5.76 x 3 floors = 17.28 m^2
The number of cells fit in one large window = 9
The number of cells fit in all large windows = 9 x 3 =27
The total number of PV cells in one dwelling = 6 + 27 = 33 (pieces)
The total area of PV cells in one building = 1m x 0.6m x 33 = 19.8 m^2

4.2.2 PV Performance and Energy Efficiency

Practically, there would be a certain percentage of electrical losses due to the inverter, transformer, electrical resistance and distribution network. Assume ASITHRU-30-SG PV panels manufactured by Schott Solar are applied in the dwellings, the efficiency is assumed to be 4.5%.(The technical data are shown in the Appendix B). (ecoWEB) The calculation of the total energy produced by the PV panels in one building is shown in Table 4.6.

Table 4.6 Calculations of Solar Energy Consumed by PV windows

The Average Solar Irradiation on the dwelling facade = 214.63 KWh / m^2/year
The Annual energy collected by PVs = 214.63 KWh/ m^2 x 19.8 m^2= 4249.67 KWh
The Annual energy produced by PVs = 214.63 KWh/ m^2 x 19.8 m^2 x 4.5%= 191.23KWh
The Total Energy Consumption in the dwelling = 5,406 KWh / year
The Percentage of Energy Produced by PVs in one dwelling = 191.23 KWh / 5406 KWh x 100% = 3.5 %

It indicates that the energy produced by PV panels installed in the facade windows is not efficient compared with the total energy demand.

As a result, in order to increase the percentage of the solar energy, other PVs could be installed on the roofs of the dwellings. Table 4.7 listed the calculation process of the green energy from roof-mounted PV panels.

Table 4.7 Calculations of Solar Energy Consumed

The Roof Area in one Dwelling = 102 m^2 / 3 floors = 34 m^2
The Number of PV Panels = 918,000 m^2 / (1m x 0.6 m) = 1,530,000
The Average Solar Irradiation on the dwelling facade = 214.63 KWh / m^2/year

The Annual energy collected by PVs = 214.63 KWh/ m^2 x 34 m^2= 7,279 KWh
The Annual energy produced by PVs = 7,279 kWh x 4.5%= 328.4 kWh
The Total Energy Consumption in the dwelling = 5,406 KWh / year
The Total Energy produced by PV panels = 191.23 KWh + 328.4 KWh = 519.63 KWh
The Percentage of Energy Produced by PVs in one dwelling = 519.63 KWh / 5406 KWh x 100% = 10.4 %

It indicates that if the PV arrays with the total efficiency of 4.5% are applied, the electricity generated only covers 10.4% of the energy demand in one dwelling. However, in order to offset more electricity demand, other options are worth considering. One of the options is the increase of the efficiency.

According to the US National Renewable Energy Laboratory (Richard M.G., 2008), the new technology of the copper indium gallium diselenide (CIGS) thin-film cell enables the PV efficiency to reach 19.9% efficiency in testing at the lab. As a result, if this technology is applied in Dongtan, there is a great potential to increase the solar electricity. Table 4.8 shows the relationship between the efficiency of the PV panels and the percentage of the solar electricity that would cover the total demand. However, the expense of the high efficiency PV panels is very expensive, because the new technology applied needs high input.

The results shows that if the PV panels with the efficiency of 20% are installed in the windows and on the roofs of 27,000 dwellings, the solar energy is converted to the green electricity of 70,995 MWh, having the potential to offset 48.6% of energy demand in dwellings, and 30.1% of that in all of the buildings. The disadvantage of the PV panels is the expensive input. While if the comparatively cheap PV panels with the efficiency of 4.5% are applied, the electricity only covers 10.4% of the energy demand in dwellings, which is not sufficient. The other limit of the PV panels is that the semi-transparent material would reduce light penetration into the dwelling, however because of the large windows, the light consumption would not increase much.

Table 4.8 Solar Energy Generated by the PV Panels with Different Efficiency

PV-Pannel Efficiency (%)	Electricity Generated (KWh)	Percentage of the Solar Electricity among Dwellings (%)	Percentage of the Solar Electricity among all of the Buildings(%)
4.5%	15,974,010	10.9%	6.8%
10.0%	35,497,800	24.3%	15.0%
20.0%	70,995,600	48.6%	30.1%

4.2.3 Carbon Dioxide Savings from the PV system

As calculated in the previous section, the electricity produced by the PV systems reaches 70,995 MWh in the dwellings. Carbon savings could be calculated out if the electricity is produced by fossil fuels. According to ECON19 (2000), the conversion factor of carbon from electricity is 0.46 kg CO_2 /KWh. As a result, the carbon savings from the PV systems in all of the dwellings equal to:

0.46 kg CO_2/KWh x 70,995 MWh x 1000 KWh/MWh = 32,658 t

As a result, every year approximately 32,658 t of CO_2 will be kept by the using of PV panels in the dwellings.

4.3 Wind Energy Application

4.3.1 Selection of Wind Turbines and Location

Other than solar energy, wind energy is another significant renewable energy which is suitable to be used in Dongtan Project. Dongtan is located in the mouth of the sea and Yangzi River, so it is probably suitable for wind energy production technologies. With reference to the weather data, there is 86% of the time throughout the whole year having the wind speed higher than 2m/s. Respectively there is 22% of the time with the wind speed of 2 m/s and 19% of the time with 3 m/s. The average wind speed is 3 m/s. It indicates that in the city wind turbines might not be so efficient because wind turbine is only considered when the wind speed is 6m/s or more.

On the other hand, the cost of the small-scale wind turbine is comparatively high (DARE), if the wind local speed in high enough. Especially due to the compact form of the town, the small-scale wind turbines will not operate efficiently. The safety issue is another potential disadvantage with regard to the compact city form. As a result, wind farms should be considered in this matter.

According to the statistic from Chongming Government, the wind speed in the eastern part of Chongming Island is much higher than the city.(Chongming Government). In wetland, the annual average wind speed is 6.7m/s. As a result, wind farms could be installed in the eastern part of the Chongming Island, inorder to efficiently convert the wind energy into electricity, not only for the Eco-city, but could also be sold to Pudong in Shanghai.

As can be seen in Section 3.1, the prevailing wind is from southeast in summer and from northwest in winter. As a result, the preferred locations of wind farms are shown in Figure 4.7. It is estimated that the dimension of the south farm is 2 km x 1.5 km. The wind turbines will be spaced at a tangent to the prevailing wind direction, facing east. The distance between each wind turbine in the line should be 300m, in order to get the highest efficiency. As a result, there are six wind turbines in a line, and two rows in total. The north-west site has the same dimension as the south one. As a result, another 12 wind turbines could be located in the two farms.

Figure 4.7 Wind Farm Location

According to the Shanghai Government Plan, large scale wind turbines with 1.5MW rated capacity are suggested to be installed. Figure 4.8 lists the technical data from GE wind turbines.

Technical data

	1.5sle	1.5xle
Operating Data		
Rated Capacity:	1,500 kW	1,500 kW
Temperature Range: (with ColdWeather Extreme Package) Operation: / Survival:	-30°C – +40°C -40°C – +50°C	-30°C – +40°C -40°C – +50°C
Cut-in Wind Speed:	3.5 m/s	3.5 m/s
Cut-out Wind Speed (10 min avg.):	25 m/s	20 m/s
Rated Wind Speed:	14 m/s	12.5 m/s
Wind Class – IEC:	IIa V_{e50} = 55 m/s V_{are} = 8.5 m/s)	IIIb (V_{e50} = 52.5 m/s V_{ave} = 8.0 m/s)
Electrical Interface		
Frequency	50/60 Hz	50/60 Hz
Voltage	690V	690V
Rotor		
Rotor Diameter:	77 m	82.5 m
Swept Area:	4657 m²	5346 m²
Tower		
Hub Heights:	65/80 m	80 m
Power Control	Active Blade Pitch Control	Active Blade Pitch Control

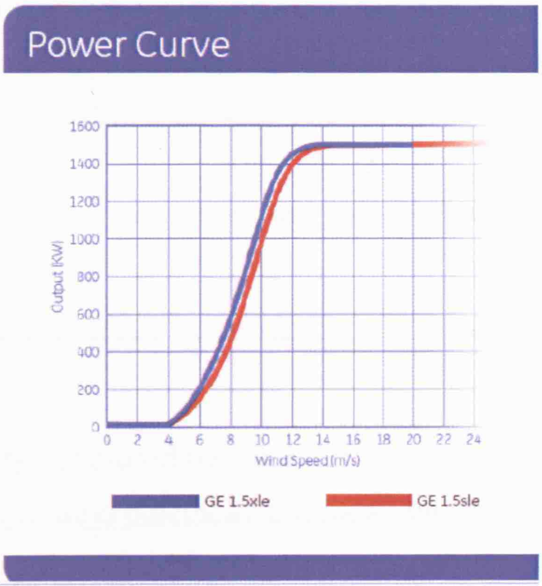


Figure 4.8 GE 1.5 MW Manufacturing Data

4.3.2 Calculation of the Energy Savings from Wind Turbine

From the data, it is shown that the rotor diameter is 77m , the swept area is 4657m^2. As designed by Shanghai Government, ten 1.5MW wind turbines will be installed in the Chongming. It shows that the rated speed is approximately 11m/s. When the wind speed is 6.7m/s, the power produced by the wind turbine is 500 KW. It could be roughly estimated that the wind energy produced by the wind-turbine is 36,792 MWh .as can be seen in Table 4.9.

According to the study by Ozgenera (2007), the average energy conversion (power factor) ratio of 1.5MW wind turbine is 35%.

Table 4.9 Energy Produced by 24 Wind turbines

The Energy Produced by the 1.5 MW wind turbine

= 500 KW x 24 h/d x 365 d/y = 4380 MWh/y

The energy converted to use = 4380 MWh/y x 0.35 =1533 MWh

The value from the Electricity= 1533 x 0.4 = £613.2

The total energy produced by wind farm = 1533 MWh x 24 = 36,792 MWh

The Percentage of the Total Demand that could be offset by Wind Electricity = 14.5%

As calculated in Table 4.9, the total electricity generated by wind turbines is 36,792 MWh per year. A certain amount of the wind electricity produced by wind could be sold to the national grid. However, although the price of wind electricity is between £0.06/KWh and £0.05/KWh, which is higher than the conventional electricity price of £0.04/KWh, the energy saving is comparatively high. The calculation of the energy saving is listed in Table 4.10. Energy saving is represented by Carbon cost.

Table 4.10 Carbon Savings by Wind

Annual electricity generated by wind = 36,792 MWh = 36,792,000 KWh

Conversion Factor of Electricity = 0.46 Kg CO_2 / KWh

Carbon Saved by Wind = 17,007,120 Kg CO_2 = 17,007 t CO_2

Based on Table 4.10, every year approximately 17,007 t of CO_2 will be kept by the using of wind turbines in the Dongtan city.

4.4 Biomass- Combined Heat and Power for District Heating

4.4.1 Biomass and CHP Plant Output Calculations

In Shanghai, cooling loads are always covered by the energy for running the air-conditioning systems. While traditionally, there are rarely heating systems because people do not have the habitat to use heating in winter. However, nowadays, during the winter, air-conditioning systems are more and more applied to make people comfortable. As a result, the district heating systems are necessary to be introduced into the eco-city.

According to the literature, many large scale projects are willing to use Distributed Energy, for both heating and cooling. As nowadays, governments encourage the design of reducing carbon emission on new development. According to the Code for Sustainable Homes, distributed energy is addressed in a proactive and creative manner. (Land securities, 2008). In Dongtan Project, using distributed system could help to achieve the target of **"zero carbon emissions". Particularly**, the compact form of buildings would save cost of grid and reduce the heat loss. As discussed in this section, the heat from Biomass-CHP system is going to be distributed around the town, so as to offset the heating and cooling load.

In order to achieve the Level 6 of Code for Sustainable Homes, which is zero net carbon emissions, the solution involving district energy system holds the best potential for delivering the energy demands without contributing to the carbon emissions. (Land Securities, 2008)

Due to the local situation near wetland area of Dongtan, rice husks from the waste product of rice mill are utilized as biomass in CHP systems. It indicates in the Arup report that the rice husks with the weight between 261tt and 285t produce 1 MWh energy per year. The density of the rice husk is just over 1 t/m3. As a result, in order to produce 1 MWh energy by biomass, 261 m^3 to 185 m3 rice husks are needed. The large quantity of rice husks is needed to be stored near the rice fields, because usually rice is harvested over a short period. As a result, the storage areas are located near the rice fields, which help to save the transport energy. The biomass CHP plant could be located near the central rice mill, the waste heat from which could be utilized drying paddy process.

According to the previous discussion, the pressurized air-free process is applied in the plant. The location of the plant is shown in Figure 4.13. The location is not near the town, so as to prevent the noise and pollution affecting the residents. It is however located close to the eco-farms, where the traffic access for feed stock delivery is easy, and the grid connection to the town is not comparatively expensive.

The plant is designed to occupy the overall site area of 15,000 m^2, with the building area of 7,000m^2. The peak electrical out put would be 4.9 MW for the first phase.

Figure 4.13 Location of the Biomass-CHP Plant

The calculations of the energy output from the Biomass-CHP plant are listed in Table 4.11. According to Biomass Handbook, the efficiency of the biomass plant is assumed to be 38%..(Biomass Energy Data Book, Edition 1,2004)

Table 4.11 Calculation of the Biomass Produced from the Biomass-CHP System

The operation hours = 7000 h/y
Peak Load = 4.9 MW
The Maximum Energy Produced = 4.9 x 7000 x 38% = 13,034 MWh
If water is pre-cooled before introduced into the system, the output power will be increased by 10%. Thus :
The Maximum Energy Produced = 13,034 x (1+0.1) = 13,164 MWh

In addition, the heat to electricity ratio in this system is assumed to be 1.5:1 right now,(Yangzi ,2006) so the electricity provided by the plant is 5,265 MWh and the heat energy is 7,898 MWh. The electricity could be offered to the eco-city as well as connected to the grid.

Based on the calculation results from section 4.2, the heating load of dwellings is 3,724 KWh, and the cooling load is 836KWh. Therefore, this biomass-CHP system could provide service for approximately 4000 dwellings.

4.4.2 Selection and Layout of Pipe Networks

On the next step, the selection of pipes has great effect on the amount of heat loss. Generally, super insulation of the pipes is necessary to minimize the heat loss. As stated in the literature review, .water pipes with 20cm insulation thickness are used with the supply temperature around 140℃ to 180℃ and return temperature 105℃-135℃. As a result, the heat loss from the pipes would be 6.46%.

The distribution of the pipe works is demonstrated in Figure 4.14.The red pipes represent the supply tubes, while the blue ones are for return water. The "tree" layout will minimize the grid length. The total length of the pipes is estimated to be approximately 6000m, providing service for 1800 dwellings.

Figure 4.14 The Layout of the District Pipe Systems

4.4.3 Carbon Savings From Biomass-CHP Plant

As a matter of fact, the thermal energy that is provided to the town is 7,388 MWh as calculated in Table 4.13. In addition, the electricity produced by biomass CHP system is 5,265 MWh. It could be delivered either to the town or to the national grid. In this matter, the carbon saving of biomass electricity is shown in Table 4.12 too.

Table 4.12 Carbon Savings by CHP system

Thermal Energy Produced by Biomass system = 7898 MWh
Heat Transferred to the Dwellings = 7898 MWh x (1-6.46)% =7388 MWh
Conversion Factor of Coal = 0.30 $KgCO_2$/KWh (BRE,2000)
Carbon Savings by District Energy system= 2,216,448 ($KgCO_2$)
Annual Electricity Generated by Wind = 5265 MWh
Conversion Factor of Electricity = 0.46 Kg CO_2 / KWh
Carbon Savings by Green Electricity = 2,422,176 ($KgCO_2$)
Carbon Savings by Biomass-CHP Plants = 4,638,624 ($KgCO_2$)

5. Discussion

5.1 Discussion and Findings

From the previous sections, the carbon savings from solar energy, wind energy, and biomass-CHP are calculated out. The results are gathered in the Table 5.1

Table 5.1. Energy Generated from Renewable Energy

Energy Type	Energy Produced (MWh)	Carbon Savings ($KgCO_2$)
Solar Energy	70,995	32,658
Wind Energy	36,792	17,007
Biomass + CHP: Heat	7898.4	2,216
Electricity	5265.6	2,422

According to the previous calculation, the solar energy and wind energy generates approximately 30.1% and 14.5% of the total energy demand in all buildings in Dongtan. As a result, in order to achieve the target that all energy used in buildings is renewable energy, the biomass-CHP plant should generate 55.4% of the total energy demand. The tendency goes with the target that biomass electricity occupies the greatest part of the green energy in Dongtan by 2020. However, with reference to Table 5.1, the energy generated from biomass occupies the least part in green electricity. Because of the leak of biomass energy, the energy consumption demand will not be offset as designed.

From above figures, it shows that the annual energy from PV panels as designed generated most energy, which indicates that the technologies and energy generating efficiency of PV arrays are comparatively high. It is the same as predicted results in PV Vision Report.

While according to the Target of Dongtan energy by 2020, the renewable energy generated from biomass should occupy the largest part of the green energy. There might be three ways that could help increase the biomass electricity. First, the number of biomass plants could increase. Secondly, the capacity of the biomass plant is only 4.9 MW, which is not enough. Thirdly, the efficiency of the biomass plant is low, which has the potential to improve greatly. If several improvements are applied in Dongtan, the target of contributing to generating 66% of the green electricity is possible to achieve.

According to Essen, RWE Innogy Cogen GmbH in Germany has developed a biomass-plant with rated power of thermal energy 30 MW and electricity 8 MW. The efficiency of the plant reaches up to 70%. (Essen, 2008)

Table 5.2 Calculation of the Biomass Produced from the Biomass-CHP System

The operation hours = 7000 h/y
Peak Power of Thermal Energy = 30 MW
The Maximum Heat Energy Produced = 30 x 7000 x 70% = 147,000 MWh
Peak Power of Electricity = 8 MW
The Maximum Electricity Produced = 8 x 7000 x 70% = 39,200 MWh
The Total Carbon Savings by Biomass-generated Energy = 0.46 Kg CO_2 / KWh x 39,200 MWh x 1000 KWh/ MWh + 0.30 Kg CO_2 / KWh x 147,000 MWh x 1000 KWh / MWh = 62,132 t

As a result, the total energy that generated from biomass-CHP plant is 186,200 MWh, including 147,000 MWh heat energy and 39,200 MWh electricity. As a result, the total green energy produced by solar, wind, and biomass reaches up to the amount of 291,500 MWh.

The calculation of the energy that should be generated to achieve the target that green energy should cover the total energy demand is shown in Table 5.3.

Table 5.3 The Energy that should be Generated by Biomass-CHP Plant

The Total Energy Demand = 236 GWh
If biomass-CHP plant would generate 55.4% of the energy (according to the previous calculation) , thus:
The Total energy should be generated by biomass-CHP plant = 236 x 0.554 = 130.7 GWh

Comparing the results of the calculation from Table 5.2 and Table 5.3, the energy produced by the biomass-CHP plant exceed the target of Dongtan. As a result, a certain percentage of the energy could be sold to the national grid. The benefits and carbon savings from it are calculated in Table 5.4.

Table 5.4 Benefits and Carbon Savings Dongtan offers to other places.

Energy sold to grid:	(186.2-130.7) GWh x 10^6 x £0.06/ KWh = £3,330,000
Carbon Savings	(186.2-130.7) GWh x 0.46 Kg CO2 /KWh = 25,530 t (ECON 19)

According to the data listed above, the percentage of the Generated Energy from different renewable energy type is shown in Figure 5.1.

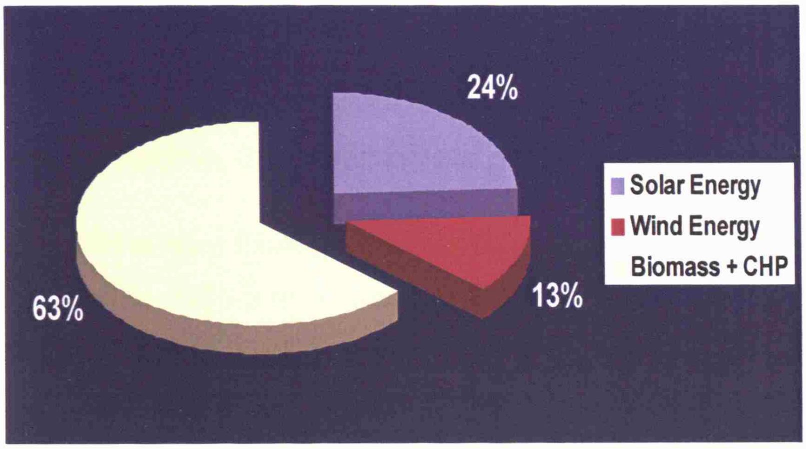


Figure 5.1 The Percentage of Generated Energy for Different Types

Based on Figure 5.1, the green energy generated by biomass-CHP plant occupies 63% of the total energy. In the target of the Dongtan Energy by 2020, the percentage of the contribution by biomass energy is aimed to generate 66% of the energy. Compared the design in this paper with the target by 2020, the energy from biomass-CHP plant almost reaches the target. The design brings the total benefits of £3,330,000 and additional carbon savings of 25,530 t for other places.

5.2 Sensitivity Study

Except from the renewable energy, water is another factor that will have impact on the performance of the sustainable community.

Recycled water and Rain water collection will have impact on the community performance. The calculation of savings from rainwater is shown as follows.

According to the data from Shanghai Water Bureau, the average daily water consumption is between 350 and 500l/person. As a result, it is estimated that the annual water consumption for each Shanghai resident is 134 m^3. Waste water recycle is the most important way to save water use in the city. It helps to get the most from limited water supplies. In addition, the use of rainwater also can be used for toilet-flushing or washing machines.

As can be seen in Section, the water recycle process is shown in Figure 3.4.

According to the data from Shanghai Water Bureau, the annual average rainfall in Shanghai is 1163.5 mm throughout 133 years.(Shanghai Water Bureau) The amount of rainwater can be stored by the rainwater collection system is calculated as shown in Table 5.5 . Based on the design, there are 166 residential buildings with the roof area of 49,800m^2. The public buildings have the roof are of 12,450 m^2. So the total roof area is 62,250 m^2. Based on the equation shown below, the available rainwater is 48,204 m^3. In Shanghai, the monthly rainfall varies greatly with the climate, so the Seasonal Reduction Coefficient is 0.85. The Early Loss Coefficient is determined by the water quality, which is 0.87. (Cao, 2002)

Table 5.5 Rainwater Collection

Equation	Coefficient
$Q = \Psi \cdot \alpha \cdot \beta \cdot A \cdot (H \cdot 10^{-3})$	Q: Available Rainwater on roof, m3
$= 0.9 \times 0.85 \times 0.87 \times 62{,}250 \times (1163.5 \times 10^{-3})$	Ψ: Surface Flow Coefficient, 0.9
$= 48{,}204$ m^3	α: Seasonal Reduction coefficient 0.85
	B: Early loss coefficient 0.87
	A: Roof Projected Area ,m2
	H: Annual Rainfall ,mm

Therefore, the rainwater availability is 48,204 m^3, which can be used to watering the green, spraying the ground, and flushing the toilets. As a result, the water saving by rainwater collection is calculated in Table 5.6.

Table 5.6 Annual saving by Rainwater

Annual Water Consumption in Dongtan by 2010 = 134 m^3 /p x 5,000 p = 670,000 m^3

The Water Saving by Rainwater = 48,204 m^3 / 670,000 m^3 = 7.2%

6. Conclusions

Based on the case studies and the target of Dongtan Eco-city in Shanghai, the design of renewable energy application pattern is proposed in this paper. The types of renewable energy including solar energy, wind energy and biomass integrated with Combined Heat and Power system have the competency to cover 100% of the total energy consumption demand in all of the buildings, among which the contribution from the biomass-CHP integrated plants occupies 55.4% of the total demand. The energy generated from all of the green resources reaches 291 GWh of energy, among which biomass integrated with CHP would cover 63% of the total energy. The amount that exceed the total demand could be sold to the national grid..

The energy consumption of all of the buildings calculation is based on TAS model results. The typical 3-storey attached dwelling with the area of 102 m^2 represents the residential houses in Dongtan Eco-city. The heating load and cooling load in the dwelling house is estimated to be 4,560 MWh/year/dwelling . Besides, based on the monitoring data from the BedZED, all of the buildings in Dongtan Project is predicted to consume the energy with total value of 236 GWh. Compared with the energy generated from the green sources, the remaining energy of 55.5 GWh could be sold to the national grid, which brings the benefit of £3,330,000.

Apart from the other possibilities to reduce consumption, this paper focuses on the contribution from renewable energy. For solar energy, the total area of 1,452,600 m^2 thin-film BIPV with high efficiency of 20% is applied in the windows and on the roofs of dwellings. The total electricity of 70,995 MWh is generated , which covers 30.1% of the total energy demand in all of the buildings in Dongtan. While if the normal PV panels with the low efficiency of 4.5% are applied, only 15,974 MWh solar energy is produced, covering 6.8% of the total demand.

In wind farms near eco-city, twenty-four 1.5 MW GE wind turbines are installed to generate green energy of 36,792 MWh, offsetting 14.5 % of the total energy demand in Dongtan.

Biomass-CHP integrated plant with the peak load of 4.9 MW runs to provide both heat and electricity to the buildings, providing 5,265 MWh electricity and 7,897 MWh heat energy. If new technology with high efficiency and high capacity is applied, the biomass-CHP plant has the potential to generate the electricity of 39,200 MWh and heat energy of 147,000 MWh, covering 55.4% of the energy demand in total, and meanwhile selling the remaining 55,500 MWh of energy to the national grid.

One of the benefits from using renewable energy includes the amount of carbon savings. Biomass energy contributes to reducing 62,132 tCO_2 per year, followed by the solar energy and wind with the value of 32,658 tCO_2 and 17,007 tCO_2 respectively.

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Appendices

Appendix A

The monitoring results from BedZED.

House type	*Worst case scenario (kWh / year)*	*Typical scenario (kWh / year)*	*Best case scenario (kWh / year)*
1 bedroom flat	4343	1723	989
2 bedroom flat	4867	2028	1189
3 bedroom maisonette	5863	2657	1663
3/4 bedroom town house	6137	2882	2449

Table 1: The predicted annual electrical energy requirements for each house type at BedZED

	Heat energy (kWh / winter day) [1]	*Electrical energy (kWh / day)* [1]	*Total energy (kWh / winter day)* [1]
Residential	1270	723	1993
Offices	300	189	489
Community facilities	396	456	852
CHP	850	51	51
Other e.g. streetlighting	n/a	251	251
Total daily energy (kWh)	2816	1670	3585
Total annual energy (kWh)	**882,977** [2]	**640,028** [3]	**1,212,755** [4]

[1] Chapter 4, Predicted Energy Use, Ove Arup and Partners, 1999
[2] Adjusted to allow for reduced summer heating demands and 20% losses in distribution
[3] Adjusted to allow for 5% losses in distribution
[4] Adjusted to allow for reduced summer heating demands and distribution losses

Table 2: The predicted daily and annual heat and electrical energy requirements at BedZED

Appendix B

ASITHRU-30-SG: technical sheet

ASITHRU-30-SG Other solar panel by Schott Solar

manufacturer	Schott Solar
nominal efficiency	4.5 %
nominal power rating	27 Watt
max voltage	1000 Volt

Electrical characteristics during Standard Test Conditions (STC)

voltage at OC	49 Volt	current at SC	1 Amp
voltage at MPP	36 Volt	current at MPP	0.75 Amp
δV/C°	-151.9 mVolt/C°	δI/C°	0.8 mAmp/C°
tolerance +ve	10 %	tolerance -ve	10 %

Electrical characteristics during load conditions (25 C°, 300 W/m²)

voltage at OC	42.595 Volt	current at SC	0.306 Amp
voltage at MPP	32.859 Volt	current at MPP	0.225 Amp

Material characteristics

incidence coefficient *(θ)*	95 %	specific heat capacity	920 J/kg/°C
absorbtion coefficient *(α)*	70 %	emission coefficient *(ε)*	85 %

Mechanical characteristics

length	600 mm	width	1000 mm
thickness	? mm	weight	14 kg

list all models from Schott Solar
list all manufacturers

(Reference: ecoWEB)

Appendix C

The land use pattern is more compact in eco-cities. They have the following advantages:

First of all, the increase of the block density will reduce the footprint. In Bedington Zero Fossil Energy Development (BedZED) eco-village, the four building-blocks have residential densities of over 100 homes per ha not including work units. If such pattern is applied in the rest of UK, the footprint in UK will reduce by 20%.

Secondly, convenient traffic is accomplished. In Sino-Singapore Tianjin Eco-city, the residential area and the social facility area are integrated into a "sustainable community", which means the people could live a convenient daily life without travelling a lot outside their own houses. In BedZED, functional services such as living, working, and leisure are gathered in one building. It not only save the commute time between home and working places, but also reduce the energy consumption in transport everyday. In Beijing Olympic City, the other social facilities such as hospitals, gyms, post offices and stores are located within the walking distance of 300 m from each house, which enables the residents to walk instead of using cars.

Thirdly, the houses in BedZED and Vauban district in the city of Freiburg im Breisgau are arranged in line in order to maximum the solar energy reaching each house.

Finally, the houses in the Vauban districts and BedZED are attached together. Compared to the stand-alone houses, the most significant advantage of the attached ones are the less external area and the less heat loss from the wall. Besides, it is more convenient to apply the central heating system in the attached houses, which could save energy consumption.

Appendix D

Building fabric and material in eco-cities had the benefit of keeping more heat inside buildings to reduce the heat consumption in winter.

The fabric of the houses in the eco-community tends to concentrate maximizing passive design strategies. For instance, in BedZED, the fabric incorporates 300mm minimum super-insulation, triple glazing, south-facing glazed sunspaces, thermally massive floors and walls and good daylight design. The insulation with the width of 300mm successfully prevents the heat from transferring from inside to outside. Because of the super insulation performance of the house fabric, there is no need for the central heating system.

The roof material could be green roof, such as ACROS Fukuoka building in Japan. They are lightweight, and suitable for large areas. On one hand, the green roofs tend to absorb heat from the surroundings and hence reduce the radiation from the warmer roof to the inside of buildings in summer. While in winter, some of the heat is radiated to the inside of the building after the sunset to warm the room. With the help of green roofs, the interior temperature is more constant; hence reduce the cooling load during the summer and heating load in winter. On the other hand, they help to absorb 50% to 90% of rainwater depending on how much it rains, which is particularly suitable for the humid weather, such as Shanghai.

More interestingly, construction materials used in eco-cities are more environmental friendly and sourced near the sites in order to reduce the shipping consumption. In BedZED, materials are all sourced from within 55km of the site. Almost the entire workspace steel frame was reclaimed, and all internal timber partitions were fabricated from reclaimed material. The traditional build techniques are adopted, slightly modified to match the requirements of the engineer's building-physics strategy.

Appendix E

In order to reduce water consumption, the collection of rainwater and the recycling of the water for life are necessary to be adopted in eco-cities.

In Germany, rainwater is usually clean enough to use as urban water, while the purification treatment is necessary for the secondary use of the sewage from the houses. Collection of the rain water is particularly economical when the water is used for year-round applications such as toilet flushing, washing machines, cleaning and production processes. In the most reliable and effective systems, rainwater falling on the building roof is recovered and filtered through a self-cleaning system before being collected in a cistern. A two stage purification process, with no maintenance requirements is carried out within the cistern, and the resulting water is stored in a cool, dark place. The recycled water is then distributed using low-energy pumps, the whole network being clearly labelled "not drinking water".

In addition to the collection of rainwater, re-use of the sewage economically save the water consumption as well. In Germany, most of the sustainable communities treat the sewage by biological wastewater treatment technologies. Particularly, the water treatment technology of "infiltration cell" has been successfully utilized. However, the infiltration rate could be either too slow or too fast. In Freiburg im Breisgau, the innovative water treatment system is successfully used, which aims to be a complete, stand-alone water management system. Used water from kitchens and bathrooms is cleaned by an on-site ventilated sand filtration system and then used for flushing the vacuum toilets. Sewage and organic waste are collected in a tank, while the biogas produced from their decomposition is used to fuel cookers, and the residue used as fertilizer.

Appendix F

D1: Food Chain Pattern

It was investigated in the previous research that the average distance from farms and kitchens was 2000 miles, which meant that the shipping of the food would cost a lot of energy over such a long distance. In order to avoid the unwanted food delivery at BedZED, the community tried to rebuild a connection between urban and suburb area, so as to build a local food chain. In this way, the local agricultural commodity stores could provide fresh seasonal farm products, rather than introducing organic food from the other side of the planet.

D2: Waste Recycling and Treatment

The recycling sites at BedZED are located at various points which are easy-accessible places around the community, which enable the residents and the company send the recycled waste conveniently.

With respect to the waste treatment solutions, BedZED show the possibility of remove all of the recyclable materials such as glass, plastic, metal, paper before putting into the Municipal Solid Waste (MSW) extractor, which help to increase the output gas energy value. In order to increase the MSW treatment efficiency, a pre waste sorting plant is necessary. In the plants, the recyclable material will be selected out in order to be made full use of the potential. By the use of the sorting process, the recyclable waste will be totally removed. In addition, the plant is fully automated. Thus, the electricity input is necessary to be taken into consideration.

Municipal solid waste is a difficult problem to deal with. The conventional combustion process of the solid waste will produce a lot of air pollution. Given that the incineration of waste is not acceptable, other options of the waste treatment are taken into account in Dongtan.

According to the research by Hong, (Hong,2006), the waste from average Shanghai person is calculated in the following table. Compared with the waste produced by British people and Norwegian people, the amount produced by Shanghai people is equivalent to 77% and 52% of them respectively.

Calculation of Waste in Dongtan

	Waste (kg/d/p)	Waste (kg/y/p)	Total waste in Dongtan by 2010 for 5,000 people (t/y)	Total waste in Dongtan by 2020 for 80,000 people (t/y)
Urban Waste	0.04	15.59	77.96	1247.28
Kitchen Waste	0.01	2.18	10.88	174.04
Rural Waste	0.29	106.48	532.39	8518.28
Total	0.34	124.25	621.23	9939.60

According to Hong (2006), the MSW in Shanghai has high moisture content of 50% to 60%.

It is referred from the Arup report that the MSW by 80,000 people in Dongtan will offer the electricity output of approximately 2,218 MWh.

Apart from intruding local waste, Dongtan could also input the waste from adjacent areas. It is designed that the plant has the processing capacity of 4 tonnes/h.. It is estimated that the waste released by 282,353 people could be treated in this plant, producing electricity of 4,380 MWh/y. The investment cost of the plant would be 17m pounds.