TECHNOLOGY • RESEARCH HIGHLIGHTS • VISIONS • SCIENCE

105

Eco-efficient solutions for China's urbanization

Guidebook

Satu Paiho | Salla Palos | Miimu Airaksinen | Mia Ala-Juusela | Guangyu Cao | Ismo Heimonen | Ha Hoang | Riikka Holopainen | Antti Knuuti | Mari Sepponen | Terttu Vainio | Teemu Vesanen | Mikko Virtanen | Jyri Nieminen

VTT TECHNOLOGY 105

Eco-efficient solutions for China's urbanization

Guidebook

Satu Paiho, Salla Palos, Miimu Airaksinen, Mia Ala-Juusela, Guangyu Cao, Ismo Heimonen, Ha Hoang, Riikka Holopainen, Antti Knuuti, Mari Sepponen, Terttu Vainio, Teemu Vesanen & Mikko Virtanen
VTT Technical Research Centre of Finland

Jyri Nieminen
Finnmap Consulting

ISBN 978-951-38-7993-8 (URL: http://www.vtt.fi/publications/index.jsp)

VTT Technology 105

ISSN-L 2242-1211
ISSN 2242-122X (Online)

JULKAISIJA – UTGIVARE – PUBLISHER

VTT
PL 1000 (Tekniikantie 4 A, Espoo)
02044 VTT
Puh. 020 722 111, faksi 020 722 7001

VTT
PB 1000 (Teknikvägen 4 A, Esbo)
FI-02044 VTT
Tfn +358 20 722 111, telefax +358 20 722 7001

VTT Technical Research Centre of Finland
P.O. Box 1000 (Tekniikantie 4 A, Espoo)
FI-02044 VTT, Finland
Tel. +358 20 722 111, fax +358 20 722 7001

Technical editing Anni Repo

Eco-efficient solutions for China's urbanization
Guidebook

Ekotehokkaat ratkaisut Kiinan kaupungistumiseen – Opas. **Satu Paiho, Salla Palos, Miimu Airaksinen, Mia Ala-Juusela, Guangyu Cao, Ismo Heimonen, Ha Hoang, Riikka Holopainen, Antti Knuuti, Mari Sepponen, Terttu Vainio, Teemu Vesanen, Mikko Virtanen & Jyri Nieminen.** Espoo 2013. VTT Technology 105. 176 p.

Abstract

China is one of the largest economies in the world and also one of the world's biggest energy consumers. China is a big country, with five major climates requiring different building and building energy solutions. In addition, China's urbanisation rate is over 40%. It is estimated that the proportion of urban dwellers out of the whole population will be about 70% by the end of 2030.

The EESCU project (Eco-efficient Solutions for China's Urbanization) aimed at building the theoretical and practical bases in order to support the implementation of the Finnish eco-efficient solutions and concepts in Chinese markets. This is the final report of the project which summarizes the main results.

The project started with an inventory phase focusing on basic building energy-related issues in China. These covered urbanisation, climate regions, energy regulations and current building energy consumption values based on the available statistics and literature. The total energy consumption in 2009 was 3 billion tons of standard coal. The project had three main research sections, namely "Zero Energy Buildings", "Regional Energy Solutions" and "Energy Renovations of Existing Buildings". All these sections consisted of theoretical sections, concept developments and examples from both Finland and China. In addition, building commissioning in China was discussed, pilots and show cases from real buildings were reported and business-related topics covered.

In "Zero Energy Buildings", the concept of net zero energy buildings was first specified, providing a definition of zero energy building, energy use and supply mismatch, and explaining the differences between the cold climate zero energy concept and the warm climate zero energy concept. After the concept overview, examples of zero energy buildings were presented from Europe and China. Then, the low-exergy principle referring to the quality of energy was discussed with examples.

In "Regional Energy Solutions", the system selection and performance evaluation principle was introduced first. This was followed by the design guidelines for district energy systems and the principles of a district energy system concept. In this study, the main emphasis was on renewable energy production technologies and, therefore, their basic production means were also discussed. Renewable energy solutions often require some energy storage solutions as well, so the basic means were also covered. This section ended with case study examples.

Building renovation is rare in China. The real average life span of China’s residential buildings is only 25 to 30 years. For non-residential buildings, it is often even shorter. The factors affecting the low renovation rate and the renovation process have been discussed and then energy-efficient and modular technologies for building renovation have been reported.

Keywords Eco efficiency, China, urbanisation, pilot project

Ekotehokkaat ratkaisut Kiinan kaupungistumiseen
Opas

Eco-efficient solutions for China’s urbanization – Guidebook. **Satu Paiho, Salla Palos, Miimu Airaksinen, Mia Ala-Juusela, Guangyu Cao, Ismo Heimonen, Ha Hoang, Riikka Holopainen, Antti Knuuti, Mari Sepponen, Terttu Vainio, Teemu Vesanen, Mikko Virtanen & Jyri Nieminen.** Espoo 2013. VTT Technology 105. 176 s.

Tiivistelmä

Kiina on yksi maailman suurimmista talouksista ja energian kuluttajista. Kiina on suuri maa, jossa on viisi merkittävää ilmastovyöhykettä. Erilaiset ilmastovyöhykkeet vaativat erityyppisiä rakennuksia ja rakennusten energiaratkaisuja. Kiinan kaupungistumisvauhti on yli 40 %. On arvioitu, että kaupunkilaisten osuus koko väestöstä on noin 70 % vuoden 2030 loppuun mennessä.

EESCU-projektin (Eco-efficient Solutions for China’s Urbanization) tavoitteena oli rakentaa teoreettiset ja käytännön lähtökohdat suomalaisten ekotehokkaiden ratkaisujen ja konseptien viennille kiinalaisille markkinoille. Tämä on EESCU-projektin loppuraportti, joka tiivistää tutkimushankkeen päätulokset.

Projekti alkoi inventaariovaiheella, joka keskittyi tavanomaisiin rakentamisen energiaan liittyviin asioihin Kiinassa. Inventaariovaihe kattoi kaupungistumisen, ilmastovyöhykkeet, energian säännöstelyt sekä nykyisen rakennuskannan energiankulutuksen perustuen saatavilla olevaan tilastotietoon ja kirjallisuuteen. Vuonna 2009 Kiinan energiantuotanto kulutti 3 miljardia tonnia hiiltä.

EESCU-projektilla oli kolme pääasiallista tutkimusosuutta: ”Zero Energy Buildings” (nollaenergiatalot), ”Regional Energy Solutions” (alueelliset energiaratkaisut) ja ”Energy Renovations of Existing Buildings” (olemassa olevien rakennusten energiakorjaukset). Kaikki osuudet koostuvat teoriasta, konseptien kehittämisestä sekä esimerkeistä Suomesta ja Kiinasta. Lisäksi selvitettiin rakennuttamisen käytännöt Kiinassa, esiteltiin pilotti- ja portfolioprojektit toteutetuista kohteista sekä raportoitiin yritystoimintaan liittyviä aiheita.

Luvussa ”Zero Energy Buildings” määritellään aluksi nollaenergiatalojen konsepti. Luvussa selitetään käsite nollaenergiatalo, käsitellään energiankäytön ja tuotannon epäsuhtaa sekä selitetään eroja kylmän ilmastovyöhykkeen ja lämpimän ilmastovyöhykkeen konseptien välillä. Konseptien yleiskäsittelyn jälkeen esitellään esimerkkejä toteutetuista nollaenergiataloista Euroopassa ja Kiinassa. Luvun lopuksi selitetään case-esimerkein matalaexergia-periaatetta, jolla viitataan energian laatuun.

Luvussa ”Regional Energy Solutions” käsitellään aluksi järjestelmän valinta ja suorituskyvyn arviointiperiaate. Tämän jälkeen selitetään suunnittelun suuntaviivat alueellisille energiajärjestelmille ja käsitteen alueellinen energiajärjestelmä periaatteet. Tutkimuksen pääpaino on uusiutuvissa energiantuotantoteknologioissa. Siksi luvussa käsitellään uusiutuvien energiatuotantoteknologioiden bruttotuotantoa. Luvussa selitetään myös uusiutuvilla energiaratkaisuilla tuotetun energian varastointia. Luku päättyy case-esimerkkeihin.

Korjausrakentaminen on harvinaista Kiinassa. Kiinalaisten asuinrakennusten todellinen keskimääräinen käyttöikä on vain 25–30 vuotta. Muilla kuin asuinrakennuksilla se on vielä alhaisempi. Julkaisussa käsitellään korjausrakentamisen vähäisen määrän ja korjausrakennusprosessin syitä. Lopuksi esitellään energiaa säästäviä ja modulaarisen rakentamisen teknologioita korjausrakentamisessa.

Avainsanat Eco efficiency, China, urbanisation, pilot project

Preface

Nowadays China is experiencing the world's most extensive urbanisation. It seems obvious that the population in rural areas will show a marked decrease by 2030. Urbanization has stimulated rapid economic growth. For the past 20 years, building energy consumption in China has been increasing at more than 10% a year. In 1996 building stocks accounted for about 24.1% of total national energy use, rising to about 27.5% in 2001, and were projected to increase to about 35% in 2020. Although carbon emissions per capita in China are low, its total emissions are second only to the US. Residential buildings constructed after 2000 will account for half of the existing civil buildings by 2015. About 70–80 million m^2 of new inefficient residential and office buildings will be built each year.

The EESCU project (Eco-efficient Solutions for China's Urbanization) is aimed at building theoretical and practical foundations for eco-efficient solutions to support the implementation of the Finnish concept of High-Tech EcoCity by utilizing and developing the social platform established in VTT's earlier China-related projects. The main research contribution to the project was made by the VTT researchers. In addition, some Chinese input – mainly in joint meetings – was provided by Tongji University, from Dalian University of Technology (DUT) and from Shenyang Jianzhu University (SJZU).

The project was funded by Tekes – the Finnish Funding Agency for Technology and Innovation, VTT Technical Research Centre of Finland and the following companies: Fatman Oy (software and services for real estate owners), Fidelix Ltd (building management and security systems), Rautaruukki Corporation (steel and steel construction), FinEnerco Ltd (heating network and ventilation ductwork balancing, and energy solutions), GES – Global EcoSolutions Ltd (commercialization of knowledge and technologies for ecological urban units and districts), Jeven Ltd (air conditioning equipment), Tengbom Eriksson Architects former Eriksson Architects Ltd (architectural design), Markku Kauriala Ltd (fire engineering and fire safety design) and Rakennusliike Reponen Oy (construction). The work was directed by the steering group, which included Reijo Kohonen (GES) as a chairman, Mika Airaksela (Reponen), Patrick Eriksson (Tengbom Eriksson Architects), Kari Hein (Fatman), Juha Kauriala (Markku Kauriala), Asko Kiiskinen (FinEnerco), Kalle Korhonen (Jeven), Virpi Mikkonen (Tekes), Arto Ranta-Eskola (Rautaruukki), Jussi Rantanen (Fidelix) and Markku Virtanen (VTT).

Contents

1. Introduction

The EESCU-project Guidebook consists of seven chapters, which are based on the EESCU-project's work packages 1–4.

Chapter 1 is the introduction. It sets the general framework for urbanisation in China. The chapter explains the difference between the climate regions of China. The introduction reviews the general situation of current Chinese building stock. The chapter reviews the challenges of high building energy consumption due to the current state of the building stock and the different needs in different climate regions.

Chapter 2 is based on EESCU WP2. Chapter 2 Zero energy building describes the definition of zero energy building, energy use and supply mismatch, and explains the differences between the cold climate zero energy concept and the warm climate zero energy concept. After the concept overview, examples of zero energy buildings are presented from Europe and China. Then the low exergy principle is discussed and examples are given.

Chapter 3 is based on EESCU WP3. Chapter 3 Regional energy solutions focus on the concept of integrated renewable energy system, and especially on the design and use of integrated renewable energy systems at a district level. The chapter summarizes the model for system selection and performance evaluation, general design guidelines and alternative renewable energy production technologies. The chapter ends with examples of district cases from China and Finland.

Chapter 4 is based on EESCU WP4. Chapter 4 Energy renovations of existing buildings describes the factors and processes involved in energy renovations of existing buildings. It explains energy-efficient and modular technologies and introduces Chinese renovation markets. This chapter combines the present advanced building technology with the novel concept of renovation.

Chapter 5 is based on EESCU WP2. Chapter 5 Building commissioning work in China explicates what standards are involved and how the Chinese commissioning process is conducted.

Chapter 6 reviews pilots and presents cases focusing on real building examples both in China and Europe, mainly in Finland.

Chapter 7 deals with Business-related Issues, which covers China's future economic prospects, the main barriers to energy efficiency in buildings, Chinese construction sector stakeholders and the ESCO service concept from the Chinese point of view.

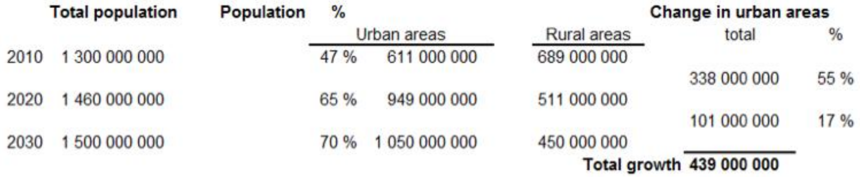
Chapter 8 discusses conclusions.

1.1 Urbanization in China

Nowadays China is experiencing the world's most extensive urbanization, and this urbanisation is expected to remain brisk in the future. By the end of 2010 every second Chinese was already living in a city, and this development continues so that the proportion of urban dwellers in the whole population will be about 70% by the end of 2030. (FINPRO 2011.)

Based on the latest population census in China in September 2010, and estimates of development, it seems obvious that the population in rural areas will have fallen dramatically by 2030. During the same period urbanisation will continue at a fast pace, particularly in the next 10 years, when it will grow 50%. See Table 1. (FINPRO 2011.)

Table 1. Population in cities and in rural area (FINPRO 2011).



	Total population	Population %				Change in urban areas	
		Urban areas		Rural areas		total	%
2010	1 300 000 000	47 %	611 000 000	689 000 000			
						338 000 000	55 %
2020	1 460 000 000	65 %	949 000 000	511 000 000			
						101 000 000	17 %
2030	1 500 000 000	70 %	1 050 000 000	450 000 000			
					Total growth	**439 000 000**	

Figure 1 shows the country's GDP in relation to the increase of urbanisation. Urbanization has stimulated rapid economic growth.

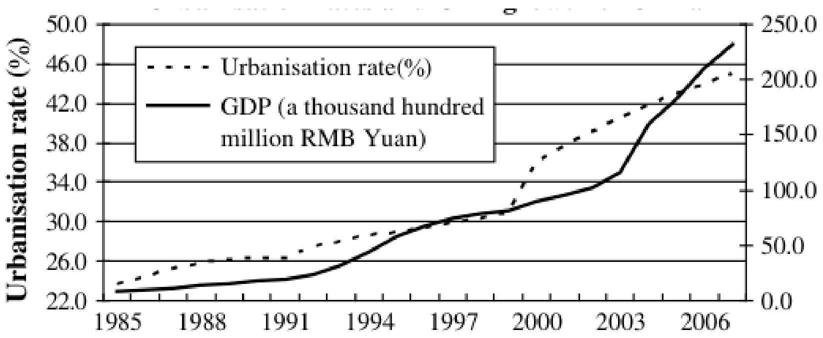


Figure 1. China's GDP in relation to the increase of urbanisation (FINPRO 2011).

The fast-developing Chinese construction industry is facing great challenges in many respects. In recent years, around 2 billion square meters of new buildings have been completed every year in China. Table 2 shows that the urbanized area increased from 12,856 km^2 in 1990 to 32,521 km^2 in 2005. There are around a 40 billion square meters of total floor area now in Chinese buildings. Completed new building areas from 1985 to 2004 totaled more than 10 billion square meters. It is predicted that the per capita housing area in China will reach 30 m^2 and 38 m^2 between 2010 and 2020, respectively, with an additional 30 billion square meters of floor space completed by 2020. (Yao et al. 2005.)

Table 2. The increase of the urbanized area (Yao 2009).

Year	1990	1995	2000	2005
Urbanised Area	12,856	19,264	22,439	32,521

1.2 Climate regions in China

China is a large country with an area of about 9.6 million km^2. Approximately 98% of the land area stretches between a latitude of 20°N and 50°N, from the subtropical zone in the south to the temperate zone (including warm-temperate and cool-temperate) in the north. The maximum solar altitudes vary a great deal, and there is a large diversity of climate, especially the temperature distribution during winter. China is situated between Eurasia (the largest continent) and the Pacific Ocean, allowing the monsoons to be well developed. A monsoon climate therefore tends to be dominant, with a marked change of wind direction between winter and summer, as well as a seasonal variation of precipitation according to whether the maritime monsoon advances or retreats. Moreover, characteristics associated with continental climates can be identified with warmer summers, cooler winters and a larger annual temperature range than other parts of the world at similar latitudes. China also has a complex topography, ranging from mountainous regions to flat plains. The land surface could be described as three steps descending from west to east. At the top is the Qingzang Plateau in the southwest, with an average altitude of about 4,500 m above sea level. The second step is the Kunlun and Qilian ranges to the north of the Qingzang Plateau and the Hungduan Mountain to the east. The terrain falls steeply to around 1,500 m above sea level. Passing through the mountains on the eastern edge of this step, the altitude decreases to less than 1,000 m above sea level, forming the third step – the plains of the Yangzi River valley and northern and eastern China. These diversities and complexities have led to many different climates with distinct climatic features. (Wan et al. 2010.)

In China, the most commonly adopted climate zone classification is the one for thermal design of buildings, which is concerned mainly with conduction heat gain/loss and corresponding thermal insulation issues. It has five major climate types, namely severe cold, cold, hot summer and cold winter, mild, and hot summer and warm winter. This simple climate classification is concerned mainly with conduction heat gain/loss and corresponding thermal insulation issues. The zoning criteria are mainly based on average temperatures in the coldest and hottest months of the year. The numbers of days that the daily average temperature is below 5 °C or above 25 °C are counted as the complementary indices for determining the zones. Figure 2 shows an overall layout of the five major climates. Because of the varying topology and hence elevations, there are nine regions – both the severe cold and cold climates have three regions. (See Figure 3.)

Figure 2. Geographical distribution of the five major climates and the five cities.

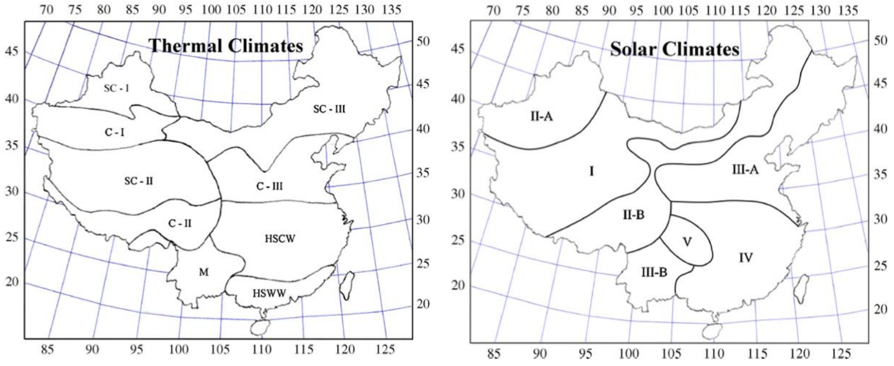


Figure 3. Geographical layout of the thermal and solar climates across China (SC = severe cold, C = cold, HSCW = hot summer and cold winter, M = mild, HSWW = hot summer and warm winter) (Wan et al. 2010).

In order to gain an idea about building design implications, the monthly average clearness index (Kt) within each solar zone was determined, and a summary is shown in Figure 4. The monthly values of Kt ranged from 0.22 in January in Solar-V to 0.69 in November in Solar-I.

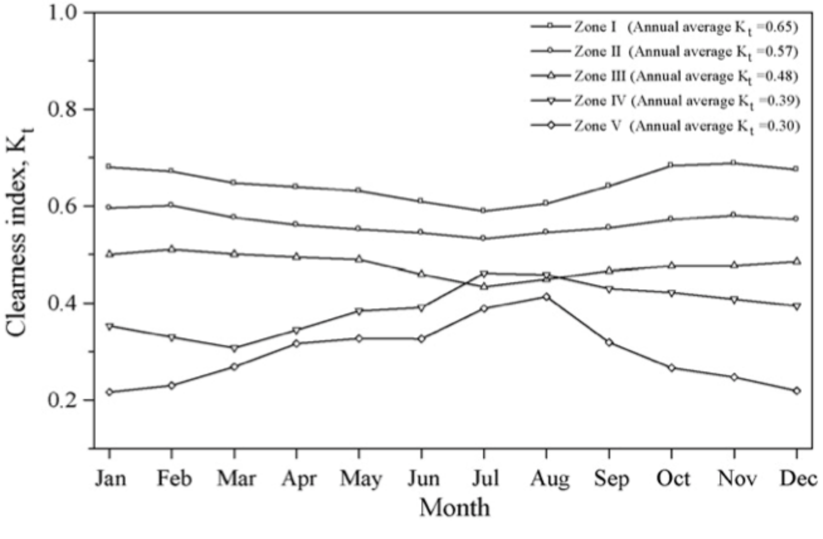


Figure 4. Monthly variations of clearness index (Kt) in the five solar zones (Wan et al. 2010).

Despite the relatively low Kt in winter, passive solar heating should be able to meet a significant proportion of the heating requirements (except in the Sichuan Basin, where the monthly Kt was just over 0.2 during the heating season) (Wan et al. 2010). See Figure 5.

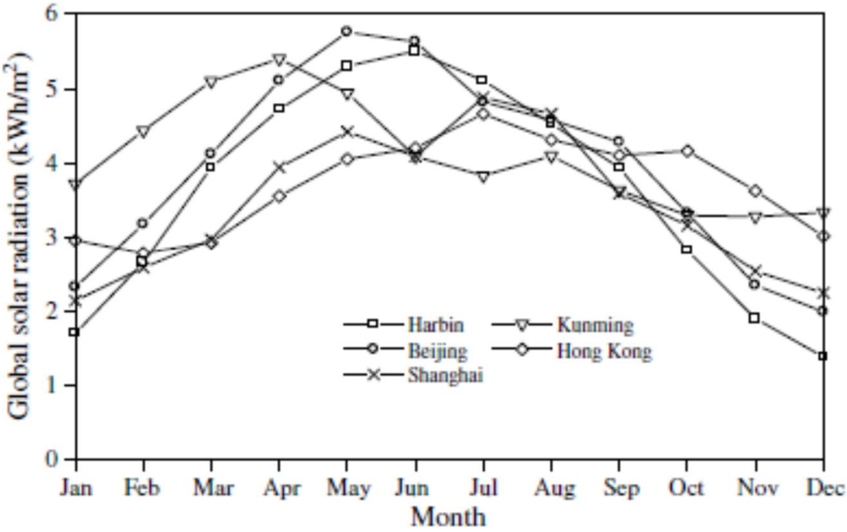


Figure 5. Monthly mean daily global solar radiation in the five cities (Yang and Jiang 2008).

For simple buildings, builders can choose to follow a prescriptive list of measures. For large and complex buildings, the designer needs to achieve a certain energy budget (typically expressed in energy use per square meter) in order to comply with the requirements. (FINPRO 2011.)

1.3 China’s energy regulations

As mentioned previously, China is divided into five climate zones. The climate varies from cold (winter temperatures correspond to the temperatures of Central Finland) to humid and hot summer and warm winter climate. National energy regulations are set as relative values due to differences in climate zones.

Recent regulations are based on the total energy needs of a building, which is defined by the 1980 energy consumption data:

- Public buildings: energy saving 50% compared to the 1980 average.
- Residential buildings: energy saving 75% compared to the 1980 average.

The following standards are for energy-efficient design of buildings:

- Design standard for energy efficiency of residential buildings in severe cold and cold zones JGJ 26-2010.
- Design standard for energy efficiency of residential buildings in hot summer and cold winter zone JGJ 34-2010.
- Design standard for energy efficiency of residential buildings in hot summer and warm winter zone JGJ 75-2003.
- Design standard for energy efficiency for public buildings GB 50189-2005.
- Standard for regional regionalization for architecture GB 50178-93.

The Central Government and cities guide construction through energy certification. The National Three Star rating system is based on the use of standard buildings and the five criteria presented in Table 3. Buildings developed by the Central Government require the highest three-star rating, and buildings developed by the District Government require a two-star rating. The Ministry of Science and Technology analyses the buildings developed by the Central Government and the Regional Government. The Science and Technology Office analyses the buildings developed by the Regional Administration.

Table 3. Criterion of certification.

Building	Building type Location Province Climate (region)
Energy efficiency	% in comparison to 1980 level
Water consumption	m^3/a
Use of resources	Materials efficiency
Indoor climate	Heat comfort Air conditioning
Building use	Building maintenance Heating and air conditioning systems control Use of standards

The City of Beijing began a program in 2012, with the aim of achieving a three-star rating for all new buildings. During the program, 22 building projects have been implemented. The energy consumption analysis will be carried out by the end of 2013.

Certification is also set as the basis for energy-efficient building aid. The amount of aid on the basis of energy efficiency is:

- 85 RMB/m^2 (about 11€), for energy savings of at least 75% in comparison to 1980 levels → a building gets a three-star rating.
- 60 RMB/m^2 (about 8€), an energy savings of at least 60% in comparison to 1980 levels → a building gets a two-star rating.

When apartment building construction costs are 1000–2000 RMB/m^2 in conventional apartment buildings, to aid is 4–8% at best.

Building energy regulations development is heavily dependent on the economic development of China. The foreseeable structural changes in China's economy (the service sector is growing, the energy-efficiency of the traditional industrial production is improving) and construction development growth related to urbanisation affect the economic development of China. China's Central Government has set a goal (the 11th 5-year plan) that in less than 20 years 75% of the Chinese people will live in cities (now 42%). This means a 400–500 million people increase in cities. At the same time, the amount of living space is increasing. Urbanization means the total growth of apartment building gross area from the current 35 billion m^2 to 70 billion m^2.

1.4 Building energy consumption

The GDP of China in 2010 was estimated to be ranked second in the world, and just behind the USA. At the same time, the total energy wastage ranks second in the world. According to statistical data, coal wastage is more than 2.74 billion tons in 2008, which ranks first in the world, oil wastage in 2008 is about 0.36 billion tons, which ranks second in the world, and natural gas wastage in 2008 is about 80.7 billion m^3. Total energy consumption in 2009 was 3 billion tons of standard coal. Figure 6 shows a graphical representation of Chinese energy structure in 2009. (L.-Q. Liu et al. 2011.)

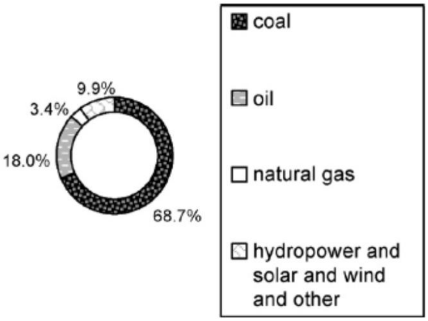


Figure 6. Chinese energy structure in 2009 (L.-Q. Liu et al. 2011).

Chinese energy supply is highly dependent on primary resources, such as coal, oil, and natural gas. Coal energy, the most important fossil fuel in China, had a share of 68.7% in 2009. Renewable energy and nuclear energy has a share of 9.9%. Oil energy has a share of 18%, and the remaining 3.4% is supplied by natural gas. (L.-Q. Liu et al. 2011.)

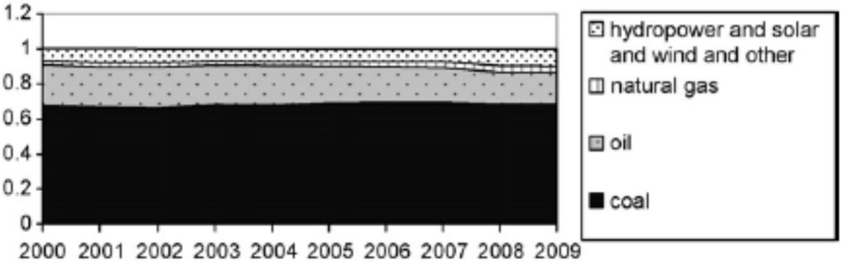
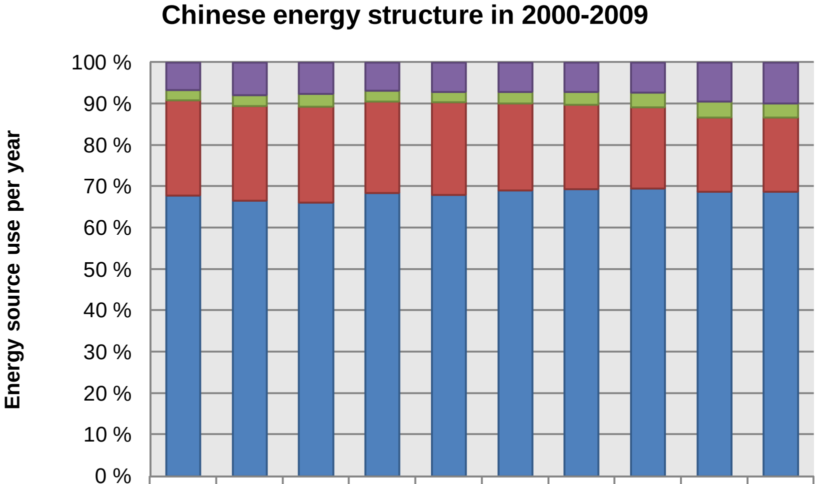


Figure 7. A graphical representation of Chinese energy structure in the past 10 years (L.-Q. Liu et al. 2011).

Table 4. Statistical data of Chinese energy structure in the past 10 years modified from L.-Q. Liu et al. (2011).



	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
🟪 Other	6,7 %	7,9 %	7,7 %	6,8 %	7,1 %	7,1 %	7,2 %	7,3 %	9,5 %	9,9 %
🟩 Natural gas	2,4 %	2,6 %	3,0 %	2,6 %	2,6 %	2,8 %	3,0 %	3,5 %	3,8 %	3,4 %
🟥 Oil	23,2	22,9	23,4	22,2	22,3	21,0	20,4	19,7	18,0	18,0
🟦 Coal	67,8	66,7	66,3	68,4	68,0	69,1	69,4	69,5	68,7	68,7

As shown in Figure 7 and Table 4 above, coal as China's most important energy resource has not changed its status in the past 10 years, and the main change is that the share of renewable energy and nuclear energy in the whole energy structure was 9.9%, up by 3.2% from 2000. The energy structure is very inappropriate to sustainable development, and the unlimited use of coal has given China serious environmental problems such as water pollution, greenhouse gas emissions and acid rain. Especially in primary energy there will be a rapid depletion situation, and a sustainable low-carbon economy is the inevitable direction for China's future development. (L.-Q. Liu et al. 2011.)

Over more than 30 years of rapid industrialization, China has also burned substantial energy and thereby produced a large amount of greenhouse gases. The average increase in per capita energy consumption has reached 15% since 2000, and this upward trend is also apparent for solid and liquid fuels; see Figure 8. (You 2011.)

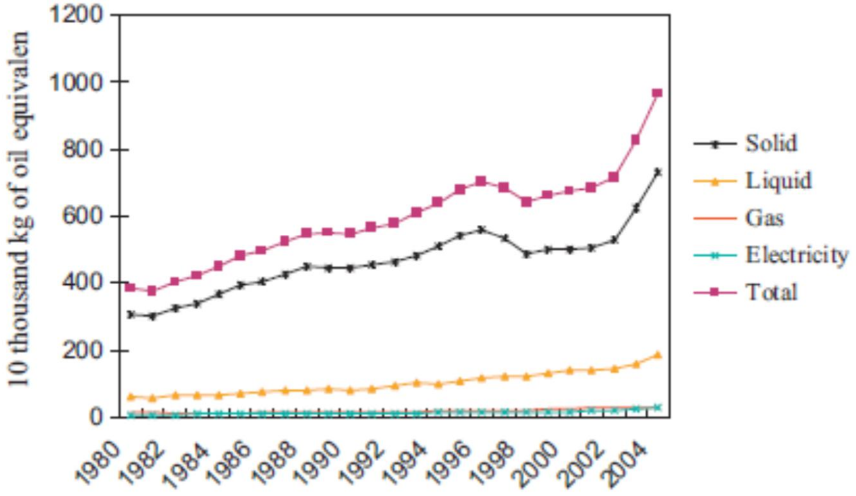


Figure 8. China's per capita energy consumption by type (United Nations Statistical Division; see You 2011).

1.4.1 Building energy consumption (BEC) – five categories

According to the statistical data, the total area of China's residential buildings is about 40 billion m^2. The total national building energy consumption (TNBEC) is 16 billion tons of standard coal, which accounts for 20.7% of the total end-use energy consumption. According to the current energy usage, building energy consumption (BEC) can be divided into the following 5 categories: BEC of rural areas; BEC of heating zones in North China where a heating system is needed; BEC of urban residential buildings excluding heating; BEC of common public buildings without heating and electricity consumption of large-scale public buildings. Energy consumption of each category is shown in Table 5. (Cai et al. 2009.)

Table 5. The building energy consumption (BEC) categories in China. (Note: standard coal is converted into electricity according to power generation efficiency, 1 kWh 1⁄4 350 g standard coal.) (Cai et al. 2009.)

Items		**Building area (billion m^2.)**	**BEC (per year)**	**BEC (kWh/m^2)**
Rural areas (exclusive of non-product energy consumption)		24	30 million tons of s.c/a (equal to 89 billion kWh) 90 billion kWh/a	7.5 kWh/m^2
Northern cities for heating		6.5	130 million tons of s.c./a (equal to 370 billion kWh)	57 kWh/m^2
Cities excluded heating	Residential	10	200 billion kWh	10-30 kWh/m^2
	Common public buildings	5.5	160 billion kWh	26–60 kWh/m^2
	Large-scale public buildings	0.5	100 billion kWh	70–300 kWh/m^2
	Subtotal	16	460 billion kWh	29 kWh/m^2
Total		40	160 billion kWh of s.c/a (equal to 550 billion kWh)	25 kWh/m^2 equal to 9 kg of s.c/a

It can be deduced from Figure 9 that there are two obvious BEC problems in China:

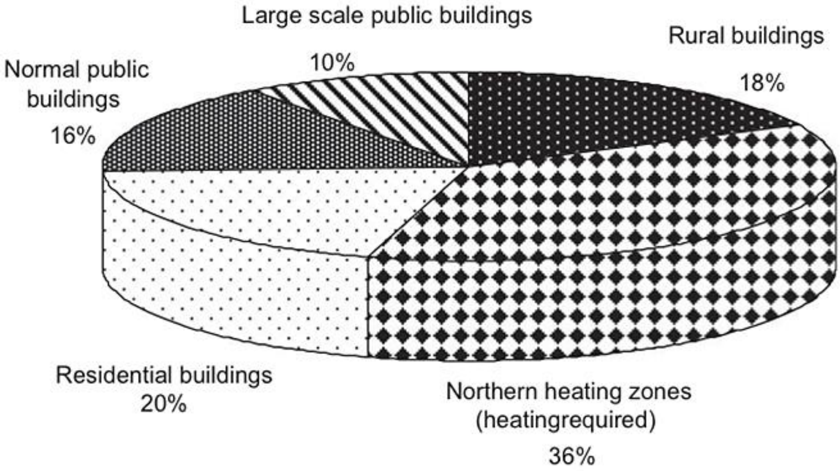


Figure 9. The BEC proportions of different building types in China (converted to %) (Cai et al. 2009).

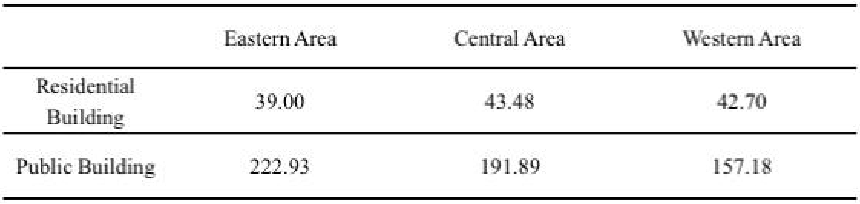
The first problem is the low energy efficiency and huge energy waste of large-scale public buildings. Large-scale public buildings are defined as those buildings with more than 20,000 m^2 gross floor area. According to the survey by Jiang and Yang (2006), the BEC of large-scale public buildings in China had reached 100 billion kWh per year, which accounts for more than 20% of the TNBEC by 2004, while the total area of these buildings was about 500 million m^2, which only constituted less than 4% of the national urban building area. That is why large-scale public buildings are regarded as the high-density field of energy consumption. This survey also shows that the energy systems of large-scale public buildings are inefficient, with huge energy waste due to a lack of energy consumption limitation and undeveloped management. BEC of these kinds of building is up to 70–300 kWh/m^2, which is 10–20 times that of common residential buildings. Therefore, these building have large saving potential in terms of energy consumption. (Cai et al. 2009.)

The second problem is the high BEC for heating in North China, which takes a large percentage from TNEC. The area of north China, where heating is needed in winter, constitutes 70% of the area of the entire country. The building area of north China is about 6.5 billion m^2 and the BEC for heating accounts for a high percentage of 45% of total national urban building energy consumption (TNUBEC). Due to the poor thermal insulation of the building envelope and low efficiency of heating systems, energy consumption for heating is about 2–4 times higher than that of Northern Europe with a similar climate. (Cai et al. 2009.)

1.4.2 Energy consumption in buildings in different regions

From the point of view of geographical distribution, the overall energy consumption per construction area (excluding heating) of all types of buildings is higher in eastern and central areas than in western areas; see Table 6. (FINPRO 2011.)

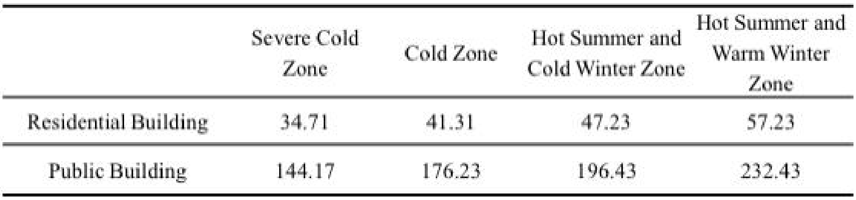
Table 6. Analysis of energy consumption per unit area of civil buildings in different regions, excluding heating (kWh/m^2/a) (FINPRO 2011).



	Eastern Area	Central Area	Western Area
Residential Building	39.00	43.48	42.70
Public Building	222.93	191.89	157.18

Energy consumption per unit area of all types of buildings gradually increases from the coldest zone to the hottest zone (Table 7). When thinking about energy consumption in China, the region having the greatest potential in terms of energy savings is the hot summer and warm winter zone in the eastern part in China. In this zone provinces such as Fujian, Guangdong, Hong Kong, Macao, Guangxi and Hainan island have the greatest savings potential. (FINPRO 2011.)

Table 7. Analysis of energy consumption per unit area of civil buildings in different climate zones, excluding heating (kWh/m^2/a) (FINPRO 2011).



	Severe Cold Zone	Cold Zone	Hot Summer and Cold Winter Zone	Hot Summer and Warm Winter Zone
Residential Building	34.71	41.31	47.23	57.23
Public Building	144.17	176.23	196.43	232.43

The relationship between monthly energy use and indoor and outdoor thermal environment is further illustrated in Figure 10. Temperature refers to the average value of the morning, noon and evening in the period examined.

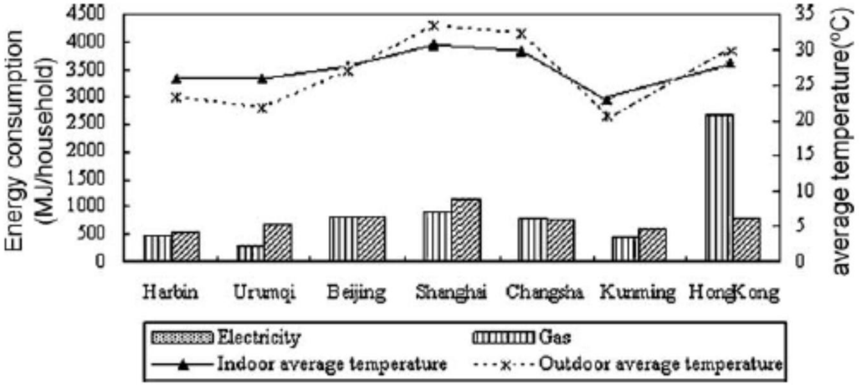


Figure 10. Monthly mean energy use amounts and indoor temperature in the seven cities (Chen et al. 2010).

1.4.3 Commercial building energy consumption

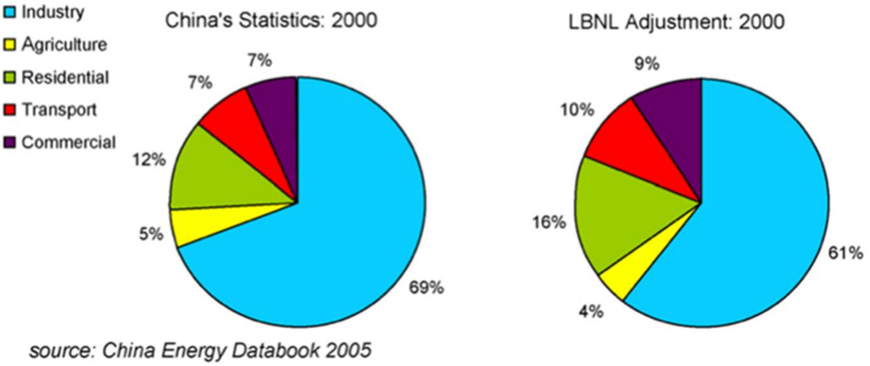
China's official energy statistics provides supply side information. Energy data reports production of all energy sources in all regions, and consumption by fuel type and sector. However, the statistics have limited information on energy demand by end-use. Further, China uses a different classification system for energy reporting (relative to OECD countries), so the sectoral energy breakdown has long been questioned. It is particularly an issue for building energy consumption. Many analysts, and even government agencies, use this figure to make judgments on China's current energy status and make projections for China's energy future – which could thus be misleading or wrong. In addition, a lack of information on end-use demand could also lead to an inadequate ability to capture the potential for efficiency improvements and impacts of efficiency policies and programs. (Zhou and Lin 2009.)

One study (Sinton 2001) points to problems with statistics published by China's National Bureau of Statistics (NBS). It states:

"Changes in definitions and coverage have raised questions about the reliability of trends observed over time. Problems like misreporting or non-reporting and difficulties in adapting systems of data collection to rapidly changing social and economic structures have led to doubts about the accuracy of some indicators, especially economic output. Some sectoral and categorical definitions do not accord with accepted practices in many other countries, and contradictions between some statistics have appeared."

By comparison, the commercial sector represents 13% of total final energy use in IEA countries (Chen et al. 2010). The discrepancy may be attributable to China's unique classification system. For example, a work unit (or, *danwei)* is a place of employment, and also a living quarters. Many residential and commercial energy uses associated with industrial enterprises or plants have thus been reported as industrial energy use. Similarly, many transportation oil uses were treated as energy use within the industrial, agriculture, and building sectors. (Zhou and Lin 2009.)

As a result, it is estimated that the industry sector uses only 61% of the total energy, rather than 69% as reported in the statistics. Simultaneously, commercial sector energy use is up to 9%, with 16% for the residential sector and 10% for the transportation sector in 2000 (Figure 11). That implies that commercial energy consumption should be 127.8 Mtce instead of 88.9 Mtce in the statistics, a 44% increase.



source: China Energy Databook 2005

Figure 11. Total energy use (Zhou and Lin 2009).

In China, building energy consumption, which belongs to the consumption section of energy statistics, is divided into many fields of energy consumption in the statistical departments and statistics are never taken separately as a single kind of energy consumption. For example, residential energy consumption usually falls under the energy consumption of civil living. (Chen et al. 2008b.)

1.4.4 Promoting the large-scale application of renewable energy in the construction industry

Applying renewable energy to buildings is an important measure for reducing traditional BEC and optimizing the BEC framework. In order to resolve the problems arising from the higher cost of the buildings using renewable energy and the low market acceptance at the initial stage, China has started to execute a financial support policy and since 2006 has provided a subsidy to those pilot projects using renewable energy. The policy mainly supports those projects applying solar energy and ground geothermal energy, which include hot water supply systems with solar energy, solar photovoltaic power generation, and ground-source heat pumps, and so on. (Cai et al. 2009.)

China’s government is attempting to make the solar energy water heater compulsory, and some provinces and cities have started to introduce it.

1.4.5 Establishing the building energy efficiency certification

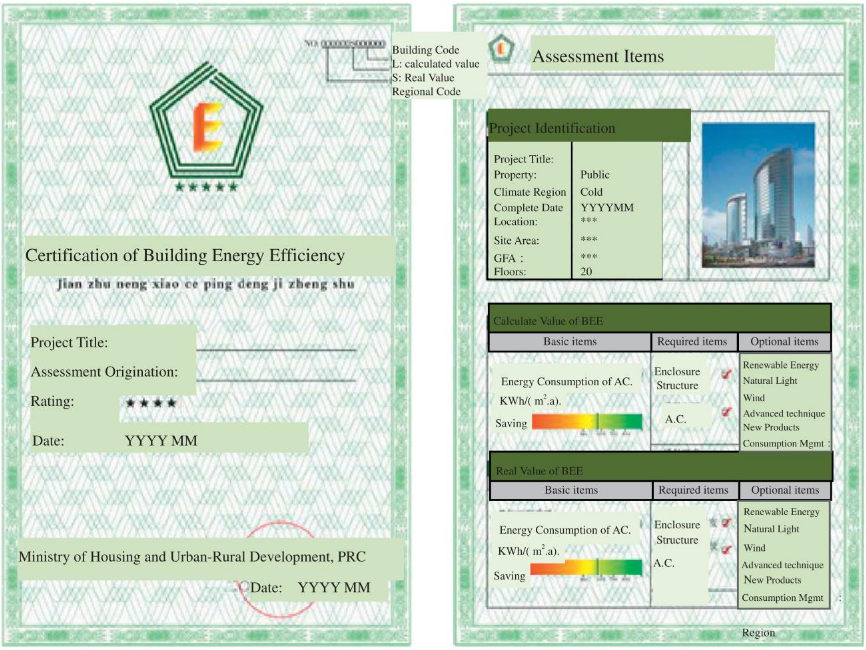
Referring to other counties’ certification systems, China established her own building energy-efficient certification system in 2008. The first level of this system has three items: basic, compulsory and optional. The basic and compulsory items are combined with the current energy-efficient design standard.

The basic item is the unit energy consumption by heating air-conditions, which is calculated according to the energy-efficient design standard.

The compulsory item is that requirements (excluding the basic item), stated by the energy-efficient design standard, have to be reached by an enclosed structure and the heating air-conditions.

The optional item is an addition score for those systems and techniques achieving higher energy efficiency than the energy-efficient design standard required, such as the renewable energy, energy recycle technique, cooling and heating storage technique, and so forth.

Five levels are used by China’s building energy-efficient certification system to indicate building energy efficiency. The energy-efficient design standard is regarded as the benchmark of this system. Figure 12 shows a sample of China’s residential building energy-efficient certification.



NO. 000000S000000

Building Code
L: calculated value
S: Real Value
Regional Code

★★★★★

Certification of Building Energy Efficiency

Jian zhu neng xiao ce ping deng ji zheng shu

Project Title: ____________________

Assessment Origination: ____________________

Rating: ★★★★

Date: YYYY MM

Ministry of Housing and Urban-Rural Development, PRC

Date: YYYY MM

Assessment Items

Project Identification

Project Title:	
Property:	Public
Climate Region	Cold
Complete Date	YYYYMM
Location:	***
Site Area:	***
GFA :	***
Floors:	20

Calculate Value of BEE

Basic items	Required items	Optional items
Energy Consumption of AC. KWh/(m^2.a). Saving	Enclosure Structure ✓ A.C. ✓	Renewable Energy Natural Light Wind Advanced technique New Products Consumption Mgmt :

Real Value of BEE

Basic items	Required items	Optional items
Energy Consumption of AC. KWh/(m^2.a). Saving	Enclosure Structure ✓ ✓ A.C.	Renewable Energy Natural Light Wind Advanced technique New Products Consumption Mgmt :

Region

Figure 12. China’s building energy-efficient certification sample (Cai et al. 2009).

Applying for energy-efficient certification is compulsory for those new large-scale public buildings which apply for financial support from government, apply for national province demonstrate project and for green building certification. For residential and common public buildings, they can choose whether to apply for the energy-efficient certification. (Cai et al. 2009.)

2. Zero energy buildings

2.1 Zero energy buildings concept

The definition of a net zero energy building (Net ZEB) is mostly based on the annual balance between energy demand and energy generation on the building site.

This publication forms the scientific definition of a Net ZEB based on the concepts found in the literature referred to above, in particular on Sartori et al. (2010b) framework and on the results of the EPBD recast (2010).

The EPBD recast provides an energy calculation framework and system boundaries associated with the definition to specify which energy flows are taken into account. The scientific definition described in the text below refers to a **net zero energy building (nZEB)** which is an on-grid ZEB. The framework accounts for all energy used in buildings including thermal (cooling and heating, also district heating) and electricity demand (appliances, lighting). These definitions here reflect a general and uniform methodology and represent a good model for the impact on national energy systems. In order to generate design guidelines, local conditions are to be taken into account in detailed definitions. Later in this section, the analysis is expanded to develop the concept and in later reports design guidelines will be developed.

A Net ZEB is not meant to be an energy autonomous building, such as described in (Goetzberger et al. 1994). The concept has been developed based on the experience that seasonal energy storage is not feasible on the scale of a single building due to a lack of technology, namely for high exergy energy demands such as electricity. A Net ZEB operates in connection with an energy infrastructure such as the power grid.

Buildings and grids exchange energy in the form of energy carriers that have been converted from natural resources. The definition is based on delivered and exported energy. Delivered energy is the energy, expressed per energy carrier, supplied by the grids to buildings. Exported energy (EPBD recast) or feed-in energy (Sartori et al. 2010b) is the energy, expressed per energy carrier, flowing from the buildings to the grids and used outside the system boundaries. The concept of balance between these two, together with any form of interaction with the grids, is central to the definition of Net ZEBs.

The performance of a building (or community, depending on where the system boundary is defined) is defined on the EPBD recast (2010) as follows:

Energy performance of the building: calculated or measured amount of energy delivered and exported, actually used or estimated to meet the different needs associated with a standardized use of the building, which may include, inter alia, energy used for heating, cooling, ventilation, domestic hot water, lighting and appliances.

The energy performance of an nZEB is, therefore, expressed with a numeric indicator of primary energy. This primary energy indicator (also primary energy rating) sums up all delivered and exported energy (electricity, district heat/cooling, fuels) in a single indicator with primary energy factors per energy carrier. These primary energy factors may be based on national or regional weighted averages or as a specific value for on-site production. In this context, the following definitions are proposed:

Net Zero energy building (nZEB) requirement has an exact performance level of 0 kWh/(m^2,a). Primary energy, i.e., has an energy use of 0 kWh/(m^2,a).

Nearly zero energy building (nZEB) means a building that has a very high energy performance. The nearly zero or very low amount of energy required should be covered to a very significant extend by energy from renewable sources, including energy from renewable sources produced on-site or nearby. This nnZEB is defined as the national cost optimal energy use of >0 kWh/(m^2,a).primary energy. The performance level of “nearly” net zero energy use is a subject of national decision

The technical meaning of “nearby” in EPBD recast includes existing district heating or cooling networks or any other technical systems serving a group of buildings.

Figure 13 summarizes the main issues for energy calculation framework specified by EPBD recast (2010):

- System boundary of net delivered energy
- Standard energy calculation input data
- Test reference year to be use in energy calculations
- Primary energy factors for energy carriers
- Energy calculation rules and methods for energy need and systems calculations, covered in relevant EPBD standards.

These all affect the estimated or measured primary energy indicator. In order to develop a complete definition in each national or local case it is then necessary to specify which energy flows will be included, what are the primary energy factors for primary energy indicators and the system boundary definitions with inclusion of renewable energy sources.

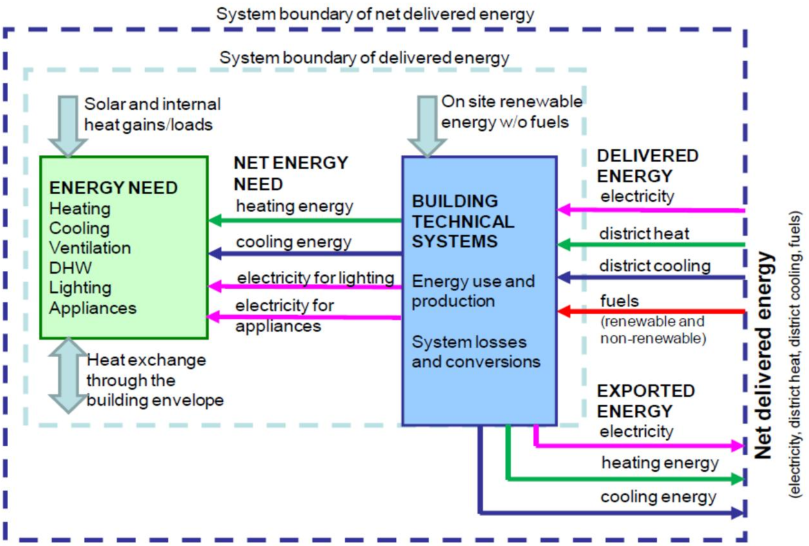


Figure 13. System boundary of zero energy building (Kurnitski et al. 2011).

The general pathway to achieve a Net ZEB consists of two steps: first, reduce energy demand using energy-efficient technologies; second, generate electricity, or other energy carriers, through utilization of RES to supply the remaining energy (Marszal and Heiselberg 2009, Sartori et al. 2010a, Sartori et al. 2010b). In practice, this logical approach to achieve nZEB means that:

- Energy use is reduced as much as is reasonably achievable (insulation, heat recovery, heat pumps etc.), and on site renewables are included.
- The annual balance of delivered and exported primary energy is nearly zero.
- Typically, a grid-connected building exporting energy in summer and using delivered energy in winter.

Figure 14 represents the balance graphically.

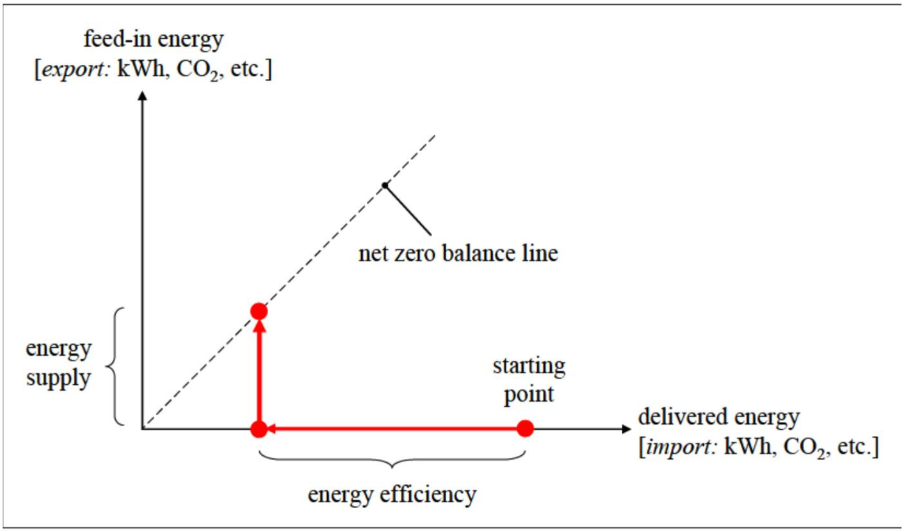


Figure 14. Graph representing the net zero balance of a Net ZEB (Sartori et al. 2010b).

2.1.1 Cold climate nearly zero energy concept

The nearly net close to zero energy concept is typically defined as a building which annually uses primary energy of 45–80 kWh/m^2, and 50–70% of the energy requirement is covered from renewable energy sources. Finland does not yet have any definition of close to zero energy building. In Finland, building code 2012 defines energy factors which are not actual primary energy factors. However, in what follows those factors are used and named as primary energy factors in order to simplify the examples. In a Finnish example, the energy factors (similar to primary energy) are according to building code 2012, in which the factors are: district heating 0.7, electricity 1.7, renewable fuels 0.5, district cooling 0.4, fossil fuels 1.

2.1.2 Warm climate nearly zero energy concept

For a warmer climate the cooling demand becomes dominant. If a hot and humid climate is considered, dehumidification becomes really important, due to a rather high heating and cooling demand. Therefore, supply air demand and demand-based ventilation are crucial factors in order to achieve the nearly zero energy concept.

2.2 Energy use and supply mismatch

The nZEB concept has been developed based on the experience that seasonal energy storage is not feasible on a single building scale due to a lack of technology, namely for the high exergy energy demands such as electricity Especially in the cold climate (heating dominated climate), the solar potential for heating is not in the same "cycle" as the energy demand. However, in cooling-dominated climates the solar potential is high and comes at the same time as the demand, Figure 15. In order to utilize solar heating effectively for space heating, some compensative means are needed to reduce the energy supply and demand mismatch. Net ZEB might differ drastically in terms of the temporal match of the energy generation on site with the building load (load matching). The temporal match/mismatch occurs on the daily level – e.g. excess solar power generation during daytime with electricity needs from the grid during night – as well as at the seasonal level (in most climates). (Voss et al. 1996.)

Typically, the energy demand and supply mismatch can be minimized by the following options:

- Optimization of yearly demand and supply
- Energy efficiency reduces the mismatch
- Other means e.g.
    - Energy storages
    - Orientation (PV): Supply responses demand more efficiently.

The storages can either be for one building or it can be utilized locally by many buildings, even it is possible to use local networks, which is not that typical in heating or cooling, but more often the case in electricity (smart grids). Increasing the match results in reducing the need for transportation and storage of energy in the connected grid.

Although building energy needs and on-site generation match on the annual level, large differences may occur for solution sets on the seasonal, monthly, daily or even hourly match. A harmonized definition should be able to visualize such differences by using suitable indicators.

Voss et al. (1996) referred to simulation studies (from Widén 2010) investigating measures to increase the load match in high latitude climates. This investigation shows that load matching is sensitive to the time resolution considered in the simulations. Based on a 10 minute data resolution, no more than 28% of the annual load can be matched. Analysing the match at the monthly level allows a maximum match of 67%, although the annual yield fully balances the annual demand.

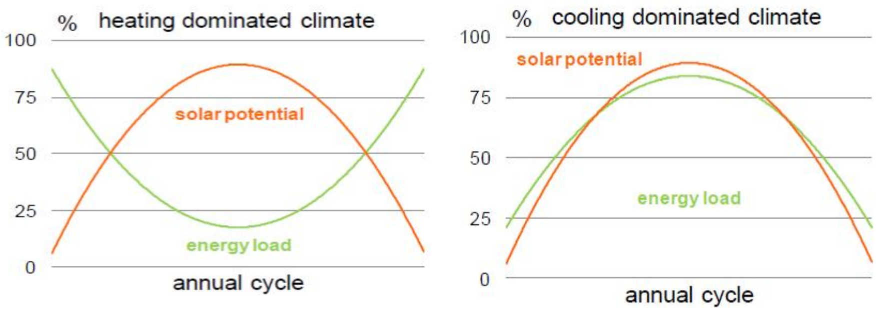


Figure 15. Principle picture of annual cycle of energy load versus solar potential in a heating-dominated climate (left) and a cooling-dominated climate (right) (Nieminen et al. 2010, Nieminen and Sepponen 2011).

The daily and hourly mismatch is typically higher as can be seen from Figure 15 and Figure 16.

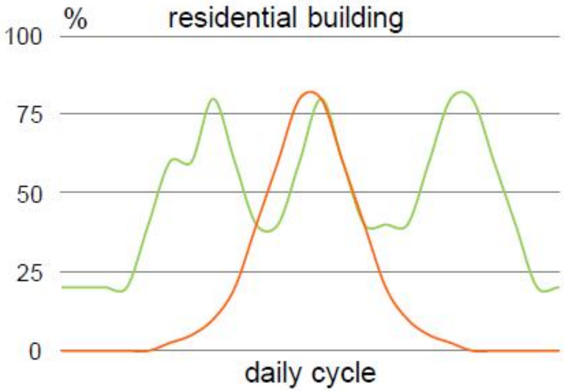


Figure 16. Principle picture of daily cycle in a typical residential building (Nieminen et al. 2010, Nieminen and Sepponen 2011).

In the Finnish climate, it is evident that during the winter months solar power is not capable of supplying the power needed, Figure 17. Thus, seasonal but also hourly capacities for storing energy are needed, or alternatively grids working bidirectionally. Bidirectional means that consumers can feed electricity into common electrical network by producing energy over their own needs with e.g. solar panels. However, it is not common in China. The challenges in designing zero energy buildings are:

- Mismatch between local energy use and production
- Dark and cold winter vs. bright and sunny summer
- Energy storages in off-grid solutions
- Grid integration (electricity, district heat and district cooling)
- System dependencies: heating, cooling, thermal mass, internal loads, solar load
- Whole building solution
- Cost effectiveness.

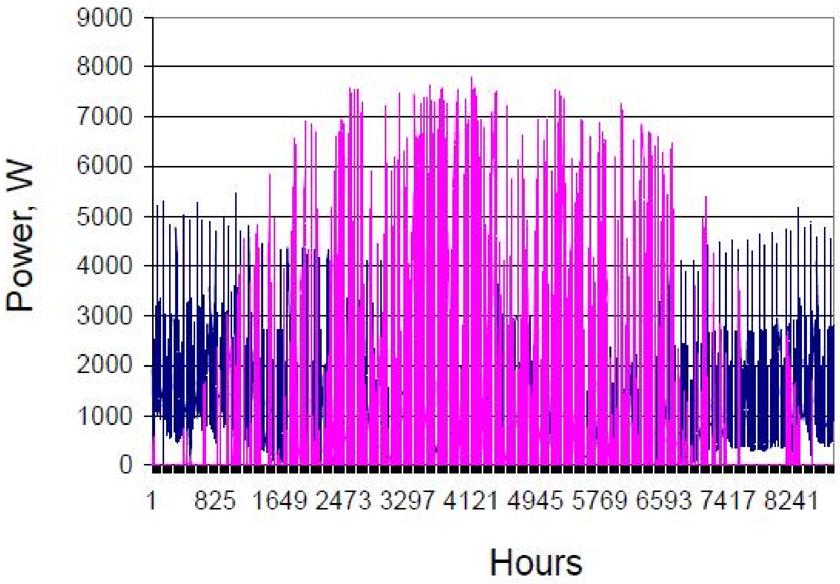


Figure 17. Hourly performance of a zero energy house in a northern climate. The blue line describes energy demand and the purple energy production from photo voltaic panels. Total yearly demand is 8,400 kWh/m^2. 10 kW PV (Nieminen et al. 2010, Nieminen and Sepponen 2011.)

From Figure 18 the need for seasonal storage is evident if solar thermal is considered in cold climates.

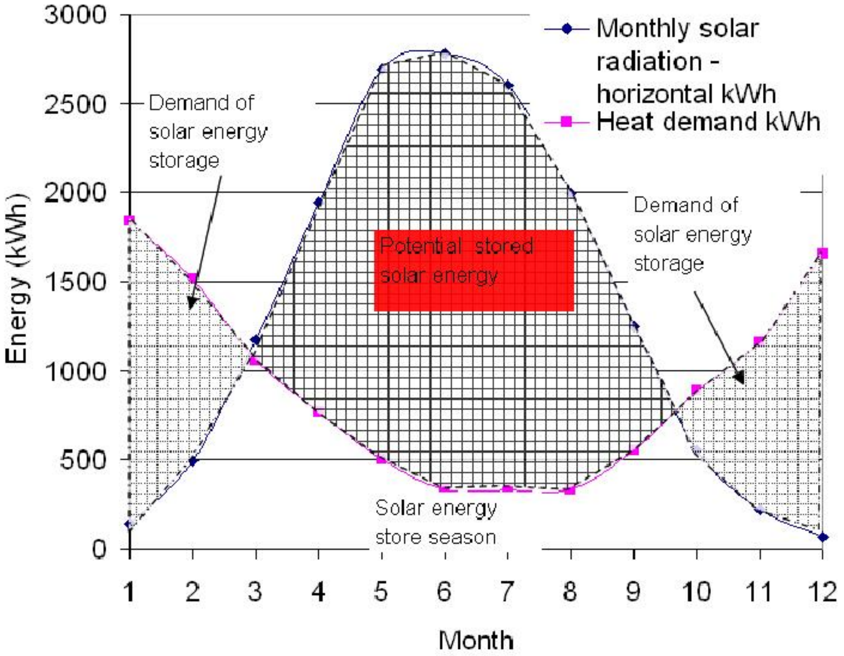
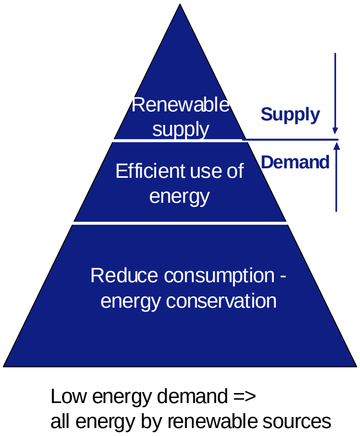


Figure 18. Solar thermal potential and demand for heat in a cold climate (Nieminen et al. 2010, Nieminen and Sepponen 2011).

2.3 Summary of the energy boundary

The basic approach towards zero energy building is to minimize the energy consumption, use energy-efficiently and use a significant amount of renewable energy in order to supply the energy demand of the building (Figure 19). Often a district level approach to energy supply is desirable.



Whole building design
- No optimisation based on parts of the whole

Minimized energy demand:
- Minimised heat losses
- Zero/minimised cooling demand
- Efficient use of energy
- Energy metering, water metering
- Low power demand

Efficient and simple supply:
- Renewables with building integrated energy systems
- Local energy systems for back-up

Skilful use in terms of simple systems

Figure 19. Basic approach to zero energy and nearly zero energy buildings.

The key factors in successful low and net zero energy buildings are first of all quality of design and on site supervision and management. Especially the design phase is important since major decisions concerning energy efficiency are made in that phase. In addition to low energy use, low power use is also important. In order to manager a ventilation system well and to protect structures from moisture problems, the air tightness of a building envelope is important, The measured air tightness should not be over 0.4 ach at 50 Pa. The insulation level should be reasonable for the climate considered. To protect from overheating during the warm months solar shading or other passive means are recommended. PV panels can be integrated to the solar shading. Since electricity use is becoming more and more important and has a relatively high share of the total energy consumption, all equipment should be classified to A++ level, or other corresponding low energy consumption classification.

Domestic hot water need to be heated to a high temperature in order to prevent *Legionella* and bacteria from growing. Thus, it has an increasing importance when other heating demand is low. Therefore, water consumption should not exceed 30 m^3/person/year. The use of water-saving fixtures, low water pipe pressure and water consumption metering are encouraged. Water metering also gives feedback to the user about water consumption and thus encourages a reduction in water use. Heating, ventilation and air conditioning systems should be chosen and dimensioned in such a way that their electricity use is low.

Renewable energy sources can be integrated into the buildings. Since the energy supply from renewable energy sources (e.g. solar) does not always match the energy demand of the building, the energy systems should be optimized and the network connections to other buildings/network should also be used. In addition storages can be applied. The district heating network can, for example, also work in work in two ways and district level storages can be applied. In addition connections, for grid and heating/cooling networks are typically used, though off-grid solutions are very seldom used.

Energy boundary

The proposed energy boundary is modified from EN 15603:2008 and, as stated in EPBD recast (2010), renewable energy produced on site is not considered as part of delivered energy, i.e. its positive influence is taken into account, see Figure 20 below.

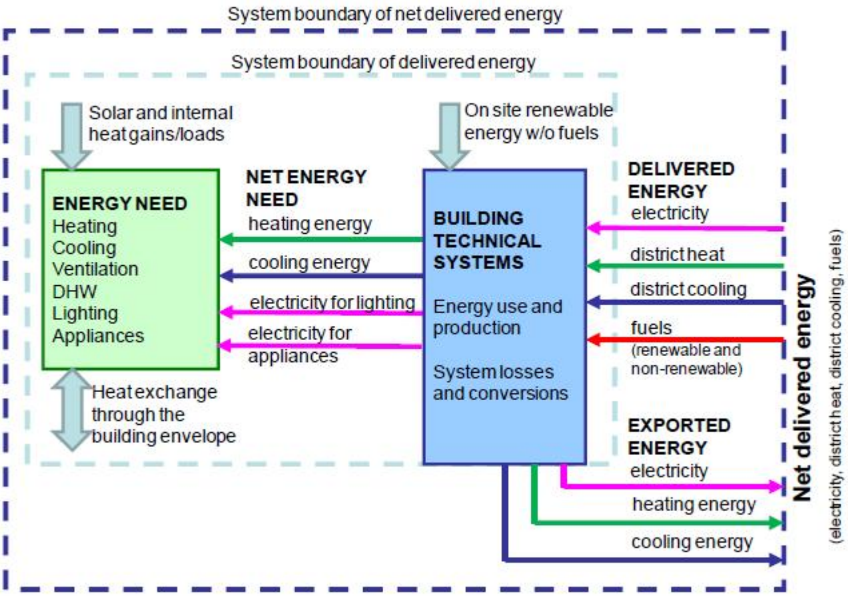


Figure 20. Energy boundary of net-delivered energy and how it is derived from energy need, energy use of technical building systems, on site renewable energy production, delivered energy and exported energy. The box of “Energy need” refers to rooms in a building, and both system boundary lines may be interpreted as the building site boundary. (Kurnitski et al. 2011.)

Energy need represents energy need in a building for heating, cooling, ventilation, domestic hot water, lighting and appliances. Energy need for heating results from heat losses and is reduced by solar and internal heat gains. Net energy need is the energy need minus heat gains, i.e. thermal energy without any system losses needed to maintain indoor climate conditions. For lighting and appliances electrical energy is needed.

Building technical systems supply the amount of net energy needs of heating, cooling and electrical energy. To supply these net energy needs, building technical systems use energy and typically have some system losses and energy conversion in some systems (i.e. heat pumps, fuel cells). The energy used by the building technical systems is from energy delivered to the building or from onsite renewable energy (without fuels).

Delivered energy to the building is grid electricity, district heat and cooling, renewable and non-renewable fuels. On-site renewable energy without fuels is energy produced from active solar and wind (and from hydro if available). Renewable fuels are not included in this term, because they are treated as delivered energy to the building, i.e. off-site renewables. Energy from heat sources via heat pumps (air, ground, water) is also renewable energy, but this information is not needed for heat pump system and delivered energy calculations, which are based on the COP data of heat pumps. (However, energy taken from heat sources via heat pumps is needed for the calculation of the share of renewable energy, which is additional information).

On-site renewable energy production systems may supply other technical building systems, thus reducing the need for the delivered energy to building, or the energy may be directly exported to energy networks. This is taken into account in the net-delivered energy balance. Net-delivered energy is delivered minus exported energy, both expressed per energy carrier.

Primary energy use is calculated from net-delivered energy, per energy carrier, as a product of the primary energy factor and net delivered energy of that energy carrier.

2.4 Examples of close to zero energy buildings in Europe

2.4.1 Dwelling, cold climate (VI), North Europe

The nearly close to zero energy concept is typically defined as a building which annually uses primary energy of 40–80 kWh/m^2, a, and where 50–70% of the energy requirement is covered from renewable energy sources. Finland does not have any definition of close to zero energy building yet. In Finland, the building code 2012 defines energy factors which are not the actual primary energy factors. However, in the following those factors are used and named as primary energy factors in order to simplify the examples. In a Finnish example, the energy factors (similar to primary energy) are according to building code 2012, in which the factors are district heating 0.7, electricity 1.7, renewable fuels 0.5, district cooling 0.4, fossil fuels 1.

Figure 21 below shows an example of a detached house in the Helsinki climate in which the primary energy use is 61 kWh/m^2,a. The main target in design was that the energy used for heating and electricity was covered by its own production on an annual basis in in the most cost-efficient way, basically that the envelope and ventilation heat recovery is designed according to passive house standards. The user appliances were excluded from the balance, which is also a rather typical way to set the balance in many European definitions.

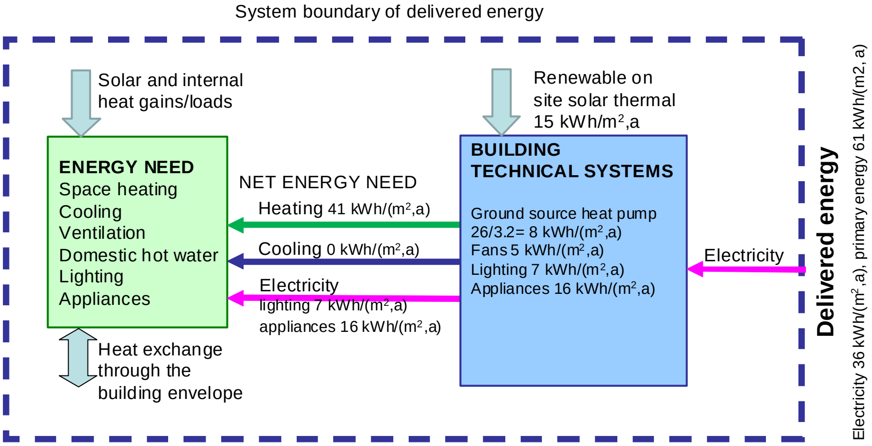


Figure 21. Calculation example of the energy flows of a detached house in south Finnish climate (Helsinki).

The typical structure U-values and ventilation heat recovery values are as follows. However, the solutions might change due to architecture or local climatic conditions.

Structures:

Exterior wall 0.08 W/m^{2}K
Base floor 0.10 W/m^{2}K
Roof 0.07 W/m^{2}K
Window 0.8 W/m^{2}K
Door 0.75 W/m^{2}K.

Ventilation:

Good indoor air quality
Air leakage $n_{50} < 0.4$ ach
Ventilation heat recovery 75%.

2.4.2 Office, mixed climate (IV), Middle Europe

The example presented in Figure 22 is of an office building in a central European climate (Paris) in which the primary energy use was 66 kWh/m^2,a (Elithis Tower in Dijon, France). The primary energy factors were French ones: electricity 2.5 and fossil fuel 1.0.

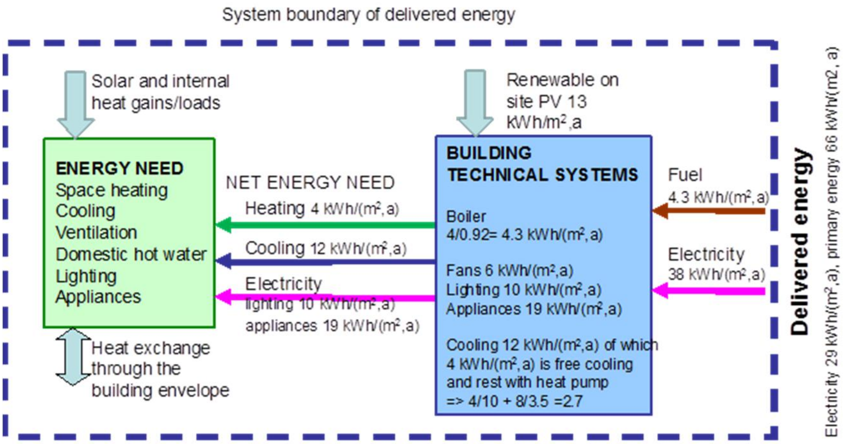


Figure 22. Example of an office building in a mixed climate zone.

The building uses boreholes for cooling (30% of the cooling) and the rest of the cooling is covered with mechanical cooling. For borehole cooling, the seasonal energy efficiency ratio of 10 is used, and for mechanical cooling 3.5. The building has a gas boiler for heating, with a seasonal efficiency of 92%.

The typical structure U-values and ventilation heat recovery values are as follows. However, the solutions might change due to architecture or local climatic conditions.

Structures:

Exterior wall 0.32 W/m^{2}K
Base floor 0.39 W/m^{2}K
Roof 0.22 W/m^{2}K
Window 1.1 W/m^{2}K.

Indoor air:

Good indoor air quality
Passive solar shading
Ventilation heat recovery during cold periods
Low pressure ventilation system.

2.5 Examples of zero energy concepts in China

2.5.1 Hotel, hot humid climate, Shanghai China

The example in Figure 23 below shows a hotel example in a hot humid climate (Shanghai) in which the delivered energy use was 73 kWh/m^2,a. This example is taken from a real design project in Shanghai. The target was to reduce energy consumption as much as possible and cover most of the energy used by using renewable energy sources. The primary energy factors were not calculated, since the Chinese values were not known. The building has Finnish ventilation rates and occupation rates, according to Finnish building code 2012, since Chinese values were not available. Thus, this concept is preliminary and needs the Chinese local input (for realization).

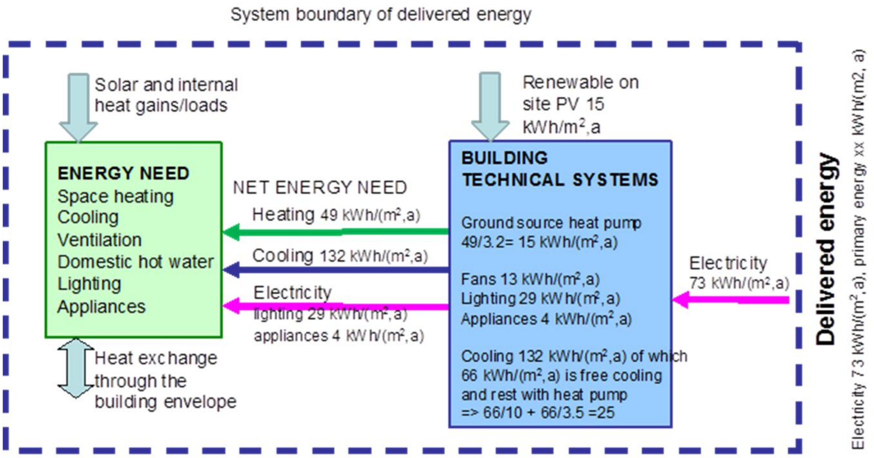


Figure 23. Example of hotel building in Shanghai.

The building uses boreholes for cooling (50% of the cooling) and the rest of the cooling is covered with mechanical cooling. For borehole cooling, a seasonal energy efficiency ratio of 10 is used and for mechanical cooling 3.5. The building uses ground source heat pump for heating with COP 3.2

The cooling need is dominant as well as the heating demand, which is due to de-humidification. The ventilation rates are calculated according to Finnish standards with variable air volumes, since Chinese input is still missing. If the ventilation rates were to be halved, the delivered energy consumption decreases from 73 kWh/m^2 to 53 kWh/m^2. The renewable energy supply on site from PV might be difficult in some cases, if there are not enough surfaces and the building is high.

Structures:

Exterior wall 0.32 W/m^{2}K
Window 0.95 W/m^{2}K
Base floor 0.39 W/m^{2}K
Roof 0.22 W/m^{2}K.

Ventilation:

Good indoor air quality, ventilation rates according to Finnish Building Code 2012 Air leakage n_{50} <1.0 ach
Ventilation heat recovery 70%.

2.5.2 Villa, hot summer, cold winter climate, Huzhou City, Zhejiang province, China

The example villa is located in Changxing, Huzhou of Zhejiang province. As regards transport facilities, it is located in the center of Shangh-Nanjing-Hanzhou.

Low temperature heating/high-temperature cooling systems are proposed inside buildings. Three scenarios were proposed to fulfill the requirement of the villa, which included Business as Usual, Low energy with moderate costs, Low energy with high-end technology:

Description of BaU scenario

- The BaU scenario is built according the local regulations
- The building uses local building materials as much as possible.

Description of low energy with moderate costs scenario

- The building uses good local technology
- Cost-efficient technologies used for renewable energies, such as solar heat for domestic hot water
- 20% of energy demand comes from renewable energy
- Demand based cooling, ventilation and heating with manual control
- High-temperature cooling and low-temperature heating
- Low noise level (good air tightness and good windows)
- Moisture safety solution
- Adaptable design
- Grey and rain water use.

Description of low energy with high-end technology scenario

- Energy-efficient structures and cooling as well as ventilation heat recovery => low energy and power demand
- Efficient and intelligent building automation, which controls the cooling, ventilation and heating as well as lightning systems according to outdoor climate and demand
- High-temperature cooling and low-temperature heating systems
- Sustainable energy systems inside building
- Low-temperature heating and high-temperature cooling system
- Energy use feedback systems to users
- 50% of energy demand comes from renewable energies
- Building integrated solar power (PV) and solar thermal, possibly ground source heat pump
- Materials used also have low carbon footprint
- Moisture safety solution
- Low noise level (good air tightness and good windows)
- Grey and rain water use
- Adaptable design
- A-class house hold appliances for users.

Detailed recommendations can be seen in Table 8 and Table 9.

Table 8. Overall recommendations of three scenarios.

	BaU	**Low-energy Cost-effective**	**Low-energy High-end**
External walls U-value	1.0 W/m^{2}K	0.5 W/m^{2}K	0.3 W/m^{2}K
Floor U-value	1.0 W/m^{2}K	0.5 W/m^{2}K	0.3 W/m^{2}K
Roof U-value	1.0 W/m^{2}K	0.5 W/m^{2}K	0.3 W/m^{2}K
Windows U-value	U = 2.5 W/m^{2}K g = 0.9	U = 1.8 W/m^{2}K g = 0.62	U = 1.2 W/m^{2}K g = 0.3
Infiltration	1 ACH	0.7 ACH	0.4 ACH
Ventilation type	Natural	Hybrid	Mechanical supply and exhaust with heat recovery
Ventilation air flow	Incl. in infiltration	0.5 l/sm^2	0.5 l/sm^2
Ventilation heat recovery	0%	0%%	65%
Cooling	Traditional	High-temperature cooling, manual control	High-temperature cooling, automatic control
Heating	Traditional	Low-temperature heating, manual control	Low-temperature heating, automatic control

Table 9. Indoor environment recommendations of each scenario.

	BaU	**Low-energy Cost-effective**	**Low-energy High-end**
Heating set point	18 °C	18–20 °C	18–20 °C
Cooling set point	26 °C	26 °C	26 °C
Fresh air change rate	1 ach	Demand based	Demand based
Indoor air quality	According to Chinese Building Code	According to Chinese Building Code	Adapted values from Finnish indoor air classification

2.6 Low exergy principle

The quantity of energy is calculated from energy balances for a system. Current energy systems in buildings are designed and improved based on the energy balance, that is the quantity of energy supplied is matched with the quantity of energy required. The energy approach intends to reduce energy demands in buildings by increasing insulation levels or increasing the air tightness of the building envelope, i.e. optimizing the building shell and later also implementing renewable energy sources. The exergy approach takes the methods of building energy assessment a step further by considering not only the quantitative aspects of demand and supply, but the qualitative aspects as well. (Torio and Schmidt 2010.)

Exergy represents the quality of energy, the part of an energy flow which can be completely transformed into any other form of energy, thereby depicting the potential of a given quantity of energy to perform work. The thermodynamic concept of exergy allows us to depict how the potential of a given energy flow is used, or lost, respectively, in the course of an energy conversion. In this way, inefficiencies within energy supply systems can be pinpointed and quantified. Applying the exergy method to energy systems in buildings can contribute to a significant increase in their efficiency (Torio and Schmidt 2010).

The exergy approach focuses on matching the quality levels between the energy supply and demand. Therefore, it requires the use of low-quality sources for low-quality demands like space heating. Demands requiring higher quality levels, such as lighting, electrical appliances or mobility, would in turn need the use of high-quality sources. Exergy analysis can be understood as optimization tool for the use of energy sources. Designing energy systems with the exergy approach increases the use of environmental heat and renewable energy sources, leading to lower primary energy consumption and CO_2 emissions. (Torio and Schmidt 2010.)

Using the exergy approach highlights the importance of using low-temperature renewable energy sources available to supply heat demands in buildings, promotes an efficient use of limited available renewable sources such as biomass and shows the importance of promoting a more efficient use of fossil fuels.

Most of the energy used in the building sector is required to maintain constant room temperatures of around 20 °C. Since the required temperature levels for the heating and cooling of indoor spaces are low, the quality of the energy demanded for applications in room conditioning are also low. Different levels of energy quality are needed for different appliances within a building. If the production of domestic hot water is considered as heating water up to temperatures of about 55 °C, the energy quality needed is slightly higher than that of heating a room to 20 °C. For energy applications such as cooking or heating a sauna, an even higher quality level is needed. For the operation of different household electrical appliances and lighting the highest possible quality of energy is needed. (Torio and Schmidt 2010.)

According to exergy analysis combustion processes should not be used for providing the low-temperature heat demands in buildings. Fossil fuels have a high energy quality and in intelligent energy systems should be used more rationally and efficiently with respect to exergy. CHP (Combined Heat and Power) units, providing equally high exergy outputs such as electricity, are a great example of an appropriate use of these energy sources. Similar conclusions exist for biomass-based fuels: although being renewable, their exergy efficiency if directly used for space heating is extremely low. Instead, low exergy sources should be promoted for heat and cold demands in buildings. Examples of such sources are solar thermal or ground source heat. For the exploitation of low exergy sources often high quality energy is required: pumping or fan power, electricity for powering heat pumps, etc. These high exergy inputs also need to be minimized. The use of hybrid technologies, coupling the use of renewable and non-renewable energy is one of the most promising trade-off between availability and exergy efficiencies. (Torio and Schmidt 2010.)

2.6.1 Using low-quality sources for space heating and cooling

Low-quality exergy sources (e.g. solar thermal heat, geothermal heat or process waste heat) should be used for space heating and cooling applications in buildings. Low-temperature heat flows existing within the built environment, such as heat in waste water or exhaust ventilation air, could also be used to supply a share of the energy demands via heat recovery systems. Utilization of these waste heat flows requires the use of innovative heat recovery concepts. (Torio and Schmidt 2010.)

The availability of low-quality exergy sources often varies strongly with time and often is not coupled with demand. Intelligent storage concepts, with maximum stratification and minimum mixing are therefore a key component of low exergy supply systems in buildings. Storage units can also be based on heat networks in order to integrate a higher share of fluctuating renewable energy supplies (e.g. thermal solar power) into the system. Similarly to seasonal storage systems, ground heat helps improve the performance of the building system by using a renewable and freely available source; is exploitation is particularly interesting with heat pumps, raising their COP to a value that makes the use of a high exergy source like its electricity convenient. (Torio and Schmidt 2010.)

Waste heat utilization can be considered a particularly efficient form from an exergy point of view: its use in the cogeneration approach is now widespread, but it has to cope with problems like the matching of heat and electricity demand in the power plant, the need for an extensive planning and energy loss due to the heat distribution. An innovative approach that would partially solve these issues is local heat recovery in the building. (Torio and Schmidt 2010.)

Low-temperature heating and high-temperature cooling systems increase the efficiency of low-exergy sources. They make the energy use in buildings even more efficient by supplying energy with low quality (exergy) and creating the possibility of using renewable energy sources. Surface heating and cooling systems operate at lower temperature levels than conventional units (radiators or fan coils), thereby also making the use of low exergy sources more effective. Since these low-temperature heating and high-temperature cooling systems deliver the required heating or cooling energy at temperature levels closer to that of the energy demand in the building, they can be called low exergy emission systems. Examples of supply and demand temperatures in a building are given in Figure 24.

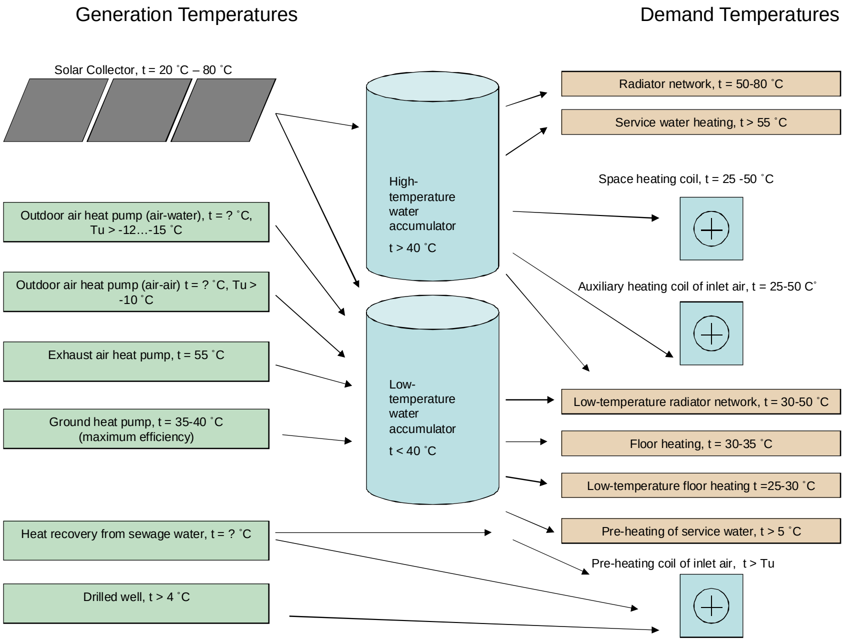


Figure 24. Examples of supply and demand temperature levels in a building. Source: Tekes (2006).

Examples of low-temperature heating systems are water-borne floor heating systems, whose exergy performance is significantly higher than the exergy performance of conventional high-temperature heating systems. The use of low exergy heating distribution systems is a necessary step towards a wider and more efficient integration of low exergy sources in building supply systems. In consequence, low exergy heating distribution systems are “more flexible”, since they allow the efficient integration of low exergy sources, but can also be supplied with high exergy sources. In turn, systems requiring higher supply and return temperatures, such as old radiators with temperature levels of 90/70 °C, cannot be efficiently coupled with low exergy systems such as ground source heat pumps (GSHP) or solar thermal systems. (Torio and Schmidt 2010.)

The choice of the heating distribution system restricts the options for low exergy sources of energy in buildings. For example, the exergy approach shows that water-based systems are able to provide the same thermal comfort as airborne systems. However, water-based systems require much lower exergy input for pumps and fans, and exergy losses in the emission process are also lower, since the emission system and the desired room temperature are very close for a water-based system. An exergy-efficient design would, therefore, necessarily begin with a change in the heating distribution systems – an important insight especially in countries with a strong tradition of airborne systems like the USA or Canada. In turn, in countries mainly using waterborne systems, e.g. most of Europe, the important choices for exergy efficient building design in the choice of energy sources. (Torio and Schmidt 2010.)

Reducing energy demands in buildings consequently reduces the required peak power for space heating and cooling applications, making the use of low exergy sources more favorable. In a low-exergy building also, the energy supply should be a low-exergy supply. The main focus in achieving an exergy-efficient building supply is to reduce the quality of the source used and to find low exergy sources to be exploited for buildings. Strategies aimed at improving the performance of low exergy systems for domestic hot water (DHW) supply are also needed.

2.6.2 Community level approach improves the utilization rate

At a community level, several low-exergy sources can be linked to each other more efficiently and economically than in a decentralized supply. The first step for a more exergy-optimized community supply is promoting a wider integration of low-temperature renewable energy sources. Combining solar thermal and ground source heat increases the utilization rate of both sources. Higher solar fractions are generally achieved if solar collector fields are used in combination with heat networks, connecting several supply systems (e.g. collector or borehole fields) with different users. As the solar fraction increases, i.e. the share of low-exergy supply increases, the exergy efficiency of the energy supply also rises. Similarly, the use of ground source-based systems in combination with heat networks will increase the energy efficiency (i.e. COP) of heat pump units, if demands for higher temperatures, such as DHW supply, can be supplied by solar thermal heat. Solar thermal heat can be used in winter to reduce the required temperature lift from the heat pump units, allowing significant increase of the COP (Coefficient of performance). This way high exergy input in terms of electricity required for operating the heat pumps can be reduced. (Torio and Schmidt 2010.)

A more exergy-efficient use of fossil fuels is also needed. One solution is substituting a decentralized supply with individual boilers by electricity-driven CHP units, maximizing the exergy output obtained from the high-quality fuels used. Distributed or centralized generation with CHP units can reduce the demand for fossil fuels and thus reduce the use of combustion processes for heat production in total, characterized by a high level of exergy losses. (Torio and Schmidt 2010.)

Heat networks play a significant role in a more exergy-efficient energy supply at a community level in different ways:

- combining several renewable energy sources with waste heat from an exergy efficient use of fossil fuels
- cascading energy flows according to their temperature so as to supply high-temperature applications such as process heat, first followed by medium temperature demands such as DHW, and finally low-temperature heat can be directly used for space heating. In this way, pumping energy, i.e. high exergy input, into the network can be minimized, and the exergy efficiency of the energy supply increases.

Higher and lower exergy demands within a building can be supplied one after another, following a cascading principle. The cascading principle means that appliances needing higher exergy levels are served prior to appliances with lower exergy demand, making use of the same energy flow several times (Figure 25). Control strategies of building systems are needed to minimize exergy losses in the supply process.

District heating grids are a promising solution for cascading available heat flows so as to supply different energy demands in an intelligent way. The coordinated management and control of district heating and electricity networks together with state-of-the-art storage systems can be used to maximize the exergy efficiency of the supply.

From an exergy perspective, pumping energy in pipes and ducts should be minimized. This is also valid for the design of heat networks. To this end, the diameter of the pipes in the networks can be increased. In this way, lower heat losses can be found in the network and lower maximum fluid speeds occur. In turn, as a result of the greater pipe diameter, thermal losses in the network increase. First results on the sizing criteria of small-scale district heating systems show that a trade-off can be found between the increase of (low-exergy) thermal losses in the network and the decrease in pumping energy for its operation. While, from the perspective of energy analysis, lower target fluid velocities for sizing the network, i.e. smaller pipes, always seem to be advantageous, exergy analysis shows that an optimum between both criteria can be found.

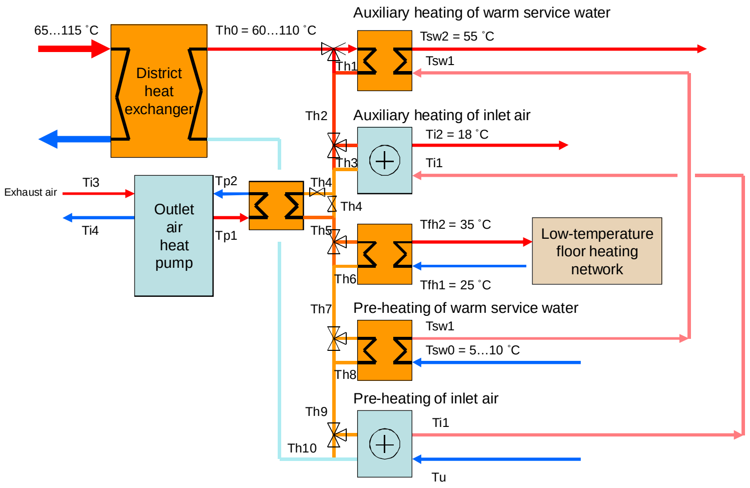


Figure 25. Example of cascading energy flows in a building. Source: Tekes (2006).

2.6.3 Finnish example of low-exergy system

Heating and cooling with ARE Sensus®

Heating and cooling with the ARE Sensus® system is described as is in VTT Research Notes 2256 *Heating and cooling with focus on increased energy efficiency and improved comfort* (Ala-Juusela 2004). The exergy consumption of the Sensus® system is lower than in comparable high-standard systems, which also decreases environmental impact during use. (See Figure 26.)

Office ventilation employs a Sensus® ventilation unit connected to the Sensus® panels by a three-pipe network. The ventilation units utilize surplus heat collected from the rooms with the cooling water system for the heating of intake air whenever heating is needed for the intake air. This conserves heating exergy. The ventilation machine also has an efficient rotating heat collector for the exhaust air (over 70% heat efficiency).

The Sensus® ventilation unit utilizes outdoor air for cooling the cooling water for the rooms when the outdoor temperature is sufficiently low (under +12–14 °C). This free cooling carried out with ventilation units operates alongside mechanical cooling when necessary. It has a considerably longer annual period of utilization (over half of the year’s working hours) than conventional free cooling. This lowers the electricity consumption of the cooling unit in the Sensus® system in comparison with conventional solutions.

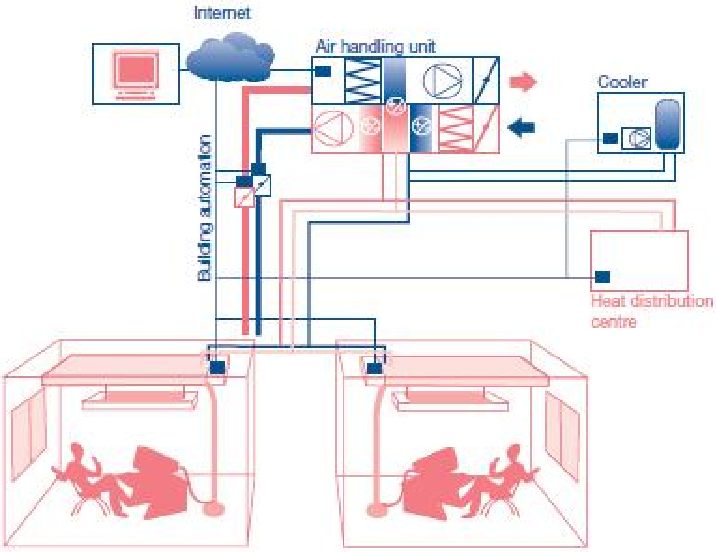


Figure 26. Main components of the ARE Sensus® system (Ala-Juusela 2004).

2.6.4 Chinese example of low-exergy system

Temperature and humidity independent control (THIC) air-conditioning system

By using outdoor dry air as the driving force, an indirect evaporative chiller takes advantage of the use of “wet” exergy contained in liquid water (which is very large) in order to produce cool exergy, and subsequently cool the air or water as a cool carrier. It produces cold water with a temperature between ~ 15 and 18 °C, lower than outdoor wet bulb and infinitely close to the dew-point temperature of the inlet air. As the heat carrier of the chiller is water rather than air, the energy consumption for transmission is greatly reduced. (Torio and Schmidt 2010.)

Temperature and humidity control are the two main tasks of air-conditioning systems. In most centralized air-conditioning systems in China, the air is cooled at the temperature below the indoor dew point temperature, dehumidified by condensation, and then supplied to the occupied spaces in order to remove both the sensible and latent load. The required chilled water temperature should be lower than the air dry bulb temperature or air dew point in order to remove the sensible load (control temperature, covers 50–70%) or the latent load (control humidity, covers 30–50%), respectively. However, the same 7 °C water is used to remove both sensible and latent load and, as a result, available energy is wasted. (Torio and Schmidt 2010.)

THIC (Temperature and Humidity Independent Control) system is composed of two separated systems: a temperature control system and a humidity control system. The temperature of chilled water in the temperature control system is raised from 7 °C in the conventional system to about 18 °C, which also allows the utilization of some natural cooling sources. Even if the chilled water is still produced by a mechanical chiller, the COP (Coefficient of Performance) increases considerably. (Torio and Schmidt 2010.)

In southeast China (Figure 27), where many large buildings are located, the outdoor air is humid (Statistical Bureau of Beijing 2006) and the main task of air-conditioning systems is to dehumidify the air. In this case, the liquid desiccant dehumidification method is recommended. In northwest China, the outdoor air is dry and the main task of air-conditioning systems is to decrease its temperature. Here a direct or indirect evaporative cooling is recommended. (Torio and Schmidt 2010.)

This system allows the control of both humidity and temperature by splitting their management into two independent systems. Due to the increased temperature for cooling from 7° to 18 °C, much better performances in terms of exergy can be obtained. Referred to an outside reference environment at 25 °C, the exergy content is respectively 6.4% and 2.4% of the produced and delivered heat. Similarly, a chiller ideally working in the same environment would perform almost three times more effectively. Consequently, relevant amounts of exergy can be saved, while still assuring good comfort conditions in the cooled areas. (Torio and Schmidt 2010.)

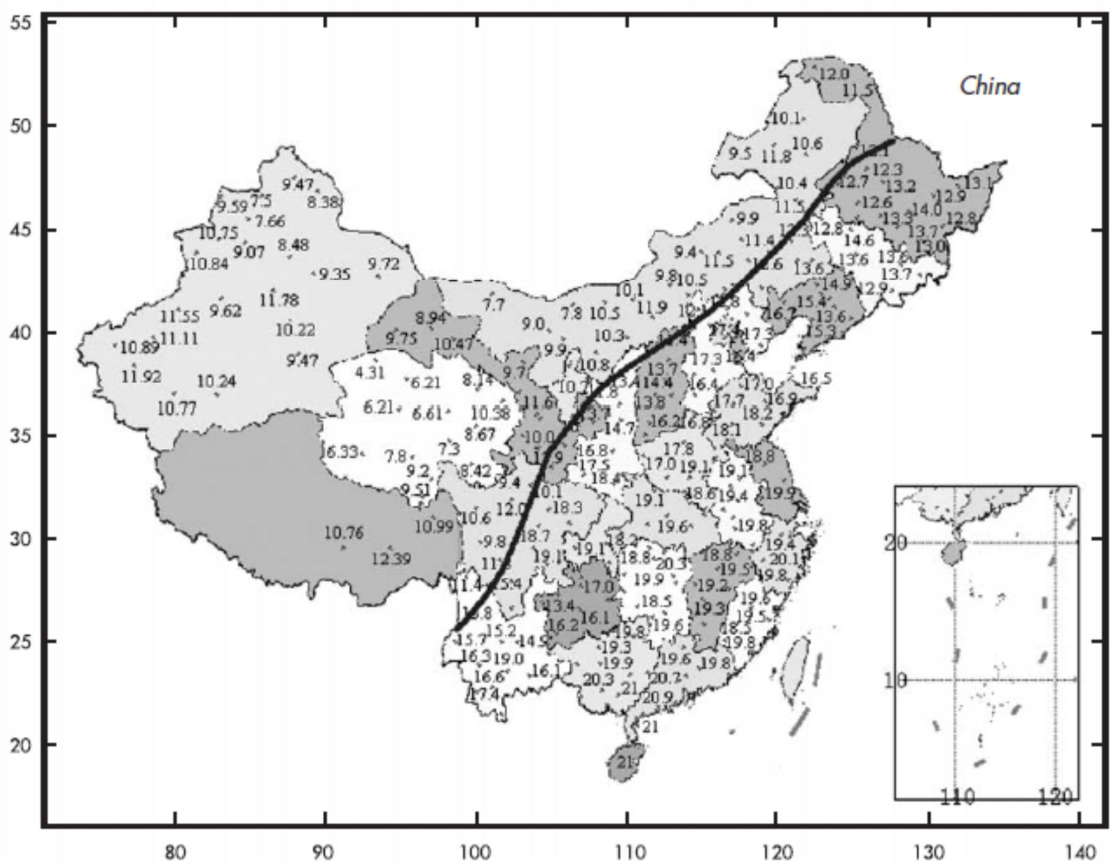
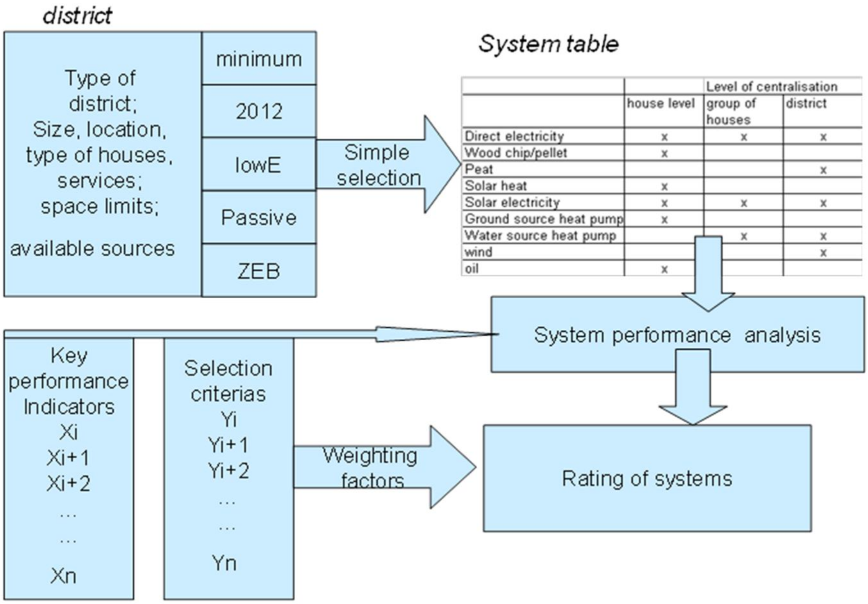


Figure 27. Average humidity ratio of the most humid month in China. Southeast of the line: outdoor air is humid. Northwest of the line: outdoor air is dry. (Statistical Bureau of Beijing 2006.)

3. Regional energy solutions

3.1 System selection and performance evaluation principle

The principle of system selection and evaluation is presented in Figure 28. The basic information on the district and area is collected for the preliminary analysis of the energy demand. This phase is gone through for several energy efficiency options. The building energy efficiency is assumed to be a standard level (based on existing building code), near future 2012 codes, low-energy house (heat losses are ~75% or standard level house), passive house or zero energy building level. The first estimation of possible energy systems is given in the pre-selection table, which is based on expert opinion and needs of the client. This table gives a list of conceptual level solutions to be used in the system analyses. The key performance indicators to be used for the analysis will be selected and the weighting factors for the rating of systems will be selected based on the demands of the client. These are typically energy costs and consumption, investment cost, emissions (greenhouse gases and/or particulates) and other possible indicators (local energy sources, maturity of proposed technology etc.). The pre-selected systems will be analyzed by the selected indicators and ranked in order. This simple approach provides the recommendations for the system types. The analysis may be re-calculated later, based on more detailed information.



		Level of centralisation	
	house level	group of houses	district
Direct electricity	x	x	x
Wood chip/pellet	x		
Peat			x
Solar heat	x		
Solar electricity	x	x	x
Ground source heat pump	x		
Water source heat pump		x	x
wind			x
oil	x		

Figure 28. The principle of system selection and evaluation.

3.1.1 District types

When analysing the feasibility of energy systems for a district, the qualities of the district must be taken into account. The district is not only defined by its size, but the location, building patterns and architecture also affect the district type.

The location of the district affects the feasibility of a majority of renewable energy production technologies. Solar irradiation and wind conditions vary depending on the location, as does the production of biomass fuels. In some areas, the installation of ground source heat pumps might be prohibited, due to the fact that the district is located in a ground water area.

The building patterns and architecture affect the feasibility of building integrated energy systems. For example, the yield of solar thermal collectors and photovoltaic panels which are installed on the façades or roofs of the buildings is highest when the buildings are orientated in the optimal direction. Higher buildings amongst lower buildings might shade the solar energy production technologies integrated on lower buildings. These examples are just few of those issues that can be affected through the planning and architecture of the district.

3.1.2 Building level design

The thermal energy consumption of a building is composed of three main factors: the heat losses through the building envelope, ventilation heat losses and the hot water thermal energy consumption. Electricity consumption of the buildings is the consequence of using the electrical appliances, lighting and building service systems.

For Finnish buildings, according to VTT definitions of a passive house, the energy consumption target varies depending on the geographic location of the building. In northern Finland, for example, the energy consumption requirements are less strict than in Southern Finland. (Lylykangas and Nieminen 2009.) The energy consumption at different energy efficiency levels of buildings is presented in Table 10.

Table 10. Requirement of different building energy efficiency levels (modified from: Saari 2009).

	Reference building	Low-energy building	Passive energy building
Performance of heating			
Thermal power demand of heating [W/m^2]	50–70	20–30	10–20
Energy consumption [kWh/m^2,a]			
Space heating and cooling	70–130	40–60	20–30
Domestic hot water	25	25	20
Heating system losses	25–50	15–25	5–10
Total thermal energy consumption	130–205	80–110	45–60
Electricity consumption of appliances	50	45	40
Total energy consumption	180–260	125–155	85–100

One of the most important means to improve the energy efficiency of a building is to reduce the heating energy demand. Two of the most important ways to achieve reductions in the heating energy demand are an improvement in the insulation and air-tightness of the structural materials and improvement in the efficiency of ventilation heat recovery. (VTT 2009, pp. 92–93.) Examples of the improvements required to improve the energy efficiency of buildings are presented in Table 11 (Saari 2009).

Table 11. Methods to improve the energy efficiency of buildings (Saari 2009).

	Reference building	Low-energy building	Passive energy building
U-values [W/m^{2}K]			
Exterior wall	0.24	0.15–0.20	0.10–0.13
Roof	0.15	0.10–0.15	0.06–0.08
Base floor	0.15–0.24	0.12–0.15	0.08–0.12
Doors	1.4	0.7	0.4–0.7
Windows	1.4	1.0	0.6–0.8

The electricity consumption can be affected by using energy-efficient appliances. The efficiency of the electric appliances, especially in low-energy and passive energy buildings, should be the BAT-level (Best Available Technology), as these are usually the most efficient technologies where energy use is concerned.

3.1.3 Energy system / pre-selection

In the actual performance evaluation, only feasible energy system alternatives are included. The energy system alternatives are defined according to the wishes of the decision-making stakeholder, but also take into account the limits set by the location of the district and possibly the size and energy demand of the district. Possible energy system alternatives are presented in Table 12.

Table 12. Energy system alternatives.

	District level	**Building group level**	**Building level**
Heat production			
Wood chip (+ solar)	X	X	X
Pellet (+ solar)	X	X	X
Natural gas (+ solar)	X	X	X
Oil (+ solar)	X	X	X
Peat	X		
Heat pumps (heat from rock/ground/water)	X	X	X
Coal			

CHP production			
Biogas	X	X	
Wood chip	X	X	
Pellet	X		X
Coal	X		
Natural gas	X	X	
Oil	X		
Peat	X		
Fuel cell systems	X	X	
Other bio-based fuels (bio oil, ethanol)	X	X	
Electricity			
Solar	X	X	X
Wind power	X	X	X
Gas engine	X	X	X
Diesel engine	X	X	X

3.1.4 Key performance indicators & selection criteria

The criteria used to rank the energy systems include:

- investment costs of the energy system
- annual costs of energy
- greenhouse gas emissions
- particulate emissions
- locality of the energy source
- technological maturity of the energy production technology.

Investment costs are generated from the actual energy production system, but also from the heat distribution systems in the buildings and from the construction of a possible heat distribution network. In the multi-criteria comparison of the energy system alternatives, the investment costs of the end-user are regarded as comparable costs. However, in district level energy systems, the investment costs of the energy supply system are also calculated in order to determine the amount of the capital costs which are added to the cost of energy.

The annual costs of energy depend on the cost of:

- resources used to generate the heat
- the operation and maintenance costs of the energy system.

For example, electric heating devices require electricity as a resource to provide thermal energy, and biomass boilers use wood chip, pellets or some other sort of biomass as their fuel. The operation and maintenance costs of the energy systems are very technology-dependent and must be defined for each alternative separately.

The greenhouse gas emissions (GHG-emissions) or CO_2-equivalent emissions represent the global warming potential of gaseous emissions produced by a certain energy system. The CO_2-equivalent emissions for the energy produced are calculated for the entire lifecycle of the energy system. The lifecycle of the energy system includes the construction and the materials, the production of energy and the disposal of the energy system. The emissions for different energy systems are calculated with GEMIS (Global Emission Model for Integrated Systems). The greenhouse gases included in the CO_2-equivalent emissions are CO_2, CH_4, N_2O, HCF, PCF and SF_6. (Fritsche and Schmidt 2008, p. 29.)

Unlike the CO_2-equivalent emissions, the effect of the particulates in the air is more local than global. As well as the CO_2-equivalent emissions, the particulate emissions per a unit of produced energy are calculated for the entire lifecycle of the energy system. The calculation is done with GEMIS, and the particulate emissions of different energy systems are presented in Table 16. The particulate emissions of district heating need to be calculated for each case separately, as the energy production method and fuels used to produce the district heat vary. The particulate emissions of heat pumps do not include the emissions of the electricity they require to operate, and these additional emissions must, therefore, be calculated when the electricity consumption is known.

Maturity of the technology is assessed by how widespread the use of a certain technology is, and the certainty of energy production using the technology. As the development of the production technologies varies, the criterion must be defined for each technology separately.

The last selection criterion is the locality of the energy source. A fundamental issue regarding this criterion is the definition of what a local energy source is, and what is not. This might be country-specific and therefore the locality must be assessed for each case study separately.

3.1.5 Workflow in selection process

Several stakeholders involved in the selection process can be identified. The deciding stakeholder might vary, for example depending on the level of centralization of the energy system. Building-specific energy systems are usually selected by the building owner who also pays the investment costs of the system.

The decision can, however, be affected by district plan regulations or recommendations at least to some degree.

While the selection of a building-specific energy system is usually made by the building owner, the selection process of a district level energy system might be more complicated. The decision might be affected by the stakeholder responsible for district planning, municipal or other authorities, energy companies and perhaps even by the providers of energy production technology. Of course, the selection of building-specific energy systems can also be affected by district planning, for example. As the means of affecting the decision by district planning are usually recommendations, the decision is usually made by the stakeholder who pays for the investment.

3.2 Design guidelines of district energy system

District energy systems include energy production and transmission inside the area, but also energy consumption issues as well. Usually, it means that there are own energy production systems inside the district area. In this study, the focus is mainly on renewable energy systems.

There are several issues that have to be taken into account when designing a renewable energy system for a district. The most important design guidelines for a renewable energy system are:

1. How much energy is needed in the area (electricity, heat, cooling, gas.)? How much renewable energy should be produced? It is important to note that the more energy-efficient the area is, the less it consumes energy and the less renewable energy production capacity is needed. Thus, in general, the less the buildings consume energy, the smaller the investment costs of the energy production system are. However, there may have some exceptions, because in some cases it may not be economically viable to invest in small systems, or there may not be small systems available. In addition, while designing as low energy a building as possible; it is also important to make sure that the living conditions in the buildings will be comfortable even after the improvements.

2. Is the system connected to the national energy systems, such as the electricity grid or gas network? Is the system connected to an existing district heating or cooling network? Or is it an off-grid solution? Off-grid systems are typically more challenging, because they have to cover all the energy production all the time, and might therefore require energy storages. Or is the annual balance enough (the same amount of renewable energy will be produced in the area, which is also consumed in the area annually)?

3. What is the energy production target, and how much energy should be produced from renewable energy sources? 100%, or less? In principle,

the renewable energy system should cover all the energy needed from the renewable energy sources.

4. Local environment and circumstances have to be taken into account. What renewable energy production technologies are feasible in the area? Are there any water sources nearby for heat pumps, or is it a groundwater area? Is it possible to drill bore holes for heat collection with ground source heat pumps? What kind of wind and solar radiation conditions are there in the area?
5. The local rules and recommendations have to be taken into account in the design process. For example, are there some special restrictions that should be noticed?
6. Are there some kinds of emission reduction targets?

The grid integration of the wind and solar energy system has to be designed according to local rules and recommendations so as to be able to fully utilize the available wind energy sources. The integration aspects such as implementation on the local grid or a larger grid, the existence of a feed tariff, safety aspects, etc. have to be solved according to local rules and recommendations.

3.3 Principles of a district energy system concept

In this chapter, a concept for renewable energy system is presented. The concept is designed for districts and can be localized to different locations based on the local operational environment. The energy system concept includes all the energy that is needed in the district area, including electricity, heat and cooling energy. Also, transportation is a significant energy consumer, and it can be included in the system as well.

The concept covers energy consumption and production as well as distribution. The key feature of the concept is integrated design. This means that the system has to be designed as a whole, instead of individual smaller parts of it. This kind of system requires extensive co-operation from the system planners.

The result of this concept is a completely optimized energy system that is as efficient, economical and sustainable as possible. In a traditional energy system, the different parts have only been optimized as a single piece, which may not lead to the best total system. Therefore, it is important to design the energy system of district as a whole. The differences between the traditional system and the integrated design have been illustrated in in Figure 29.

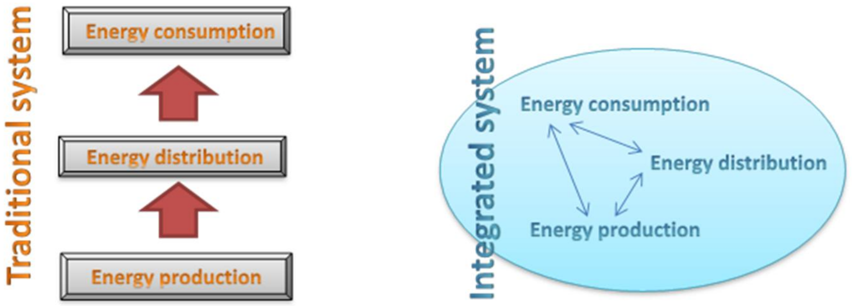


Figure 29. The traditional energy system and integrated design.

The concept of the renewable energy system of districts has three main elements: energy usage, energy distribution and energy production. The process of improving the overall energy and eco-efficiency of a district is presented in Figure 30. It gives an overview of the phases that are needed for implementing an energy-efficient district that causes less emissions, and thus smaller environmental impacts.

Firstly, the energy consumption of the district has to be minimized. Often the most important energy consumers in the districts are dependent on the socio-economic structure of the district, in some districts, the major energy consumers are buildings. Building energy efficiency is very important. The energy consumption has to be reduced, but at the same time the living conditions have to be kept at a comfortable level. Building heating energy consumption is reduced with a good insulation level, air tightness of the building and with efficient heat recovery from air exchange. Also, techniques for reducing the hot water usage are necessary. Electricity consumption can be reduced with energy-efficient electrical equipment and energy-efficient lighting (for example LED lights). The cooling energy consumption has at first to be minimized with good building design, for example by utilizing passive solar energy solutions, and ensuring sufficient solar shading. If spaces have to be cooled, it has to be done energy-efficiently. Also, the energy consumption of the transportation may be included in the concept.

Energy distribution has to be carried out efficiently. Losses of energy distribution have to be minimized.

Energy production is based on renewable energy sources. The production can either be centralized or distributed, or it can be a mix of these. Electricity is produced with solar panels, wind turbines, hydropower or with CHP (combined heat and power production) fuelled by biomass. Heat energy is produced with solar collectors, bio-CHP, boiler fuelled with biomass, heat pumps (ground, water or air) and with waste-to-energy technologies. Energy storages may be needed in the system. Different energy production systems are described briefly in the following chapter.

One of the goals is that the energy supply is secured and the system is reliable. The optimal design and use of this energy concept is based on real time two-way communication between the consumer and the energy producers. This is enabled by ICT solutions. Smart grid solutions are needed. Smart meters in the buildings help to reduce the energy consumption and to cut the peak power demand. Demand response technologies can be utilized.

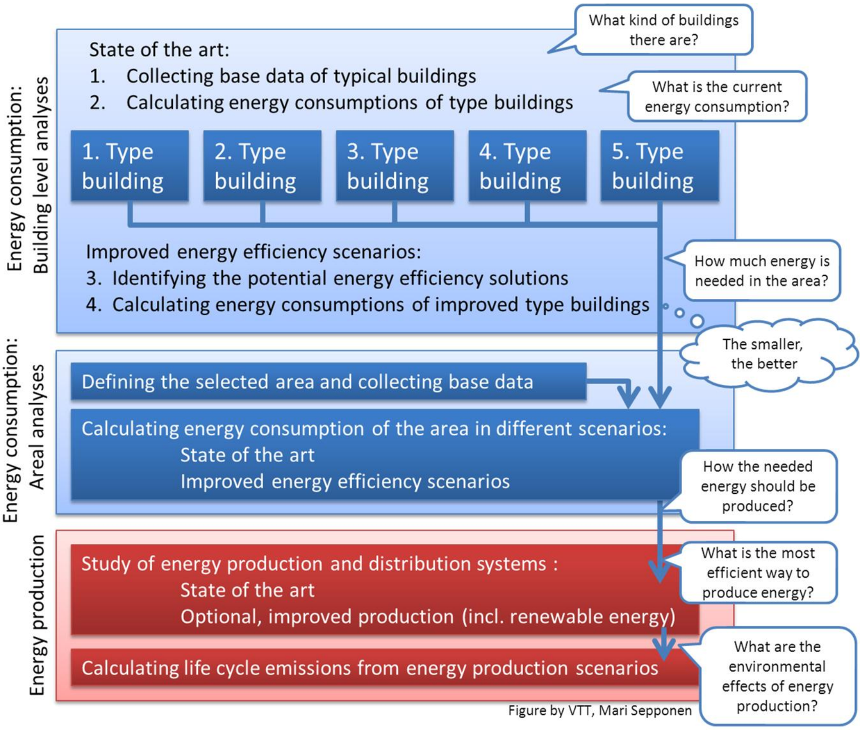


Figure 30. The process of improving overall energy and eco-efficiency of a district.

3.4 Renewable energy production technologies

This section gives an overview of energy production technologies utilizing renewable energy sources. The level of centralization varies between the technologies, but most of the technologies presented below can be used for both centralized and distributed energy production.

Possible renewable energy production technologies are solar energy, wind turbines for electricity production, heat pumps, biomass-based fuels and also fuel cells in the future. For example, biogas can be produced from biodegradable waste, and from waste water sludge. Biogas can then be further utilized for energy production.

Energy storages may also be needed, depending on the renewable energy production technologies and the targets of the renewable energy system. These solutions are discussed in more detail in Chapter 3.5.

3.4.1 Solar energy

The energy from solar radiation can be exploited either actively or passively. Active solutions are used for generating electricity or energy for heating or cooling purposes. Passive means are mainly used for heating the inside spaces of buildings, and would require pre-construction planning so as to provide maximal profit. This usually involves careful planning of the position, direction and different elements of the building.

In this publication, solar thermal energy (active) denotes energy produced by using solar collectors to convert solar radiation into thermal energy. The thermal energy can then be used either for heating purposes (solar thermal heat) or in a steam process for generating electricity (solar thermal power). The collectors can be of concentrating or non-concentrating types. Non-concentrating collectors are used for distributed solar heating whereas concentrating collectors are used for centralized heat or power production. Solar thermal power necessitates concentrated collectors due to the need for high process temperatures.

Solar energy can be converted directly to electricity by the photovoltaic cells (PV) in a solar panel. PV panels enable distributed electricity generation since they can either be attached to buildings or integrated into their elements.

The output of solar collectors and panels depend to a great extent on the level of solar irradiance, which varies with location and time of year. The yearly irradiation level is higher for locations closer to the equator. Other factors that usually affect the production of solar collector and panels are their tilt angle, orientation and weather conditions (cloudiness, ground cover, temperature etc.). Collectors or panels need to be installed with optimal tilt angle and orientation to ensure the maximal production for a whole year when they are not equipped with tracking devices.

3.4.2 Wind power

Electricity generation with wind turbines is a clean and emission-free way to utilize the energy potential of the wind. The effects on the environment are more aesthetic in their nature as wind turbines shape the landscape and make noise. Wind turbines can be roughly categorized into two types of devices (see Figure 31). The more common type is the horizontal-axis wind turbine, which is also called HAWT. The more exceptional, but still constructed type is the vertical-axis wind turbine or VAWT. Although the two types have the same basic components, their construction and the conditions affecting the energy generation with the two types of wind turbines differ.

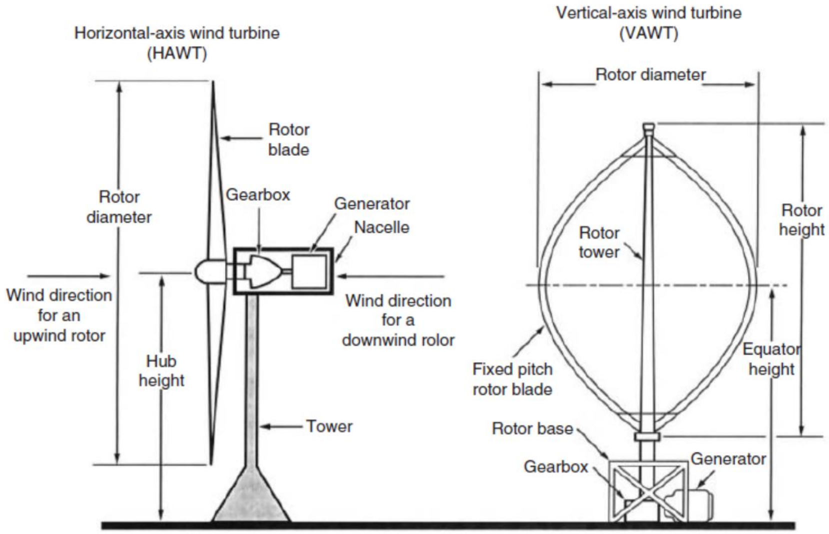


Figure 31. Wind turbine types (Berg 2007, p. 22:4).

Both commonly used large wind turbines exist, as well as smaller wind turbines. If the target area is densely built, it is possible that especially larger wind turbines will not be a suitable solution for renewable electricity production. However, it might be possible to utilize smaller wind turbines that could even be integrated into the buildings. Depending on the type of the small wind turbine, they do not cause usually significant noise or other disadvantages. A detailed study of the wind conditions of the area is needed to ensure the profitability of wind electricity production.

3.4.3 Heat pumps

Heat pumps can use either ground or water (if there are some lakes or ocean nearby the area) as a heat source. They can be used both for producing heat and cooling energy. On the other hand, heat pumps consume electricity (typically approximately 1/3 of the heat or cooling energy produced, depending on the coefficient of performance (COP) of the heat pump).

The operation of heat pumps is based on the evaporation and condensing of the working fluid, called the refrigerant. When, for example, the inside air of a house is warmed, the heat required to evaporate the refrigerant is taken from the outside air, ground or water. The pressure of the refrigerant is then raised in a compressor, which also raises the temperature of the refrigerant. The thermal energy of the refrigerant is then collected in a condenser, where the refrigerant condensates and passes heat to the indoor air.

It is important that the heat transfer fluid used in the heat collection pipes of the system is not harmful to the environment. Moreover, it should be noted that a ground source heat pump may be challenging in the groundwater area. For these reasons, heat pump installations also need more detailed studies in the planning phase of the energy system.

3.4.4 Biomass

Biomass-based fuels are available from several sources such as agricultural and wood residues, slurries from industrial processes and energy crops which are purposely grown to be used as a fuel. Biomass-based fuels can be used in both heat generation and cogeneration, where the power plant produces both electricity and heat. One option is also trigeneration facilities, which produce cool energy in addition to electricity and heat.

Combined heat and power generation (CHP) or cogeneration is a term used to describe the production of heat and power from the same process. The efficiency of CHP plants is higher than that of conventional plants, as the surplus heat from the power generation process can be used for heating or cooling. Cogeneration can decrease the fuel consumption by 25–35% when comparing to a conventional plants, which produces the same amount of power and heat in separate processes.

3.4.5 Fuel cells

Fuel cells are a crucial part of the hydrogen economy, which is a candidate to replace fossil fuels in the future. The hydrogen chain offers clean and environmentally friendly energy production and storage from the point that hydrogen is produced to the point where it is used as the fuel of a fuel cell. Producing hydrogen with renewable energy sources such as solar energy in particular provides a way to store, transfer and produce energy with very low emissions.

Several different types of fuel cell concepts are available. The first commercial fuel cell was the alkaline fuel cell or AFC, but due to its high cost it has been widely replaced by other types. The properties of different types of fuel cells vary greatly. There properties include operating temperature, fuel efficiency, usable fuel, power levels and costs. Power density affects the applications where the specific type of fuel cell can be used.

3.4.6 Waste-to-energy solutions

Waste and waste water can be utilized in energy production in many ways. Municipal solid waste consists of solid waste collected from residences and enterprises as well as institutional waste. Primarily, the target of waste management should be to minimize the production of waste by reducing consumption, and then reusing and recycling it as a material or energy. Recycling the waste as energy should be favored if the material recovery is less feasible or more energy consuming than the production of virgin raw materials. Energy from waste can be utilized in different forms: refuse-derived fuel, biogas and bioethanol.

Plastics and non-recyclable combustible wastes can be utilized for energy production through incineration, gasification or pyrolysis technologies. The purpose of the waste-to-energy facility is both to reduce solid waste to an inert residue with minimum adverse impact on the environment and to produce energy. The capacity of the facility depends on the area and population to be served, as well as the rate of waste production and recycling. The location of the waste-to-energy plant has to be optimized considering the waste transportation systems, e.g. if it has to be close to a railway or main roads. The mass-burn systems are large facilities that burn the waste in a single combustion chamber under conditions of excess air. Another option is refuse-derived fuel systems, in which the waste is at first processed by mechanical means to produce a more homogeneous material. Next the waste is burned in dedicated boilers. With this technology, some materials, such as steel and glass, can be recovered for recycling during the initial processing step. Wastes can also be incinerated with fluidized bed technology with higher efficiency and lower NO_x emissions. (Velzy and Grillo 2007, pp. 24:7–24:10.)

One of the key issues in waste incineration process is the high-quality treatment of flue gases to reduce the emissions, which can be high in waste incineration. Emissions include small particles, gaseous emissions (e.g. CO_2, SO_2, HCl, CO, NO_x and hydrocarbons), organic compounds (e.g. polycyclic aromatic hydrocarbons (PAHs), polychlorinated dibenzodioxins (PCDDs)) and trace elements. The main target is to minimize all environmental impacts, and for this a good combustion practice and equipment specially designed to remove the targeted pollutants is required. For example, particles can be controlled with electrostatic precipitators and fabric filters, gaseous emissions with scrubbing devices, good combustion practice and selective non-catalytic reduction (SNCR), as well as organic compounds with scrubbers or fabric filters and trace elements with spray dryers and fabric filters. (Velzy and Grillo 2007, pp. 24:24–24:32.)

Biodegradable waste and waste water sludge can be utilized for producing biogas or bioethanol or syngas in bioconversion. Biogas can be used, similarly to natural gas, so as to generate thermal or electricity in boilers, gas turbines, micro-turbines, internal combustion engines and fuel cells. Biogas is formed during anaerobic digestion, in which micro-organisms convert biodegradable biomass material into methane. The process of producing bio gas includes feedstock preparation, producing the biogas and stabilization of digested solids, and finally gas is cleaned. The biogas generated contains 60–70% of methane and 30–40% of carbon dioxide, as well as small amounts of nitrogen, hydrogen, hydrogen sulfide and oxygen. Major sources of feedstock for anaerobic digestion processes in a city are biowaste and sludge or black water from waste water treatment plants. Other possible sources are agricultural and animal waste, crop residues, biomass, and energy crops. (Kauhanian and Tchobanoglous 2000, pp. 25:2–25:3.)

Bioethanol has been traditionally produced primarily from crops, such as sugarcane, maize (corn) and soybeans. Lately, for example, Finnish ST1 has studied and developed a bioethanol producing process from biowastes. Ethanol fermentation is a biological process, by which sugar/starch/lignocellulose is converted into ethanol and carbon dioxide through biological metabolism. Bioethanol can be used in vehicles in various fuel mixtures. (HighTech Finland 2009, pp. 34–35.)

And finally, heat can be also recovered from waste water with heat exchangers. It can be done both close to water consumers, and in the waste water treatment plant, depending on the other technologies used. If the waste water is treated with biological water purification process, the temperature of incoming waste water has to be high enough in order to accomplish efficient water purification. In this case, some of the remaining heat could be recovered after water purification. On the other hand, a remarkable share of heat recovery potential is lost in the pipes when transferring the waste water from buildings to the purification plant.

3.5 Energy storage

Matching energy production and demand can be made more effective by the use of energy storage. The main advantage of energy storage is so-called energy management where energy is being stored during periods of low demand or/and high yield for later distribution during times of high demand, as is being demonstrated in Figure 32. To exemplify the basic principle of how energy storages can be utilized, electricity from solar panels during the daytime is used for charging batteries which later in the evening are used for powering lamps. In some cases energy storage is also used as backup power or to stabilize disturbances in power grids. Energy storages are especially necessary when utilizing renewable energy systems based on solar or wind energy, since the production from these tends to fluctuate depending on time and weather.

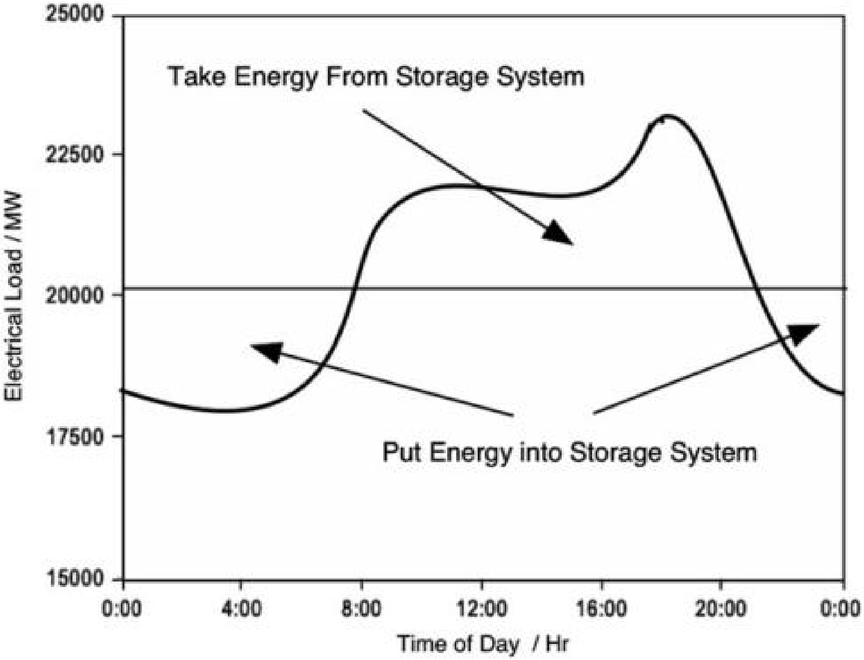
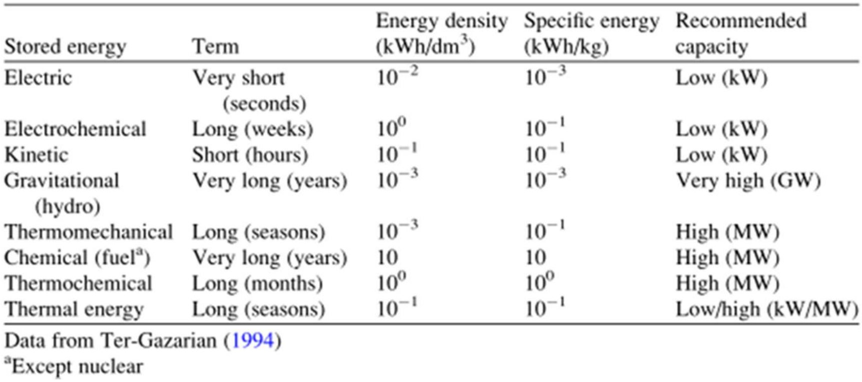


Figure 32. Fluctuation in daily electricity demand and production (Dincer and Zamfirescu 2011).

Energy storages can be of different sizes depending on their intended use and technology (see Table 13**.** Comparison of energy storage methods). It is possible to store generated energy in various forms with the help of the methods available today. For example, heat could be stored in so-called thermal storages and later used for heating purposes, while electricity could be used either for charging batteries, charging potential or kinetic energy storages or for the production of synthetic fuels. Some of the available methods for storing energy relevant to this study will now be introduced. (Dincer and Zamfirescu 2011.)

Table 13. Comparison of energy storage methods (Dincer and Zamfirescu 2011).



Stored energy	Term	Energy density (kWh/dm^3)	Specific energy (kWh/kg)	Recommended capacity
Electric	Very short (seconds)	10^{-2}	10^{-3}	Low (kW)
Electrochemical	Long (weeks)	10^{0}	10^{-1}	Low (kW)
Kinetic	Short (hours)	10^{-1}	10^{-1}	Low (kW)
Gravitational (hydro)	Very long (years)	10^{-3}	10^{-3}	Very high (GW)
Thermomechanical	Long (seasons)	10^{-3}	10^{-1}	High (MW)
Chemical (fuel[a])	Very long (years)	10	10	High (MW)
Thermochemical	Long (months)	10^{0}	10^{0}	High (MW)
Thermal energy	Long (seasons)	10^{-1}	10^{-1}	Low/high (kW/MW)

Data from Ter-Gazarian (1994)

[a]Except nuclear

3.5.1 Thermal storages

Heat can be stored in so-called thermal storages containing a material of high thermal capacity. There are different categories of thermal storages, depending on operating temperature, length of time of the stored energy and status of the energy storage material. Regarding the temperature, there are technologies available for both hot and cold thermal storages. The storing time of a thermal storage depends on its capacity, insulation, and the demand for connected buildings. Small-sized water tanks used in separate buildings are often short-term storages that could last several days while seasonal types such as large hot water, gravel/water or earth-duct storages could serve the heating needs of multiple houses for several months. (Fisch and Huckemann 2006.)

Depending on the status of the storage material, a thermal storage can in general be categorized either as sensible heat, latent heat or thermochemical heat storage. In sensible heat storages, which are commonly in use in relation with buildings, the storage material is kept in one phase all of the time. The storage material in latent heat storages, on the other hand, undergoes phase changes during the storage process. In so-called thermochemical storages, endothermic and exothermic reactions are taking place where heat is either absorbed or released by the chemical reactions of the compounds inside. However, the existing technology either requires very high operational temperatures or advanced reactions, which makes it unfavorable for normal building applications. The concept of a large-scale underground storage is shown in Figure 33 a and b. (Sunliang 2010.)

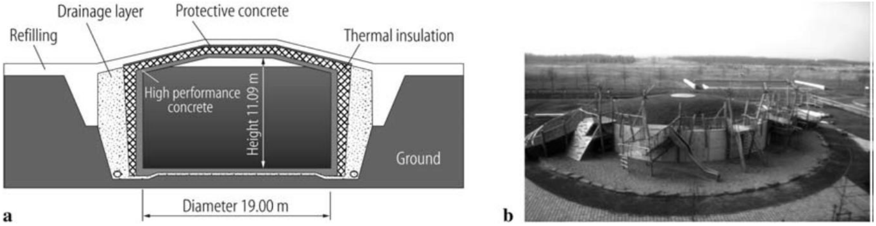
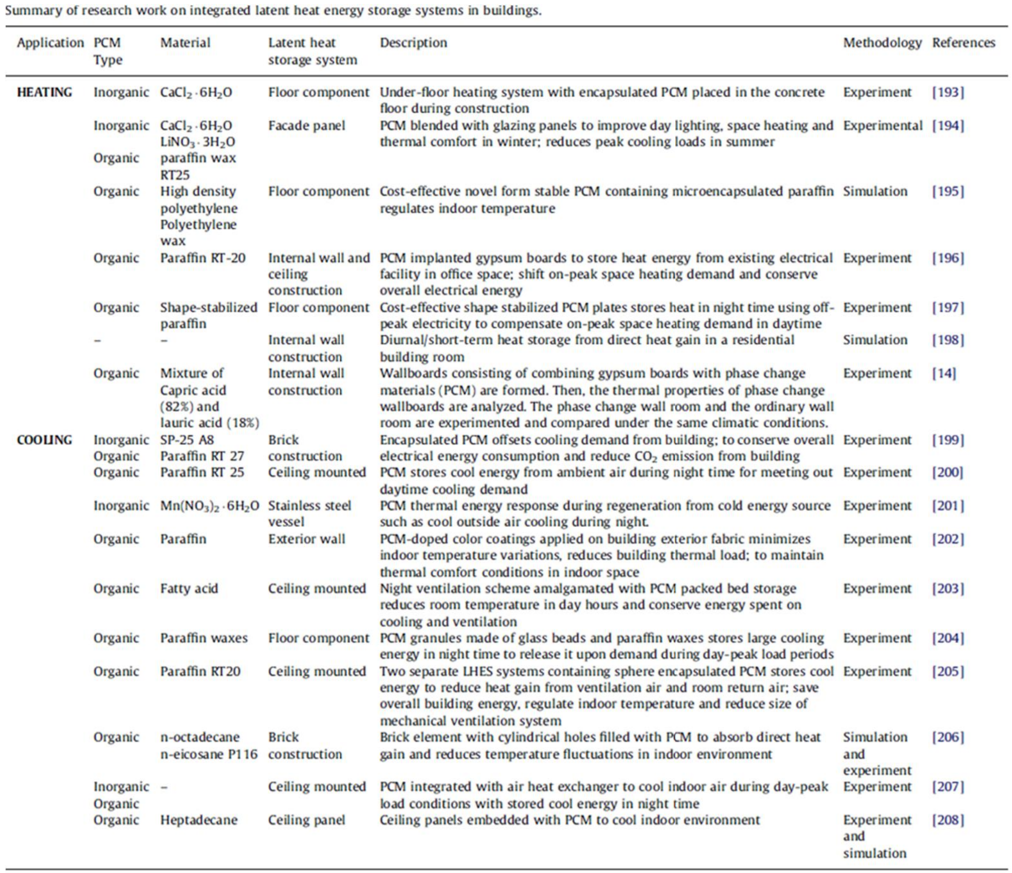


Figure 33. (a) Simplified cross section of the storage in Hanover-Kronsberg. (b) Finished area surrounding the storage with a playground. (Fisch and Huckemann 2006.)

3.5.2 Thermal energy storage materials for in-building applications

Heating and cooling can be made effective in buildings by choosing the right material and coating for building structures and surfaces. In Table 14, (Tatsidjodoung et al. 2013) have composed a list of materials that can be used for thermal energy storing purposes in buildings. However, phase change materials (PCM) have proved to be promising in the search for proper storage material for buildings. In another study by Waqas and Ud Din (2013), the potential of using a certain PCM material for passive cooling was evaluated. Conclusions from the study were that PCM material has a crucial role in the passive cooling of buildings in climatic conditions, and that PCM material and its melting point is of importance when designing the cooling system. Furthermore, the initial costs of PCM-based cooling systems are still high, since the technology has not yet been commercialized. Even though there have been numerous studies performed on different materials for heat storing applications, the thermophysical properties of these have not been fully assessed. Examples of materials that have reached an advanced stage of research are silica gel/water, magnesium sulfate/water, lithium bromide/water, lithium chloride/water, and sodium hydroxide/water.

Table 14. List of integrated latent heat energy systems in buildings by (Tatsidjodoung et al. 2013).



Summary of research work on integrated latent heat energy storage systems in buildings.

Application	PCM Type	Material	Latent heat storage system	Description	Methodology	References
HEATING	Inorganic	$CaCl_2 \cdot 6H_2O$	Floor component	Under-floor heating system with encapsulated PCM placed in the concrete floor during construction	Experiment	[193]
	Inorganic Organic	$CaCl_2 \cdot 6H_2O$ $LiNO_3 \cdot 3H_2O$ paraffin wax RT25	Facade panel	PCM blended with glazing panels to improve day lighting, space heating and thermal comfort in winter; reduces peak cooling loads in summer	Experimental	[194]
	Organic	High density polyethylene Polyethylene wax	Floor component	Cost-effective novel form stable PCM containing microencapsulated paraffin regulates indoor temperature	Simulation	[195]
	Organic	Paraffin RT-20	Internal wall and ceiling construction	PCM implanted gypsum boards to store heat energy from existing electrical facility in office space; shift on-peak space heating demand and conserve overall electrical energy	Experiment	[196]
	Organic	Shape-stabilized paraffin	Floor component	Cost-effective shape stabilized PCM plates stores heat in night time using off-peak electricity to compensate on-peak space heating demand in daytime	Experiment	[197]
	–	–	Internal wall construction	Diurnal/short-term heat storage from direct heat gain in a residential building room	Simulation	[198]
	Organic	Mixture of Capric acid (82%) and lauric acid (18%)	Internal wall construction	Wallboards consisting of combining gypsum boards with phase change materials (PCM) are formed. Then, the thermal properties of phase change wallboards are analyzed. The phase change wall room and the ordinary wall room are experimented and compared under the same climatic conditions.	Experiment	[14]
COOLING	Inorganic Organic	SP-25 A8 Paraffin RT 27	Brick construction	Encapsulated PCM offsets cooling demand from building; to conserve overall electrical energy consumption and reduce CO_2 emission from building	Experiment	[199]
	Organic	Paraffin RT 25	Ceiling mounted	PCM stores cool energy from ambient air during night time for meeting out daytime cooling demand	Experiment	[200]
	Inorganic	$Mn(NO_3)_2 \cdot 6H_2O$	Stainless steel vessel	PCM thermal energy response during regeneration from cold energy source such as cool outside air cooling during night.	Experiment	[201]
	Organic	Paraffin	Exterior wall	PCM-doped color coatings applied on building exterior fabric minimizes indoor temperature variations, reduces building thermal load; to maintain thermal comfort conditions in indoor space	Experiment	[202]
	Organic	Fatty acid	Ceiling mounted	Night ventilation scheme amalgamated with PCM packed bed storage reduces room temperature in day hours and conserve energy spent on cooling and ventilation	Experiment	[203]
	Organic	Paraffin waxes	Floor component	PCM granules made of glass beads and paraffin waxes stores large cooling energy in night time to release it upon demand during day-peak load periods	Experiment	[204]
	Organic	Paraffin RT20	Ceiling mounted	Two separate LHES systems containing sphere encapsulated PCM stores cool energy to reduce heat gain from ventilation air and room return air; save overall building energy, regulate indoor temperature and reduce size of mechanical ventilation system	Experiment	[205]
	Organic	n-octadecane n-eicosane P116	Brick construction	Brick element with cylindrical holes filled with PCM to absorb direct heat gain and reduces temperature fluctuations in indoor environment	Simulation and experiment	[206]
	Inorganic Organic	–	Ceiling mounted	PCM integrated with air heat exchanger to cool indoor air during day-peak load conditions with stored cool energy in night time	Experiment	[207]
	Organic	Heptadecane	Ceiling panel	Ceiling panels embedded with PCM to cool indoor environment	Experiment and simulation	[208]

3.5.3 Pumped hydrostorage

Pumped hydrostorages are based on the principle of pumping water from a lower into a higher reservoir during times of low demand. The water is released back by gravitational forces to the lower reservoir through turbines, where electricity is generated. Usually, charging of pumped hydrostorage takes place during the day and discharging during the night (see Figure 34). However, new systems installed with variable-speed pumps can better respond to the production of renewable energy sources and are more flexible in stabilizing fluctuations of the power grid. This means that charging and discharging of the reservoir can happen several times during a day without technical complications. (Inage 2009.)

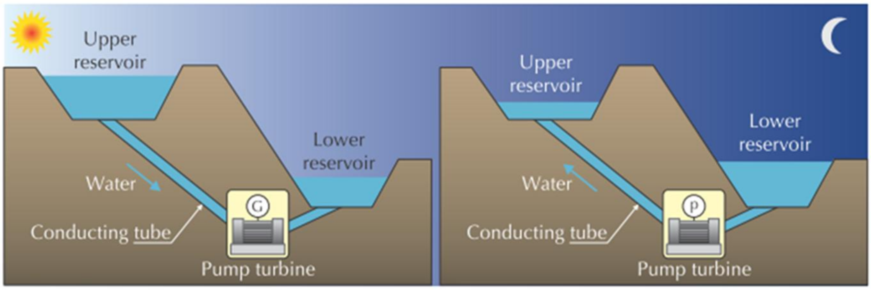


Figure 34. Concept of pumped hydrostorage; the reservoir is discharged during the day when power demand is high and pumped back to the reservoir during the night. (Inage 2009.)

3.5.4 Flywheel

Generated electricity can be stored as kinetic energy by using it for the rotation of a flywheel. The concept is bases on a superconducting magnetic radial and thrust bearing to reduce mechanical losses. The flywheel rotates faster when being charged and slows down during discharge. When discharging, the kinetic energy from the flywheel is transformed into electricity by a generator. See Figure 35 for further description of a flywheel storage structure. (Inage 2009.)

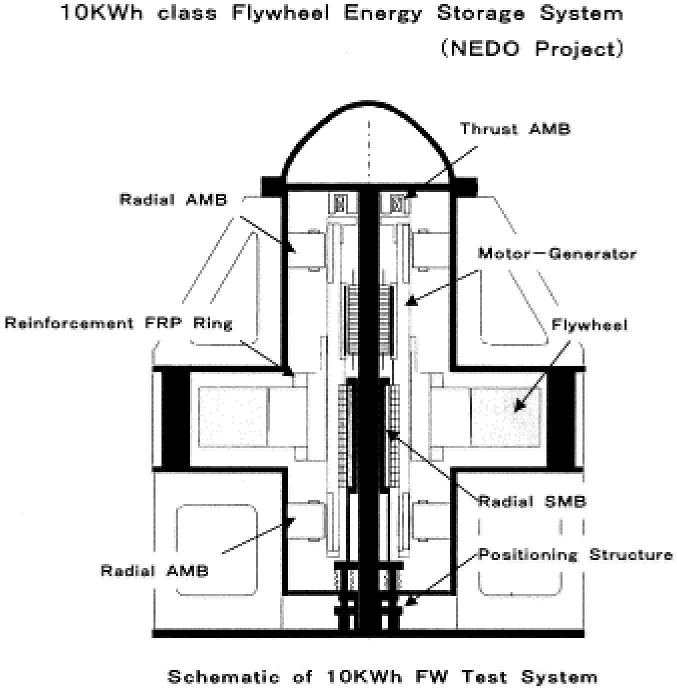


Figure 35. Simplified structure of a flywheel (Koshizuka et al. 2002).

3.5.5 Compressed air energy storage (CAES)

The main idea of CAES is to store energy in the form of compressed air in geological cavities (see Figure 36). Excess electricity is used for compressing the air which is, when needed, allowed to expand in a turbine for generating electricity. Since some of the heat is lost during air compression, CAES systems have to depend on additional heating during the stage of decompression. Burning natural gas has been a tested solution for this. The effect of heat losses during compression has been reduced in the concept of Advanced Adiabatic Compressed Air Energy Storage (AA-CAES). In this concept, the heat during compression is stored separately to be used later during decompression. AA-CAES therefore has a better round-trip efficiency than CAES. (Inage 2009, IEA 2011a.)

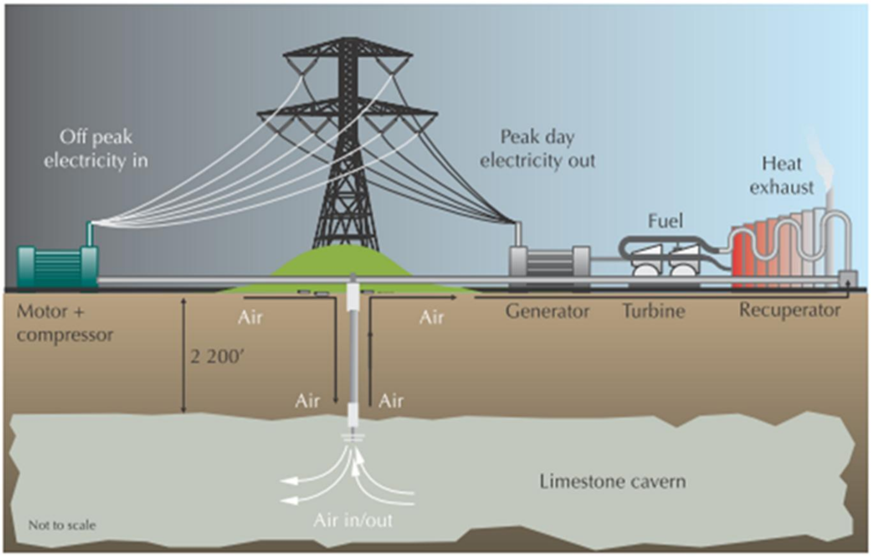


Figure 36. Principle of compressed air energy storage. Source: IEA (2011).

3.5.6 Superconducting magnetic energy storage (SMES)

The principle of SMES is to charge a superconducting coil inside a magnetic material with electricity for inducing so-called magnetic energy. SMES systems are expected to have high energy and power densities, and are known to have the advantage of having quick response time compared to other storage methods. However, one major problem with superconductor materials is that they have to be kept within the range of their specific critical temperature, which is often is very low. This means that additional energy is required for the cooling of components in SMES systems. Superconducting materials would lose their superconductive properties otherwise if the critical temperature is not achieved or their critical current is exceeded. The working principle of a SMES system is demonstrated in Figure 37. (Inage 2009, Huggins 2010.)

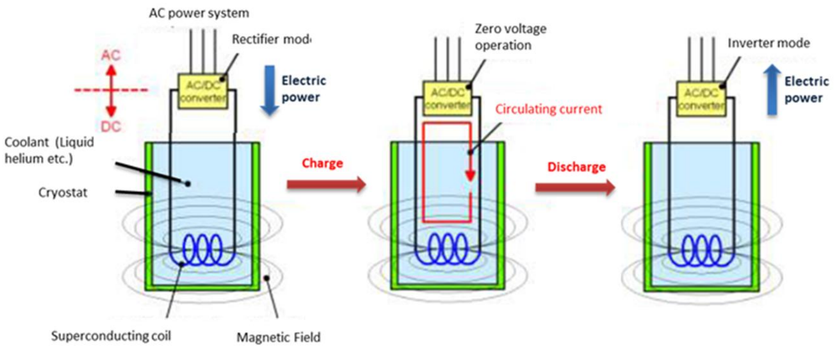


Figure 37. Working principle of a superconducting magnetic energy storage. Source: Inage (2009).

3.5.7 Electrical batteries

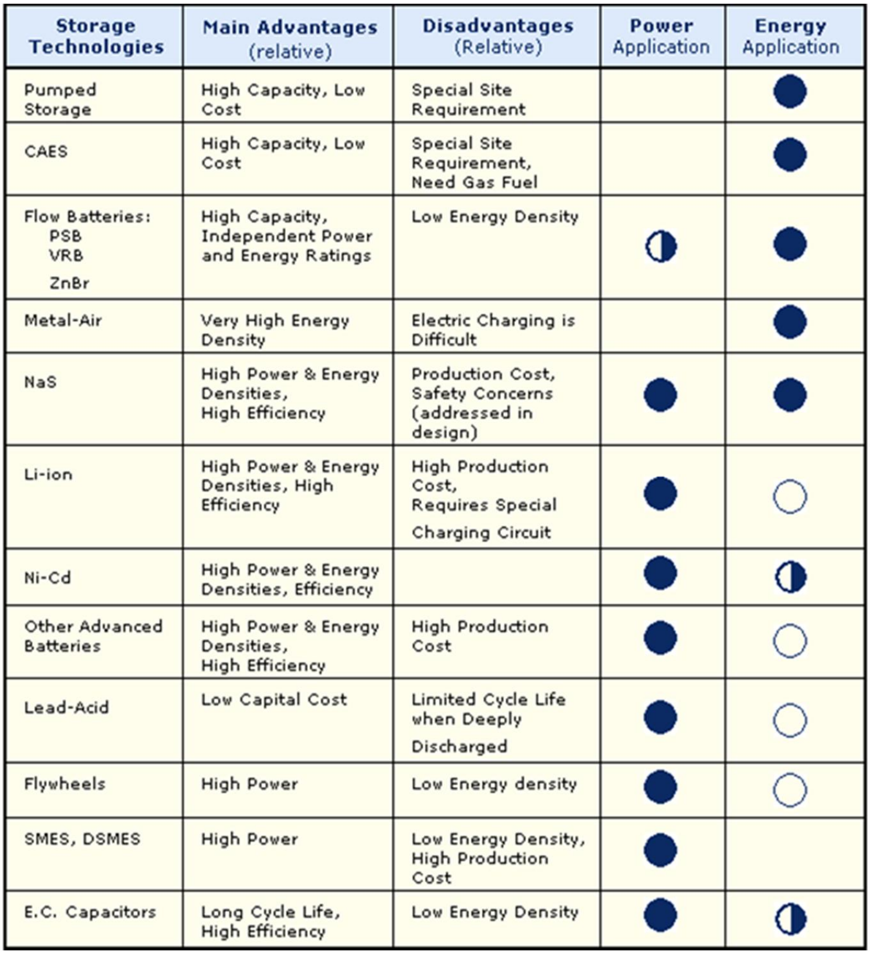
Storing energy in electrical batteries has been widely explored, as can be recognized by their wide use in electronic devices today. Batteries are usually formed from several interconnected cells to provide for required voltage and capacity. Each cell is in turn composed of basically positive and negative electrode(s), and an electrolyte that connects these. There are numerous types of electrical batteries based on the material used for the electrodes and the electrolyte. Batteries are usually named after their electrode material. Types dominating the market of today are lead-acid, nickel-cadmium (NiCd), nickel-metal hydride (NiMH) and lithium batteries. (Fisch and Huckemann 2006, Sunliang 2010, ESA 2011, Pop et al. 2008.)

Depending on their technology and material, batteries can be used either for:

- ensuring continuity of quality power where high power is transferred for a few seconds or less
- assuring continuity of service for seconds to minutes when switching between power sources
- energy management where energy is stored to cover the gaps between electricity generation and consumption, thus providing better energy efficiency.

Batteries are therefore rated according to their energy and power densities, price and discharge time. Table 15 shows the most common battery technologies, their properties and fields of use. The capital costs per capacity and power comparison of different energy storage types (mainly batteries) are shown in Figure 38. (ESA 2011.)

Table 15. Energy storages with their advantages and disadvantages in terms of application (ESA 2011).



Storage Technologies	Main Advantages (relative)	Disadvantages (Relative)	Power Application	Energy Application
Pumped Storage	High Capacity, Low Cost	Special Site Requirement		●
CAES	High Capacity, Low Cost	Special Site Requirement, Need Gas Fuel		●
Flow Batteries: PSB VRB ZnBr	High Capacity, Independent Power and Energy Ratings	Low Energy Density	◐	●
Metal-Air	Very High Energy Density	Electric Charging is Difficult		●
NaS	High Power & Energy Densities, High Efficiency	Production Cost, Safety Concerns (addressed in design)	●	●
Li-ion	High Power & Energy Densities, High Efficiency	High Production Cost, Requires Special Charging Circuit	●	○
Ni-Cd	High Power & Energy Densities, Efficiency		●	◐
Other Advanced Batteries	High Power & Energy Densities, High Efficiency	High Production Cost	●	○
Lead-Acid	Low Capital Cost	Limited Cycle Life when Deeply Discharged	●	○
Flywheels	High Power	Low Energy density	●	○
SMES, DSMES	High Power	Low Energy Density, High Production Cost	●	
E.C. Capacitors	Long Cycle Life, High Efficiency	Low Energy Density	●	◐

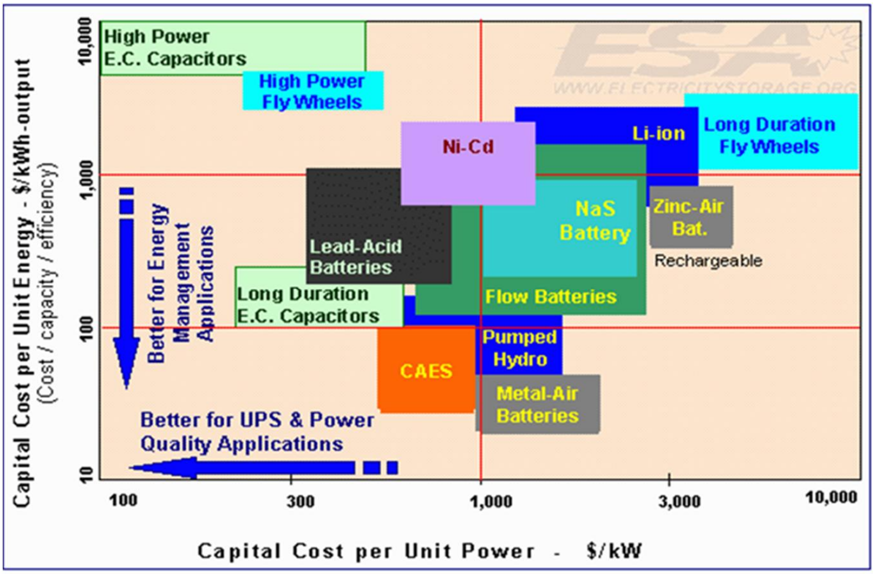


Figure 38. Cost of different energy storage technologies (ESA 2011).

3.5.8 Synthetic fuel storage

Chemical energy can be stored as synthetic fuels, such as are ammonia, ethanol, Fischer–Tropsch diesel, syngas, and methane. The production of these can be carried out during low demand periods, and the fuel is stored to be used in either power production (combustion) or other appliances where the same type of fuel is utilized, such as for cooking or powering vehicles. Energy stored as synthetic fuel can in general be considered to be higher energy per unit of mass but lower power extraction per unit of mass due to the high mass involved in the fuel and power-generating facilities.

Producing hydrogen from the excess power generation of a renewable energy source such as wind or solar is currently an area of development. One of the biggest advantages of using hydrogen as a fuel is its versatility as regards both how it can be produced and utilized. This is demonstrated in Figure 39. Hydrogen is also the primary element from which other synthetic fuels or chemicals can be produced. However, storing hydrogen is expensive for longer periods due to leakage and high compression and hydrogen liquefaction costs. (Dincer and Zamfirescu 2011, Fisch and Huckemann 2006.)

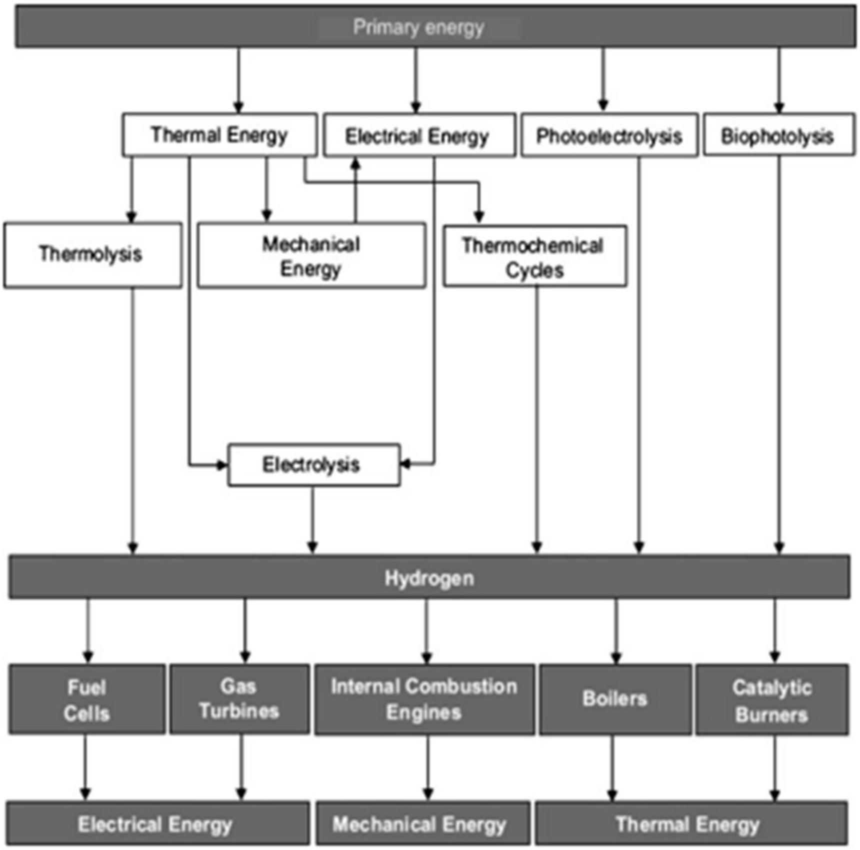
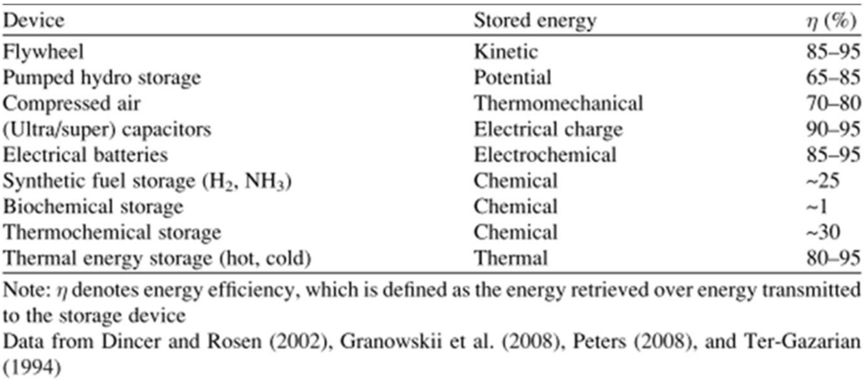


Figure 39. Methods for the producing and utilizing hydrogen. Source: Fish and Huckemann 2006.

As has been shown in this chapter, there are many technologies available for storing energy. Which one is to be applied depends on circumstantial factors such as available space, demand fluctuations, capacity required, response time, cost, etc. An important factor when it comes to the profitability of storing energy is the energy efficiency of the technology. This number denotes how much of the transmitted energy can be retrieved after being stored by a certain technology. The energy efficiency of different storage technologies is put into relation to each other in Table 16.

Table 16. Energy efficiencies of different energy storage technologies (Sunliang 2010).



Device	Stored energy	η (%)
Flywheel	Kinetic	85–95
Pumped hydro storage	Potential	65–85
Compressed air	Thermomechanical	70–80
(Ultra/super) capacitors	Electrical charge	90–95
Electrical batteries	Electrochemical	85–95
Synthetic fuel storage (H_2, NH_3)	Chemical	~25
Biochemical storage	Chemical	~1
Thermochemical storage	Chemical	~30
Thermal energy storage (hot, cold)	Thermal	80–95

Note: η denotes energy efficiency, which is defined as the energy retrieved over energy transmitted to the storage device

Data from Dincer and Rosen (2002), Granowskii et al. (2008), Peters (2008), and Ter-Gazarian (1994)

3.6 Implementation of design principle in case studies

This section describes the cases studies using methods depicted in section 2 for evaluation of the systems. Two of the cases (Section 3.6.1) are based on Finnish districts evaluated in Virtanen (2011). The system selection and performance evaluation principle has been applied in two Finnish case districts in a master's thesis called "Choosing the optimal energy system for buildings and districts". The districts differ by their size but also by their structure. The smaller case district is located in Central Finland, in the city of Jämsä. The larger case district is located in the city of Tampere, Finland.

The collection of data in both case studies was done both by interviewing the municipal authorities and other stakeholders involved in the case study districts and by studying the documentation regarding the district, for example district plans. The energy consumption of the type buildings was calculated on the assumption that each building within the case study districts was a low-energy building. In addition, the energy consumption of the case districts was evaluated on the basis of the buildings' energy consumption and the thermal energy losses of the heat distribution network in alternatives, where the district energy system was centralized.

A number of energy system alternatives were defined for both case districts, taking into account the limits and requirements set by the developers of the case districts, location of the districts and other factors affecting the feasibility of the energy system alternatives.

The Chinese example is from the planning phase of a 100k district. This case study is presented in Chapter 3.6.3.

3.6.1 Case study 1: Jämsä small case district in Finland

Jämsä case district is located in the city of Jämsä in the Central-Finland. The district is one of six case districts which are part of the national EcoDistrict project. The district plan, which is presented in Figure 40, shows that 45 single-family houses are planned to be built in the district. There are also three existing plots which are already built and will not be taken into account in these calculations, as the energy systems in the buildings are already determined.

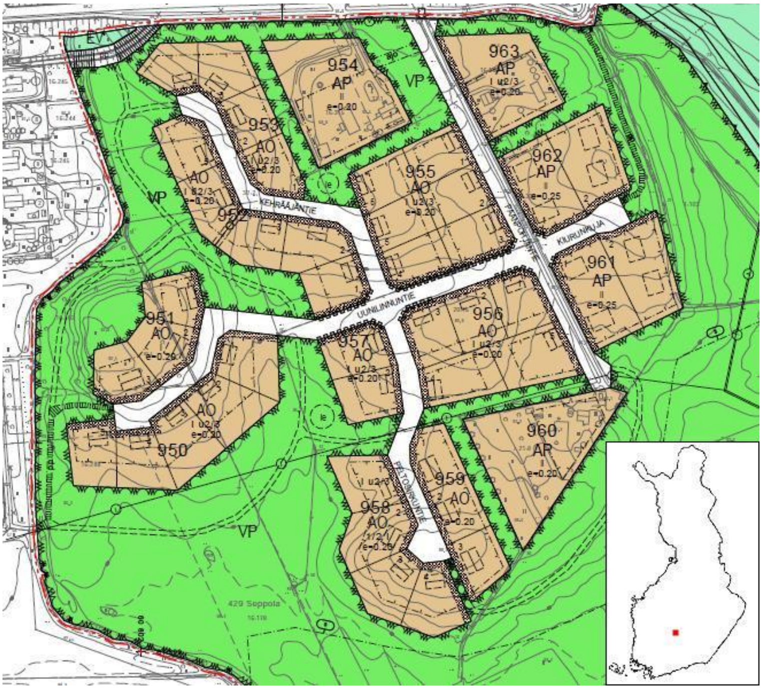


Figure 40. Proposed district plan of the case district (modified from: City of Jämsä 2011).

Energy consumption calculations

The energy consumption of two type buildings with different sizes was calculated for the case district. The energy consumption calculations were made with WinEtana using the values presented in Table 17. The estimates regarding the number and size of the buildings were approved by the city of Jämsä.

Table 17. Size and number of type buildings.

Building type	Size of building [m^2]	Number of buildings [-]
Detached house, large	220	6
Detached house, small	125	39

The thermal energy consumption of heating and domestic hot water is presented separately in Table 18 as well as the electricity consumption of the type buildings. The energy consumption values are the energy consumption of the total number of each of the two type buildings.

Table 18. Energy consumption of the buildings in the case district.

Building type	Heating [MWh/a]	Domestic hot water [MWh/a]	Electricity [MWh/a]
Detached house, large	57	18	36
Detached house, small	199	55	185
Total	256	73	221

For district level energy systems, a heat distribution network is required. The length of the distribution network was estimated on the basis of the district plan proposal. The length of the distribution network, annual thermal energy losses and the loss heat flux of the heat distribution network is presented in Table 19.

Table 19. Heat distribution network.

Pipe size	Length [m]	Total thermal energy loss [MWh/a]	Total loss heat flux [kW]
DN25	2050	211	32

Energy system alternatives

The energy system alternatives selected for the performance evaluation are presented in Table 20. The information received from the district and requirements set by the client were taken into account when defining the alternatives. A district heating network exists near the case district. However, it is unclear whether the network will be expanded to the case district area. Therefore, the existing district heating network was not considered as an alternative for the energy system comparison.

The alternatives include energy systems for building, building group and district level system. Alternatives 1, 2 and 3 are the building-specific energy systems. Ground source heat pumps are also considered as a building group-specific energy system in alternative 4. The district level energy systems are alternatives 5 and 6.

Table 20. Energy system alternatives.

	Energy system
Alternative 1	Electric heating
Alternative 2	Pellet boilers
Alternative 3	Ground source heat pump, building
Alternative 4	Ground source heat pump, building group
Alternative 5	District heat plant
Alternative 6	Solar thermal, seasonal storage

In alternative 4, the buildings of the case district are divided into building groups. The groups are presented in Figure 41. Each building group acquires the thermal energy from a group-specific ground source heat pump system, forming a small scale heat network.

The lengths of the distribution network piping are estimated on the basis of the building groups and the district plan proposal. The estimated distribution network lengths for each building group and the distribution network losses are presented in Table 21.

Figure 41. Case district divided into building groups.

Table 21. Building group-specific heat distribution systems.

Building group	Number of buildings		Thermal energy demand in buildings	Pipe length	Energy loss	Loss heat flux	Total thermal energy
	Large	Small	[MWh/a]	[m]	[MWh/a]	[kW]	[MWh/a]
1		5	32.6	125	17	2.0	50
2	3		37.6	75	10	1.2	48
3		3	19.5	75	10	1.2	30
4, 5		6	78.1	600	83	9.5	161
6, 7		4	52.1	200	28	3.2	80
8	1	2	25.6	50	7	0.8	32
9	2	2	38.1	100	14	1.6	52
10		7	45.6	300	42	4.7	87
Total	6	39		1525	211	24.1	540

In alternative 6, the thermal energy for the buildings is produced using solar thermal collectors. A seasonal thermal storage is required in this alternative, as the yield of the solar thermal collectors varies during the year.

The yield of 1 m^2 solar thermal collector in the location of the case district is 595 kWh. Taking into account the thermal losses of the seasonal storage, the total solar thermal collector area required to provide the thermal energy for both heating and domestic hot water is approximately 1100 $m^{2.}$

The results of the evaluation are presented in Table 22.

Table 22. The outranking flows and ranks of the energy system alternatives.

	Positive flow ϕ^+	Negative flow ϕ^-	Net flow ϕ	Rank
Alternative 1 - Electric heating	0.1500	0.3944	-0.2444	6
Alternative 2 - Pellet boilers	0.3150	0.0341	0.2809	1
Alternative 3 - Ground source heat pump, building	0.1795	0.1759	0.0037	3
Alternative 4 - Ground source heat pump, building group	0.1090	0.3467	-0.2377	5
Alternative 5 - District heat plant	0.2750	0.0540	0.2210	2
Alternative 6 - Solar thermal, seasonal storage	0.2350	0.2584	-0.0234	4

Alternative 2, building specific pellet boilers, ranked first in the evaluation. The second highest alternative was the district heat plant, operated using wood chip. The relatively low cost of the biomass fuels in both alternatives as well as the low emissions of the energy production were definitely key factors affecting the high ranking of the two alternatives.

3.6.2 Case study 2: Large case district – Tampere, Finland

Tampere case district, Koukkuranta, is located in the City of Tampere in Finland. The district belongs to a series of case districts in a national EcoDrive project. The gross floor area on the district will be over 50 000 m^2, consisting of detached houses, row houses and apartment blocks. The number of apartments will be approximately 450.

The case district is separated into two distinguishable parts. The buildings in the northern part are detached houses and the southern part consists mainly of row houses and apartment buildings. The district plan of Koukkuranta is presented in Figure 42.

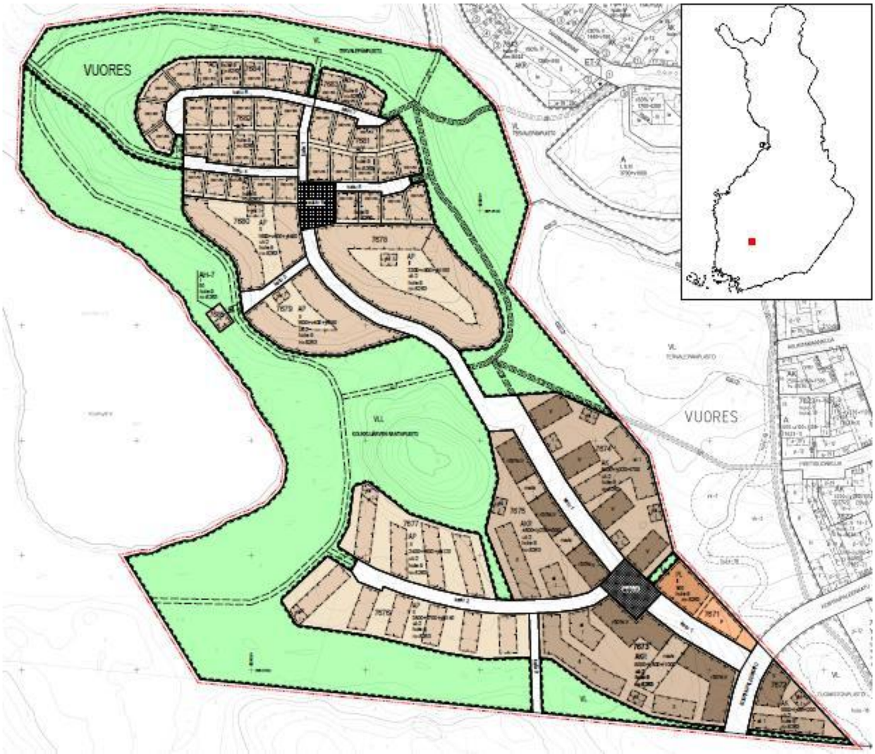


Figure 42. Proposed district plan for the case district (modified from: City of Tampere 2010).

Energy consumption calculations

The buildings within the Koukkuranta district were assumed to be low-energy buildings. Specific energy consumption figures for each building type are presented in Table 23. The energy consumption calculations were made with the following type buildings:

- Apartment building
- Row house
- Detached building.

Table 23. Energy consumption of different building types.

Building type	Heating [kWh/m^2]	Domestic hot water [kWh/m^2]	Electricity [kWh/m^2]
Apartment building	37	21	29
Row house	47	16	32
Detached house	52	16	17

In district level energy systems, the heat has to be distributed from the production point to the buildings. The distribution adds up to the total energy consumption of the district in the form of heat distribution losses. The length of the heat distribution network is calculated on the basis of the district plan. The results of the calculations are presented in Table 24.

Table 24. District heating network.

	Pipe size	Length [m]	Thermal energy loss [MWh/a]	Loss heat flux [kW]
South	DN25	1 035	143	16
	DN40	225	45	5
	DN65	285	68	8
	Total	1 545	256	29
North	DN25	1 685	233	27
Total		4 775	489	56

Energy system alternatives

The energy system alternatives selected for comparison in the Tampere case are presented in Table 25. The existing district heating network is planned to be extended at least to the southern part of the case district, but in one alternative the network is assumed to be expanded to provide thermal energy for the whole case district.

Table 25. Energy system alternatives.

	Energy system
Alternative 1	Electric heating
Alternative 2	District heating network
Alternative 3	Pellet boilers (Building specific)
Alternative 4	Building group ground source heat (North part) District heating network (South part)
Alternative 5	Building group ground source heat north and solar energy (North part)

	District heating network (South part)
Alternative 6	Water source heat pump (District level energy system)
Alternative 7	Water source heat pump and wind energy (District level energy system)
Alternative 8	CHP (District level energy system)

The building group ground source heat pump with additional solar energy in alternative 5 is illustrated in Figure 43.

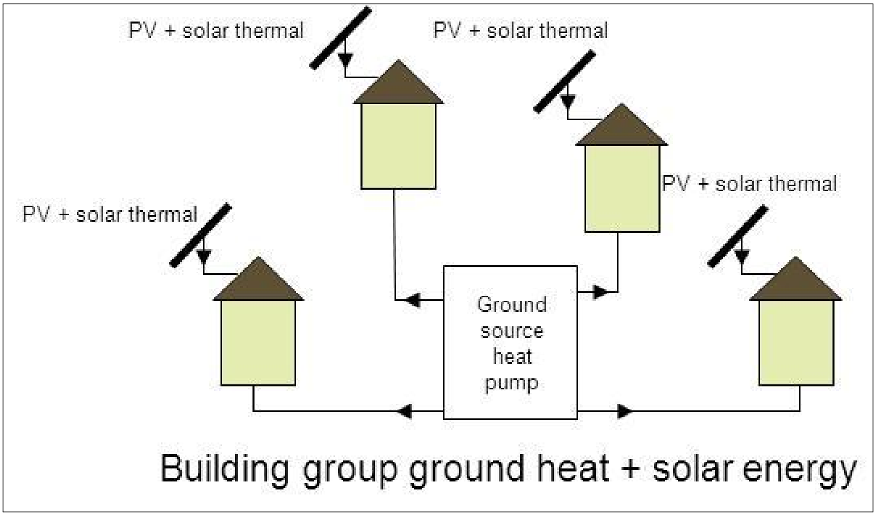


Figure 43. Alternative 5.

In Alternative 4, the ground source heat pump systems in the northern part of the district are considered as building group specific systems. The building groups in this alternative are formed by the city blocks presented in the district plan. Each building group requires an individual heat distribution network. The details of the building group heat distribution networks are presented in Table 26.

Photovoltaic panels are included in alternative 5; the panels are assumed to be installed on the roofs of the buildings in the northern part of the case district. Each row house was assumed to have a 8 kW_p and each detached house a 2 kW_p photovoltaic module installed on the roof. The estimated electricity yield of the photovoltaic panels is presented in Table 27.

Table 26. Heat distribution within building groups.

Block	Pipe length (DN25) [m]	Thermal energy loss [MWh/a]	Loss heat flux [kW]
7678	320	44.3	5.1
7679	240	33.2	3.8
7680	140	19.4	2.2
7681	160	22.1	2.5
7682	240	33.2	3.8
7683	60	8.3	0.9
7684	180	24.9	2.8

Table 27. Photovoltaic yield.

	Total yield [kWh]
January	2 729
February	8 589
March	13 820
April	19 068
May	22 391
June	20 642
July	21 342
August	16 584
September	11 633
October	6 630
November	2 572
December	1 503
Total	147 502

The results of the evaluation are presented in Table 28.

In the larger case district, the highest ranking energy system alternative is a pellet boiler, as it was in the smaller case district. Again, the rather low cost of the fuel and the low lifecycle emissions of the energy system are one of the key factors affecting the ranking.

Table 28. The outranking flows and ranks of the energy system alternatives.

		Positive flow ϕ^+	Negative flow ϕ^-	Net flow ϕ	Rank
Alternative 1	Electric heating	0.1168	0.4269	-0.3101	8
Alternative 2	District heating network	0.1413	0.2218	-0.0805	6
Alternative 3	Pellet boilers	0.3442	0.0555	0.2887	1
Alternative 4	Building group ground source heat (North) District heating network (South part)	0.1440	0.1952	-0.0511	4
Alternative 5	Building group ground source heat and solar energy (North part) District heating network (South part)	0.1320	0.3185	-0.1865	7
Alternative 6	Water source heat pump	0.1542	0.2086	-0.0544	5
Alternative 7	Water source heat pump and wind energy	0.2593	0.1531	0.1062	3
Alternative 8	CHP	0.3219	0.0342	0.2876	2

3.6.3 Case study 3: 100k district in China

The following case will be a study of a district planned for 100 000 inhabitants that represents the typical urban area in Dalian, China. The district is currently under planning, which caused uncertainties in the initial data needed for making the intended energy analyses. Assumptions and estimations have been made to compensate for this lack of information instead. This case study is, however, intended not to present a final solution for the energy systems of the 100k district but to demonstrate the principle of selecting and evaluating performance of energy systems for districts. The first step is to collect information about the district, local environment and the need of the clients (planners of the district).

Local conditions

The 100k district is sited in the colder part of China, where the outside temperature can vary from -19 to +35 °C between winter and summer. The heating period was estimated to be five months long, lasting from October to April, while cooling would be needed from June to August. The potential to utilize solar energy is high in the area, which has over 2 800 hours of sunshine a year. Furthermore, the possible percentage of sunshine is close to 70% in wintertime.

Local wind measurements show that the average monthly wind speed is around 5m/s (100 meter above sea level) (Chen et al. 2007, WindFinder 2012). The district is exposed to the coast, which means that water heat pumps could be effective for both heating and cooling in the area.

Buildings and their attributes

The 100k district covers almost 14 square kilometer of land that has been divided into several segments. Each of the segments was planned to contain one of the following building categories: residential, commercial, public and industrial buildings. Residential buildings have the least energy demand per square meter, but have a considerable effect on the overall annual demand of the district since they account for most of the total floor area. Commercial buildings have the highest annual demand for both heating and cooling energy of all the types presented due to high energy demands per floor area. The energy demands of industrial and public buildings are on the same level. Totally, the district needs 1 350 GWh of heating and 1 730 GWh of cooling energy per annum. The properties and energy consumption of each building category are shown in Table 29. Since the buildings have not been built yet, energy consumption and other crucial data (structural and material properties, home devices, etc.) were not available for analysing opportunities for improving the energy efficiency in these.

The 100k district is considered to be of medium built density (25% of total area). This means that the numbers of floors in residential building varies from 4–6 according to the building code China (MIT Building Technology Group 2000). Also, according to Yoshino et al. (2006), most buildings in larger cities in China are in average between 7 and 9 storeys high. The average number of floors in each building category is estimated based on these values. The total roof area of each building category was assumed to equal the total floor area divided by the average number of floors.

Table 29. 100k district: properties and, heating and cooling energy consumption of different building types.

100k district: properties and, heating and cooling energy consumption of different building types					
	Residential	Commercial	Public	Industry	Sum
Construction area [ha]	300	197	93	87	677
Space Heating/m^2 [kW/m^2/a]	133	305	240	335	
Total annual space heating demand [MWh/a]	400 071	602 954	222 747	289 963	1515 735
Cooling/m^2 [kW/m^2/a]	140	442	377	361	
Total annual cooling demand [MWh/a]	359 248	682 953	349 504	312 648	1704 354
Average floor number [-]	7	3	3	1	
Roof area [ha]	47	62	31	87	227

Estimated energy demand profile

The energy demand profile of the area will in this study be estimated based on data from both Table 29 and average values from the whole of China. This energy demand profile would in the future be useful for choosing proper energy production and transfer solutions and combinations for the area.

According to Zhou et al. (2007), the electricity consumption in a Chinese household is about half of the domestic hot water and heating consumption (see Figure 44). Furthermore, annual electricity needs for lighting and household appliances in this case are 203 GWh. Energy needed for cooking, which in China is mainly supplied by gas, would in this case be 47 GWh annually.

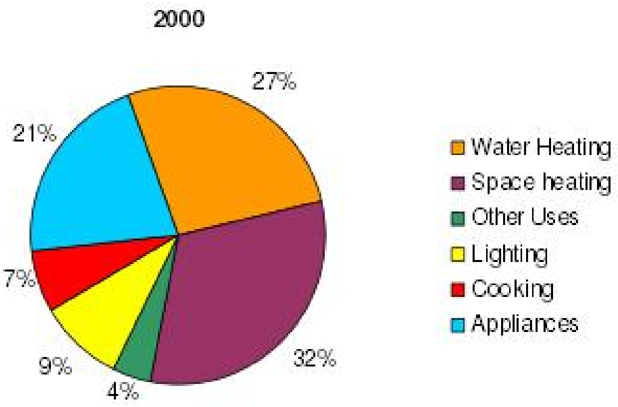


Figure 44. Residential energy consumption by end-use (Zhou et al. 2007).

The total energy demands (besides heating and cooling) of the buildings were predicted by using average values in China due to insufficient initial data. The sectoral final consumption of heat and electricity in China can be seen in Figure 45 and Figure 46 (IEA 2007). Based on these quotes, the total energy demand for the area is predicted in Table 30. Agriculture, other non-specified and transport has been excluded from this table.

Table 30. Heat and electricity consumption of building stock in the 100k district.

100k district: Total yearly energy consumption of different building types [MWh/a]					
	Residential	Commercial	Public	Industry	Sum
Heating (domestic hot water incl.)	400 000	603 000	223 000	896 000	2 122 000
Cooling	359 000	683 000	350 000	313 000	1 705 000
Electricity	203 000	70 000	70 000	850 000	1 193 000

The heating of buildings is assumed during heating periods when the outdoor temperature drops below 18 °C from October to April. To correlate with Figure 44 by Zhou et al. (2007) domestic hot water (50 °C) demand was estimated to be 86 liters per person per day. The heating consumption of industrial buildings was calculated according to the relationship in Figure 45 in order to account also for the process heat needed during production. The electricity consumption for appliances of the different building types was estimated based on the relationship in Figure 46.

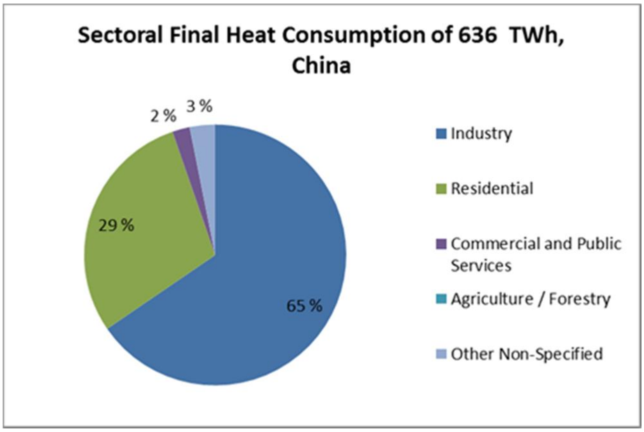


Figure 45. Sectoral final heat consumption of 636 TWh, China.

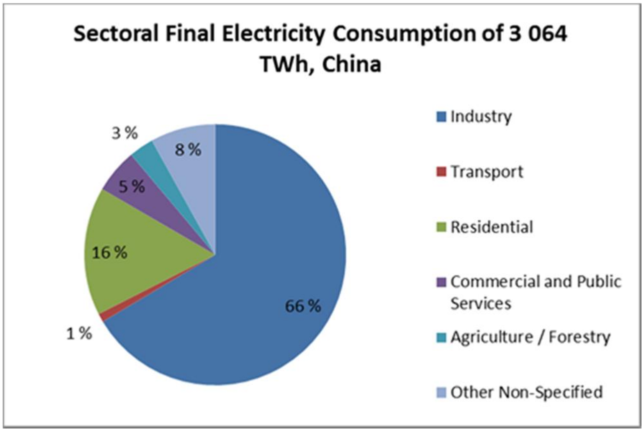


Figure 46. Sectoral final electricity consumption of 3064 TWh, China.

Considering space heating to vary with outside temperature and domestic hot water and industrial heat consumption to be evenly distributed throughout the year, the heat consumption for the 100k district would result in the graph presented in Figure 47.

Assuming cooling to take place when the outside temperature exceeded 26 °C, the cooling period of the 100k would last two months from July to September. Air and water source heat pumps were accounted to provide for the cooling needed in the buildings.

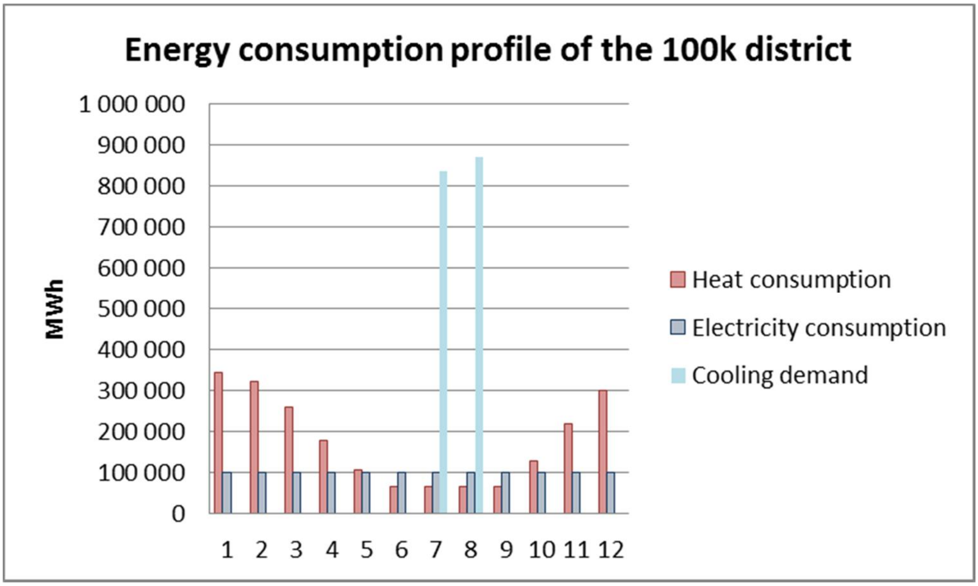


Figure 47. Combined energy demand for all buildings in the 100k district.

The electricity consumption of the 100k district has been considered to be evenly distributed over the year, which is why the columns in Figure 47 are on the same level. This would presumably be different in reality because of seasonal variations in consumer and industry demand.

Energy production and efficiency solutions

The energy production of the 100k district can now be examined once the energy demand curve has been estimated. In order to achieve better environmental sustainability, the potential sources for renewable energy in the area need first to be found and evaluated. The planned infrastructure of the area needs also to be considered in order to find optimized solutions for energy efficiency. For example, since gas is preferred for cooking, there will eventually be gas pipelines leading to most buildings. This means that there is also the opportunity to use gas for heating. By equipping buildings with combination buffer tanks, different heating systems based on e.g. solar heat, gas, wood, geothermal or electricity, can be combined and utilized according to their availability/profitability. The list of energy system alternatives presented in an earlier chapter is analyzed in Table 31 for the case of the 100k district.

Table 31. Energy system alternatives their suitability for the 100k district.

	District level	Building group level	Building level	Comment
Heat production				
Wood chip (+ solar)		X	X	- Fuel availability unknown! + Good solar energy potential
Pellet (+ solar)		X	X	- Fuel availability unknown! + Good solar energy potential
Natural gas (+ solar)	X	X	X	+ Other infrastructure using natural gas + Good solar energy potential - Emissions
Oil (+ solar)	X	X	X	- Oil prices and emissions + Good solar energy potential
Peat	X			- Fuel availability unknown!
Heat pumps (heat from rock/ground/water)	X	X	X	+ Water available (Shores)
Coal				
CHP production				
Biogas	X	X		- Fuel availability unknown! + Natural gas applications can be replaced with

				biogas in the future
Wood chip	X	X		- Fuel availability unknown!
Pellet	X		X	- Fuel availability unknown!
Coal	X			+ Price + Known technology - Emissions
Natural gas	X	X		+ Other infrastructure using natural gas + Fast starting time (peak demand) - Emissions
Oil	X			- Price - Emissions
Peat	X			- Fuel availability unknown!
Fuel cell systems	X	X		- Fuel availability unknown!
Other bio-based fuels (bio oil, ethanol)	X	X		- Fuel availability unknown!
Electricity				
Solar	X	X	X	+ Good solar energy potential
Wind power	X	X	X	- Low wind speed
Gas engine	X	X	X	+ Natural gas is widely used
Diesel engine	X	X	X	+ Flexible start and stop - Emissions - Oil prices

Exploiting the advantages and disadvantages of the solution presented in Table 31, the following solutions were chosen:

- building integrated solar heat and power,
- air and water pump heating and cooling for buildings and building groups
- gas turbines for both building group and district level combined heat and power (CHP) production.

However, this does not exclude other solutions, but some might have to be properly investigated (fuel availability and logistics, production capacity, costs, etc.) before they can be suggested for the target district. The systems chosen will be discussed further in the section below.

Building integrated solar heat and power

As discussed earlier, the solar energy utilization potential is good in the 100k district. The estimated monthly solar radiation of the area in Figure 48 is based on converted data from Chen et al. (2007). Since residential buildings require a considerable amount of energy for heating and hot water purposes, it would be convenient to produce that energy locally by installing solar thermal collectors on the roof of these building. By covering 60% of the roof of residential buildings with optimally tilted (30°) solar collectors, 225 GWh of solar thermal heat is produced annually in the district (60% of the demand of residential buildings). Utilizing energy that has been produced locally such as in this case also gives the advantage of reduced transfer losses.

Photovoltaic cells are estimated to cover 60% of the roof of commercial buildings, 70% for public building and seventy% for industrial buildings. These would generate 246 GWh of electricity, which is about 14% of the annual electricity consumption of the 100k district. One advantage of solar photovoltaic is the storage and distribution of electricity whenever storage capacity is available. Excess production from solar panels can either be stored in batteries for later use or possibly sold to the electricity grid. Losses in electricity distribution and storage have not been accounted for in the calculations regarding solar energy, since they are estimated to be utilized locally, and the losses are therefore small. The solar thermal system is estimated to have an overall efficiency of 50%, and the photovoltaic systems an efficiency of 12%.

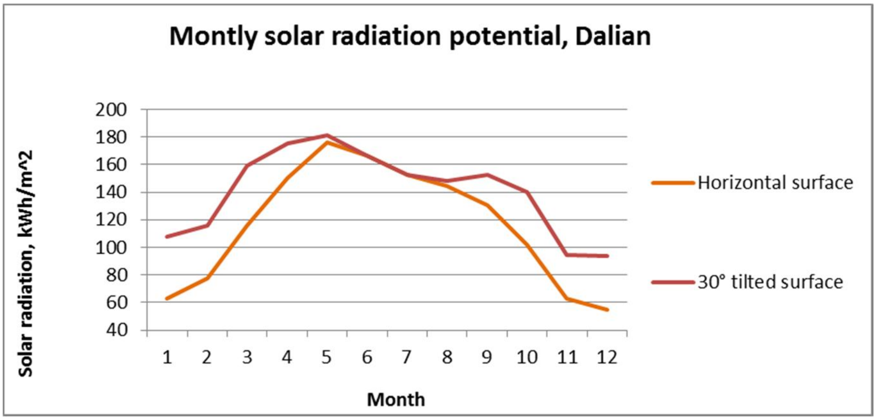


Figure 48. Monthly solar energy gain per square meter for a horizontal and a 30 degree inclined (azimuth to south) surface in Dalian, China (Chen et al. 2007).

Some areas in the district might be designated for solar photovoltaic or collector fields. This would enable better operational conditions for these technologies. Solar photovoltaic technologies would also be integrated into public places, thus providing electricity for smaller applications such as lighting, water pumps and vending machines, or for charging of mobile devices

Cooling by air and water source heat pumps

Since the area is situated close to the coast, water source heat pumps can be used for heating and cooling purposes. The water heat pumps in this case are estimated to have a coefficient of performance (COP) of 3 for heating and COP of 5 for cooling (estimated based on Waide et al. (2011) and Payne and Domanski (2002)). Considering water source heat pumps to supply 15% of the heating and 20% cooling demands of residential, commercial and official buildings, 117 GWh of electricity would provide for 184 GWh of heat and 278 GWh of cooling.

Air source heat pumps with a COP of 4 were assumed to supply the rest of the cooling demand of the district (Waide et al. 2011, IEA 2011b). This means that 1 426 GWh of cooling will be delivered by 357 GWh of electricity.

Energy and heat from gas turbines

Gas turbines should be used in the 100k district for both heat and electricity generation once the district has an infrastructure including gas lines It would be advantageous to fit gas turbines into those industrial complexes where high-temperature steam is required for the production processes. Heat distribution losses are then kept low due to shorter distribution distance. Excess heat with temperatures suitable for district heating should then be recovered for heating purposes. Combined cycle gas turbines used for combined heat and power (CHP) production might convert around 40% of the energy in the fuel into electricity while another 30% can be utilized for heat production. (Kehlhofer et al. 2011.)

Once the renewable energy opportunities in the district have been exploited the next step would be to focus on the base load of heat and electricity that needs to be provided by gas turbines (or other types of large scale energy systems). In Table 31 can be seen that the energy demand and production in the area when the earlier discussed energy system solutions (solar heat and power, heat pumps for heating and cooling) have been applied. It has been assumed that the rest of the heat and electricity required will be distributed by respectively district heating networks and power grids. Distribution losses for district heating networks in China were estimated to be 20% (IEA 2007a) and 5% for power grids (IEA 2009).

Table 32. 100k district energy balance including renewable sources [GWh].

100k district energy balance including renewable sources [GWh]						
Energy production/consumption	Heat (GWh)		Cooling (GWh)		Electricity (GWh)	
	+	-	+	-	+	-
Solar Collectors	225					
Solar PV					246	
Water source heat pumps	184		278			117
Air source heat pumps			1426			357
District consumption		2 122		1704		1 573
Sum	409	2122	1704	1704	246	2047
Additional energy need	1 713		0		1 801	
Losses in distribution	428				95	
Generation by gas turbines/ other power plants	2 141				1 896	

Looking at the monthly energy demand curves after subtracting the proposed solution in Table 32, it can be recognized that there are still large monthly variations in both electricity and heat demand. As mentioned earlier, gas turbines could be used in the 100k district to provide both heat and power. Gas turbines have in this case the advantage of a fast start-up time, so those could be used for providing energy during peak demand times. This means that idle units can be put into full production when necessary. Including distribution losses, gas turbines should cover around 1 924 GWh of heat and 1 890 GWh of electricity annually. Since most of the buildings would have combination buffer tanks, natural gas or electricity could be used for heating during colder periods and thereby keep the consumption ratio of heat and electricity close to the corresponding production ratio of gas turbines.

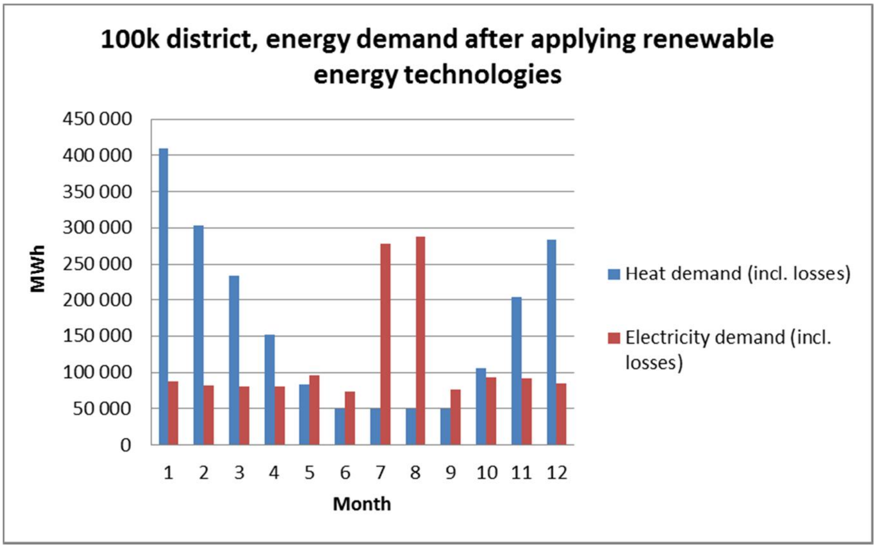


Figure 49. 100k district, energy demand after applying renewable energy technologies.

Another option would be to cut the energy demand peaks and drops by using energy storages. Certain areas could be designated for solar collectors or photovoltaic fields from which the excess energy is stored to be used during periods of high demand. This solution would be costly, but would on the other hand offer the advantage of environmental friendliness and implementation of smart grids and technologies. A further solution could also be to use the national or regional electricity grid to bridge the gap between electricity demand and supply.

Case discussion

Since the district is currently being planned, a detailed energy analysis for the whole district is difficult to prepare in detail, due to the lack of sufficient base data. The solutions for energy production have in this case study been suggested by taking into account local environmental conditions, energy consumption and surrounding resources. Solar energy was widely utilized in the district due to the high level of annual solar radiation. Water and air source heat pumps can be used for heating and cooling.

A basic step to energy efficiency is, however, to lower the energy demand by different means such as reducing heating, cooling and electricity demand as well as energy distribution losses, directing consumer behavior towards better awareness of energy efficiency, and applying technologies with lower energy consumption. Lower energy demand will ultimately lead to a lower need for energy production and therefore also less strains on the environment (fuel, material, resources, and emission), and thus also the reduced investment costs for energy production units. Regarding this, it would be important to look at the energy consumption of the buildings in case it can be lowered by, for example, better thermal insulation, low U-value windows, heat recovery technologies, effective use of spaces, efficient ventilation systems, improved air tightness of the buildings and passive cooling. Also utilization of efficient electrical appliances (classified/rated products, e.g. A+), and usage of water saving appliances (taps, shower etc.) would be recommended.

Natural gas has been taken advantage of in this case, since it is commonly used in Chinese households for cooking. An infrastructure including gas pipelines should also be exploited for other fields of usage such as heating, transportation, and electricity generation. The intended natural gas could later be replaced by biogas in order to reduce the environmental impact of energy production. A share of the biogas could be produced locally from biodegradable organic waste and waste water sludge. Waste management and recycling is also an important step to sustainability. Effective waste handling would mean a smaller amount going to landfill and a larger share being recycled or used in energy production (incineration, biogas etc.).

Regarding the suggested solution for the 100k district, there are still some issues to be solved before an optimized strategy can be found. This relates mostly to uncertain data and predictions. However, the case study was mainly for demonstrating the principles of district energy system concepts and exploiting local opportunities for renewable energy technologies.

4. Energy renovations of existing buildings

4.1 Factors

4.1.1 Migration drives building construction

China is one of the world’s largest economies and the world’s second largest energy consumer. Half of the world’s buildings constructed between now and 2020 are expected to be in China. (Austrade 2011.) One reason of the boom is migration: 13 to 21 million rural people migrating to cities each year require housing. The pace of new building does not cover the need (International Herald Tribune 2011).

As part of the effort to curb the excessively rapid rise of housing prices in some cities, the Chinese government will further implement and improve policies for regulating the real estate market. The total number of units of new low-income housing and units in run-down areas that will undergo renovation will reach 10 million, and 1.5 million dilapidated rural houses will be renovated. (Industry Updates 2011.)

Today’s Chinese renovation industry has accumulated revenue of more than US$ 225.22 billion, covering 170,000 companies; more than 99% are SMEs with over 14 million employees (Dong 2011). The renovation of existing building stock already offers major market opportunities.

The construction boom is a central reason why China passed the United States last year as the world’s largest consumer of electricity. China has also passed the United States as the world’s largest emitter of global warming gases, although it lags far behind in emissions and electricity consumption per person, because it has four times as many people as the United States. (International Herald Tribune 2011.)

4.1.2 Life span of buildings

In China, generally speaking, the planned building service life is 50 years, and if buildings exceed that, they should be retrofitted or reconstructed. Besides technical life span, land use issues can also define the coming life span. The state may requisition land owned by collectives according to a law on public interests. Table 33 shows the land usage term (a lifecycle) for different uses (Sjzu 2011).

Table 33. Land-usage terms for different users in China (Sjzu 2011).

Building types	Land usage term (years)
Residence	70
Affordable housing (for poor people)	50
Industry (workshops, etc.)	50
Education (schools, etc.)	50
Culture activities (cultural centers, etc.)	50
Sports activities (gymnasiums, etc.)	50
Health (hospitals, etc.)	50
Commercial (shopping malls, etc.)	40
Tourism (parks, etc.)	40
Entertainment (cinemas, etc.)	40
Others	50

The People’s Republic of China resorts to a socialist public ownership of land, i.e. an ownership by the whole people and ownership by collectives. In ownership by the whole people, the state council is empowered – on behalf of the state – to administer the land owned by the state. Units or individual are not allowed to occupy, trade or illegally transfer land by other means. Land use rights may be transferred by law.

The property owners can be one or more individuals, units, or the state, and this mainly depend on who buys the land-use right. They have the right to use, retrofit and rebuild the buildings. If the energy consumption of the old buildings’ is higher than the national standard, the local building and construction commission normally have the right to approve or decline a retrofit. (Sjzu 2011.)

The real average life span of China’s residential buildings is only 25 to 30 years, much shorter than their intended life span at the blueprint stage (Qian 2010). Also, the life span of non-residential buildings can be short. Some local governments gained money through building removal and increased GDP at the same time. Service lives as short as 13 years have been recorded in some cases. (Sjzu 2011.)

4.1.3 High demolition rate equals large amount of waste

According to the statistics, China demolishes buildings at the rate of 400 million square meters each year. However, an area of about 2.6 billion square meters of urban and rural new buildings were built in 2010, and there were more than 46 billion square meters of' old buildings in the country (Sjzu 2011). Compared with Europe (<0.25%), the demolition rate (0.9%) is very high (Thomsen 2009).

In China, construction waste comprises 30 to 40% of total urban waste. The construction of a 10,000 square meter building will create 500 to 600 tons of waste, while the demolition of a 10,000 square meter old building will create 7,000 to 12,000 tons of waste. In addition to the growing problem with waste management, the short life-span also raises questions about the structural quality and security of the buildings. (Qian 2010.)

4.1.4 Current trends calling for a change in tradition

Senior executives in the glass manufacturing and other material industries have said that Chinese construction companies had for a long time chosen low-cost, less-insulating materials because buildings in China tended to change hands so frequently that the owners seldom looked at long-term paybacks from electricity savings. (International Herald Tribune 2011.)

Building-related energy consumption accounts for 30% of the country's total energy use. This figure rises to 40% if manufacture and transport of building materials is considered. It is believed that, if nothing is done to check the energy situation, building-related energy consumption in China will double by 2020. (Austrade 2011.)

Most of the old buildings have the problem of low counter-disaster, high operating energy consumption, and poor use function. It is not realistic to demolish all the old buildings which have the above-mentioned problems. So now, the government has paid more attention to retrofit of the old buildings. (Sjzu 2011.)

China's heightened interest in saving energy, a response to recently occurring electricity shortages and blackouts as well as longer-term security worries about dependence on energy imports, comes as the country's construction industry continues to barrel ahead at a breath taking pace. (International Herald Tribune 2011.)

4.1.5 Actions taken by the public sector

In the new, 12th Five-Year-Plan from 2011–2015, the Chinese government has launched an ambitious plan to renovate existing buildings so as to make them more energy-efficient. 25% of the buildings in medium-sized cities and 10% of those in small cities will be refurbished by 2020. (Austrade 2011.)

The report on the implementation of the Energy Conservation Law was submitted to the Standing Committee of the National People's Congress (NPC), the country's top legislature. The report proposes several measures to accelerate the development of energy-efficient buildings, including one measure that aims to have people pay for heating costs on a metered basis. This would come as a radical change in China, where people have only had to pay for heating since

2004, and most heating charges are based on floor space, not energy consumption. Prior to 2004, the government totally subsidized heating costs, and in northern China the government still provides the heating supply to households during the winter. (Xinhua 2011a.)

The report also states that buildings with a total floor space of 400 million square meters or more should complete renovations of their heating facilities by 2015. Furthermore, efforts to boost the number of energy-efficient buildings will also target government buildings and large public facilities, according to the report. In rural areas, the focus is on updating stoves to ones that save wood or coal. (Xinhua 2011b.)

The central government has already renovated nearly 5,000 of its own buildings in northern China, installing more insulation. It has subsidized similar renovations for buildings owned by provincial, municipal and village governments. (International Herald Tribune 2011)

China planned to renovate 2.65 million dilapidated houses for poor rural households in the central and western regions in 2011. The first stage includes renovation of 200,000 houses of poor farmers living along the country’s borders. The plans also include the renovation of 90,000 dilapidated houses into energy-efficient housing units in northeast, northwest and north China and the Tibet autonomous region. The government allocated up to 8,000 Yuan ($1,234) for each household to subsidize the project. In March 2011, the government earmarked 10 billion Yuan in the first subsidizing phase. (Xinhua 2011b.)

What is more, many local governments have set up green building regulations in line with the national policies, in the majority of the first tier cities, energy saving guidelines are set for all new buildings at the design stage:

- The Beijing government is determined to implement building energy saving policies by applying strict energy saving design standards in new building construction, and gradually conduct technical energy-saving renovations to existing buildings. The municipal government of Beijing plans to spend more than 15 billion Yuan ($2.32 billion) on a program to renovate old houses as part of major efforts to achieve its ambitious goal of providing more comfortable and affordable housing for residents. As many as 40 million square meters of old buildings in the city will be targeted in the upcoming renovation works, which will improve the anti-earthquake and energy-efficiency capabilities of old houses. What is more, people will be able to enlarge their houses by 5 to 15 square meters on average. Homeowners will be responsible for the costs. (Xinhua 2011a.)

By 2010, energy consumption in Shanghai was expected to drop by 20% compared to that in 2005, with 15% from energy-efficient buildings. Energy saving renovations was planned on 30 million square meters of buildings, including 10 million square meters of residential buildings. (Austrade 2011.)

4.2 Process

The starting point of a renovation project is the existing building, its properties and values, as well as its occupants or residents. Good property management requires a knowledge of the condition of the building. Available tools include a real estate strategy and renovation plan (LTP) where future renovations are scheduled. Those properties of a building that are related to the production and consumption of energy play a key role when renovation aims to improve the building’s energy efficiency. If the building is fully or partly occupied during the renovation, the presence of the occupants must also be considered in the renovation.

The cornerstones of the planning of energy renovation projects are overall design, minimization of energy consumption and efficient energy production preferably with renewable energy sources.

In all renovation projects success is based on a systematic project process in which all tasks related to the project are taken into account. The client must organize the project so that all essential tasks are carried out in the correct order and at the right time. He must also steer the project towards the set goals at all stages of the project.

A construction process includes an analysis of renovation needs (briefing), programming, global and detailed design, construction and hand-over/take-over process. There are some differences between new building and renovation projects. The most important difference is that there is an existing building. In energy renovation project there are some practicalities that have to be taken into account in a feasibility study, selection of actions, delivery and use.

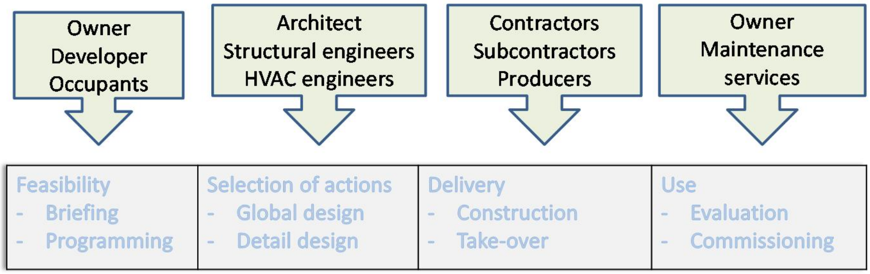


Figure 50. Stakeholders involved in different phases of the retrofit process.

4.2.1 Feasibility

The justifications for the continued existence of a building should be assessed (see Figure 51), especially if it has recently been underused. Are the building(s) in the area in the best possible occupancy, or would the building or area be better suited for some other occupancy? If there are no special circumstances, such as architectural or cultural values, favoring its preservation, this assessment alone could result in demolition of the building. Further useful steps in the feasibility study are an energy audit, condition assessment and cost calculations.

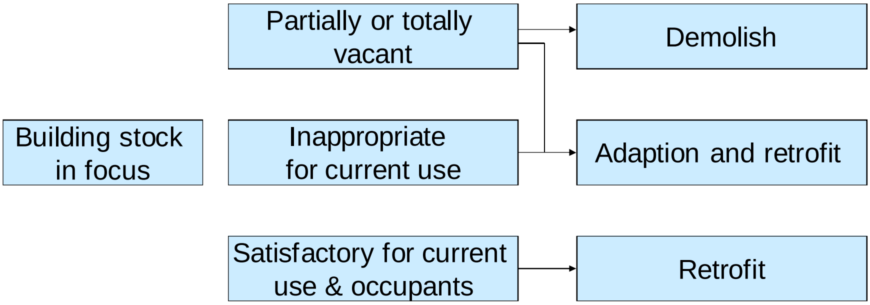


Figure 51. Assessing the justifications for the existence of a building.

Energy audit

A condition inspection that focuses on the essential aspects of energy efficiency is called an energy audit. The energy audit is conducted by HVAC and electrical experts. The people who know the building best also participate in the audit start-up session.

Data to be determined for the key systems and equipment include control and regulation modes, running and operating times, air volumes of ventilation equipment, nominal power ratings of electrical equipment and water flow rates of water equipment. In the case of industrial buildings, the electricity consumption of production equipment should also be determined. Regarding windows, doors and occasionally other structures, their number, tightness and thermal insulation level are assessed.

The energy audit and any possible more detailed related condition inspections give recommendations for corrective actions and changes:

- a clear proposal of what to do and how
- implementation sequence of the measures
- implementation method and costs
- required investments and overall costs impact of the measure
- payback time
- energy conservation and energy cost savings and their sources (initial situation and situation after the conservation measure)
- effect on CO_2 emissions of energy consumption
- possibilities of using renewable energy sources.

Energy renovations may also include other measures such as the repair of existing technical systems. New technical systems or equipment may be installed in the building, such as mechanical ventilation, heat recovery, solar panels or a geothermal heat pump. Their installation sets requirements for existing structures.

Condition assessment

Sensory and empirical methods include inspections of structures known to be risk-prone. Non-destructive methods include thermal imaging to detect leaks and tightness measurements on the building. The analysis of needs may be in favor of renovation. If repairs are made energy-efficiently, considerable savings may be attained with relatively modest additional investments in the consumption of heating energy compared to conventional renovation.

The renovation needs survey or condition inspection may reveal such severe damage or expensive repair needs that it is preferable to demolish the building instead of renovating it. Demolition is justified e.g. by moisture damage that has contaminated structures or hazardous substances that are detected in the building. The problems detected may also be due to poor foundations, contaminated soil, soil movements or other factors related to the location that make repairing the damage to the envelope useless.

Demolition includes the recycling and re-use of demolition waste. The foundations of the old house and the underground infrastructure may also be saved for use by the new building. The construction of a new building on top of old but still solid and functional foundations is cheaper than rebuilding from scratch. After rebuilding, the energy efficiency of the building corresponds to that of future new buildings.

Cost/benefit analysis

When the target of renovation is to save energy, the decision is based on profitability. In this process the energy efficiency improvement related costs are considered and how many years it takes to pay back investment by savings in energy expenses. One example of the process is presented in Figure 52. The most environmentally conscious organizations may also base their decisions on energy payback time measured in kWh. Very often the method used is a standard Life cycle cost (LCC) method.

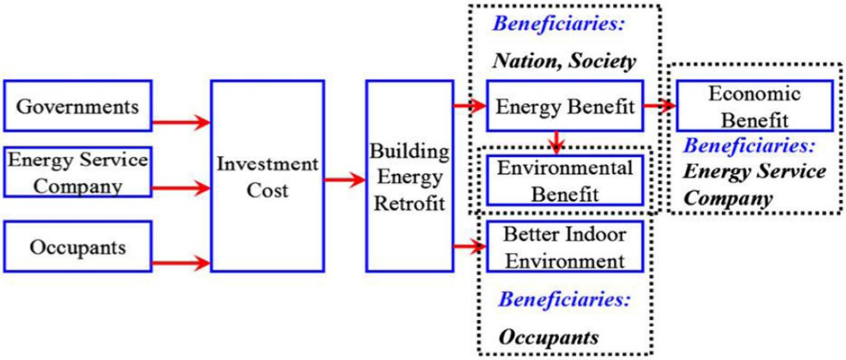


Figure 52. A model for distribution of investment cost and benefits from building energy retrofit (Ouyang et al. 2011).

Many analyses have concluded that energy renovations are too expensive and therefore not worth doing. The phenomenon is global, and common also in China. However, energy saving measures can also bring other benefits, such as improvement of the indoor environment (e.g. thermal comfort, indoor air quality), better functionality (e.g. of windows or doors) or improved aesthetics (e.g. a better looking façade). This makes the allocation of the costs more complicated – all renovation costs should not be allocated only to energy saving if there are also these other benefits. In a Chinese study, the costs and benefits were examined closely. After detailed analysis of the energy saving measures and distribution of all benefits from building energy retrofit, it was found that actually only 1/3 of the original cost was spent on energy savings, the second 1/3 on both energy savings and good facade appearance, and the last 1/3 had nothing to do with energy. The results proved that the first 1/3 of the investment cost could be drawn back within residue life cycle, and so the investment could be accepted in a purely market economy.

4.2.2 Selection of actions

If the feasibility study has concluded that the building both needs and is worthy of renovation, the next step is the selection of actions. During project planning, the alternatives presented in the project survey are studied in more detail, and the most suitable one is selected as a starting point for planning. The owner must specify his own objectives for the project. Examples of these objectives are improvement of energy efficiency, use of renewable energy sources, utilization of free energy sources, generation of energy in excess of own needs, etc.

In an energy renovation project, it is important to examine several solutions from the viewpoint of the energy use, GHG emissions and life cycle costs.

Responsibility for the quality and functionality of the end result also presupposes in practice responsibility for design or at least participation in it. In a traditional renovation project where the design and the building are largely separated, the responsibility lies with the client. Design may be included as the responsibility of the contractor in the building contract. When the contractor is also given the responsibility for operating costs, we speak of a life-cycle responsibility project.

In projects aimed at energy efficiency, it is particularly important that the design objectives are met and functionality is ensured. Energy conservation by the selected renovation solution must be proved by calculations. The building-physical performance of the renovation solutions must also be proved.

4.2.3 Delivery

It is critical to ensure that any technology or system installed is properly commissioned and handed over to the buildings' management team with good supporting documentation and any necessary training so as to ensure successful operation and verifiable performance.

In the handover inspection, the result of the work is compared to the plans. The party who implemented the renovation is responsible for ensuring that the end result conforms to the agreement and is free from defects. The guarantee period for construction work varies.

Measures to improve energy efficiency should be verified either during the project or after its completion. Verification means include tightness measurements, thermal imaging and monitoring of energy consumption over a period of several years.

4.2.4 Use

Evaluation is a vital process once a retrofit project has been carried, out for two main reasons. Firstly, lessons learnt should be fed back into the business and cover all aspects of the retrofit process. This can help improve the implementation of any future retrofit projects and should include a commentary on how occupants were engaged, what financial mechanisms were used, the type of technology chosen, how performance was verified and payback calculated.

Secondly, it is important to publicize successful retrofit projects to the wider industry in the form of best practice case studies. The uptake of retrofit will greatly increase once more information on proven examples are in the public domain, as it will demonstrate and educate the market, particularly in terms of the commercial and finance structures used and the most appropriate type of technologies which can be applied.

The follow-up research has proved that the energy efficiency of a building is not a lasting state. After energy upgrading, the performance may decline. Partly it comes with people’s behavior, partly with automatic control. The continuous measuring and adjustment of automatic control are in a key position in maintaining the set energy saving targets.

4.3 Energy-efficient and modular technologies

One way to make energy renovations more profitable is to speed-up the retrofit process by the use of modular, pre-fabricated building elements and systems. Integrated modular and pre-engineered/pre-fabricated system solutions enable mass-customization and lead to highly efficient productivity and also better quality.

The main causes of energy loss in a cold climate are heat losses through the envelope (walls, doors, windows, roof), heat losses through ventilation (free and intentional) and heat losses through wastewater. In hot climates, the cooling load is caused by the need to shed the extra heat coming through the shell or ventilation and the internal heat gains produced by the people and appliances. In addition to this, the different electrical appliances need electricity, and a small amount of energy is used for cooking.

The most efficient measures to improve the energy efficiency, therefore, addressed the improvement of the envelope, which is usually beneficial also in case of cooling load reduction.

Examples of innovative solutions for large-scale retrofit are presented below. These include glazed balconies, pre-fabricated building facades, solar walls, additional floor modules, bathroom modules, prefabricated ducts for building services, lift shafts and staircases as well as individual measurement of water, gas and heating.

4.3.1 Glazed balconies

In buildings where there are balconies (see Figure 53), adding glazing will have two major benefits: The useful living area will be increased for the major part of the year and secondly, the heat loss from the exterior wall or windows will be reduced. In southern climates overheating of exterior wall or windows will be reduced. In southern climates overheating should be prevented by allowing natural ventilation and by solar shading.

Figure 53. Glazed balconies in Finland (Lumon 2012).

4.3.2 Pre-fabricated building facades (TES Energy Façade)

TES Energy Façade (Figure 54, Lattke 2011) is a prefabricated building system of large-scale timber frame elements that introduces the benefits of modern timber construction to the modernisation process of the existing building stock:

- a precise prefabrication technique off-site
- a fast installation process on-site reducing the disturbance to the residents of
- noise and dirt
- integration of other building elements, such as windows, balconies, solar active components or plumbing and electricity
- the ecological performance of timber and other biogenic building materials.

Figure 54. TES Energy Facade, Innova-project in Finland, Peltosaari (Lattke 2011).

TES Energy Facade is a systematical process of surveying, renovation planning, construction and maintenance of the building stock. With TES Energy Facade, basic guidelines for the measuring actions of the different stages of the fabrication process are defined, and data is gathered for building information modeling (BIM).

From survey to off-site fabrication TES Energy Facade systematizes and optimizes the digital workflow of the renovation process. Modern methods for measuring (i.e. photogrammetry and laser scanning) generate precise data on the target buildings for 3D building information models, which are used to design prefabricated timber-based elements for the modernisation of the building envelope. The dataflow suits the requirements of the digital process chain, from site measuring through planning to prefabrication.

The prefabricated building elements are mounted to the existing building structure either as an additional layer or as a replacement of the entire wall of the building envelope.

4.3.3 Additional floor modules

Building new apartments or other spaces on the roof of existing buildings (as, e.g. in Figure 55) is a good opportunity for the real estate, but with some limitations. In order not to overload the existing structure, a lightweight construction should be chosen. The position of the new apartments or spaces offers good possibilities for solar energy use through ideal places for PV panels or solar thermal collectors. These apartments can be very interesting due to the spectacular views and reduced street noise levels. The renovation costs for the rest of the building can often be covered by the rental or sales income from these new apartments. The energy saving aspect of the new floors is the additional insulation they offer for roofs. (Herkel and Kagerer 2011.) Normally, due to structural limitations, only one or two floors are added. Additional floors may also require changes in city plans (e.g. in Finland).

Figure 55. When the roof of this 19th century building in Brussels needed renovation, it was replaced with three additional wooden-structure floors (Desmedt et al. 2010).

4.3.4 Bathroom modules

By adding water and energy-efficient bathroom ware inside prefabricated modules, important energy savings can be achieved and the inhabitants' living quality increased at the same time. The bathroom modules can either be installed inside the building or as external elements. When properly insulated, these will at the same time act as extra insulation. They also increase the living space of the apartments.

Figure 56. Parma-bathroom elements are delivered on site as completely ready-to-use wet room units, with all the furnishings, fittings and HEPAC equipment installed either from the top or from the side prior to the installation of facades (Parmarine 2012).

In Central Europe and in Sweden, solutions[1] have been developed and utilized where in pipe repairs combinations of water and sewage pipes, toilet bowls and washbasins are installed in installation modules (Lindstedt and Junnonen 2009). These modules may contain a whole installation wall.

4.3.5 Installation modules for building services

Improvement of the building services can reduce the energy use by improving the efficiency of the building services systems. The prefabricated installation modules can be installed either inside the building (Figure 57) or as part of the façade elements, as described above in TES.

---

[1] E.g. Prebad (http://www.prefabteknik.se/prebad.php), Modulsystem (http://www.modulsystem.nu/) and LinTec (http://lintec.se/).

Figure 57. Left: Prefabricated water duct in a stairwell. Right: Prefabricated duct for water, heating and electrical installations. (Pipe-Modul 2011.)

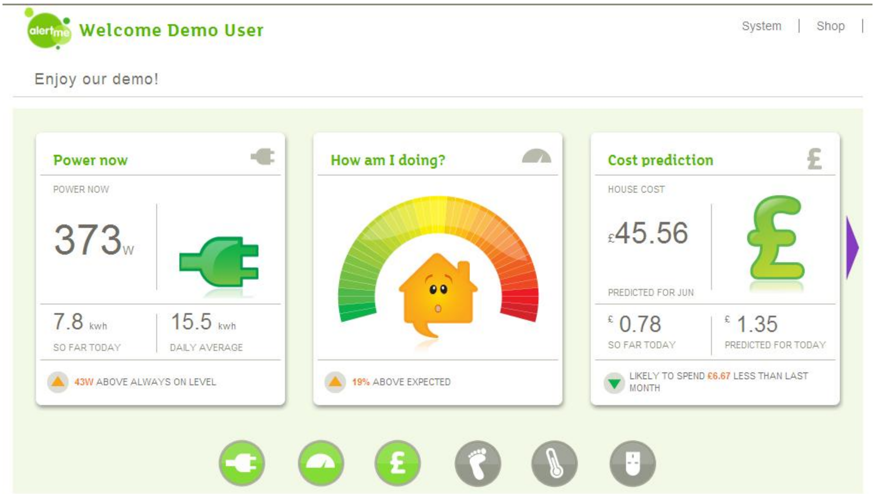
Several products[2] exist for installing ventilation ducts, water and sewage water pipes, heating pipes, gas pipes and electricity cables into elements or enclosures to the stairwells. These elements are usually steel-structured and can be easily opened in case of leakages or the need for other repairs. Typically, the elements can be installed both horizontally and vertically.

4.3.6 Individual measurement of water and heating

Usually, when people receive information on their own energy use, this will motivate them into energy-saving actions, especially if this is rewarded by lower energy bills. Even better results can be achieved when the users can compare their own consumption to an average or to that of neighbors. Attention must be paid to the way to present the comparison results (Figure 58).

---

[2] E.g. Silotek® (http://www.emctalotekniikka.fi/emc-en/products/), Pipe-Modul (http://www.pipemodul.com/), Moduc (http://www.moduc.fi/) and Cefo (http://www.cefo.fi/).



Welcome Demo User

Enjoy our demo!

Power now

POWER NOW 373 W

7.8 kwh SO FAR TODAY

15.5 kwh DAILY AVERAGE

43W ABOVE ALWAYS ON LEVEL

How am I doing?

19% ABOVE EXPECTED

Cost prediction

HOUSE COST £45.56 PREDICTED FOR JUN

£ 0.78 SO FAR TODAY

£ 1.35 PREDICTED FOR TODAY

LIKELY TO SPEND £6.67 LESS THAN LAST MONTH

Figure 58. An example of an easily understandable user interface showing the occupant his/her energy use (AlertMe 2012).

4.3.7 Solar facades

When the renovation of outer walls is necessary, then solar wall heaters are an option to be considered. There are different alternatives to utilize the solar energy through walls, either by air or water heating. The heat can be utilized for heating of spaces or hot water (like in the swimming hall in Pori, Figure 59). A typical application is to pre-heat the incoming air behind a metal cladding, either glazed or unglazed.

Figure 59. The water in the new swimming hall in Pori is heated with the façade-integrated Nordic Solar collectors. (Picture by Esa Kyyrö, source: Mörk 2011.)

Another alternative to use solar energy through façade integration is to replace the façade material with PV-panels (Figure 60). These are normally more expensive than solar heating applications, but can, for example, support the targets of energy self-sufficiency or improved energy supply security. In the latter case, the PV-system should be supported with accumulators. If security of supply is not an issue, then the PV-panels can feed the extra energy into the general electricity network, and the system can be simpler. PV-panels can also be used to create a special aesthetic value to the appearance of the building.

Figure 60. The façade of this residential building in the Viikki area in Helsinki is covered with PV-panels. (Photo: Christer Nyman.)

4.3.8 Lift shafts and staircases

Lift shafts and staircases[3] can be prefabricated and attached to the existing building as separate modules. These modules could also include building services systems. On the construction site, just foundations and joints need to be done. See Figure 61.

---

[3] Like NEAPO Tubetower® (http://www.neapo.fi/en/www/page.php?id=38).

Figure 61. In the Lehdokkipolku 3 housing cooperative in Helsinki, NEAPO adopted a new approach of installing elevator cars and machinery inside the lift shaft while this was still in the factory (NEAPO 2009). Thanks to factory-installation, the lifts became available for residential use too.

5. Building commissioning work in China

Commissioning as understood in Finland is not that common a procedure in China and thus there are not any standards in China. However, there are many related requirements for every phase of the commissioning procedure, and the main procedures of Cx are similar to Finnish shown in Figure 62.

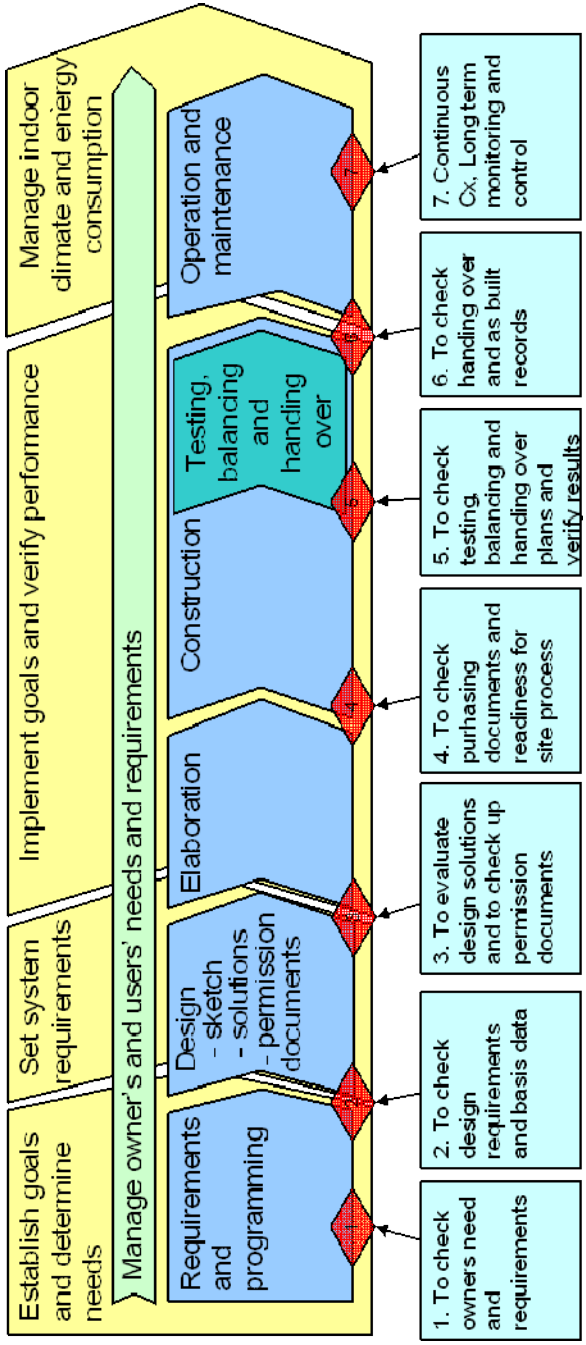


Figure 62. The Cx process (Nykänen et al. 2007).

For the pre-design phase, some legislations are published, and in addition other guidelines exist for other stakeholders in the building process. For the design and construction phases of Commissioning, Cx, there are many corresponding standards in China, and some of these standards are implemented compulsorily. The relevant standards are both national and local legislations.

5.1 National and local legislation

Due to raised concerns about energy efficiency in building and new building codes, some Energy-Saving Regulations are introduced for different stakeholders in the process. The typical actors for whom the regulations and legislations are introduced are project owners, construction organizations, designers, project supervising units, construction drawings reviewing agencies and quality of building engineering testing agencies. The regulations and legislations are as follows:

- construction quality management regulations
- civil construction of energy-saving regulations
- Shanghai construction of energy-efficient management practices
- Energy Saving Regulations for Civil Constructions.

5.1.1 National standards

Chinese national standards close to commissioning procedures are the following:

- Unified standard for constructional quality acceptance of building engineering GB50300-2001
- Code of acceptance for construction quality of ventilation and air conditioning works GB50243-2002
- Code for acceptance of energy-efficient building construction GB50411-2007
- Code for acceptance of quality of Intelligent building systems GB 50339-2003
- Code for operation and management of central air conditioning system GB 50365-2005
- Evaluation standard for green building GB 50378–2006.

5.1.2 Local standards

Local Chinese standards concerning commissioning process are the following:

- Standard for Energy Efficiency Evaluation and Labeling of Civil Buildings DGJ08-2078-2010
- Specification for Performance Testing Of Ventilation and Air Conditioning System in Shanghai DGJ08-802-2005

- Specification for energy-efficient constructional quality acceptance of residential buildings in Shanghai DGJ08-113-2005
- Energy conservation on-site testing standard for heating civil building in Beijing DB11/T555-2008
- Code for acceptance of energy-efficient building construction in Shanghai DGJ08-113-2009.

For the standards mentioned above, the details will be listed in the relevant phase of commissioning.

5.2 Chinese commissioning

Although there is no integrated system for commissioning in China, HVAC commissioning is very common in China. In addition, since the LEED certification is increasing in China, commissioning work is growing in importance.

In China the related commissioning work phases are pre-design, design, construction, operation and maintenance. The related stakeholders and actors as well as requirements (technological or standards) in each work phase in Chinese commissioning procedure are shown in Figure 63.

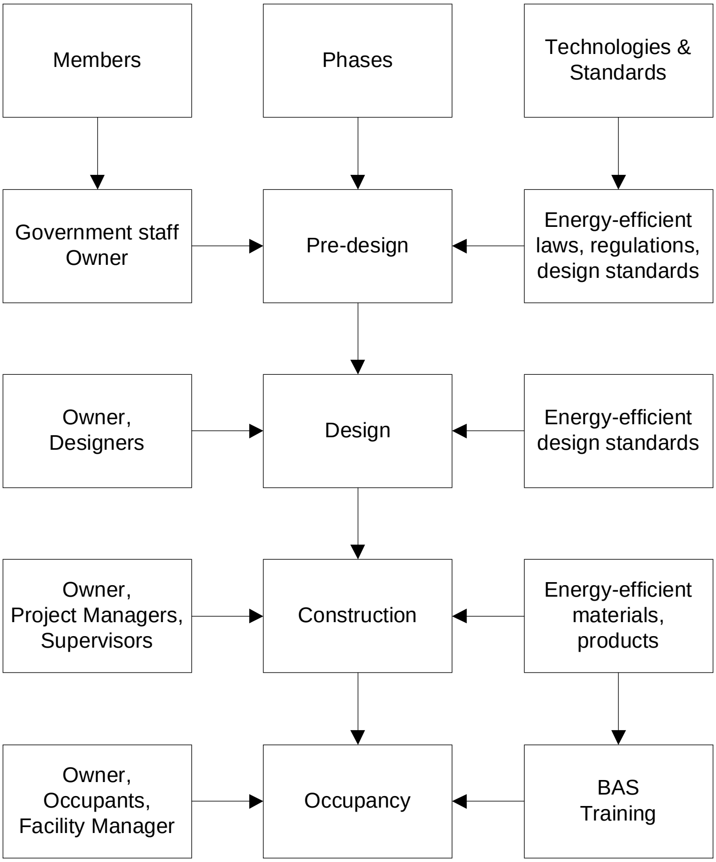


Figure 63. The stakeholders and requirements for each building phase in China.

5.2.1 The pre-design phase

The activities for the pre-design phase do not belong to the commissioning processes, at the beginning of project inception, owners need to submit the project themselves, and some relevant documents need to be checked by a government department. The key requirements and documents are mentioned in the list below.

Project materials like an FSR (feasibility study report), reviews of construction design documents.

- Initial planning scheme
- Environmental impact assessment
- Reviews of water, heating, electricity, gas, fire fight used etc.
- Reviews of geology.

Activities

The activities just take place between project owners and the government agencies, owners and planning designer teams; there are no commissioning teams included.

- Check the owner's future strategies and actions, the construction site and detailed plan, goals and requirements
- Check to satisfy applicable regulatory requirements, standards, and guidelines
- The Owner's Project Requirements (OPR) are drawn up at the end of the pre-design phase.

Legislation or building codes

All the activities are based on some relevant legislation and building standards. The standards are about the energy-efficient in building, such as "Design Standard for Energy Efficiency in Public Buildings", "Design Standard for Energy Efficiency in residential Buildings", and so on. And they must meet the requirements of national standards as well as the local standards.

At the same time, the owner's project requirement and the planning design work must satisfy the legislation, like "Energy Saving Regulations for Civil Constructions".

5.2.2 The design phase

During design, the design team makes decisions about how to accomplish the owner's goals. The key requirements and actives:

- Check the review of construction design documents
- Check the specification of building energy efficiency
- Check the concepts of design to meet the requirement of owners and the standards
- Verify the Basis of design and update the OPR.

Legislation or building codes:

- The responsibilities of designer are given by the legislation of "Energy Saving Regulations for Civil Constructions" and "civil construction of energy-saving regulations"
- The design must meet the requirement of criteria of energy efficiency such as Design Standard for Energy Efficiency in Public Buildings", "Design Standard for Energy Efficiency in residential Buildings".

5.2.3 The construction phase

As part of the construction phase, commissioning involves functional testing to determine how well mechanical and electrical systems meet the operational goals established during the design process. The performance of the purchased products also needs to be tested before there are on-site.

The activities and requirements are as follows:

- Check the manufacturer certificates of products which are related to the energy efficiency in the building
- The thermal insulation materials for walls and roof need to be tested
- Check the testing reports of air permeability water tightness, wind load resistance performance for building external windows and doors
- Check the testing report of energy-efficient structure for the external wall envelope
- The inspection report and acceptance report of the energy-efficient program and concealed work
- **The report of HVAC system commissioning.** This is mainly about the functional testing, and the work is compelled by the standards
- **Field test of energy-efficient systems.** The contents of energy-efficient systems include the indoor temperature, heating system, energy efficiency ratio of outdoor pipe network, volume of every airport, the total air volume of the ventilation and air-conditioning, total water volume of air-conditioning water system, lighting illumination and power density
- The other new energy-efficient measures used.

Standards and measurements:

For the construction phase, three testing codes are executed compulsorily, and they have a closed relation to the commissioning work.

The first standard is “Unified standard for constructional quality acceptance of building engineering GB50300-2001”; it is about how to inspect the constructed quality of building engineering, and the requirements of inspection.

The second is the “Code for acceptance of energy-efficient building construction GB50411-2007”. The standard is compiled based on the laws, regulations and management of building energy efficiency. The requirements of energy efficiency are established for the construction organization and design team. The building materials and related products are defined in the codes.

The acceptance of energy-efficient engineering includes every party of building construction, such as wall, curtain wall, outside doors and windows, floor, roof, heating system, ventilation and air-conditioning, cooling/heating source of HVAC, lighting system, monitor and control system. For every energy-efficient part, the measurement method and numbers are defined.

The third standard is the “Code of acceptance for construction quality of ventilation and air conditioning works GB50243-2002”. The standard is mainly about the acceptance of the HVAC system and the HVAC commissioning. The acceptance of air ducts made and installed, equipment for ventilation and air-conditioning installation and the refrigerating units of HVAC are defined.

5.2.4 The operation and maintenance phase

No commissioning work is involved in the phase; when the project completed, it is delivered to the owners, and some facilities managers and staffs will be employed.

Although the facilities managers do not take part in the commissioning work, they are rich in experience. In Shanghai, every operation staff of an HVAC system must have a license, and training courses are held every two years for operators.

5.3 The challenges of commissioning work in China

In China, the related commissioning work phases are pre-design, design, construction, operation and maintenance. The related stakeholders and actors as well as requirements (technological or standards) in each work phase in the Chinese commissioning procedure is shown in Figure 63. There are no professional associations for commissioning, but in many cities they have professional test associations, which include all the testing for the construction phase.

There are no commissioning codes, but many related standards and legislation for every phase of commissioning. In addition there are no integrated commissioning processes in China, but a separate commission for e.g. HVAC, electrical systems, firefighting systems, monitoring and control systems.

For the HVAC commissioning, the procedure begins in the construction phase before building acceptance, and the commissioning teams are often the equipment manufacturers or a third party (such as building engineering testing agencies). For a large-scale public building, the results must be tested and checked by the third party.

Besides these, there are some standards and project works which are similar to the commissioning work, such as the standard for Energy Efficiency Evaluation and Labeling of Civil Buildings, which is divided into three parts: the theoretical energy efficiency values, measured energy efficiency values and energy efficiency labeling. Checking the documents related to the pre-design, design and construction phases is part of the project work.

The Energy Management Contract (EMC) has the responsibility to encourage the third party to pay more attention to the performance of the HVAC system.

The work for Building Energy Audit is about the energy consumption of the existing buildings, and after the auditing work, the retrofitting and commissioning work will be done.

6. Pilots and show cases

6.1 Zero energy building cases

The following section describes different nZEB experiences for residential apartment and single-family houses in Finland, a cold climate with heating dominated construction and design. One case study in France is described as a best practice for an nZEB commercial/ office building. Table 34 summarizes the cases presented.

Table 34. Location and type of cases described.

Location	ZEB	Type of pilot	Area
Kuopio	nZEB	apartment buildings	2124 m^2
Järvenpää	nZEB	apartment building	2124 m^2
Mäntyharju1		Demo house – Aalto university	50 m^2
Mäntyharju2	nZEB	single-family house	154 m^2
Hyvinkää	nZEB	single-family house	Design phase
Pietarsaari (1994)	nnZEB	single-family house	165 m^2
Dijon, France	nnZEB	Elithis Tower commercial/office building	5000 m^2

The pilots in Finland are in Kuopio, Järvenpää, Mäntyharju, Hyvinkää (2013), Luukku/Aalto-Yliopisto (Solar Decathlon competition) (Nieminen et al. 2010).

The nearly zero energy buildings according to EPBD are buildings with very high energy performance, and their energy requirements are covered to a significant extent by renewable energy sources, examples of these kind of buildings in Finland are in Pietarsaari (1994) (Nieminen and Kouhia 1997, Nieminen 1996, Nieminen et al. 2010). See Figure 64.

Two net zero apartment buildings with basically similar architecture were constructed in Finland, in Kuopio (latitude 62.9°) and in Järvenpää (latitude 60.5°).

Two net zero energy single family houses, one already finished in Mäntyharju and one at the design stage in Hyvinkää, will complete recent experiences of zero energy buildings. In addition to net zero energy buildings, one nearly zero energy building was built as early as 1994 as an international collaboration within International Energy Agency's Solar Heating and Cooling program. (Nieminen et al. 2010, Nieminen and Sepponen 2011.)

The net zero apartment buildings prove that a zero energy building is possible at high latitudes. The preliminary cost analysis of the Järvenpää case also proves that the extra costs of the net zero energy approach are in the range of 10–15%. As the extra costs of the basic solution for a zero energy building, a very low-energy building, are in the range 2–5% compared to typical apartment houses, the further development of concepts and increasing know-how will set the extra costs at about 10% and below. New solutions for building integrated renewable energy production will as well make the net zero energy construction be more attractive in the future. The Energy Performance of Buildings Directive's defined nearly zero energy building is already possible for wide adoption in new construction. (Nieminen et al. 2010.)

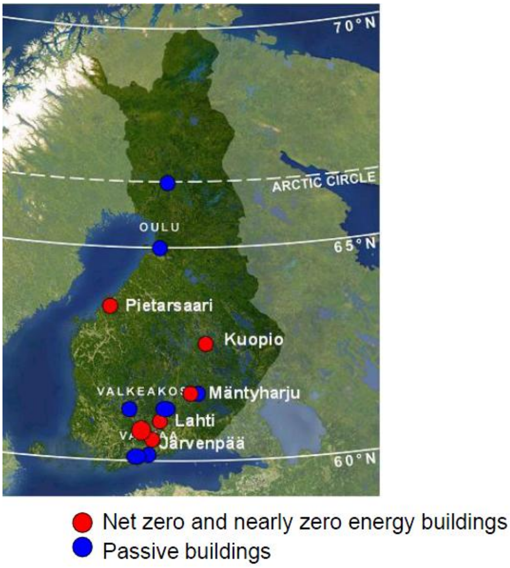


Figure 64. Finnish examples of zero energy buildings and passive buildings (Holopainen and Nieminen 2010).

6.1.1 Apartment buildings in Finland

Two net zero apartment buildings with basically similar architecture were constructed in Finland, in **Kuopio** (latitude 62.9°) and in **Järvenpää** (latitude

60.5°); see Figure 65. The aim was to test the possibilities of building zero energy buildings at high latitudes. The Kuopio case is a student hostel, and the Järvenpää case a home for elderly people. The total energy demand in the buildings is 102 MWh for Kuopio and 94.3 for Järvenpää corresponding to 48 and 45 and kWh/gross-m^2. The buildings utilize district heat and are connected to the local grid. The renewable energy production in the Kuopio case is based on solar heat and photovoltaics. In Järvenpää also, building integrated wind power is an option. It is of importance to notice that, although Finland is a space heating-dominated country, the space heating is not the dominant energy consumption in a zero energy design. The Järvenpää apartment house has a preliminary total cost estimate of around 2 900 €/m^2. The typical values for new elderly homes are between 2 400 and 3 000 €/m^2. This building also supplies energy to neighboring buildings (Nieminen et al. 2010, Nieminen and Sepponen 2011).

Figure 65. Net zero energy buildings in Kuopio (left) and Järvenpää (right) (Nieminen 2011).

The environmental impacts of a net zero energy building as carbon footprint were assessed using life cycle assessment approach. The calculations cover raw material extraction, production, and material transportation.

In the example building in Kuopio (

Table **35**), the total energy demand is 31 kWh/ m^2. The total energy demand does not include the residents' electricity (16 kWh/ m^2). The energy is supplied by PV (7 kWh/m^2), solar thermal (12 kWh/ m^2) and ground heat (12 kWh/ m^2). This building would have not passed the net zero energy building definition if the primary energy and residents' electricity had been taken into account.

A net zero energy building is a rather challenging target in the Finnish climate. Minimizing the residents' energy use is crucial, because electrical energy used for home appliances and lighting is the largest single use of energy in zero energy housing. Especially in the case of the Kuopio net zero energy building, the space demand of solar thermal and PV systems is too high compared to the space available, and thus these two measures are not enough to fulfill the demand. The building's location in the city center is not optimal for the target, but taking into account requirements for the whole urban structure, the location of a new building in a densely built area is better than outside the dense center. The level of technology is not sufficient for the zero energy target.

Table 35. Energy flows in Kuopio nZEB (Nieminen 2011).

Energy Demand	
Space heating	12 kWh/m^2
Water heating	13 kWh/m^2
Electricity, facility	6 kWh/m^2
Total	31 kWh/m^2
Renewable energy	
PV	7 kWh/m^2
Solar thermal	16 kWh/m^2
Ground heat	12 kWh/m^2
Total	35 kWh/m^2
Excluded	
Residences electricity	16 kWh/m^2

6.1.2 Net zero energy single-family houses in Finland

The Mäntyharju2 nZEB single-family house is based on the development of a previous concept and pilot project of a very-low energy single-family house also built in Mäntyharju1. The specific features of the concept design are integrated energy design and design of building envelope details. Integrated energy design provides a possibility of optimizing the structural solutions and energy systems of the house. Detailed building envelope design results in extremely good air-tightness of the building envelope. An air-tightness test in the commissioning phase gave an n_{50} value of 0.09 and 0.25 1/h when the test was repeated four months later. (Nieminen 2011.)

The net zero single-family house in Mäntyharju is a two storey compact building with simulated total purchased energy consumption of 45 kWh/m^2 floor area excluding the use of firewood in the stove. Solar thermal system will produce heat for hot water and space heating. A ground source heat pump is the primary space heating system. A photovoltaic system of 8 kWp covers the total energy demand of the building, and this energy can be fed into the local grid. (Nieminen et al. 2010, Nieminen 2011.)

The net zero energy single-family house in **Hyvinkää** is a showcase for the national housing fair in 2013. The building is based on a competition where architects and design teams can give their view of comfortable living in a very low energy demand building with renewable energy systems covering the total demand of the building. (Nieminen et al. 2010, Nieminen 2011.)

Another single-family house pilot is located in **Pietarsaari** (latitude 62°). This is the Finnish demonstration house IEA5 for the International Energy Agency's Solar Heating and Cooling program Task 13 'Advanced Solar Low Energy Buildings' and it was built in 1994 for the annual housing fair held in Pietarsaari. The aim of the IEA5 solar house (Figure 66) was to reduce the consumption of purchased energy to as low a level as possible by utilizing the available best practice technology of 1993. Good indoor climate and comfortable living conditions were set as requirements for the design. The building performance has been good over the years. The results from a three-year monitoring project and annual follow-up to the present has proved that the total consumption of purchased energy is about 30%, and the heating energy consumption less than 20% of the consumption of a new single-family house of 2010. Although the technical systems of the house are performing well, the ventilation system with heat recovery and ground source heat pump were replaced two years ago with new more efficient equipment, thus reducing the energy consumption considerably. (Nieminen and Kouhia 1997, Nieminen 1996, Nieminen et al. 2010.)

Figure 66. Left, the Solar House IEA5, Pietarsaari Finland and a detail of its solar energy systems, right (Nieminen and Kouhia 1997, Nieminen 1996).

The heated floor area of the IEA5 Solar House is 166 m^2. To satisfy the need for heat in winter, a ground heat pump with a capacity of about 7 kW is included in the system. The 3m^3 water-filled heat storage is the heart of the building's heating system. The heat distribution system is floor heating. The floor heating system can be used with a low air to floor temperature difference for cooling as well; however, there has not been a demand for cooling so far. (Nieminen and Kouhia 1997, Nieminen 1996, Nieminen et al. 2010.)

The building has an extremely well-insulated timber-framed envelope. All necessary technical systems are in the center of the two-storey house. This makes it possible to utilize the heat losses of the installations in the heating of the house. All the ducting and pipelines are installed in an installation shaft next to the heat storage and suspended ceiling in the first floor. (Nieminen and Kouhia 1997, Nieminen 1996, Nieminen et al. 2010.)

The 10 m^2 solar collector system on the south side of the roof consists of four modules connected in parallel. The original heat pump of the house had a capacity of 7 kW, while the new pump's capacity is 5 kW. The change improved the efficiency (COP) from an annual average of 2.4 up to 4.0. A new ventilation system with heat recovery efficiency of 80% was introduced as well. These changes reduced the electricity consumption to below 40 kWh/m^2 from the original 48 kWh/m^2. (Nieminen and Kouhia 1997, Nieminen 1996, Nieminen et al. 2010.)

The Energy Performance of Buildings Directive requires that all new buildings need to fulfill the principle of a nearly zero energy building as of the beginning of 2021. A nearly zero energy building has a very low energy demand achieved with technologies that are cost-effective in a life-cycle perspective. The IEA5 project has shown that such a building is possible even in the cold Nordic climate. (Nieminen and Kouhia 1997, Nieminen 1996, Nieminen et al. 2010.)

6.1.3 Commercial building in Dijon, France

The Elithis tower, located in Dijon, France (Figure 67), is an nnZEB building with architecture adapted to an urban environment. The main aim of the building is to use passive means and natural resources such as sun and wood to achieve thermal and visual comfort in the building. Figure 68 shows the energy consumption balance for the first year (Hernandez 2011).

The design concepts to achieve nnZEB included:

- Compact building shape: very compact rounded shape effectively reducing the building envelope area, which has a positive effect regarding heat losses and solar gains.
- Passive solar shading: a special solar shading shield gives the building the necessary natural light and solar glare protection in summer and mid-season.
- Ventilation strategy: the building is ventilated by a mechanical supply and exhaust system with heat recovery controlled by the BEM system.
- Lighting system: increased rate of the glass surface reduces energy use needed for artificial lighting. Light fittings in the ceiling provide the average lighting.
- Heating and cooling system: The major part of the heating needs is covered by solar and internal heat gains. A triple flow ventilation system covers the most important of the cooling needs.

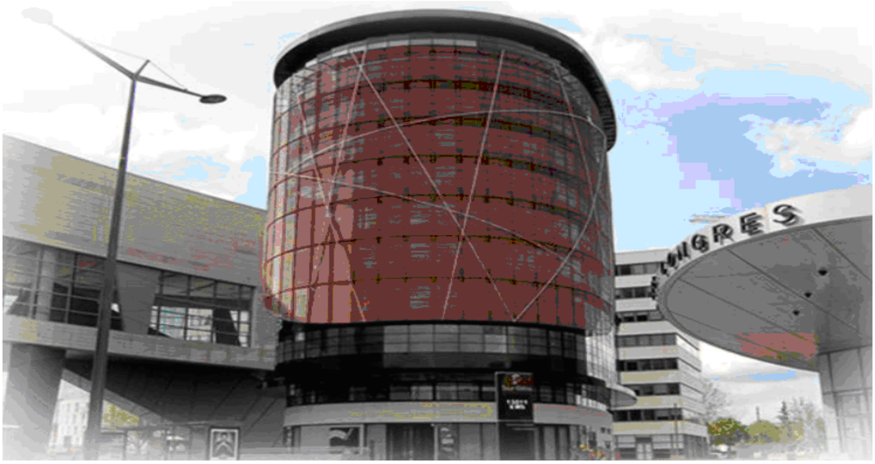


Figure 67. Elithis tower, France (Hernandez 2011).

	Design phase			2009
	Net delivered energy Calculated kWh/m^2, a	**Primary energy factor**	**Primary energy Calculated kWh/m^2, a**	**Primary energy Measured kWh/m^2, a**
Heating (wood)	3,3	0,6	2,0	6,3
Cooling	4,1	2,58	10,6	6,2
Ventilation	5,1	2,58	13,2	14,1
Pumps and auxilliaries	0,4	2,58	1,0	2,6
Lighting	4,1	2,58	10,6	9,5
Elevators	1,4	2,58	3,6	3,6
Appliances	9,4	2,58	24,3	54,6
Photovoltaic	-16	2,58	-41,3	-40,2
Total	**12**		**24**	**57**

Figure 68. Elithis tower energy consumption balance, first year. Coefficients of conversion into primary energy: wood (0.6) and electricity (2.58). (Hernandez 2011.)

6.1.4 Office building in Shanghai

For the low-energy buildings in China, the number of the buildings is low, but it is increasing. The low-energy buildings are often the demonstration projects. What follows is a brief introduction to a famous project in China, including technologies used, design/ test values and energy consumption.

The Office building, which belongs to the Shanghai Research Institute of Building Sciences (SRIBS), is one of the most famous eco-buildings in Shanghai, the area of the building is 1994 m^2, three floors, and the construction was complete in September 2004 (Figure 69).

Many eco-efficient technologies have been demonstrated in the building, such as natural ventilation, daylight use, renewable energy use, building automation, green building materials, energy-efficient HVAC system and so on. The estimated total energy saving of the eco-building is 75% compared to the common one.

Figure 69. The picture of eco-building for SRIBS (SRIBS 2010).

Technologies used

Natural ventilation

For better natural ventilation, the building shape is optimized based on a simulation.

Energy-efficient building structures were utilized. The basic property values for external walls are shown in Table 36, for the roofs in Table 37, and for windows in Table 38.

Table 36. U-values of external wall.

Part of building	Coefficient of heat transfer (W/m^2K)	Index of thermal inertia （D-value）
East wall	0.32	4.3
South wall	0.27	3.2
West wall	0.29	4.3
North wall	0.33	3.2

Table 37. U-values of roof.

Part of building	Coefficient of heat transfer (W/m^{2}K)	Index of thermal inertia (D-value）
Non-sloping roof	0.31	3.2
	0.31	3.2
Sloping roof	0.16	5.0

Table 38. Energy-efficient windows.

Part of building	Type of windows	Heat transfer coefficient of glass	Shading coefficient	Visible light transmittance
Windows of sloping roof	PETLOW-E	1.8 W/(m^{2}K)	0.62	68%
All external windows	LOW-E	1.65 W/(m^{2}K)	0.58	65%

External shadings are used based on the building shape and sunlight. Daylight utilization can reduce lighting energy by about 30%. The heat and moisture load of HVAC system are controlled respectively, heat recovery technologies are used for air exhaust systems. The renewable energy used is 20% of the total building energy consumption.

6.2 Energy renovation examples

6.2.1 Renovation projects in China

Examples of (large-scale) renovation projects that have recently been realized in China, and where energy efficiency has been improved, are presented below. They include public buildings (the main building of the China Academy of Building Research, the Wen Yuan Building at Tongji University Campus and the Tongji Technical Garden-Building A), a hotel and restaurant building (Jing Yan Hotel) and a residential building (Pinggu residential building).

Pinggu residential building

Before retrofit, these old masonry concrete structure buildings did not adopt household-based heat metering (Bless Construction 2011). The buildings were cold in winter and hot in summer. The retrofit area was 300 000 square meters. The measures reduced energy use and improved living standards.

Retrofit contents:

- energy-saving design, feasibility study

Used new technologies and new equipment:

- external thermal insulation and energy-saving doors
- waterproof roofing heat preservation and sloping roof along the streets
- household based heat metering.

Figure 70. Pinggu residential area (Bless Construction 2011).

The main building of the China Academy of Building Research

Retrofit time:	2007.5
Land Area:	1900.84 m^2
Building Area:	23000 m^2
Retrofit Area:	23000 m^2
Cost:	2.55 million Yuan
Structure:	Frame shear force wall
Finish time:	2008.5

The building was taken into use in 1993, and its main function was for office and experimentation (Sjzu 2011). The retrofit involved the following aspects: construction technology (facades and sightseeing elevators), structure technology (strengthening technology, steel construction technology and curtain wall technology), energy saving technology (external window and insulation, and air-conditioning), water supply and drainage technology (water conservation), lighting technology (indoor lighting and outdoor neon). Among these, the facades retrofit meant a great deal. (See Figure 71.)

After retrofit, the building could save 6.502×105 kWh a year. Supposing the power cost of 0.49 Yuan/kWh, it could save 318 thousand Yuan a year. After 8 years running, it would repay the cost and save 5.2×106 kWh for the state.

Figure 71. China Academy of Building Research before and after retrofit (Sjzu 2011).

Wen Yuan Building at Tongji University Campus

A Bauhaus Style building built in 1953.
Retrofit area: 5500 m^2.
Contents (Zhou 2011):

- Internal heating insulation of the external wall (40 mm mineral wool). The overall coefficient of heat transfer is no more than 0.77 W/m^2·K.
- Low-e glass windows, heat transfer coefficient of the windows is no more than 2.0 W/m^2·K
- Internal shading, the shading coefficient is no more than 0.55.
- Roof – several advanced energy-saving technologies including roof garden and thermal insulation material. Average heat transfer coefficient is no more than 0.7 W/m^2·K. Ecological and economical roof garden system needs no maintenance.
- Different HVAC systems in different parts of the Wen Yuan Building:

- Middle part of the building: Ground source heat pump and radiation ceilings.
- 300 seat lecture hall: Gas-driven heat pump and dehumidifying using waste heat.

160 seat lecture rooms: Absorption heat pump driven by solar energy

- Intelligent building controlling including temperature, humidity, lighting and security.

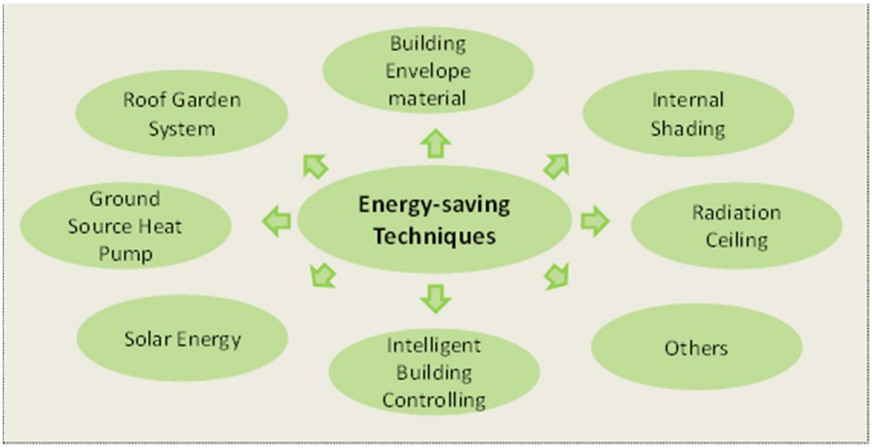


Figure 72. The Wen Yuan Building’s energy-saving renovation (Zhou 2011).

Tongji Technical Garden-Building A

Respecting the original architectural appearance and preserving it is an important part of the low carbon design in this renovation project. This building reflects the sustainable concept, where natural ventilation, natural lighting, external shading, solar-panel system, green roof, vertical greenery are included (Zhou 2011). Ecological energy-saving technologies are also included, such as a rain water recycling system, a heat recovery system, an energy saving for power distribution system, individual metering, etc. See Figure 73.

General introduction

1. Total area:	65 420 m^2
2. Total cooling load:	7734 kW
Average cooling load:	0.118 kW/m^2
3. Total heating load:	3842 kW
Average heating load:	0.06 kW/m^2

Design principles

1. To respect the character of the existing building, and the façade design follows the original design character.
2. To achieve natural ventilation and lighting as well as providing individual working space according to the users' demands, the removal of some parts of the floors was needed to form an inner space (atrium).
3. To create a pleasant and ecological working environment by organizing the inner space and the roof with multi-level landscape.
4. Most of the spaces are occupied with large space offices as usual. Some individual spaces were added on levels 1 and 4 so as to achieve an economical and interesting design.
5. Ecological techniques and energy efficiency:
6. Solar panels – To provide the power for garage and corridor lighting, a solar panel system will be installed on the roof, and panels are also incorporated in the solar shadings.
7. Rain water collection system will be included for irrigation.

Figure 73. The Tongji Technical Garden-Building before renovation (on the left), and after renovation (on the right) (Zhou 2012).

In addition to the special focus on providing natural lighting to the building, the details of the lighting system are controlled according to the different needs of the spaces, e.g. a dedicated intelligent lighting control system will operate in the Large space office, Auditorium and VIP room (Figure 74), including customized "SCENE MODE" triggered by one touch on the control panel.

Figure 74. The lights in the auditorium are operated with an intelligent control system (Zhou 2012).

Figure 75. Vertical greening for the parking garage not only improves the building's appearance but also provides natural shading (Zhou 2012).

The building design includes the use of plants as part of the sustainable solutions, like vertical greening (Figure 75) and green the roof. The function of the green roof, which will be planted on level 4 of the building, is to:

- Reduce the heat-island effect
- Improve the energy efficiency
- Purify the air and reduce the noise
- Provide a comfortable working space
- Improve the landscape and increase the building quality.

The HVAC system design consists of three different parts, which are designed according to the function of the spaces: The two pipe closed system is used for the public area of the first floor (mainly the auditorium, meeting room, restaurant, administrative office), with two sets of screw type air source heat pumps as cooling/heating source. Second, a “direct evaporation type variable refrigerant heat pump with fresh air system” is used for the large space office area because of its characteristic feature, which are flexibility and separation. Third, precise air conditioning units are used for special spaces according to their requirements such as the archive repository and computer room.

An efficient Energy Management System (EMS) is installed so as to further reduce the energy consumption of the building. To enhance energy conservation management and supervision, multi-function measurement meters are employed so as to realize real-time monitoring of energy and evaluation.

6.2.2 Renovation projects in Finland

This chapter describes two innovative renovation examples from Finland: A residential building (Innova-project in Riihimäki) and an office building (Blomstedt Hall, ARE office in Jyväskylä).

Apartment building in Riihimäki

Innova is a pilot project where an apartment building built in 1975 in Riihimäki is renovated to the passive building level (Paroc, 2012). In Southern Finland, the passive level means that the heating energy demand is ≤ 20 kWh/m^2/a, the total primary energy demand is ≤ 130 kWh/m^2/a and the airtightness n50 is ≤ 0.6 1/h (Paroc, 2010).

In this pilot project, the prefabricated TES EnergyFacades are being utilized for the first time in Finland (Cronhjort 2011). In Innova, the prefabricated elements include extra insulations, claddings, windows and ventilation ducts. Figure 76 shows prefabrication of the elements in the factory. In Figure 77, some elements are already installed to the building.

Figure 76. Prefabrication of the elements. (Picture: Ilpo Kouhia/VTT.)

Figure 77. Installed TES elements. (Picture: Ilpo Kouhia/VTT.)

Blomstedt Hall, office building in Jyväskylä

This plywood factory was built in 1912 and was renovated in 2000 (Ala-Juusela 2004). It is situated in an old industrial area. The building has 2000 m^2 of floor space on 2 storeys. There are 6 businesses on the first floor and office space on the second Figure 78. The building has been occupied since November 2000.

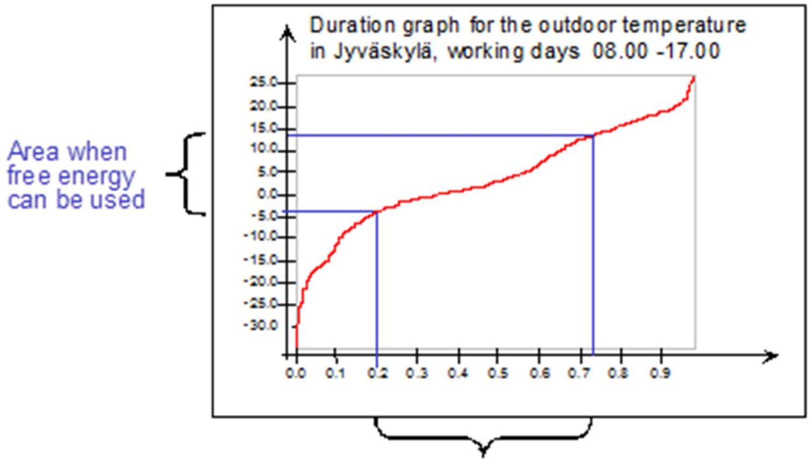
Figure 78. The only thing that was left of the old plywood factory was the original brick facade of the building with a special rose window and ten steel roof trusses. These were integrated into the new building as a reminder of the old architecture and construction tradition. (Photo: ARE Oy.)

Water is circulated in the ceiling panels to heat or cool the rooms in the building. Each room has individual temperature control. The panels are also used as a reflecting element for the indirect lighting (Figure 79).

Figure 79. The Sensus® panels provide the heating, cooling and indirect lighting to the offices in Blomstedt Hall. (Photo: ARE Oy.)

The heating and cooling to the building is supplied by a Sensus® system. Sensus® is the name for an integrated building services product, which includes the design and installation of systems for heating, cooling, ventilation, electricity, lighting, fire protection, water and sewage. The Sensus® system uses primarily the waste heat from the building for heating. When additional heating is needed, it is delivered with a heat exchanger from the district heating network. Cooling is primarily delivered by free cooling. When this is not enough, the system uses vapor compression chillers to cool the cooling water.

The building automation system plays an important part in the energy management of Blomstedt Hall (Figure 80). A LonWorks® based distributed system controls the room temperatures and lighting. There is a demand-controlled ventilation system (Nemus®), which maintains the duct pressures at an optimal level. The automation system is controlled by both temperature and occupation sensors.



Area when free energy can be used

The energy circulation can be gained for a period of more than half of the working time

Figure 80. Substantial energy savings can be achieved by using waste heat and free cooling with the help of the automation system (Ala-Juusela 2004).

6.3 Fidelix pilot in Dalian, China

Fidelix Inc. has signed an agreement with the China Educational Instrument & Equipment Corporation on the delivery of the building automation system to the University of Dalian in China. The equipment is meant for research use in the university. The objective is to examine and compare the function of different energy forms, energy accumulators and their controllability. The University of

Dalian has built, a geothermal heating and cooling systems and a solar panel system for the project.

The basic requirement for the Fidelix system was flexibility in programming. The Fidelix system is based on an open source industry PC architecture. The objective of the Fidelix pilot in China is to create an energy conservation concept that observes the local conditions for national use.

6.4 Possible future co-operation

6.4.1 Areas of co-operation

One of the tasks in the EESCU project was to assess the applicability of Finnish energy efficiency technologies and design and construction processes in China. The aim was to find potential technologies and methodologies for construction processes that Finnish companies can offer to Chinese pilot projects. The following areas of co-operation were of interest:

- Efficient district heating and cooling technologies for both new systems and refurbishment of existing systems
- Energy-efficient building concepts and technologies for new buildings and refurbishment in severe cold, cold, and hot summer and cold winter regions in China
- Requirements, environmental assessment and certification of green buildings and districts
- Joint ventures and pilot buildings for efficient utilization of Finnish technologies.

District heating in cities is typically provided by several different companies (e.g. in Beijing more than 30 providers). The systems are rather inefficient and are based on district heating substations delivering heat directly to buildings without a district heating center in individual buildings. The main problem in these systems is the unbalanced distribution of heat and high distribution heat losses. The utilization of Finnish technologies will be further developed in a joint project between VTT, Tsinghua University of Beijing and Finnish and Chinese companies.

Another area of interest in district heating and cooling systems is ground or water source heating and cooling. The energy sources in these systems can be sea water, lake water, or shallow ground heat wells and geothermal energy based on warm water flows in the ground. These systems relate typically to development of new business parks or neighborhoods. The co-operation within this field depends on a start-up of new projects in the near future.

Energy-efficient buildings are a very promising area of co-operation. The level and volume of this co-operation depends on the applicability of the existing technologies to Chinese construction processes. Figure 81 shows a summary of technical and performance requirements for technologies for buildings. The summary is based on discussions with various stakeholders in the Chinese construction markets.

Environmental certification can be a strong advantage for Finnish companies as well. Three star certification is required for public buildings, and more and more often for apartments as well. Office and technology parks are looking for international certification, especially LEED labeling. Target setting for city planning is also an interesting area. The Chinese cities often look for examples from Europe for an image for new neighborhoods. Experiences from European city planning help planning offices to enter the markets. The planning work needs to be carried out in co-operation with Chinese partners so as to avoid issues related to requirements and legislation. Finnish architectural offices have a good reputation in China.

The cost level is quite a strong barrier to utilization of the technologies and corresponding solutions in China. The basic construction cost for an apartment house in small or medium sized cities in China is only 1000–3000 RMB/m^2. This cost level covers the costs of a building typically without internal finishing. The cost level drives usage of local technologies in volume construction or production of materials, components and solutions in China The latter choice is often recommended by the Chinese stakeholders. It would give the Finnish companies a possibility of growing internationally. Possibilities for partnering and networks for the SME industries are a problem. However, city administrations are keen to persuade foreign companies to produce in China. Partners can thus be found also with the aid of the city administration.

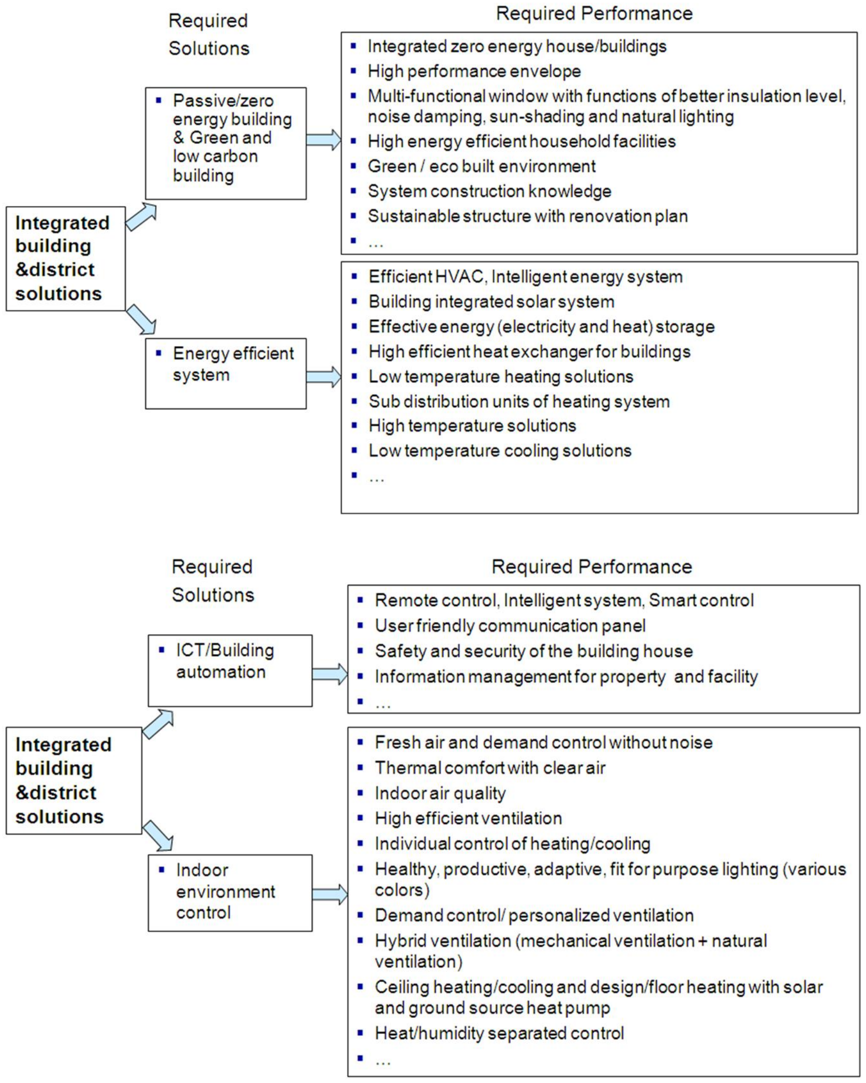


Figure 81. Requirements for new technologies.

6.4.2 Possible pilot projects

During the EESCU project, one pilot project was finished. A new monitoring system was piloted at the Dalian University of Technology (see Chapter 6.3).

A Chinese partner is looking for solutions for passive houses in China. The project location is a new neighborhood in Jianxhu Province. One of the pilot apartment buildings of 3000 m^2 is in the design phase. This project is coordinated and by and large funded by German financing organizations. The basic aim was a passive house by German definition, but the definition was modified to suit the cold winter and hot and humid summer conditions of the region.

There is also a possibility to design and construct a Finnish solution for a passive house. The same modified requirements would be utilized as with the German pilot. A pre-requisite for this project is co-funding between the Chinese and Finnish funding organizations. The basic project would be a commercial project between the builder and Finnish companies. The role of the Finnish partners would be in services on the design, construction and commercial evaluation of the concept and customizing the concept for the Chinese markets. This kind of a project could also serve as a show case of Finnish low-temperature heating and high-temperature cooling systems, ventilation systems suitable for humid summer conditions, building automations systems (incl. security) and especially the Finnish knowhow on very energy-efficient buildings.

There are many planning and design projects for new housing and working areas in China. A number of such projects are located in the city of Dalian. The largest of these projects is the Dalian New Airport City. The project is a new part of the city including all the facilities of a city. The preliminary master plan was drawn up by a French architectural office. Possible demonstration topics are new energy systems based on renewable energies and utilization of sea water heat pump systems for heating, energy-efficient buildings and an overall assessment of the master plan.

Another new part of the city of Dalian comprises 10 planning areas with pre-defined targets of use including a science park and high-technology enterprises, housing and leisure. The area aims at the development of a smart city with high environmental targets, high technology solutions and environmental certification. The builder offers an opportunity to demonstrate energy efficiency technologies and the establishment of a research and development center for the development of green buildings and districts. The prerequisites of these demonstrations are a commercial project base, localization of activities and industrial funding for R&D. Also, environmental certification of the 10 planning areas is possible. A co-operation framework was suggested for the development of the area, Figure 82. The suggestion is still pending due to economic restrictions set by the central government impacting on the schedule of the project.

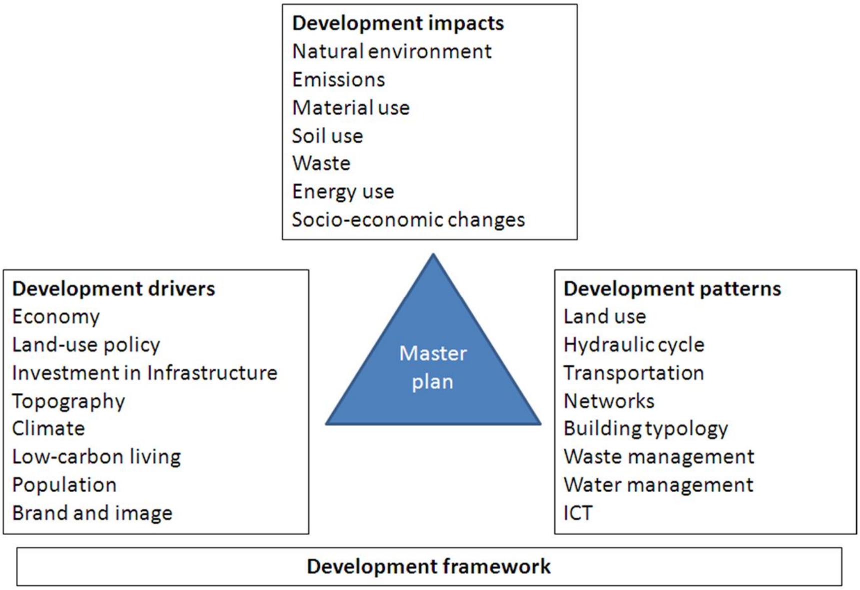


Figure 82. Development frame work for a new district in Dalian.

Two energy companies in Dalian are interested in technologies and methods for balancing existing district heating networks. The aim is to improve the efficiency of heat delivery and to reduce distribution losses and at the same time maintain better indoor air quality in terms of more stable indoor conditions. These are considered to commercial projects with Finnish expert services.

A new office park and housing area is under design and partly already under construction in the city of Pokou. The energy provider considers there is a possibility to utilize the lake as a source for heating and cooling. Demonstration projects are possible, provided that the energy provider finds local customers who need district energy planning. The energy provider has their own heat pump system. The demonstration activities would also include new monitoring and a system for testing and management of the district energy system based of heat pumps.

A series of simulations on improvement of energy efficiency of a hotel building under design were carried out. The simulations gave a possibility of reducing the total energy demand of the hotel by at least 60% without any changes in the architecture and spatial plans of the building. The extra costs of the improvements were estimated to be less than 10% of the contract price. The main demonstration activity was considered to be the building services systems, including the hotel restaurant kitchen equipment. The hotel is under construction at the moment and thus the possibilities to utilize this project are rather difficult.

7. Business-related Issues

7.1 China's future economic prospects

China is the world's fastest growing economy. Economic growth has been continuing for nearly thirty years, and for the last 15 years the annual growth rate has averaged 10%. The gradual opening up of the economy and huge market potential have attracted a great deal of foreign investment, especially in Chinese industrial production, since the 1980's. The rapid growth of foreign trade has resulted in record high international reserves. At the same time, competition has increased and costs have risen sharply in the 2000's, especially in the growth centers in Shanghai, Beijing and the Guangdong region. The global economic crisis is causing additional challenges in export markets and the general uncertainty. (Kettunen et al. 2008)

Changes in the Chinese government leadership are expected to cause changes in the state-owned or state-controlled enterprises. During the period in office of President Hu Jintao, China had an average of more than 10% growth in GDP, had massive export growth, as well as a rapid increase in global influence (Kosonen et al. 2012). During the Hu Jintao presidency, economic reforms progressed slowly. The new leaders are expected, at least initially, to bring in very moderate measures of reform. The problem of decision-makers is to keep the jobs that maintain high economic growth, while it is at the same time necessary to struggle with the real estate bubble and the increasing inflation rate. Cost levels will also increase and the estimated size of the workforce decline for decades. Population aging, the development of social protection and pension schemes will at the same time increase the pressures on public finances.

In the last decade, the growth was also driven by China's accession to the World Trade Organisation, as well as a major investment in large enterprises and investments to accelerate the national economy. The downsides of development have included e.g. worsening environmental problems. In addition, the economic structural problems of China have become worse, as growth has relied on exports, particularly investments, even though the aim has been to move domestic consumption demand and a higher degree of added value based on the model of economic direction (Kosonen et al. 2012).

China’s export growth prospects are weakened by the currently over-indebted western economic predicament, for which there is no quick solution in sight. Although exports to Asian markets are rising, foreign trade growth has clearly slowed down. China’s economy has relied too heavily at the expense of consumers, financed by soaring investment growth, a side effect of the regional government’s indebtedness has worsened. Investment losses have increased and the industrial capacity utilization rate has dropped to 60%. As a result, for example the grey market banking sector has quickly expanded, which complicates corporate funding and the implementation of government economic policy. The situation is beginning to resemble Japan in the late 1980’s, before the debt bubble burst. A modern innovation and high technology-based economic model is difficult to achieve in the public sector, as well as more conducive to social and economic controls that maintain the environment. (Kosonen et al. 2012.)

The current Chinese five-year plan aims to raise public wage levels, to reduce regional disparities in economic growth and to raise the technological level of production. The Plan emphasizes the example of the minimum wage increase, innovation, and investment guidance in central and western China. At the same time, the management strongly supports Chinese companies’ investments abroad so as to secure energy, raw materials, and the availability of technology. Technology and innovation in China are actively being developed, and many multinational companies have shifted research and development activities to the country. (Kosonen et al. 2012.)

China has several strengths in market prospects and opportunities. Modernisation of commercial life and rapid westernization open up viable business opportunities for foreign-owned enterprises, while large domestic markets maintain economic growth. 1.3 billion consumers of China demand almost everything. Production lines are built for a wide range of products; thus the foreign machinery and equipment industry products will continue to sell well in China in the future. a 100% foreign-owned company is easy to set up in almost all industries, although a Chinese partner is needed to speed up access to the market. (FINPRO, 2010)

Investment in education, the dismantling of regulations and restrictions support China’s rise as a serious factor in international economics and politics. Substandard legislation affects the business climate, as foreign trade rules vary by region and guarantees of access to markets are unclear. Also, the complexity of the decision-making process, a high level of corruption and IPR problems of piracy are challenges from the point of view of a foreign company.

China is rich in natural resources, and large-scale infrastructure development projects and infrastructure projects are supported by the State. In addition to the development of basic industries, China has begun to develop the service sector. Other potential business sectors are: information and communications technology, afforestation and wood processing machinery and equipment, construction materials and timber buildings, (standards and norms are missing), environmental technology, the shipbuilding industry equipment, automation, medicine and food production technology. (FINPRO 2010.)

7.2 Barriers to energy efficiency in buildings

Currently, nearly 45% of buildings in China need heating, and largely in the north of China, heat is delivered by central or district heating plants fuelled primarily by coal. It is projected that housing stock in the heating zone will double by 2020. Figure 83 shows that space heating and water heating together account for nearly 60% of energy consumption in residential buildings in China, while space heating and cooling represent the largest proportion in commercial buildings. (Li 2008.)

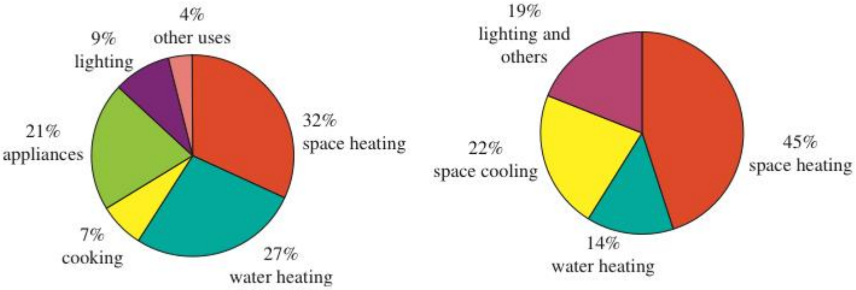


Figure 83. Residential and commercial building energy consumption by end-use in China. Source: Li (2008).

The share of water heating share is relatively high, partly because of the cooking culture and, more specifically, more and more Chinese households use an independent electric-resistance water heater, which is an energy-intensive device; furthermore, centralized hot water distribution systems have been little developed in most of the cities. (Li 2008.)

Electricity consumption in the residential sector is also significantly lower than in the developed world; this gap implies a large potential of increase in the residential energy demand over the next decades, as appliance consumption is positively correlated to household income. In the meantime, there is a significant disparity between the developed provinces and underdeveloped areas within China; for example, a consumer in Shanghai consumes more than three times the electricity as China's average in the residential sector (NBS 2006).

The implementation of green elements for property development projects meet with various barriers that conventional buildings do not, such as the 'higher costs for green appliance design and energy-saving material at design stage', 'lengthy planning and approval process for new green technologies and recycled materials' and 'unfamiliarity with green technologies resulting in delays in the design and construction process'. Overall, the high additional cost is considered as the major barrier to applying green technologies in China. Consequentially, a Green Strategy Plan (GSP) is proposed, which may help improve green property development practices and technologies in China. This will help bring costs down and increase professional capacity, providing an opportunity to create an experience-sharing channel for achieving the sustainable development in the property development process. (Zhang et al. 2011.)

7.2.1 Technical barriers

Heating in the northern urban areas in China is the most important energy consumer in the building sector. Each year, more than 130 million tons of coal equivalent (tce) are burned for heating, which represents about 52% of the total energy used in China's urban buildings (Jiang 2005).

Figure 84 illustrates the regulatory thermal performance requirement in Chinese building codes in comparison with the developed countries.

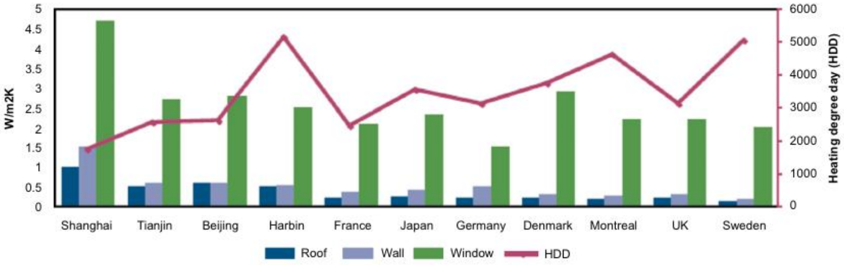


Figure 84. Cross-national comparison of efficiency compliance standards of building envelope U-value (Li 2008).

The development of renewable energy is one of the key measures to create a low carbon energy structure. At present, the share of fossil energy in the total energy consumption in China accounts for about 90%. The highest carbon emissions coefficient of coal accounts for nearly 70%, and even by 2020 still will account for about 60%, so there is a need to strengthen the greening of coal production and clean utilization, and vigorously develop renewable energy. The technology of renewable energy application in China is not regarded by government and the experts and university and graduate schools at present, and the technical investment is not enough, in that it is impossible to exploit the pivotal technology. Some pivotal technologies of renewable energy exploitation are purchased from the developed countries. (L.-Q. Liu et al. 2011.)

7.2.2 Financial barriers

The development of a low carbon economy is in need of abundant funding, which cannot be borne by the ordinary people and small and medium-size enterprise, so the economic incentives of government are indispensable. For example, house prices in China are very high as compared with the common people's incomes at present. In certain Chinese cities, each square meter of housing has already reached the astonishing figure of 5,000–10,000$, and the Chinese people's per capita income in 2009 is about 3,800$, so such high house prices cannot be borne by the common people. If they buy a low carbon building, the unit price will increase by about 5–10%, so although the populace know the benefits of a low carbon economy, they will not buy expensive low carbon buildings. Furthermore, the changes in the industrial structure of small and medium-size enterprise needs abundant funding, which cannot add to the financial pressure, so government financial support is necessary. (L.-Q. Liu et al. 2011.)

7.2.3 Policy barriers

The low carbon policy has been established by the central government, but the policies are difficult to be implemented by local governments due to the behalf of local government cannot ensure. To take an actual example, Shanxi Province in China is a very important energy province, and its annual coal production is more than 0.5 billion tons, which accounts for approximately 25% of the national coal output. 80% of GDP in Shanxi relates to coal. If the country promotes low carbon technologies and adjusts the energy structure, the reduction in coal wastage will directly affect the economic development of Shanxi, so the degree of central policy applied in different provinces varies. (L.-Q. Liu et al. 2011.)

7.2.4 Institutional barriers

In most northern cities, the heating service is still widely considered as welfare provided by the government's subsidy and not as a commercial service. Heating consumption is billed on the basis of floor space area instead of actual consumption. The consumers are not given any price signal to conserve energy; no economic incentive is available for housing developers to build more efficient houses than according to the building codes. Although, in 2003, the central government issued a guideline that urged local governments to launch a nation-wide heating reform, the billing and pricing system remains almost intact. A handful of individual billing services and consumption-based heating pricing are only practiced in the pilot projects for demonstration purposes. The pricing reform has been postponed after the government's reform schedule. More specifically, most energy suppliers and building constructors remain reluctant to install individual heating meters and thermostatic valves at the expense of energy loss, and the consumers are not allowed to regulate interior temperature freely according to the ambient environment and comfort requirement diversities. (Li 2008.)

In addition, the development of distributed energy systems, such as small and medium-size high-efficient CHPs, confront many difficulties in competing with the low-cost coal-fired small boilers, due to an institutional barrier in terms of a power grid purchasing contract. The central government encourages the development of CHP only with a large generating capacity, to the disadvantage of distributed small-size cogeneration with a flexible regulation capability. (Li 2008.)

7.3 Chinese construction sector stakeholders

Half of the world's building construction is predicted to take place in China by 2025 (World Bank 2001). In addition, the urbanisation rate is expected to rise enormously. Between 2000 and 2005 the urban residential living space increased by 50%. The increase was due to a growing population and the increased floor space per capita (Richerzhagen et al. 2008). China's GDP is very dependent of the construction sector. In the share of China's GDP of the construction sector has increased from 4.3% in 2000 to 7% in 2004, and investment in construction and installations rose by 208% during the same period (Richerzhagen et al. 2008). Real-estate investment has been the fastest-growing area of capital spending in China. It has increased by over 20% every year since 2000 (The Economist Intelligence Unit 2006).

Figure 85 illustrates the linear value chain and relatively organized actor constellation of the Chinese construction sector. In the process, the developers are the starting point of the value chain.

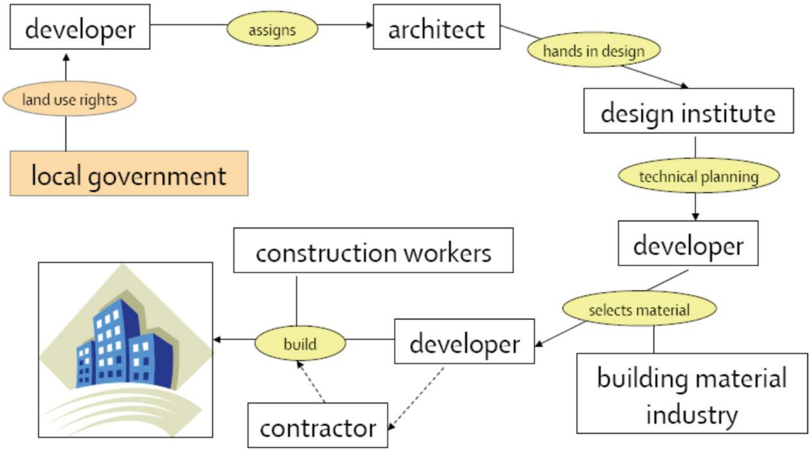


Figure 85. Actor constellation in the Chinese housing sector (Richerzhagen et al. 2008).

The developers obtain land use rights from their respective local government. The land use rights are generally 70-year contracts in China, and after the 70-year period of time they are returned back to the government (Chen 2007).

After the developer receives the land use rights, an architect is assigned to design the building. The Ministry of Housing and Urban-Rural Development (MOHURD) issues a license to the architectural firm in order to allow the technical planning work for a building (Richerzhagen et al. 2008). Architectural firms or design institutes can work on the technical planning of their own designs or on buildings that have been designed by other architects. A requirement is that the final plan is cross-checked by another design institute before approval from the building authority (Richerzhagen et al. 2008). After the plan is completed and approved, the developer procures the building materials and begins construction. Depending on their capacities, some developers construct the building with their own company and some assign a contractor to carry out the construction.

Improvements in EEB have been successful with new buildings, while in old buildings a great deal remains to be done (Richerzhagen et al. 2008). In the heating zone of Northern China, only 1% of the existing building stock is energy-efficient according to Chinese government officials (Chinagb.net 2008). Older buildings which hardly contain any thermal insulation and are still equipped with a one-pipe heating system have the greatest potential for increasing energy efficiency and reducing CO_2 emissions with retrofitting. It would be economically viable to retrofit 2.5bn m^2 of existing residential buildings in Northern China. These buildings represent a saving potential of 55 million tons of CO_2 emissions per year (GIZ, 2007). Older buildings in China require the following retrofitting procedures: 1) a two-pipe-heating system, 2) thermostats, and 3) heat-meters to allow individual regulation, metering and billing (Richerzhagen et al. 2008). In addition, the heat-provision systems require renovations to prepare for the expected high variations in demand (Richerzhagen et al. 2008).

Technical conditions for the full implementation of the heat billing and metering system reform are created with retrofitting (Richerzhagen et al. 2008). Apartments that need retrofitting are inhabited by residents who have scarce economic resources. Retrofitting of old buildings lowers heating bills, raises indoor temperatures, supports a healthier living environment, increases the value of apartments and improves the overall quality of living (Richerzhagen et al. 2008).

Figure 86 illustrates how much more complex retrofitting of old buildings is compared to the construction of new buildings.

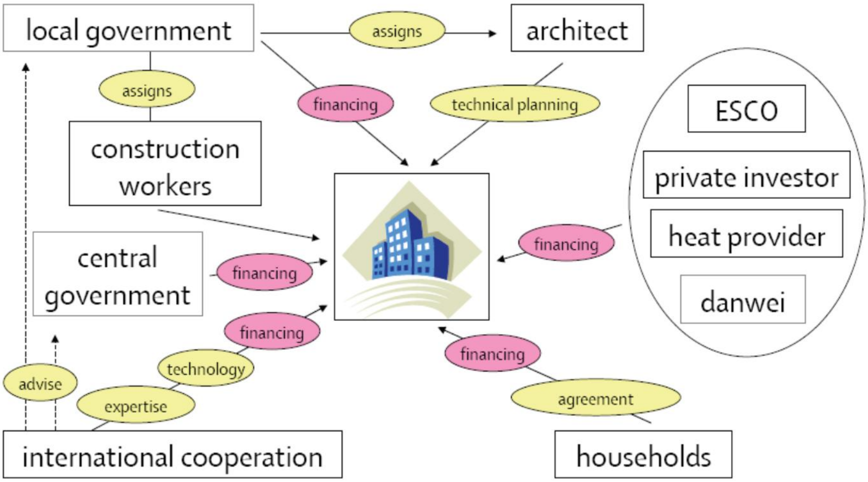


Figure 86. Actor constellation for retrofitting (Richerzhagen et al. 2008).

It is common in China that the retrofitting process begins with an initiative from the local municipal government that partly finances retrofitting (Richerzhagen et al. 2008). The local municipal government contacts local households to discuss the possibility of retrofitting of their building. Obtaining the residents' agreement and agreeing to financing conditions usually constitutes a long and complex negotiation process (Richerzhagen et al. 2008).

International cooperation agencies can join the process in order to moderate the discussion between the different parties and their interests. In addition, they can offer financing options, technical advice, access to advanced foreign technology and knowledge about retrofitting projects in their respective countries (Richerzhagen et al. 2008).

Once the households and the government agents have reached a consensus in their discussions, the local government assigns an architect to draw up the technical plan documents that serve as the blueprints for the project. The construction workers are then assigned by the local government (Richerzhagen et al. 2008). The central government usually participates in the financing of retrofitting projects. Sometimes an Energy Service Company (ESCO), a private investor, the local heat provider or the development company of the apartment building contribute to financing the retrofitting (Richerzhagen et al. 2008).

7.4 Special energy renovation service – ESCO concept

Special business models have been developed for promoting energy renovations. One of the new models is ESCO (EPC Watch 2011). A turnkey delivery of the widest scope may include financing and service time maintenance.

The ESCO acronym derives from Energy Service Company. An ESCO actor implements energy efficiency and energy-saving measures on behalf of their client and grants a conservation warranty for the measures undertaken. The energy renovation is financed by the savings generated either by shared savings or by guaranteed savings (Figure 87). ESCO services may, for example, be offered by hardware vendors or companies specializing in this service.

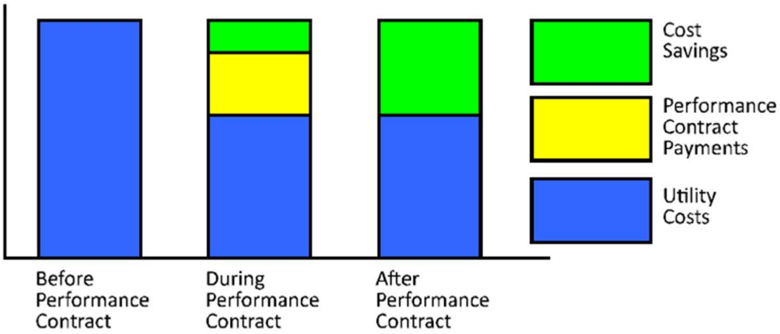


Figure 87. Financing in the ESCO concept (Xu et al. 2011).

The ESCO service suits industrial enterprises as well as the public and private service sector. Feasible applications for ESCO projects are found, for instance, in building services systems, industrial utility systems and energy production.

Clients may choose whether they want to finance the renovation project themselves or use the ESCO financing concept, where the project is paid directly by the generated savings. In the latter case, the saved own financing may be spent on other repairs to be carried out in the same connection. The ESCO concept also includes a maintenance agreement which guarantees that the condition of the property remains good (Figure 88).

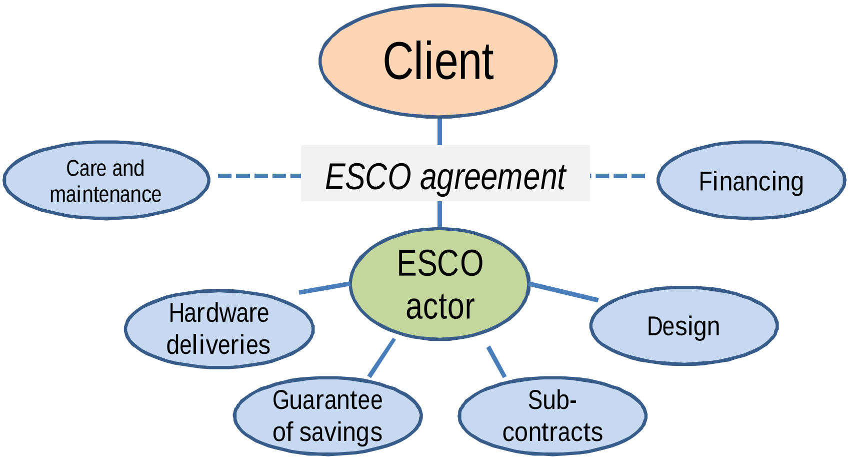


Figure 88. The structure and stakeholders in ESCO energy renovation delivery concept (Xu et al. 2011).

The ESCO service is suitable for projects where

- the aims are energy conservation and renovation
- there is not enough own expertise, human resources or financing
- the project is a big one, encompassing several pieces of equipment, systems or buildings
- the conservation guarantee is important to the customer.

Typical ESCO projects include renovation of building services, renovation or addition of heat recovery systems and the introduction of a renewable energy source.

ESCO-type energy performance contracting (EPC) has been introduced into China recently. In Figure 89 there is a process description of how EPC projects are carried out in China (Xu et al. 2011).

It has many challenges to overcome. The critical success factors have been identified by analysing hotel EPC projects. They are (1) process organization, (2) EPC financing, (3) knowledge and innovation, sustainable development, measure & verification (4) implementation of sustainable development strategy, (5) contractual arrangement, and (6) external economic environment.

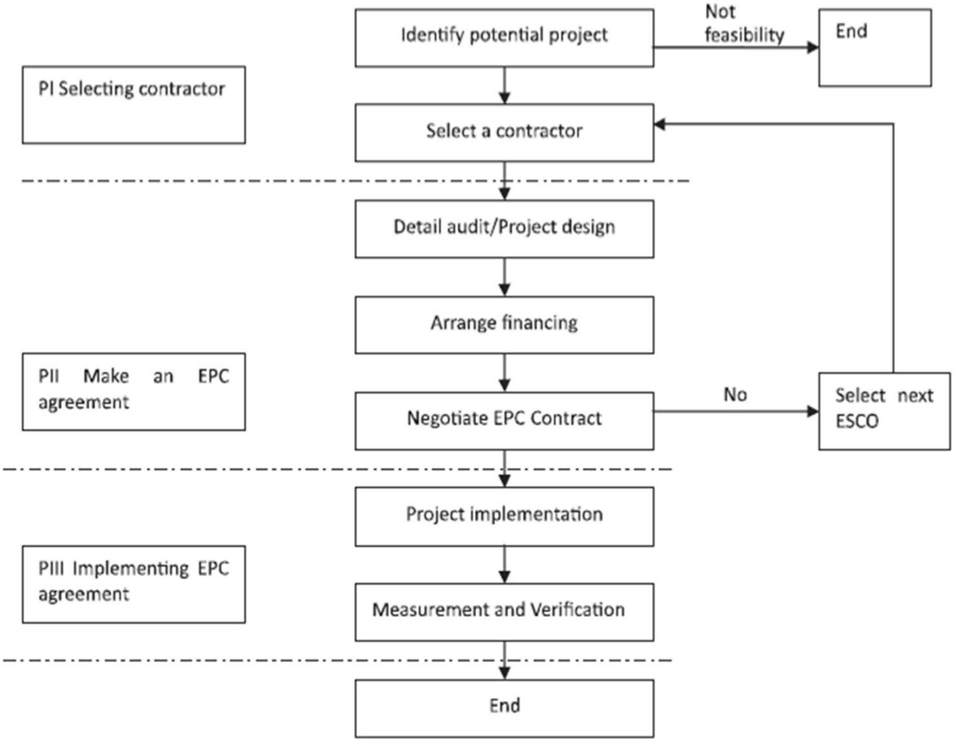


Figure 89. Process description of EPC projects in China (Xu et al. 2011).

In order to achieve EPC success in Chinese demonstration programs, education programs and training are needed, because EPC is not a mature way of delivering building renovation projects. Some economic incentive or policy support, such as special funding support, tax preferences, and loan warranty, etc., improve the investment environment and project financial status

Development of new technologies and energy efficiency products are needed. A credit system could promote ESCO contractors and clients to trust each other. A standard contract procedure could share risk, task, and profit reasonably. A measure and verification protocol agreed by clients and contractors could reduce disputes and make coordination easier during the renovation process.

8. Conclusions

China is one of the world's largest economies and the world's second largest energy consumer. In addition, China is experiencing the world's most extensive urbanisation. By 2015, half of the world's new buildings will be constructed in China; more than 50% of China's urban residential and commercial building stock in 2015 will probably be constructed after the year 2000.

The inventory analysis made concludes that there are two obvious building energy consumption problems in China. The first problem is the low energy efficiency and large amount of waste energy in large-scale public buildings. The second problem is the high energy consumption for heating in North China, which comprises a large percentage of total net energy consumption. The heating-dominated North China constitutes 70% of the whole country's area. The building area of north China is approximately 6.5 billion m^2, and the heating energy consumption of buildings accounts for up to as much as 45% of total national urban building energy consumption. Due to the poor thermal insulation of the building envelope and low efficiency of heating systems, heating energy consumption is approximately 2–4 times higher compared to that of Northern Europe with a similar climate. (Cai et al. 2009.)

The project had three main research sections, namely "Zero Energy Buildings", "Regional Energy Solutions" and "Energy Renovations of Existing Buildings". All the sections consist of theoretical parts, concept developments and examples from both Finland and China.

The basic approach towards zero energy building is to minimize the energy consumption, exploit energy-efficient solutions and supply the energy demand of the building to a significant extent with renewable energy sources. A district level approach to energy supply is generally desirable. The concept of NetZero energy building with a low-exergy system has been specified by examples of energy-efficient construction concepts from China and Europe.

The section on "Regional Energy Solutions" concentrates on principles for selecting energy system for districts and design guidelines for those kind of solutions. In addition, renewable energy production technologies and energy storage solutions are described. The design concept starts with selecting the building level energy efficiency. The set of buildings is combined to determine the district level energy demand. The possible energy generation and supply systems are selected based on expert opinion or the requirements of the client. These systems are evaluated by the criteria selected by the evaluator. The result is a weighted decision between energy consumption, energy costs, investment costs, environmental aspects (e.g. emissions) and other criteria defined by the client. Case study examples from both Finland and China are also introduced.

In the Chinese building market, there are trends showing that the renovation of existing buildings will necessarily become an increasing market in the future. For example, the urbanisation rate is so high that the new buildings alone will not be able to cover the need of the expanding urban population. Also, the government has been setting goals for renovation, and more importantly, for energy efficiency improvements in existing building stock.

Energy-efficiency upgrades have been uncommon in China. The reason is that the building lots are often being recycled. In Finland, some renovations improving energy-efficiency have turned out to be costly. With the savings achieved, the repayment periods may become longer than the technical service life of the renovated buildings, if the allocation between the energy saving and other benefits is not conducted carefully. In case the energy saving estimations and other benefits are not thoroughly exploited, the payback period might be longer than the technical service lifetime of the building.

Commissioning (Cx), as understood in Finland, is not a common procedure in China. Thus, there is no standard for it in China. However, there are many related requirements for each phase of the commissioning procedure, and the main procedures of the Cx process are similar to the Finnish Cx process.

The cost level is quite a major barrier to utilization of the technologies and corresponding solutions in China. The basic construction cost without internal finishing for an apartment building in small or medium-sized cities in China is only around 100–300 €/m^2, so, product or material importing to China is rarely profitable.

References

Ala-Juusela, M. (ed.) 2004. *Heating and Cooling with Focus on Increased Energy Efficiency and Improved Comfort. Guidebook to IEA ECBCS Annex 37 Low Exergy Systems for Heating and Cooling of Buildings. Full version.* Available at: http://www.lowex.net/english/inside/guidebook.html.

AlertMe. 2012. *SmartMonitoring.* Available at: https://www.alertme.com/how-we-do-it/products-and-services/smart-monitoring/. [Accessed 16 January 2012].

Austrade. 2011. *Green Building to China – Trends and Opportunities.* Last updated on 25 March 2011. Available at: ttp://www.austrade.gov.au/Green-building-to-China/default.aspx. [Accessed 16 October 2011].

Berg, D. 2007. Wind Energy Conversion. In: F. Kreith & D. Y. Goswami (eds.) *Handbook of Energy Efficiency and Renewable Energy.* Boca Raton, FL, USA: CRC Press – Taylor & Francis Group, p. 30.

Bless Construction. 2011. *Brochure of Zhufu real estate company.* Shanghai, China: Bless Construction.

Cai, W. G., Wu, W. G. Y., Zhong, Y. & Ren, H. 2009. China building energy consumption: Situation, challenges and corresponding measures. *Energy Policy,* XXXVII(6), p. 2054–2059.

Chen, B., Zhuang, Z., Chen, X. & Jia, X. 2007. Field survey on indoor thermal environment of rural residences with coupled Chinese kang and passive solar collecting wall heating in Northeast China. *Solar Energy,* LXXXI(6), pp. 781–790.

Chen, L. 2007. The new Chinese property code: a giant step forward? *Electronic Journal of Comparative Law,* XI(2), pp. 1–24.

Chen, S., Li, N. & Guan, J. 2008a. Research on statistical methodology to investigate energy consumption in public buildings sector in China. *Energy Conversion and Management,* XLIX(8), pp. 2152–2159.

Chen, S. et al. 2008b. A statistical method to investigate national energy consumption in the residential building sector of China. *Energy and Buildings,* XL(4), pp. 654–665.

Chen, S., Yoshino, H. & Li, N. 2010. Statistical analyses on summer energy consumption characteristics of residential buildings in some cities of China. *Energy and Buildings,* XLII(1), pp. 136–146.

Chinagb.net. 2008. *China incorporates energy-saving efforts into performance rating of officials.* Available at: http://www.chinagb.net/english/news/20080326/21269.shtml [Accessed 7 March 2013].

City of Jämsä. 2011. *Tiedotteet ja kuulutukset.* Available at: http://www.jamsa.fi[Accessed 7 March 2011].

City of Tampere, 2010. *Asemakaavoitus.* Available at: http://www.tampere.fi/vuores/kaavoitus/koukkuranta.html [Accessed 2 March 2011].

Cronhjort, Y. 2011. *Improving the energy efficiency of our built environment through retrofitting and urban infill: TES EnergyFacade in the Finnish context.* Helsinki, Finland, 18–21 October, World Sustainable Building Conference SB11.

Desmedt, J., Cre, J. & Hilderson, W. 2010. *IEA SHC Task 37: Examples of Advanced Housing Renovation with Solar and Conservation – Belgium – 19th Century Building in Brussels.* Available at: http://members.iea-shc.org/publications/downloads/task37-250-Brussels.pdf [Accessed 12 February 2013].

Dincer, I. & Zamfirescu, C. 2011. *Sustainable Energy Systems and Applications.* New York, NY, USA: Springer.

Dong, Y. 2011. Overview of China's Market: Manufacturing – a fastest developing market. February 1, 2011 Winnipeg, Manitoba.

EPBD recast. 2010. Brussels: Directive of the European Parliament and of the Council on the energy performance of buildings (recast).

EPC Watch. 2011. *Energy Performnce Contracting.* Available at: http://energyperformancecontracting.org [Accessed 30 October 2011].

ESA. 2011. *Technology Comparison.* Available at: http://www.electricitystorage.org/technology/storage_technologies/technology_comparison [Accessed 8 November 2012].

FINPRO. 2010. *Kiinan maaraportti.* Helsinki, Finland: FINPRO.

FINPRO. 2011. *Energy Efficiency in Buildings in China.* Helsinki, Finland: FINPRO.

Fisch, M. N. & Huckemann, V. 2006. Nonfocusing solar heat collection (incl. seasonal heat storage). In: K. Heinloth (ed.) *Landolt-Börnstein – Group VIII Advanced Materials and Technologies Renewable Energy.* Berlin Heidelberg, Germany: Springer, pp. 304–333.

Fritsche, U. R. & Schmidt, G. 2008. *Global Emission Model of Integrated Systems (GEMIS), Manual.* Available at: http://www.oeko.de/service/gemis/files/doku/g45_manual.pdf [Accessed 30 September 2011].

GIZ. 2007. *Energieeffizienz in Gebäuden: Projektkurzbeschreibung.* Bonn, Germany: Deutsche Gesellschaft für Technische Zusammenarbeit (GIZ).

Goetzberger, A. et al. 1994. The Self-Sufficient Solar House Freiburg. Advances in Solar Energy, Vol. 9, pp. 1–70. Solarsiedlung Freiburg am Schlierberg, Germany, Journal of Green Building, Vol. 4, No. 4.

Herkel, S. & Kagerer, F. 2011. *Advances in Housing retrofit – Process, Concepts and Technologies.* Available at: http://archive.iea-shc.org/publications/downloads/Advances_in_Housing_Retrofit.pdf [Accessed 12 February 2013].

Hernandez , O. 2011. nZEB case studies: Elithis Tower in Dijon, France. *The REHVA European HVAC journal,* XXXVIII(3), pp. 53–57.

HighTech Finland. 2009. Energy & The Environment. In: P. Herring (ed.) *HighTech Finland 2009 – A word of ideas and innovations….* Helsinki, Finland: Published in partnership with Tekes – the Finnish Funding Agency for Technology and Innovation, Ministry of Employment and the Economy, Ministry for Foreign Affairs and Finpro, pp. 1–164.

Holopainen, R. & Nieminen, J. 2010. *IEE-project NorthPass: Promotion of the Very Low-Energy House Concept to the North European Building Market.* Aalborg, Denmark 7.–8. October, 3rd Nordic Passive House Conference, pp. 1–5.

Huggins, R. 2010. *Energy storage.* New York, NY, USA: Springer.

IEA. 2007a. *CHP and DHC in China: An Assessment of Market and Policy Potential.* Available at: http://www.iea.org/media/files/chp/profiles/China.pdf [Accessed 13 March 2013].

IEA. 2007b. *Energy efficiency of air conditioners in developing countries and the role of CDM.* Paris, France: International Energy Agency (IEA) (IEA Information Paper).

IEA. 2009. *Electricity/Heat in China (People's Republic of China and Hong Kong China) in 2009.* Available at: www.iea.org [Accessed 13 March 2013].

IEA. 2011a. *Solar Energy Perspectives.* Paris, France: International Energy Agency (IEA).

IEA. 2011b. *Technology Roadmap Energy-efficient Buildings: Heating and Cooling Equipment.* Paris, France: International Energy Agency (IEA).

Inage, S. 2009. *Prospects for Large-Scale Energy Storage in Decarbonised Power Grids.* Paris, France: International Energy Agency (IEA).

Industry Updates. 2011. China to curb rise of housing prices. 7 March 2011.

International Herald Tribune. 2011. Beijing takes new interest in energy use; Amid constrution boom, China hopes to reverse widespread inefficiencies. 16 June 2011.

Jiang, Y. 2005. Current situation of building energy consumption and effective conservation means. *HV&AC,* 2005(35) (in Chinese).

Jiang, Y. & Yang, X. 2006. China building energy consumption situation and the problems exist in the energy conservation works. *China Construction,* Volume II, pp. 12–17 (in Chinese).

Kauhanian, M. & Tchobanoglous, G. 2000. Biomass Conversion Processes For Energy Recovery. In: F. Kreith & Y. D. Goswami (eds.) *Handbook of Energy Efficiency and Renewable Energy.* Boca Raton, FL, USA: CRC Press – Taylor Francis Group, pp. 1–68 in Chapter 22 .

Kehlhofer, R., Rukes, B., Hahnemann, F. & Stirnimann, F. 2011. *Combined-Cycle Gas and Steam Turbine Power Plants.* 3rd ed. Tulsa, OK, USA: PennWell Books.

Kettunen, E., Lintunen, J., Lu, W. & Kosonen, R. 2008. *Suomalaisyritysten strategiat Kiinan muuttuvassa toimintaympäristössä.* Helsinki, Finland: University of Helsinki School of Business.

Koshizuka, N. et al. 2002. Present status of R&D on superconducting magnetic bearing technologies for flywheel energy storage system. Physica C: Superconductivity, Vol. 378–381, Part 1, pp. 11–17.

Kosonen, R. et al. 2012. *CEMAT Kiinan talousnäkymät 2/2012.* Helsinki, Finland: The Center for Markets in Transition (CEMAT) of the Aalto University School of Business.

Kurnitski, J. et al. 2011. How to define nearly net zero energy buildings nZEB. *The REHVA European HVAC Journal,* XLVIII(3), pp. 53–57.

Lattke, F. 2011. *TES EnergyFacade.* Available at: http://www.tesenergyfacade.com/index.php?id=10_news [Accessed 30 October 2011].

Li, J. 2008. Towards a low-carbon future in China's building sector – A review of energy and climate models forecast. *Energy Policy,* XXXVI(5), pp. 1736–1747.

Lindstedt, T. & Junnonen, J.-M. 2009. *Energiatehokkaat ja teolliset korjaus-rakentamisratkaisut Suomessa ja kansainvälisesti.* Helsinki, Finland: Sitra.

Liu , L.-Q., Liu, C.-X. & Sun, Z.-Y. 2011. A survey of China's low-carbon application practice – Opportunity goes with challenge. *Renewable and Sustainable Energy Reviews,* XV(6), pp. 2895–2903.

Lumon. 2012. *A new research confirms: Balcony glazing saves energy.* Available at: http://www.lumon.com/balcony-glazing/research/balcony-glazing-saves-energy [Accessed 16 January 2012].

Lylykangas, K. & Nieminen, J. 2009. *Instructions for the architectural desing of passive building.* Available at: http://www.passiivi.info/data.php?sivu=etusivu [Accessed 7 April 2011].

Marszal, A. J. & Heiselberg, P. 2009. *A literature review of Zero Energy Building (ZEB) definitions.* Aalborg, Denmark: Aalborg University.

MIT Building Technology Group. 2000. *Sustainable Urban Housing in China.* Available at: http://chinahousing.mit.edu/english/home/index.html
[Accessed 24 February 2013].

Mörk, P. 2011. *Aurubiksen materiaali-innovaatiosta uutta vapautta energia tehokkaiden rakennusten suunnitteluun.* Available at: http://www.tekes.fi/ohjelmat/Materiaalit/Ajankohtaista/Aurubiksen+materiaali+innovaatiosta+uutta+vapautta?type=news [Accessed 16 January 2012].

National Bureau of Statistics (NBS). 2006. China Statistical Yearbook 2006. NBS, Beijing.

NEAPO. 2009. *Lehdokkipolku 3 Housing Cooperative.* Available at: http://www.neapo.fi/en/www/popupcard.php?id=5 [Accessed 7 February 2012].

Nieminen, J. 1996. *A single-family house in Pietarsaari: Combining active solar and PV, IEA Task 13: Advanced solar low energy buildings: Proc. from the IEA Task 13.* Stuttgart, Germany: International Energy Agency, pp. 21–26.

Nieminen, J. 2011. *Finnish experiences on very low and zero energy buildings.* Tallinn, Estonia, May 19–20, REHVA Seminar – Zero energy buildings.

Nieminen, J. & Kouhia, I. 1997. *The Finnish IEA task 13 experimental building in Pietarsaari: Completed results.* Espoo, Finland, 9–11 June, 7th International Conference on Solar Energy at High Lattitudes North Sun '97. Pp. 876–883.

Nieminen, J. & Sepponen, M. 2011. *Future home for the elderly.* Helsinki, Finland, 18–21 October, World Sustainable Building Conference SB11.

Nieminen, J., Vartiainen, T. & Simunaniemi, V. 2010. *Net zero energy buildings – cold climate applications.* Espoo, Finland, September 22–24, Finnish Association of Civil Engineers RIL and VTT Technical Research Centre of Finland.

Nykänen, V. et al. 2007. *WellBeing Indoors.* Helsinki, Finland, 10–14 June, Clima 2007. An Official Congress of REHVA, The Federation of European Heating and Air-Conditioning Associations.

Ouyang, J., Lu, M., Li, B., Wang, C. & Hokao, K. 2011. Economic analysis of upgrading aging residential buildings in China based on dynamic energy consumption and energy price in a market economy, Energy Policy, Vol. 39, no. 9. Pp. 4902–4910.

Parmarine. 2012. *Prefabricated Bathrooms for Ships.* Available at: http://www.nauticexpo.com/prod/parmarine/prefabricated-bathrooms-for-ship-31458-191897.html [Accessed 12 February 2013].

Paroc. 2010. *Kerrostalosta passiivitalo.* Available at: http://parocfi.virtual35.nebula.fi/innova/assets/pdf/isannoitsijan_esittelypaketti.pdf [Accessed 17 January 2012].

Paroc. 2012. *INNOVA – Kerrostalon passiivisaneeraus Riihimäellä.* Available at: http://innova.molentum.fi/etusivu [Accessed 17 January 2012].

Payne, W. V. & Domanski, P. A. 2002. *Rating Water-Source Heat Pumps Using ARI Standard 320 and ISO Standard 13256-1.* Lexington, KY, USA, March 25–27, International Appliance Technical Conference.

Pipe-Modul. 2011. *Pipe-Modul Oy Homepage.* Available at: http://www.pipemodul.com [Accessed 16 January 2012].

Pop, V. et al. 2008. Battery Management Systems – Accurate State-of-Charge Indication for Battery-Powered Applications. Volume 9. Springer. ISBN: 978-1-4020-6944-4.

Qian, W. 2010. Short-lived buildings create huge waste. *China Daily*, 6 April, p. 1.

Richerzhagen, C. et al. 2008. *Energy Efficiency in Buildings in China – Policies, Barriers and Opportunities.* Available at: http://www.die-gdi.de/CMS-Homepage/openwebcms3.nsf/(ynDK_contentByKey)/ANES-7NJGTV/$FILE/Studies%2041.2008.pdf [Accessed 12 February 2013].

Saari, M. 2009. *Energiatehokkaan talon tunnusmerkit. Powerpoint slides.* Available at: https://wiki.metropolia.fi/download/attachments/12167956/VTT_energiatehokkaan+talon+tunnusmerkit_Mikko+Saari.pdf?version=1&modificationDate=1254941851000 [Accessed 5 April 2011].

Sartori, I. et al. 2010a. *Comfort and Energy Performance Recommendations for Net Zero Energy Buildings.* Graz, Austria, 28 September – 1 October, International Conference on Solar Heating, Cooling and Buildings EuroSun '10, p. 8.

Sartori, I. et al. 2010b. *Criteria for Definition of Net Zero Energy Buildings.* Graz, Austria, 28 September – 1 October, International Conference on Solar Heating, Cooling and Buildings EuroSun '10, p. 8.

Sinton, J. 2001. Changing energy intensity in chinese industry. Lawrence Berkeley National Laboratory, LBNL-48919.

Sjzu. 2011. Personal communication 27.10.2011 [e-mail].

SRIBS. 2010. *Shanghai Research Institute of Building Sciences Green Building Engineering Research Center.* Available at: http://www.gbmap.org/data/article/1332177891825739849.jpg [Accessed 15 April 2013].

Statistical Bureau of Beijing. 2006. Beijing Statistical Yearbook. In: I. Xiuqin (ed.) *China Statistical Yearbooks Database.* Beijing, China: China Statistics Press (in English). Available at: http://tongji.cnki.net/overseas/engnavi/YearBook.aspx?id=N2007020009&floor=1, pp. 1–462.

Sunliang, C. 2010. *State of the art thermal energy storage solutions for high performance buildings.* Jyväskylä, Finland: University of Jyväskylä, Department of Physics.

Tatsidjodoung, P., Le Pierres, N. & Luo, L. 2013. A review of potential materials for thermal energy storage in building applications. *Renewable and Sustainable Energy Reviews,* XVIII(2), pp. 327–349.

Tekes. 2006. *CUBE – Talotekniikan teknologiaohjelma 2002–2006.* Helsinki, Finland: Tekes – the Finnish Funding Agency for Technology and Innovation.

The Economist Intelligence Unit. 2006. *Country profile 2006 China.* London, UK: The Economist Intelligence Unit.

Thomsen, A. 2009. *Demolition – a sustainable choice?.* Helsinki, Finland: Housing Research Day, 18 November, 2009.

Torio, H. & Schmidt, D. 2010. *Low Exergy Systems for High-Performance Buildings and Communities, ECBCS Annex 49 summary report.* Available at: http://www.annex49.info/download/summary_report.pdf

Velzy, C. O. & Grillo, L. M. 2007. Waste-to-Energy Combustion. In: F. Kreith & D. Y. Goswami (eds.) *Handbook of Energy Efficiency and Renewable Energy.* Boca Raton, FL, USA: CRC Press – Taylor & Francis Group, pp. 1–38, Chapter 24.

Virtanen, M. 2011. *Choosing the optimal energy system for buildings and districts.* Lappeenranta, Finland: Lappeenranta University of Technology, Faculty of Technology, Department of Energy Technology.

Voss, K. et al. 1996. The self-sufficient solar house in Freiburg – Results of 3 years of operation. *Solar Energy,* LVIII(1–3), pp. 17–23.

VTT. 2009. Energy Visions 2050. Espoo, FInland: VTT. 381 p.

Waide, P., Rivière, P. & Watson, R. 2011. *Cooling benchmarking study – Part 2: Benchmarking Component Report.* Brussels, Belgium: The Collaborative Labeling and Appliance Standards Program (CLASP).

Wan, K. K. W., Li, D. H. W., Yang, L. & Lam, J. C. 2010. Climate classifications and building energy use implications in China. *Energy and Buildings,* XLII(9), pp. 1463–1471.

Waqas, A. & Ud Din, Z. 2013. Phase change material (PCM) storage for free cooling of buildings – A review. *Renewable and Sustainable Energy Reviews,* XVIII(2), pp. 607–625.

Widén, J. 2010. Value of on-site electricity generation – example calculations with different types of metering for an individual household. Working document. Uppsala University, Dep. Of Engineering & Science.

WindFinder. 2012. *Windfinder.* Available at: http://www.windfinder.com/
[Accessed 2 February 2012].

World Bank. 2001. *China: opportunities to improve energy efficiency in buildings.* Washington, DC: World Bank (Working Paper 2001/05/01).

Xinhua. 2011a. China to curb rise of housing prices. *China Daily*, 5 March, p. 1.

Xinhua. 2011b. China to renovate 2.65 m rural run-down houses. *China Daily*, 07 June, p. 1.

Xu, P., Chan, E. H. & Qian, Q. K. 2011. Success factors of energy performance contracting (EPC) for sustainable building energy efficiency retrofit (BEER) of hotel buildings in China. *Energy Policy,* XXXIX(11), pp. 7389–7398.

Yang, X. D. & Jiang, Y. 2008. *Energy and Environment in Chinese Rural Housing: Road to Sustainability.* Dalian, China, July 13–16, The First International Conference on Building Energy and Environment (COBEE), pp. 1–19.

Yao, R., Li, Z. & Steemers, K. 2005. Energy policy and standards for build environment in China. *Renewable Energy,* XXX(13), pp. 1973–1988.

Yoshino, H. et al. 2006. Indoor thermal environment and energy saving for urban residential buildings in China. *Energy and Buildings,* XXXVIII(11), pp. 1308–1319.

You, J. 2011. China's energy consumption and sustainable development: Comparative evidence from GDP and genuine savings. *Renewable and Sustainable Energy Reviews,* XV(6), pp. 2984–2989.

Zhang, X., Platten, A. & Shen, L. 2011. Green property development practice in China: Costs and barriers. *Building and Environment,* XLVI(11), pp. 2153–2160.

Zhou, N. et al. 2007. *Energy Use in China: Sectoral Trends and Future Outlook.* Available at: http://eaei.lbl.gov/sites/all/files/LBL_61904_Sectoral_Energy_Trend.Jan_.2007_1.pdf [Accessed 12 February 2013].

Zhou, N. & Lin, J. 2008. The reality and future scenarios of commercial building energy consumption in China. Energy and Buildings, 40, pp. 2121–2127.

Zhou, X. 2012. WP4 Retrofit Case of Tongji Technical Garden-Building A. Personal communication 4.3.2012 [e-mail].

Series title and number
VTT Technology 105

Title

Eco-efficient solutions for China’s urbanization
Guidebook

Author(s)

Satu Paiho, Salla Palos, Miimu Airaksinen, Mia Ala-Juusela, Guangyu Cao, Ismo Heimonen, Ha Hoang, Riikka Holopainen, Antti Knuuti, Mari Sepponen, Terttu Vainio, Teemu Vesanen, Mikko Virtanen & Jyri Nieminen

Abstract

China is one of the largest economies in the world and also one of the biggest energy consumers. China is a big country with five major climates requiring different building and building energy solutions. In addition, China’s urbanisation rate is over 40%. It is estimated that the number of urban dwellers from the whole population will be about 70% by the end of 2030.

The EESCU project (Eco Efficient Solutions for China’s Urbanization) aims at building theoretical and practical bases to support the implementation of the Finnish eco-efficient solutions and concepts into Chinese markets. This is the final report of the project summarizing its main results.

The project started with an inventory phase, focusing on basic building energy-related issues in China. These covered the urbanisation, the climate regions, energy regulations and current building energy consumption values based on the available statistics and literature. The total energy consumption in 2009 was 3 billion tons of standard coal. The project had three main research sections, namely “Zero Energy Buildings”, “Regional Energy Solutions” and “Energy Renovations of Existing Buildings”. All these sections consist of theoretical parts, concept developments and examples from both Finland and China. In addition, building commissioning in China was discussed, pilots and show cases from real buildings reported and business related topics are covered.

In “Zero Energy Buildings”, the concept of net zero energy buildings is first specified, describing the definition of zero energy building, energy use and supply mismatch, and explaining the differences between cold climate zero energy concept and warm climate zero energy concept. After the concept overview, examples of zero energy buildings are presented from Europe and China. Then, the low exergy principle referring to the quality of energy was discussed with examples.

In “Regional Energy Solutions”, the system selection and performance evaluation principle is introduced first. This is followed by the design guidelines of district energy systems and the principles of a district energy system concept. In this study, the main emphasis is on renewable energy production technologies, and therefore their basic production means are also discussed. Renewable energy solutions often require some energy storage solutions as well, so the basic means are also described. This section ends with case study examples.

Building renovation is rare in China. The real average life span of China’s residential buildings is only 25 to 30 years. For non-residential buildings it is often even shorter. The factors effecting on the low renovation rate and the renovation process are discussed. Then energy-efficient and modular technologies for building renovation are reported.

ISBN, ISSN

ISBN 978-951-38-7993-8 (URL: http://www.vtt.fi/publications/index.jsp)
ISSN-L 2242-1211
ISSN 2242-122X (Online)

Date

May 2013

Language

English, Finnish abstract

Pages

176 p.

Name of the project

EESCU – Eco Efficient Solutions for China’s Urbanization

Keywords

Eco efficiency, China, urbanisation, pilot project

Publisher

VTT Technical Research Centre of Finland
P.O. Box 1000, FI-02044 VTT, Finland, Tel. +358 20 722 111

Julkaisun sarja ja numero
VTT Technology 105

Nimike	**Ekotehokkaat ratkaisut Kiinan kaupungistumiseen** Opas
Tekijä(t)	Satu Paiho, Salla Palos, Miimu Airaksinen, Mia Ala-Juusela, Guangyu Cao, Ismo Heimonen, Ha Hoang, Riikka Holopainen, Antti Knuuti, Mari Sepponen, Terttu Vainio, Teemu Vesanen, Mikko Virtanen & Jyri Nieminen
Tiivistelmä	Kiina on yksi maailman suurimmista talouksista ja energian kuluttajista. Kiina on suuri maa, jossa on viisi merkittävää ilmastovyöhykettä. Erilaiset ilmastovyöhykkeet vaativat erityyppisiä rakennuksia ja rakennusten energiaratkaisuja. Kiinan kaupungistumisvauhti on yli 40 %. On arvioitu, että kaupunkilaisten osuus koko väestöstä on noin 70 % vuoden 2030 loppuun mennessä. EESCU-projektin (Eco-efficient Solutions for China’s Urbanization) tavoitteena oli rakentaa teoreettiset ja käytännön lähtökohdat suomalaisten ekotehokkaiden ratkaisujen ja konseptien viennille kiinalaisille markkinoille. Tämä on EESCU-projektin loppuraportti, joka tiivistää tutkimushankkeen päätulokset. Projekti alkoi inventaariovaiheella, joka keskittyi tavanomaisiin rakentamisen energiaan liittyviin asioihin Kiinassa. Inventaariovaihe kattoi kaupungistumisen, ilmastovyöhykkeet, energian säännöstelyt sekä nykyisen rakennuskannan energiankulutuksen perustuen saatavilla olevaan tilastotietoon ja kirjallisuuteen. Vuonna 2009 Kiinan energiantuotanto kulutti 3 miljardia tonnia hiiltä. EESCU-projektilla oli kolme pääasiallista tutkimusosuutta: ”Zero Energy Buildings” (nollaenergiatalot), ”Regional Energy Solutions” (alueelliset energiaratkaisut) ja ”Energy Renovations of Existing Buildings” (olemassa olevien rakennusten energiakorjaukset). Kaikki osuudet koostuvat teoriasta, konseptien kehittämisestä sekä esimerkeistä Suomesta ja Kiinasta. Lisäksi selvitettiin rakennuttamisen käytännöt Kiinassa, esiteltiin pilotti- ja portfolioprojektit toteutetuista kohteista sekä raportoitiin yritystoimintaan liittyviä aiheita. Luvussa ”Zero Energy Buildings” määritellään aluksi nollaenergiatalojen konsepti. Luvussa selitetään käsite nollaenergiatalo, käsitellään energiankäytön ja tuotannon epäsuhtaa sekä selitetään eroja kylmän ilmastovyöhykkeen ja lämpimän ilmastovyöhykkeen konseptien välillä. Konseptien yleiskäsittelyn jälkeen esitellään esimerkkejä toteutetuista nollaenergiataloista Euroopassa ja Kiinassa. Luvun lopuksi selitetään case-esimerkein matalaexergia-periaatetta, jolla viitataan energian laatuun. Luvussa ”Regional Energy Solutions” käsitellään aluksi järjestelmän valinta ja suorituskyvyn arviointiperiaate. Tämän jälkeen selitetään suunnittelun suuntaviivat alueellisille energiajärjestelmille ja käsitteen alueellinen energiajärjestelmä periaatteet. Tutkimuksen pääpaino on uusiutuvissa energiantuotantoteknologioissa. Siksi luvussa käsitellään uusiutuvien energiatuotantoteknologioiden bruttotuotantoa. Luvussa selitetään myös uusiutuvilla energiaratkaisuilla tuotetun energian varastointia. Luku päättyy case-esimerkkeihin. Korjausrakentaminen on harvinaista Kiinassa. Kiinalaisten asuinrakennusten todellinen keskimääräinen käyttöikä on vain 25–30 vuotta. Muilla kuin asuinrakennuksilla se on vielä alhaisempi. Julkaisussa käsitellään korjausrakentamisen vähäisen määrän ja korjausrakennusprosessin syitä. Lopuksi esitellään energiaa säästäviä ja modulaarisen rakentamisen teknologioita korjausrakentamisessa.
ISBN, ISSN	ISBN 978-951-38-7993-8 (URL: http://www.vtt.fi/publications/index.jsp) ISSN-L 2242–1211 ISSN 2242-122X (verkkojulkaisu)
Julkaisuaika	Toukokuu 2013
Kieli	Englanti, suomenk. tiivistelmä
Sivumäärä	176 s.
Projektin nimi	EESCU – Eco Efficient Solutions for China’s Urbanization
Avainsanat	Eco efficiency, China, urbanisation, pilot project
Julkaisija	VTT PL 1000, 02044 VTT, puh. 020 722 111

VTT Technical Research Centre of Finland is a globally networked multitechnological contract research organization. VTT provides high-end technology solutions, research and innovation services. We enhance our customers' competitiveness, thereby creating prerequisites for society's sustainable development, employment, and wellbeing.

Turnover:	EUR 300 million
Personnel:	3,200

VTT publications

VTT employees publish their research results in Finnish and foreign scientific journals, trade periodicals and publication series, in books, in conference papers, in patents and in VTT's own publication series. The VTT publication series are VTT Visions, VTT Science, VTT Technology and VTT Research Highlights. About 100 high-quality scientific and professional publications are released in these series each year. All the publications are released in electronic format and most of them also in print.

VTT Visions

This series contains future visions and foresights on technological, societal and business topics that VTT considers important. It is aimed primarily at decision-makers and experts in companies and in public administration.

VTT Science

This series showcases VTT's scientific expertise and features doctoral dissertations and other peer-reviewed publications. It is aimed primarily at researchers and the scientific community.

VTT Technology

This series features the outcomes of public research projects, technology and market reviews, literature reviews, manuals and papers from conferences organised by VTT. It is aimed at professionals, developers and practical users.

VTT Research Highlights

This series presents summaries of recent research results, solutions and impacts in selected VTT research areas. Its target group consists of customers, decision-makers and collaborators.

VTT TECHNOLOGY 105 Eco-efficient solutions for China´s urbanization. Guidebook

ISBN 978-951-38-7993-8 (URL: http://www.vtt.fi/publications/index.jsp)
ISSN-L 2242-1211
ISSN 2242-122X (Online)