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THEORY-BASED EVALUATION OF THE IMPLEMENTATION OF ENERGY EFFICIENCY POLICIES FOR COMMERCIAL BUILDINGS IN CHINA

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Chapter 8 – Case Study Analysis: University of Nottingham Administration Building, Ningbo

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Abstract

This work investigates the current situation of energy efficiency policies for commercial buildings in China and evaluates their effectiveness using theory-based policy evaluation methodology. The thesis covers three main research areas: a discussion of energy efficiency improvement measures suitable for commercial buildings in the Chinese national context; a technical support for the theory-based policy evaluation presented in a form of four detailed case studies following the Design Standard for Energy Efficiency of Public Buildings GB20189-2005 (the Standard); and a discussion of the effectiveness of this Standard that was evaluated using theory-based policy evaluation. Future improvements for the energy efficiency in commercial building in China are suggested.

Four case studies in different climate zones are used to examine the technical and economical effectiveness of the Design Standard for Energy Efficiency of Public Buildings GB20189-2005, and investigate the main problems of buildings as energy consumers. The results show that the case study buildings have poor thermal insulation qualities as well as low energy efficiencies of lighting and equipment. The implementation of the Standard allows for the achievement of its individual targets aimed at the thermal insulation quality improvements as well as being cost effective. For a further energy consumption reduction, installation of renewable energy technologies is simulated, however it is limited by economic constraints.

The theory-based policy evaluation shows that the Standard is an important tool in energy efficiency encouragement for commercial buildings in China. However, its effectiveness is negatively affected by a lack of monitoring system and a lack of awareness among the involved parties.

Improvement of building energy efficiency is the quickest and the most effective way of creating energy savings in buildings. In order to make a better use of the Standard, the Chinese government should stimulate more interest among construction companies and building owners by creating carrot and stick policies.

ABBREVIATIONS

a-Si	Amorphous Silicon
AC	Air Conditioner
ADB	Asian Development Bank
AID-EE	Active Implementation Of The European Directive On Energy Efficiency
APP	Asia-Pacific Partnership
AQSIQ	General Administration of Quality, Supervision, Inspection and Quarantine
ASHRAE	American Society of Heating, Refrigeration and Air-Conditioning Engineers
BAU	Business As Usual
BEE	Building Energy Efficiency
CAAC	General Administration Of Civil Aviation Of China
CANMET	Canada Centre for Mineral and Energy Technology
CAS	Chinese Academy Of Science
CASBEE	Comprehensive Assessment System For Building Environmental Efficiency
CCP	Chinese Communist Party
CCS	Carbon Capture and Storage
CDM	Clean Development Mechanism
CdTE	Cadmium Telluride
CER	Certified Emissions Reduction
CH_4	Methane
CHP	Combined Heat And Power
CIS	Copper Indium Deselenide
CMA	China Meteorological Administration
CMA	Coldest Month Average
CMB	Chinese Meteorological Bureau
CNCA	Certification and Accreditation Administration
CO_2	Carbon Dioxide
CoP	Coefficient of Performance
COP	Conference of Parties

CP	Cleaner Production
CREIA	China Renewable Energy Industrial Association
CSB	China Statistical Bureau
CSEP	China Sustainable Energy Programme
CSLF	International Carbon Sequestration Leadership
DNA	Designated National Authority
DRC	Development Research Centre
DSM	Demand Site Management
EE	Energy Efficiency
EES	Energy Efficiency Standards
EPB	Environmental Protection Bureau
EPC	Environmental Protection Commission
EREC	European Renewable Energy Council
ERI	Energy Research Institute
ESCO	Energy Service Company
EU	European Union
FCCC	Framework Convention on Climate Change
FIT	Feed-in Tariff
GBP	Great British Pound
GCHP	Ground-Coupled Heat Pump
GDP	Growth Domestic Product
GEF	Global Environmental Facility
GHG	Green House Gas
GSHP	Ground-Source Heat Pump
GHX	Ground - Coupled Heat Pump
GIEC	Groupe International d'Experts Sur Le Climat (French: International Group Of Experts On The Climate)
GOBAS	Green Olympic Building Assessment System
GVEC	Global Wind Energy Council
GWHP	Ground Water Heat Pump

GWP	Global Warming Potential
HFC	Hydroflourocarbons
HMA	Hottest Month Average
HVAC	Heating, Ventilation And Air Conditioning
IEA	International Energy Agency
INC	Intergovernmental Negotiation Committee
IPCC	International Panel On Climate Change
JI	Joint Implementation
JV	Joint Venture
Lat.(N)	Latitude
Long.(E)	Longitude
LEED	Leadership In Energy And Environmental Design
LFG	Liquefied Gas
LPD	Local Projects Database
LS-PV	Large Scale Photovoltaic
MBI	Market-Based Instrument
Mcom	Ministry of Communication
MEP	Ministry Of Environmental Protection
MEPS	Minimum Energy Performance Standards
MFA	Ministry Of Foreign Affairs
MMS	Mandatory Market Share
MOA	Ministry of Agriculture
MOC	Ministry Of Construction
MOF	Ministry Of Finance
Mofcom	Ministry of Commerce
MPC	Municipal People's Congress
MST	Ministry Of Science And Technology
MWR	Ministry of Water Resources
N_2O	Nitrous oxide
NASA	National Aeronautic and Space Administration

NCCCC	National Coordination Committee On Climate Change
NDRC	National Development And Reform Commission
NEPA	National Environmental Protection Agency
NPC	National People's Congress
ODP	Ozone Depletion Potential
OECD	Organisation Of Economic Co-Operation And Development
OWC	Oscillating Water Column
PC	Personal Computer
PCF	Prototype Carbon Fund
PIR	Polyisocyanurate
PPC	Provincial People's Congress
ppp	Purchasing Power Parities
PRC	People's Republic Of China
PV	Photovoltaic
R&D	Research And Development
RCSD	Research Centre For Sustainable Development
RD&D	Research, Development And Demonstration
RE	Renewable Energy
REEEP	Renewable Energy And Energy Efficiency Partnership
RET	Renewable Energy Technology
RMB	China's National Currency
S	Scenario
SAC	Standardisation Administration of PRC
SC	State Council
SDPC	State Development And Planning Commission
SDTC	Sustainable Development Technology Canada
SEPA	State Environmental Protection Agency
SETC	State Economic And Trade Commission
SFA	State Forestry Administration
SMA	State Meteorological Administration

SO_2	Sulphur Dioxide
SOA	State oceanic Administration
SPC	State Planning Commission
SSTC	State Science And Technology Commission
SWH	Solar Water Heating
TNC	Transnational Corporation
TV	Television
UK	United Kingdom
UN	United Nations
UNDP	United Nations Development Programme
UNEP	United Nations Environmental Programme
UNFCCC	United Nations Framework Convention On Climate Change
uPVC	Unplasticized Poly Vinyl Chloride
USA	United States Of America
USD	United State Dollar
VAT	Value Added Tax
WEC	World Energy Council
WWR	Window-Wall Ratio

NOMENCLATURE

A	Area of the surface [m^2]
A_g	Glazed area [m^2]
Ac/h	Air change per hour
bb	Billion barrels
bcm	Billions of cubic meters
bln	Billion
$^{\circ}C$	Degrees centigrade
C_{pa}	Specific heat of air [W/kgk]
C_{pw}	Specific heat for water; equals 4.186 J/gmk
d	Discount rate as a decimal
d_m	Thickness of proposed insulated material [m]
D_i	Infiltration rate [ach]
DF	Discount factor
E_{hw}	Hot water energy consumption [Wh]
E_{sp}	Monthly space heating requirements [Wh]
E_t	Monthly heating load [Wh]
EEC_a	Air source heat pump electric energy consumption [kwh]
EEC_e	Equipment electric energy consumption [kwh]
EEC_l	Lighting electric energy consumption [kwh]
FV	Future amount of money savings [GBP]
Gt	Gigaton
GW	Gigawatt
H_m	Hours per month
h	Height [m]
I	Solar radiation intensity [W/m^2]
k	K-value of proposed insulated material [W/m^2k]
Kg/m^2	Kilogramme per cubed meter
km	kilometre

kWh	Kilowatt hours
l	Litre
lux	Light level
m	Meter
m^2	Square meters
$m^2\,^{\circ}C/W$	Square meter Celsius per Watt
m^3	Cubed meter
M_a	Amount of water consumed by person [l]
mb/d	Million barrels per day
mln	Million
mm	Millimetres
$mm/10a$	Millimetres per ten years
Mt	Million tonnes
$Mtce$	Million tonnes of coal equivalent
$Mtoe$	Million tonnes of oil equivalent
MWp	Megawatt peak
N	Air exchange rate [ach]
n	Future year being evaluated
N_d	Number of days used per month
$N_{equipment}$	Number of the equipment in the room
N_h	Number of hours used per month
N_l	Number of light bulb/tubes
N_{lux}	Amount of lux used in the room [lux]
N_{people}	Number of people occupying the room
N_{Watt}	Amount of Watt consumed by the light bulb/tube
ρ	Density of air [kg/m^3]
PV	Present value of savings, which will be derived in some future year n
Q_e	Heat gain from equipment (PC, PC monitor, TV, printer, scanner) [W]
$q_{equipment}$	Heat gain from one piece of the equipment [W]
Q_f	Fabric heat loss [W]

Q_{hw}	Hot water heating load [W]
Q_i	Infiltration loss [W]
Q_l	Heat gain from lighting [W]
Q_p	Heat gain from people [W]
q_{person}	Heat gain from one person according to his/her activity [W]
Q_{solar}	Solar heat gain [W]
Q_{sp}	Space heating heat loss [W]
Q_t	Total heat gain [W]
Q_v	Ventilation heat loss [W]
R_1	Target total resistance [m^2 °C/W]
R_2	Existing total resistance [m^2 °C/W]
R_e	Extra resistance required [m^2 °C/W]
S	Solar gain factor [W/m^2]
SP_{yr}	Simple payback period [years]
ΔT	Temperature difference in winter [°C]
T_{in}	Internal temperature [°C]
T_{out}	External temperature [°C]
tc/year	Tonnes of coal per year
tce	Tonnes of coal equivalent
tCO_2e	Tonnes of carbon dioxide equivalent
TE_{kWh}	Annual electricity/heat generated by the renewable energy technology [kwh]
trl	trillion
tsc	Tonnes of standard coal
TW	Terawatt
U	U-value of the surface [W/m^2 °C]
V	Volume [m^3]
W	Watt
W/h	Watt hours
W/kgK	Watt per kilogramme Kelvin

W/m^2	Watts per square meter
$W/m^2\,^{\circ}C$	Watts per meter square Celsius
$£_{invest}$	Initial investment cost of a conservation investment [GBP]
$£_{kWh}$	Cost per unit of electricity [GBP]
$£_{oper}$	Annual operation and maintenance costs [GBP]
$£_{sav\text{-}yr}$	Savings achieved by a conservation investment per year [GBP]

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Chapter 1 – Introduction

This thesis investigates the energy efficiency situation of commercial buildings in China and analyses the current energy efficiency policies for this sector. It also evaluates the effectiveness of the energy efficiency policies towards commercial buildings based on a theory-based policy evaluation.

1.1 Introduction

Climate change is the greatest environmental challenge facing world today. The primary cause of climate change is identified to be a basket of green house gases (CO_2, SO_2, CH_4, etc), which are associated with fossil fuel consumption [Li, 2009]. Under the Kyoto agreement, industrialised countries have agreed to reduce their overall emissions of such gases by at least 5% below the 1990s levels in the commitment period 2008-2012 [UN, 1998].

Currently the impact on climate change on China can be seen in the sea level rise in the coastal area, glacial retreat in northwest area and other phenomena, such as drought, flooding, and extreme weather events. In the near future it is believed climate change will impact both China's natural ecosystem and social economic system. However, today, as a developing country with the largest population in the world, a coal-dominant energy mix, and a relatively low capacity to tackle climate change, China will face more severe challenges, which will be fostered by the acceleration of urbanisation and industrialisation [NDRC, 2007].

Daniel Franklin, the executive editor of *The Economist*, once said: "In China and other emerging economies, the current rapid growth momentum is expected to continue, but the challenges from resources and sustainable development will accompany with the economic growth" [CBH, 2007]. Today, China's dramatic economic growth goes together with a rapid urbanisation process. China's annual GDP growth rate for the period from 1979 to 2007 was around 2% [SCB, 2005]. The result of this process is a huge number of people migrating to cities and towns across the country. Such a rapid process of urbanisation creates massive pressure on urban development. It is predicted that the urbanisation rate will continue to grow reaching 48% by 2012 [Li, 2009]. Urbanisation is one of the keys to China's economic development, but it creates large pressure on energy, resources and environment, as considerable resources are needed to invest in urban public utilities, infrastructure and services such as housing, water supply, roads, bridges, waste disposal, etc. The emerging environmental issues such as air pollution, water pollution, industrial pollution, traffic, solid waste and carbon emissions are also an attribute of the urbanisation and are of major concern.

A major consequence of the urbanisation is the rapid speed of construction. According to UNEP (2007), worldwide buildings (both residential and commercial) account for ¼ of all energy-related CO_2 emissions. The IPCC (2007) has conducted research that states that about 30% of these emissions can be mitigated by 2020 in a cost-effective way, using a variety of technological options. Therefore, the building sector alone can considerably contribute to solving the climate change problem.

There are three main ways to reduce GHG emissions: energy use reduction, fossil fuels replacement with renewables, and energy efficiency increase. All these can be achieved by using policy instruments. Policy instruments targeting energy use and emissions reduction are proven the cheapest and most effective way to reduce emissions from buildings [IPCC, 2007]. Additionally energy efficiency technologies can reduce costs to businesses and consumers and at the same time reduce the environmental impact of existing buildings [SDTC, 2009].

Historically, the improvement of the energy efficiency of buildings began in the 1960s when the first minimum energy efficiency standards for appliances were set in France and Poland and then adopted by other countries. The first building energy code was introduced in the 1970s during the oil crisis [IEA, 2008]. Since then, the amount and types of instruments have grown dramatically, varying from voluntary to economic instruments. China joined the effort to reduce building energy consumption later than most of the developed countries. However, since then China has developed a significant policy framework that aims to reduce the energy consumption of its building sector.

This thesis presents the results of an investigation into the evaluation of the policy tools that are currently used in China to encourage energy efficiency of commercial buildings.

1.2 Aims and definitions

Today, buildings play an important role in the energy demand sector as they account for more than ¼ of total primary energy consumption, and are likely to increase to 35% by 2030 with the GHG produced in building sector of roughly 25% [Fridley et al., 2008]. Commercial buildings account for approximately 15% of the whole building stock and play an important role in energy efficiency implementation and the reduction of GHG emissions from buildings.

Up to now, there have been no comprehensive studies on the implementation of energy efficiency policies in the Chinese commercial building sector (also known in China as public buildings sector), and there is very little information on the overview of the existing policies and actions in this field. Research has been mainly focused on residential housing buildings energy efficiency (Richerzhagen; Wang) or on tools for energy efficiency policy implementation (Wang; Huang). This project's aim is to fill this gap.

This work analysed the policy instruments China has implemented in order to achieve better energy efficiency in its commercial buildings and evaluates the only standard that currently aims to reduce energy consumption in commercial buildings – the "Design Standard for Energy Efficiency of Public buildings GB 50189-2005". This has been achieved using a theory–based policy evaluation. Building codes are the policy instruments govern best practices of energy efficiency measures and techniques used in construction industry. In order for a building code to improve the energy efficiency of the building significantly, it is crucial to have effective implementation, verification, and monitoring.

To date, a limited amount of quantitative research has been done on effectiveness of energy codes and this revealed that building energy codes are very effective in CO_2 emissions reduction. As for their cost-effectiveness, this was considered as 'medium' due to the necessary compliance monitoring and enforcement, as well as regular updates [SDTC, 2009].

To contribute to the field of commercial buildings energy efficiency assessment, this thesis has the following overall aims:

- To analyse the available means for commercial buildings energy efficiency measures implementation and improvement in China;
- To evaluate the effectiveness of these tools taking into account the national context.

More specifically, the key objectives are:

- To utilise commercial building laws and regulations in order to understand the level of energy efficiency implementation;
- To describe the ways of energy efficiency improvement in commercial buildings;
- To identify barriers to energy efficiency policy implementation in commercial buildings;
- To evaluate existing energy efficiency measures using both qualitative and quantitative methods.

Relatively few countries (Norway, Italy, Sweden, etc) have conducted evaluation on their building codes and standards; moreover, according to the research in those countries where evaluation has taken place, the actual performance of the buildings according to new regulations is actually lower than expected. The main reasons tend to be the behaviour of the occupants and non-compliance with the regulations. Another issue is that only few countries have estimated the additional costs caused by the new regulations [AID-EE, 2007].

In order to be able to analyse the energy efficiency tools used to achieve energy efficiency in commercial buildings, it is important to look at the country's energy use pattern and the measures that have been implemented in order to achieve energy efficiency.

Energy efficiency improvement can be defined as "*a reduction in the energy used for a given service (heating, lighting, etc) or level of activity*" [p. 9, WEC, 2008]. This reduction is generally associated with technical changes, but is not always the case, as it can be a result of better organisation or management or improved economical situation. Price of energy can also affect the energy use and create its reduction or increase. However, these types of reductions can be easily reversible and therefore are not associated with energy efficiency.

The definition used by the economists differs slightly from the one above: energy efficiency "*encompasses all changes that result in decreasing the amount of energy used to produce one unit of economic activity*". From this definition, it can be seen that energy efficiency is associated with economic efficiency, which includes economic, technical, and behavioural changes [WEC, 2008].

In many countries, commercial buildings have a very large share in energy consumption; therefore these countries have enforced mandatory or voluntarily standards for non-residential buildings. Thermal building standards have been transformed from simple standards on building components to more complex energy performance standards, which consider not just building elements but also HVAC, water and, in some cases, even electrical equipment [WEC, 2008].

For this project, the following definition of commercial buildings is used. Commercial buildings are "*structures that are used, in all or in part, for the activities focusing on the exchanging of goods and/ or services for a profit*" (stores, office buildings, warehouses, restaurants, hotels, etc). "*Institutional buildings [...] are used, in all or in part, for activities focusing on not-for-profit services in the public interest*" (schools, hospitals, foster homes etc). Here commercial buildings and institutional buildings are both used to refer to the term commercial buildings [SDTC, 2009]. It is also important to reiterate that in China commercial buildings are also known as public buildings. Commercial buildings of all sizes are considered for this project. Industrial buildings and multi-residential buildings are excluded from this project. The research and analysis focus on energy consumption and emissions of the building operation; construction and demolition phases are excluded from the analysis. This is because more than 80% of energy consumption is consumed during the buildings operational lifetime. The primary focus for energy consumption reduction is energy efficiency measures, such as building renovation and renewable energy technology implementation.

1.3 Methodology overview

Thagaard (1998) [in Buan, 2008] emphasises that the credibility, validity, and transferability of research depend upon the explicit knowledge base: the ways in which the data has been collected, analysed, and interpreted. Yin argues that conclusions reached during research projects are more convincing and accurate when they are based on several sources [Yin, 1994]. The simultaneous use of different methods of research is very important as both qualitative and quantitative methods have their advantages as well as disadvantages. Therefore it is important to describe the data collection and analysis process, as well as discuss the fieldwork in China. Both qualitative and quantitative methods were used while conducting this research. Qualitative research is considered inductive, whereas quantitative research is deductive. Bergene (2005) calls this approach 'disciplined-configurative' meaning that it "involves an attempt to interpret findings in light of a general theory, thus running from theory to case interpretation" [Buan, 2008].

1.3.1 Qualitative method

Taking into account the nature of the research questions posed here, the use of a qualitative method of research is appropriate. A qualitative method has been used for this project as one of the aims of this research is to examine the issue related to China's environmental challenges, namely the energy efficiency policies and standards and their role in China's society today.

A preliminary desk study based on the analysis of the primary and secondary sources published in both English and Chinese (Mandarin) has been conducted. Literature on policy analysis and evaluation and the role of the political actors in it, as well as examples of energy efficiency studies in other countries has been studied to develop an analytical framework for the empirical data interpretation. Information on the implementation of China's energy related policies and other energy efficiency measures were used for the development of the preliminary hypothesis. The main sources for information about China's situation are books, articles, and newspapers covering China's politics, the climate change regime, and Chinese climate policy. Internet sources were also useful; however it was appreciated that these sources should be used with caution as information given in Chinese is subject to censorship and governmental control in China and therefore may be biased. Moreover, the reliability of Chinese statistics about energy use, economic growth, emission reduction levels, etc. is controversial and subject to debate. It is not possible to avoid this problem totally when dealing with a state like China, but using multiple sources and personal observation may improve the reliability of the information.

An exploratory approach to data collection through interviews, questionnaires, and case studies has been chosen in order to achieve the research goals. In order to collect the data for the case studies and liaise with academics doing research in similar fields, visits to China were conducted in October to December 2008 and January 2010. The author of the thesis is sufficiently fluent in Mandarin to be able to discuss the research topic and read material in Mandarin. Questionnaires were distributed towards the end of the research in March-April 2010. Based on these sources of information, two types of data have therefore been collected: factual data based on case studies, and the subjective data based on the opinions of researchers and other actors involved in energy efficiency policy making in China. The results are a basis and are discussed in chapter 10.

A case study approach has been chosen as a research method, as it is the most appropriate method when questions *whether* and *how* are asked [Yin, 1994]. The case study method of research is often criticised for not being able to lead to any generalisations in the classical sense of the world, as individual cases do not represent the whole population [Bergene in Buan, 2008]. However, according to Yin (1994) the aim of the case study is "*not to generalise in order to formulate a scientific law, but to generalise to theoretical propositions*"; therefore the conclusions taken from the case studies can be used for the development of new theories and concepts and revise the existing ones.

In this project, case studies are presented for commercial buildings in urban areas in four different climate zones. The case selection was based on the research categories, which are significant for this project. They include building type, climate zone, floor area, life-cycle stage, and energy use. The case study focused on existing commercial buildings, excluding residential and industrial buildings. The four different climate zones represent areas where heating or cooling or both heating and cooling are required. The cities chosen represent big wealthy cities with developed infrastructure that attract the construction of commercial buildings. Beijing is the capital of China and is famous for its political and economic strength. Kunming is one of the most developed cities in the western part of China and is the administrative centre of Yunnan province. Ningbo is located near

Shanghai and is currently in the top five most developing cities in China. In the North, Heihe is situated on the border with Russia and is a part of a special economic zone that attracts foreign capital and investment. The focus on the urban areas is explained by the fact that 80% of energy consumption is consumed in urban areas. This is due to the high speed of urbanisation. The project also concentrates on building operation (see section 1.2).

The main aim of the case studies in this work has been to provide a quantitative analysis of the effectiveness of the policy tools in case where it has been implemented. The data collected from the case studies included blue prints of the case study buildings, information about energy consumption (meter readings), construction materials used in the buildings, and building lighting and HVAC systems. The main problem with the case studies data collections was the lack of information, as some of the case study buildings did not provide the data about their actual building energy consumption, or the data provided was not sufficient, therefore some of the data had to be assumed using the information on a typical Chinese buildings.

Qualitative interviews were conducted with academics involved in energy efficiency policy making and business people from the construction industry (see Appendix A for the list of those who were interviewed). The aim of the interviews was to gain more information about the policy making process and the involvement of the construction industry in this process. The interviews also aimed to find out the views of academics and business people on the subject of the energy efficiency of commercial buildings in China. The interviews conducted were unstructured, which allowed the interviewees to respond about the topic of discussion freely, with only a few questions from the interviewer. This type of interview was found to be useful as matters the interviewer had not considered were raised. The results of the interview were used to confirm some points raised in chapter 10. Some examples of the information received through the interviews in presented in chapter 10.

Questionnaires were conducted in order to find out the level of awareness among the commercial buildings' users (different to those interviewed) about the energy efficiency measures. The questionnaires were in English and Chinese (see Appendix B). The questionnaires were distributed via email to 30 Chinese companies that occupy typical office buildings in different climate zones of China. The aim of the questionnaire was to evaluate the awareness of the owners and tenants of office spaces about energy efficiency and renewable energy technologies and to find out their opinion about the subject. The questionnaire consists of five sections covering general information about the office building and information about energy efficiency, renewable energy technology and energy consumption. The questionnaire is anonymous: no information about the company except for its general climatic location was required. The questionnaire can be answered by the estate officer or by the head of the company. Some questions suggest answer or multiple answers, whereas others are open questions and require the input of the respondents' own answer. The limitation of the questionnaire was a low response rate. Out of 30 companies, only 20 responded, with four responses being not fully answered and therefore the data collected from these questionnaires was not complete and had to be either ignored or assumed .

1.3.2 Quantitative method

Quantitative methods were employed for the case studies analysis, with mathematical models being used in order to calculate the results. In order to appreciate what energy savings difference can be achieved if the energy efficiency standard was implemented into the building construction, four case studies in different climate zones were assessed. For each of the case studies two scenarios are presented. The first scenario represents the real operation of the building. The second scenario represents the building operation based on the Standard for Energy Efficiency of Public buildings GB500189-2005. In addition, for each of the case studies, possible renewable technologies have been suggested.

The same calculation methods were been used for all case studies. The aim of the calculations was to see if the Standard is able to achieve its aim of energy consumption reduction (see section 5.4.2). The mathematical equations used for the calculations are introduced in section 6.1.1.

1.3.3. Software description

A piece of software called RETScreen International Clean Project Analysis Software was used to simulate an installation of renewable energy technologies onto the case study buildings. It is a free-of-charge software that can be used anywhere in the world to aid energy production evaluation, life-cycle cost analysis and potential GHG reductions using various types of proposed energy efficient and renewable energy technologies. The aim of the software is to overcome the barriers to clean energy technology implementation at the preliminary feasibility stage. Using a proven methodology for comparing conventional and clean energy technologies, the analysis mainly focuses on pre-feasibility stage. The tool requires minimal data inputs and has a built-in weather and product database, which allows fast, accurate analysis [CAMNET, 2005]. It is important to mention, however, that this piece of software cannot be used for a precise sizing of the renewable energy technologies, and was used in this project as an way to suggest the implementation of the renewable energy technologies and show its possible outcomes.

The fundamental output of RETSceen is a comparison between a 'base case', which is the conventional technology or measure, and a 'proposed case', which is the clean energy technology. The GHG analysis has the same analysis approach: it reports the reduction in GHG emissions associated with changing from a 'base case' to a 'proposed case' technology.

All clean energy technology models in the software have a common look and follow a standard approach for decision-making. Each model includes weather, cost, and product data, and RETScreen is supported by a detailed online user manual. RETScreen projects have a similar five-step procedure, as Figure 1-1 shows, associated with one or more Excel worksheets.

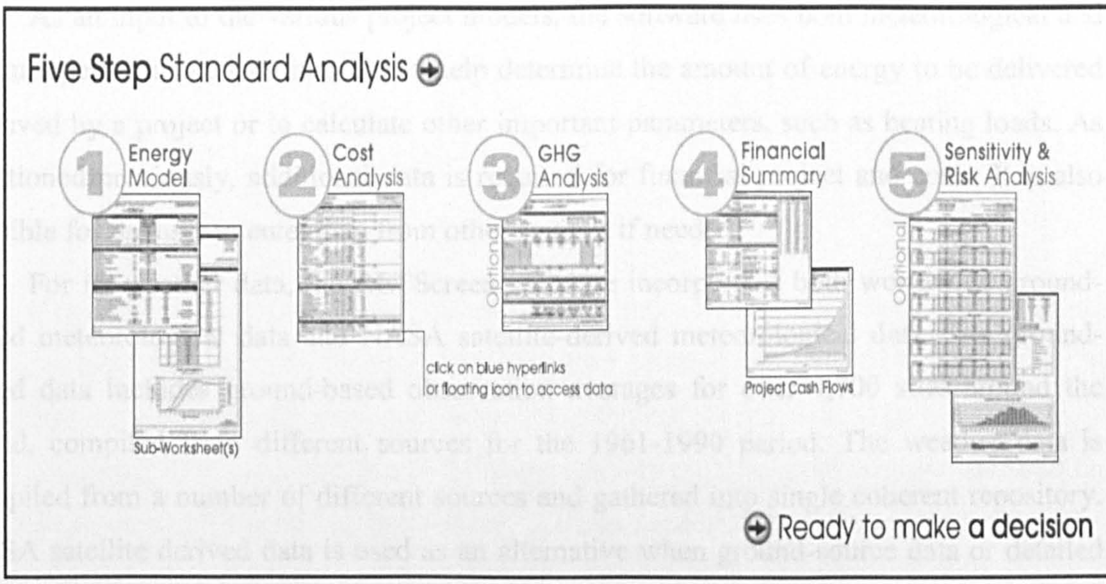

Figure 1-1 RETScreen Software model flow chart: a five-step standard analysis

Step One is an energy model worksheet, where the user specifies parameters describing the location of the energy project, the type of system used in the base case, the technology for the proposed case, the loads (where necessary) and the renewable energy resource. The software then calculates the annual energy productions or energy savings. Step Two is a cost analysis worksheet, where the user enters initial, annual, and periodic costs for the proposed case system as well as credits for any base case costs. This Step has not been used for this project, as not all the costs data required by the software were available for the case studies. Step Three is a GHG analysis worksheet, which determines the annual reduction in the emission of GHGs stemming from using the proposed technology in place of the base case technology. Steps Four and Five are financial summary, and sensitivity and risk analysis worksheets. They have not been considered for this project.

1.3.3.1. Software database

RETScreen software can be used to evaluate industrial, commercial, and residential applications. It offers the following energy technology models: wind energy, small hydro, photovoltaics, biomass heating, solar air heating, solar water heating, passive solar heating, ground-source heat pump project model, and Combined Heat and Power (CHP) .

As an input to the various project models, the software uses both meteorological and product performance data in order to help determine the amount of energy to be delivered or saved by a project or to calculate other important parameters, such as heating loads. As mentioned previously, additional data is required for financial project and costs. It is also possible for the user to enter data from other sources if needed.

For its weather data, the RETScreen software incorporates both worldwide ground-based meteorological data and NASA satellite-derived meteorological data. The ground-based data includes ground-based observation averages for over 4,700 sites around the world, compiled from different sources for the 1961-1990 period. The weather data is compiled from a number of different sources and gathered into single coherent repository. NASA satellite derived data is used as an alternative when ground-source data or detailed resource maps are not available from the project location [CAMNET, 2006].

The product data incorporated into the RETScreen software provides access to over 1,600 product performance and specialisation data needed to describe the performance of the proposed clean energy is the first step of the RETScreen analysis. The data for these products is passed directly into the relevant cells. Moreover, the product database provides access to contact information for clean energy technology manufacturers via website links.

1.3.3.2 Validation

"An Impact assessment of RETSceen" done by S. Graham and S. Higgins (2004), shows that RETScreen, as an instrument, allows large time and cost savings in terms of the acceleration of clean energy project implementation and market expansion [Graham and Higgins, 2004].

The RETScreen GHG emissions reduction analysis model allows users to estimate the GHG emissions reduction potential. The methodology implemented in the software has been developed by Natural Resources Canada in collaboration with the UNEP and the World Banks' PCF. Additionally, it has been validated by a team of experts from government and industry [CAMNET, 2006].

In terms of energy projects validation, numerous experts have contributed to this. They include renewable energy technology experts, cost engineering experts, GHG modelling specialists, financial analysis professionals, and ground station and satellite weather database scientists. Links to examples of validations methods are presented in the Appendix C.

1.4 Outline of the study

Chapter 2 introduces the energy situation in China. Then it discusses the problem of green house gas (GHG) emissions and outlines how climate change is affecting China. It also gives the scenarios of Chinese development in the era of climate change.

Chapter 3 introduces the energy efficiency policy making process in general and in China in particular. The main climate-related policies are described and the role of China in international climate change negotiations is analysed.

Chapter 4 describes the development of renewable energy technologies in China. In addition, the legislation for renewable energy is discussed, as well as the barriers and problems the renewable energy technologies face in China.

Chapter 5 describes the commercial building sector as an energy consumer in China and outlines the main policy tool aimed at energy consumption reduction in this sector.

Chapters 6, 7, 8 and 9 are the case studies, which are used as a technical basis for the evaluation of the effectiveness of the chosen policy tool. Each of the four case studies introduce two scenarios of energy consumption and suggest measures for energy efficiency improvements.

Chapter 10 is the main chapter of the thesis, as it brings together the policy context analysed in previous chapters and outlines the theoretical basis for the policy tool evaluations and evaluates the effectiveness of the chosen policy tool.

Chapter 11 presents conclusions and suggestions for the further work in the field of energy efficiency policies for commercial buildings in China.

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Chapter 2 – Energy Situation and the Impact of Climate Change in China

2.1 Introduction

China entered a period of high economic growth in 1978. In 2005, the annual economic growth rate was 9.5 and the real GDP had expanded 9.7 times when compared to the GDP in 1980. The growth in energy demand was slower because of energy savings and energy conservation actions due to the measures implemented by Deng Xiaoping (such as demolishing of non-effective small scale coal burners and illegal mines introduced during the Cultural Revolution in order to boost industry performance). However, energy consumption in China is still high, as will be discussed later, and with the dramatic increase in energy demand, China faces serious challenges in the areas of energy security, air pollution, ecological degradation, and climate change. It is difficult to assess the overall impact of climate change on China; however, it can be seen that there is an impact and it is unavoidable. China spends around 1.5% of their GDP annually on environmental protection, however, it is estimated that the pollution costs to the Chinese economy is 7-10% of GDP [Lu et al, 2006].

Currently, China faces major problems of air pollution and water pollution, deforestisation, and desertification. Air pollution is traditionally caused by the use of fossil fuels in the industrial and domestic sectors and increasingly in transport sector [Gallagher, 2006]. Fossil fuel combustion causes acid rain, which poison soil, vegetation, and groundwater, consequently causing damage to human, livestock, and agriculture [Economy, 2007]. Water pollution and access to water are very serious problems China is facing today. Runoffs from petroleum processing and petrochemical plants result in the dumping of the toxic waste into waters [Economy, 2004].

The main problems of China in mitigating climate change are the following [NDRC 2007]: inferior climatic conditions and severe natural disasters and a vulnerable ecosystem; a coal dominant energy mix; a huge population with relatively low level of economic development.

This chapter introduces the energy situation in China. Then it introduces the problem of green house gas (GHG) emissions and outlines how climate change affects China. It further gives the scenarios of Chinese development in the era of climate change.

2.2 Energy situation in China

China's economic growth is extraordinary, but the cost of this growth is a heavy reliance on increasingly expensive foreign oil, a vast environmental toll, persistent rural poverty, and periodic power shortages. The *de facto* slogan of 1960s - 1980s "Development first, environment later" is having severe consequences: the development of the country was based on the rapid exploitation of natural resources to build up heavy industry. Moreover, from the mid-1950s until the 1970s population growth was used as a tool to boost economic growth [Andrews –Speed, 2003]. All these trends can be seen in Figure 2-1 below.

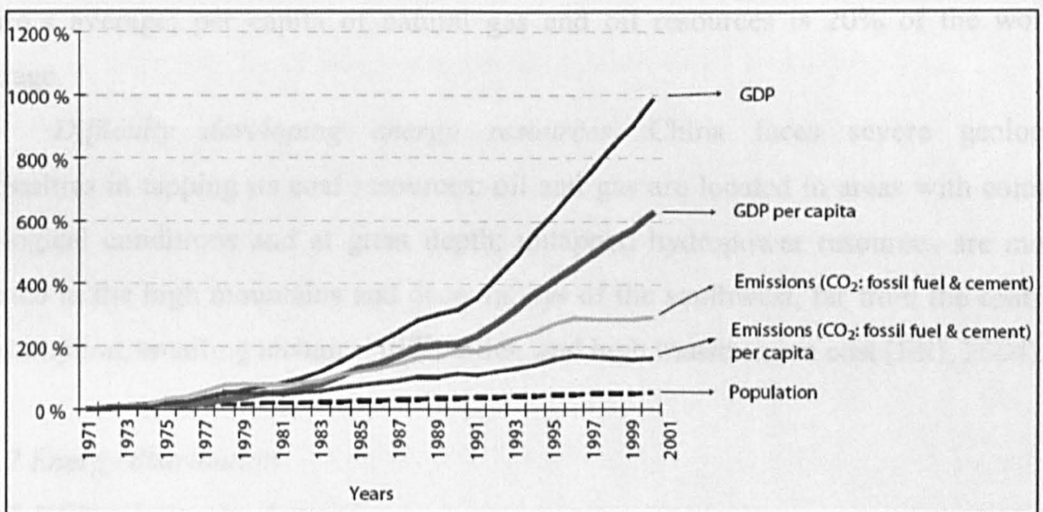

Figure 2-1 Economic development, population growth and CO_2 emissions in China[1] [Bjorkum, 2005]

Though the development of the energy sector is dramatic, when compared to per capita use of commercial energy, it is still about 1/8 of the OECD level. About 23 mln people in rural areas still lack access to commercial energy supplies and instead use firewood and crop waste for cooking and heating. The use of biomass in its non-commercial form accounted for about 14% of the total energy mix at the beginning of 2000 [Chandler et al., 2002].

2.1.1 Energy resources characteristics

China's energy resources have the following characteristics [SC, 2008]:

- *Abundant energy resources*. China has rich energy resources, dominated by coal. In 2006, the reserves of coal were 1,034.5 bln tonnes (13% of the world's total), ranking

[1] All value are compared to 1970 level

China third in the world. The verified reserves of oil and natural gas are relatively small, but have a large potential for exploitation. China's renewable resources are also substantial (they will be discussed in more details in Chapter 4) [Smil, 2005].

- *Unbalanced energy resources distribution.* Coal is found mainly in the north and northwest of China, hydropower in the southwest, and oil and natural gas in the eastern, central, and western regions and along the coast. However, the consumers of energy resources are mostly in the southeast coastal areas, where the economy is the most developed.
- *Low average per capita energy resources.* This can be explained by the large population of China. The per capita of the coal and hydropower recourses is 50% of the world's average; per capita of natural gas and oil resources is 20% of the world's average.
- *Difficulty developing energy resources.* China faces severe geological difficulties in tapping its coal resources; oil and gas are located in areas with complex geological conditions and at great depth; untapped hydropower resources are mostly located in the high mountains and deep valleys of the southwest, far from the centre of consumption, entailing technical difficulties, and high transmission cost [ERI, 2004].

2.1.2 Energy distribution

2.1.2.1 China's energy demand

Due to the China's economic growth and the processes of urbanisation and industrialisation, energy use increased by 208% in 20 years (from 1970 to 1990), and projections show that the growth is likely to continue [Hatch, 2003]. China's annual total primary energy consumption increased from 5,275 GWh in 1980 to 22,859 GWh in 2008, and is projected to reach 28,809 GWh by 2020 [IEA, 1999; 2010].

In 1953, total energy consumption in China was 54 Mtce and it increased to 1,389 Mtce in 1996 with the average annual growth of 9%. It fell in 1997 to 1,377 Mtce and then in 1999 to 1,301 Mtce, but recovered in 2001 to 1,349 Mtce and in 2003 reached 1,678 Mtce. As mentioned previously, coal consumption accounted for 67%; oil was next, accounting for 23%; natural gas accounted for 3% and the rest was accounted for by hydro and renewable energy sources, as can be seen in Figure 2-2 [Crompton and Wu, 2004].

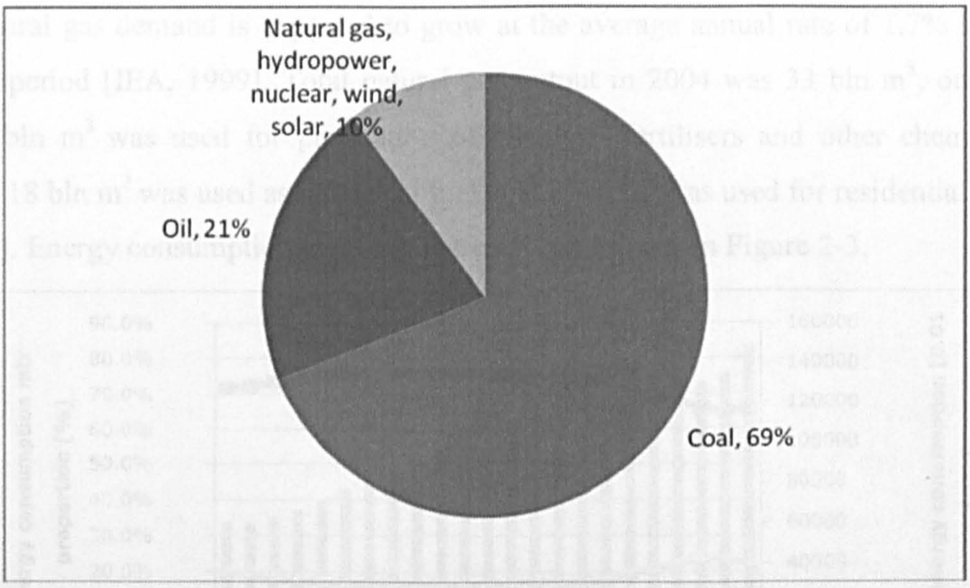

Figure 2-2 China's total primary energy consumption in 2006 [NDRC 2007]

China's energy consumption has several characteristics [Crompton and Wu, 2004]:

- A growth in energy consumption accompanied by a decline in energy intensity;
- An unbalanced composition of energy consumption with heavy reliance on coal;
- A low energy consumption per capita value;
- An unbalanced energy consumption between rural and urban sectors and across Chinese provinces (see Appendix D);
- An influence on China's energy demand by the growth in demand for energy-intensive products.

Currently, China's primary energy mix is dominated by coal. In 2005, raw coal accounted for 76.4% of the primary energy production and 69% of the total primary energy consumption [Li, 2007]. Since the 1970s, China's energy industry has been growing dramatically and by doing this it has been supporting the growth of its national economy. China has a group of extra-large coal mines, each with an annual output of over 10 mln tonnes. In 2006, the output of primary energy equalled 2.21 bln tsc, ranking second in the world with raw coal accounting for 2.37 bln tonnes, ranking it first in the world [SC, 2007].

Oil demand is growing steadily at an average rate of 3.8% annually. Oil consumption in 1996 was 3.5 mb/d and is projected to increase to 8.8 mb/d by 2020. The total oil output in 2004 was 149 Mt produced in land and 18 Mt produced offshore [Li, 2007]. However, the share of oil in China's energy mix still remains at around 20%, as the Chinese government prefers to expand natural gas production and consumption.

Natural gas demand is expected to grow at the average annual rate of 1.7% over the same period [IEA, 1999]. Total natural gas output in 2004 was 33 bln m^3, out of which 9 bln m^3 was used for production of chemical fertilisers and other chemical products, 18 bln m^3 was used as industrial fuel, and 6 bln m^3 was used for residential use [Li, 2007]. Energy consumption mix and its trends can be seen in Figure 2-3.

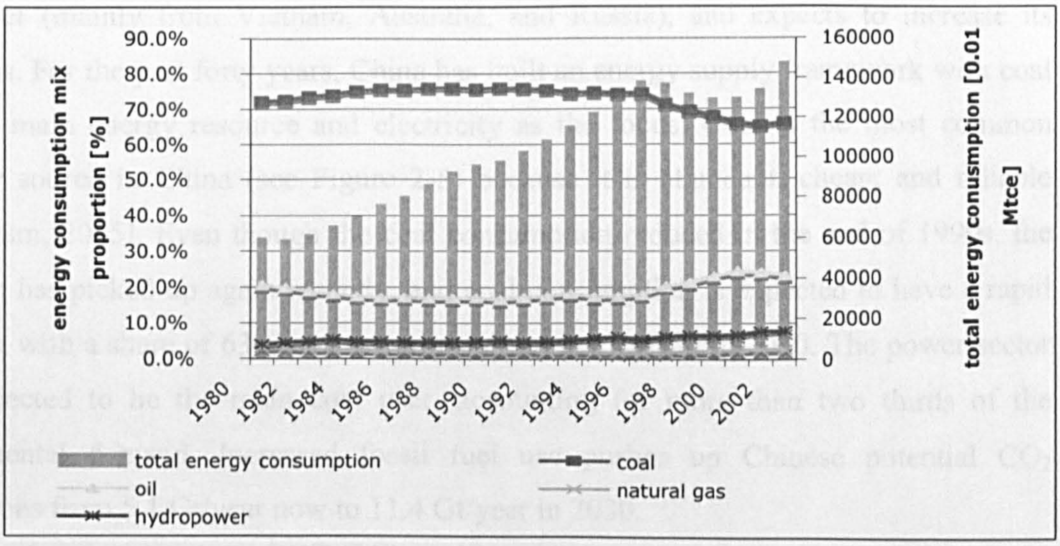

Figure 2-3 Energy consumption mix [ERI, 2004]

China's primary energy demand is projected to more than double from 2005 to 2030. To meet the rising energy demand, China will have to install 635-860 GW of additional generation capacity by 2020 (as can be seen in Figure 2-4), which means that 59-66% of China's 2020 generating capacity needs to be built [Hang et al., 2008].

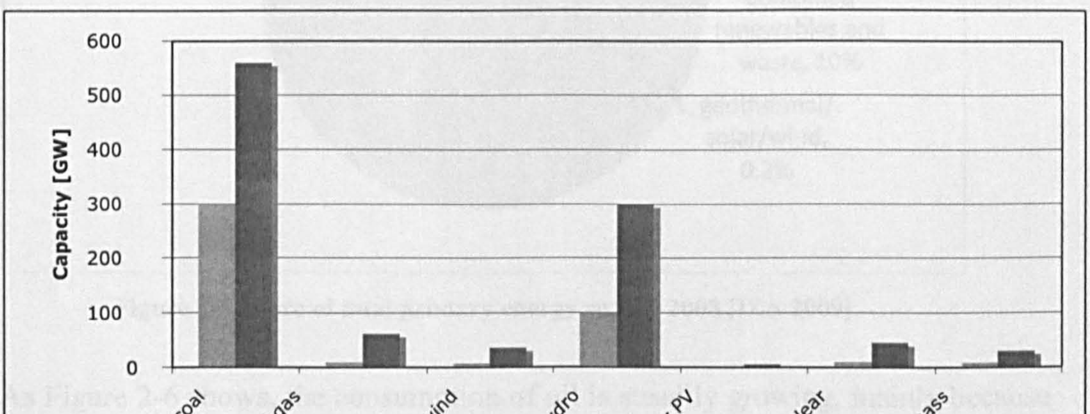

Figure 2-4 Chinese power sources in 2004 and forecast [online source]

2.1.2.2 China's energy supply

China's energy resources (especially coal) are extensive, but they still cannot meet all the planned growth in China's energy needs. More than 90% of Chinese coal resources are located in inland provinces, though the biggest increase in demand is expected in coastal zones [Weidou, 1998]. China has already become a net coal importer (mainly from Vietnam, Australia, and Russia), and expects to increase its imports. For the past forty years, China has built an energy supply framework with coal as the main energy resource and electricity as the focus. Coal is the most common energy source in China (see Figure 2-5) because it is abundant, cheap, and reliable [Bjorkum, 2005]. Even though the coal consumption reduced in the end of 1990s. the growth has picked up again recently, and coal consumption is expected to have a rapid growth with a share of 63% of total primary energy demand in 2030. The power sector is projected to be the main coal user, accounting for more than two thirds of the incremental demand. Increased fossil fuel use pushes up Chinese potential CO_2 emissions from 5.1 Gt/year now to 11.4 Gt/year in 2030.

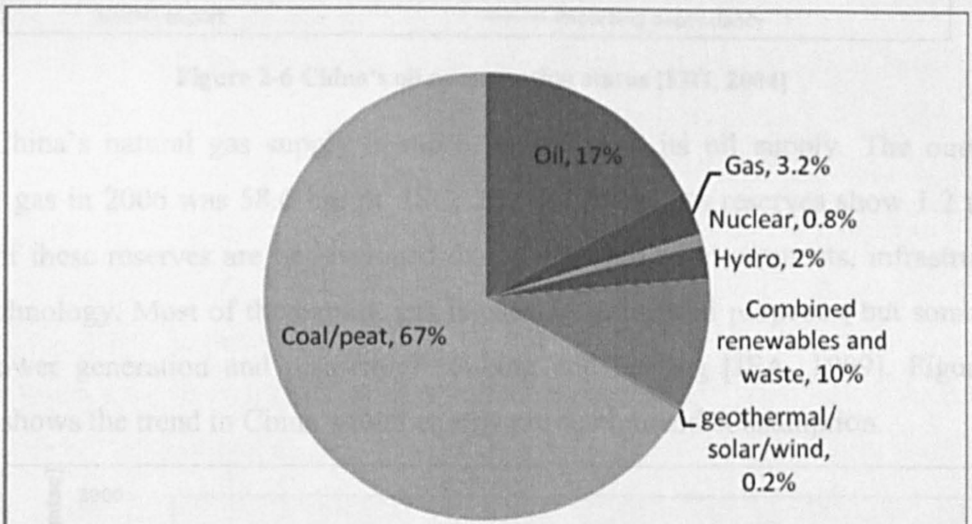

Figure 2-5 Share of total primary energy supply 2008 [IEA 2009]

As Figure 2-6 shows, the consumption of oil is steadily growing, mainly because of the expansion of transport and industry. China became an oil importer in 1993 and its oil imports are expected to grow [Bjorkum, 2005]. China has also built oil production bases: the largest oilfields are Daqing, Shengli, Liaohe and Tarim. In 2006, China was ranked as fifth largest oil producer in the world. The output of natural gas in 2006 was 58.6 bln m^3 [SC, 2007]. However, estimated oil reserves are very speculative, and figures provided by the Chinese government might be artificial in order to attract investors. The evidence suggests an industry consensus of around 68 bb for total proven and potential reserves; these estimates includes 39 bb for onshore reserves and 29 bb for offshore reserves in the East China Sea, the South China Sea, Yellow Sea, and the Bohai Gulf [Salameh, 1996]. To match demand, China needs to import about 13.1 mb/d of oil in 2030 (with import of 3.5 mb/d of oil in 2006) [SC, 2007].

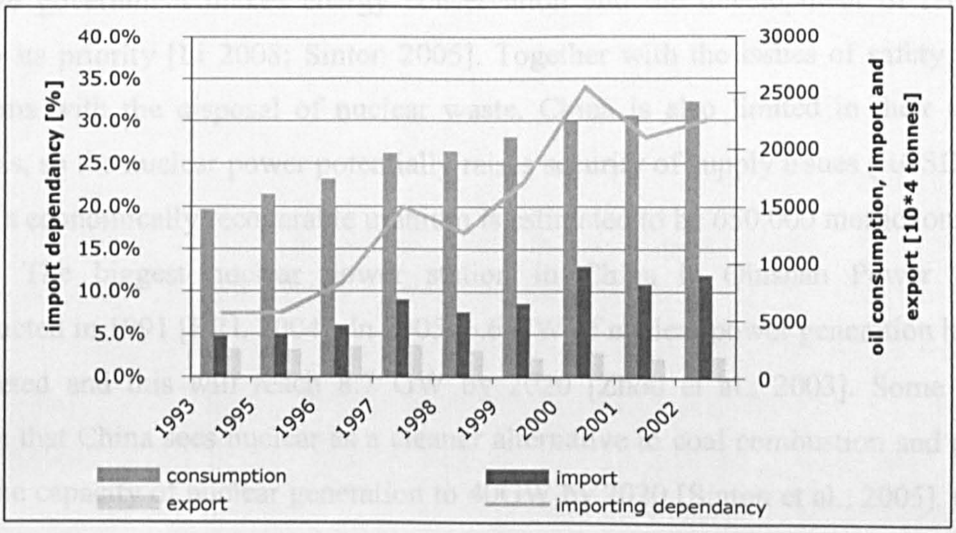

Figure 2-6 China's oil consumption status [ERI, 2004]

China's natural gas supply is more limited than its oil supply. The output of natural gas in 2006 was 58.6 bln m^3 [SC, 2007]. Proven gas reserves show 1.2 trl m^3. Most of these reserves are undeveloped due to the lack of investments, infrastructure, and technology. Most of the natural gas is used for industrial purposes, but some goes into power generation and residential cooking and heating [IEA, 1999]. Figure 2-7 below shows the trend in China's total energy production and consumption.

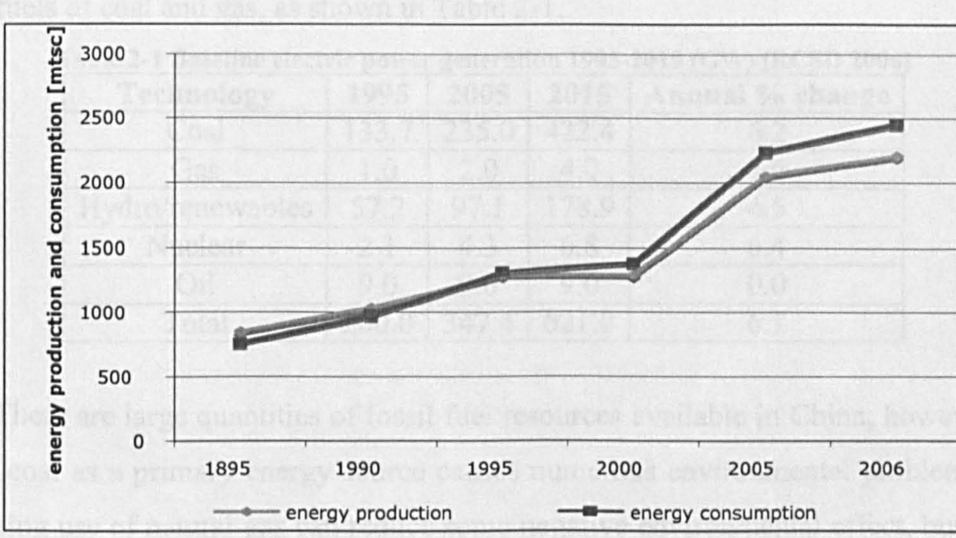

Figure 2-7 Energy production and consumption [Ma et al 2009]

Additionally, China needs to add more than 1,300 GW to its electricity-generating capacity. Projected cumulative investment in China's energy supply infrastructure over the period 2006-2030 would account for up to $3.7 trl [IEA, 2007].

There are hardly any official documents in China opposing nuclear development, however, some views suggest that it's development is considered carefully and the Chinese government makes energy conservation and the development of renewable energy its priority [Li 2008; Sinton 2005]. Together with the issues of safety and the problems with the disposal of nuclear waste, China is also limited in their uranium reserves, so the nuclear power potentially raises security of supply issues [RCSD, 2006]. China's economically recoverable uranium is estimated to be 650,000 metric tonnes [Li, 2008]. The biggest nuclear power station in China is Qinshan Power Station, constructed in 1991 [ERI, 2004]. In 2005, 6.6 GW of nuclear power generation has been completed and this will reach 8.7 GW by 2020 [Zhou et al., 2003]. Some authors believe that China sees nuclear as a cleaner alternative to coal combustion and plans to raise the capacity of nuclear generation to 40GW by 2020 [Sinton et al., 2005]. China's National energy strategy and policy states that the proportion of nuclear in its energy mix will potentially reach 5% by 2020 as currently abundant uranium resources have some potential for long-term development. However, if China expands its nuclear electric capacity of uranium to 40 GW, it will bring the annual consumption to 9,000 metric tonnes annually; at this rate, China's domestic uranium resources will be exhausted in about 70 years [Li, 2008].

It raises a lot of concern in China that the power sector is very dependent on the fossil fuels of coal and gas, as shown in Table 2-1.

Table 2-1 Baseline electric power generation 1995-2015 (GW) [RCSD 2006]

Technology	1995	2005	2015	Annual % change
Coal	133.7	235.0	422.4	6.2
Gas	1.0	2.0	4.0	7.6
Hydro/renewables	57.2	97.1	178.9	6.5
Nuclear	2.1	4.3	6.8	6.4
Oil	9.0	9.0	9.0	0.0
Total	200.0	347.4	621.0	6.1

There are large quantities of fossil fuel resources available in China; however, the use of coal as a primary energy source causes numerous environmental problems. The increasing use of natural gas can reduce some negative environmental effect, but it will also contribute to climate change through increased CO_2 emissions. Moreover, China will be largely dependent on gas imports, as Chinese per capita natural gas reserves are only 5% of that of the world. Therefore, a large part of China's export earnings will have to be paid for the imports. The only way to reduce the dependency and the environmental problems caused by the fossil fuels is to use the renewable energy sources that are available in China. Currently, except for the hydropower plants contributing 24.5% of the whole power generation, very little of the grid capacity is provided by the renewable energy [Hang et at, 2008].

2.1.2.3 Energy intensity in China

Energy intensity is defined as the ratio of energy consumption and GDP for a given year, which makes it a measure within economy [Berkovitch, 1996]. In China, energy intensity has been reducing over the past 20 years due to an increase in the energy efficiency of the primary, secondary, and tertiary industries [Han and Wei, 2004]. From 1980 to 2001, China's energy intensity decreased dramatically from 13.34 tce per 10,000RMB (1,472 USD) to 4.21 tce per 10,000RMB. However, since 2002, China's energy consumption has started to grow faster than its GDP due to the completion of a large number of infrastructure projects. The energy intensity in China increased in 2005 and reached 4.77 tce per 10,000RMB [RCSD, 2006]. Figure 2-8 shows the above described trend.

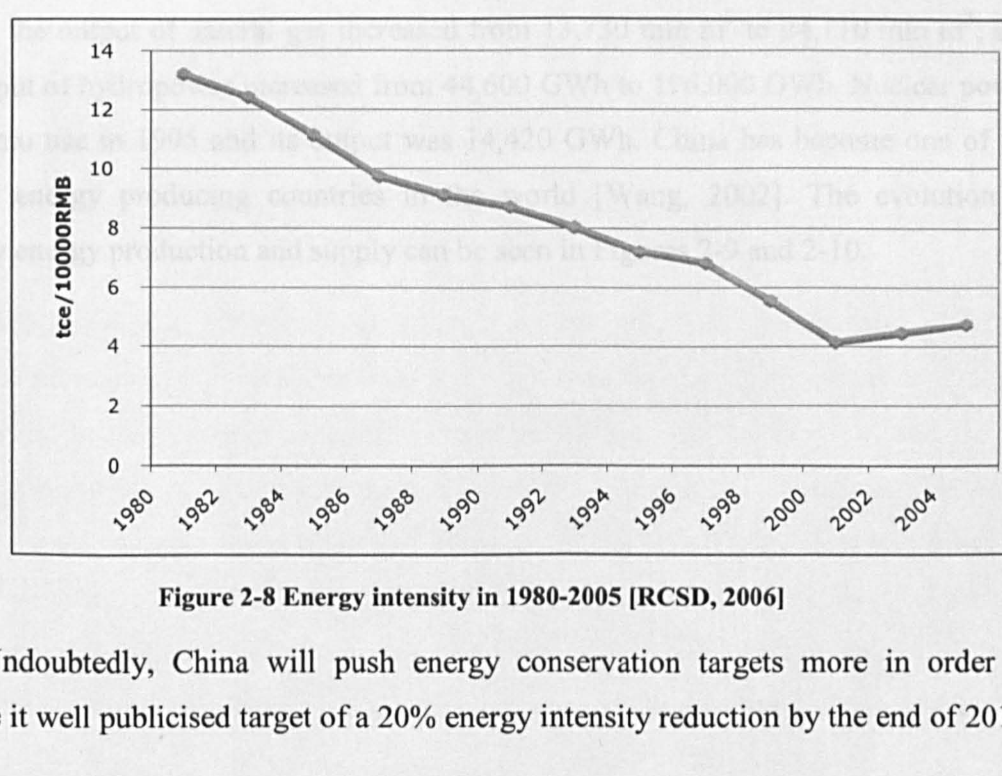

Figure 2-8 Energy intensity in 1980-2005 [RCSD, 2006]

Undoubtedly, China will push energy conservation targets more in order to achieve it well publicised target of a 20% energy intensity reduction by the end of 2010;

however, this can only be achieved through the development of the domestic energy market, which means stronger incentives are needed [Ma, 2009].

2.1.3 Energy-related targets

China's energy development is a very important area for China's government. The development's main principle is to rely on domestic resources, and the country is striving to ensure a stable supply of energy. China's energy strategy has the following priorities: relying on domestic production, encouraging a diverse pattern of development, relying on science and development, protecting the environment, and increasing international cooperation [SC, 2007].

The energy industry was put as the highest priority sector in the investment list in China in the process of its economic development. The aim was to increase the capacity of energy production. The 11th Five-Year Plan states that by 2010 the energy supply will meet the demands of national economic and social development. This will be discussed in more details in section 3.4.3. Officials understand that it is important to make more progress on energy conservation and enhance energy efficiency and optimise the energy structure [SC, 2007]. From 1978 to 1997, the output of primary energy increased from 628 Mtce to 1,387 Mtce. Of this total the output of coal increased from 618 mln tonnes to 1,324 mln tonnes; the output of crude oil increased from 104 mln tonnes to 163 mln tonnes; the output of natural gas increased from 13,730 mln m^3 to 24,110 mln m^3; and the output of hydropower increased from 44,600 GWh to 196,000 GWh. Nuclear power came into use in 1995 and its output was 14,420 GWh. China has become one of the biggest energy producing countries in the world [Wang, 2002]. The evolution of primary energy production and supply can be seen in Figures 2-9 and 2-10.

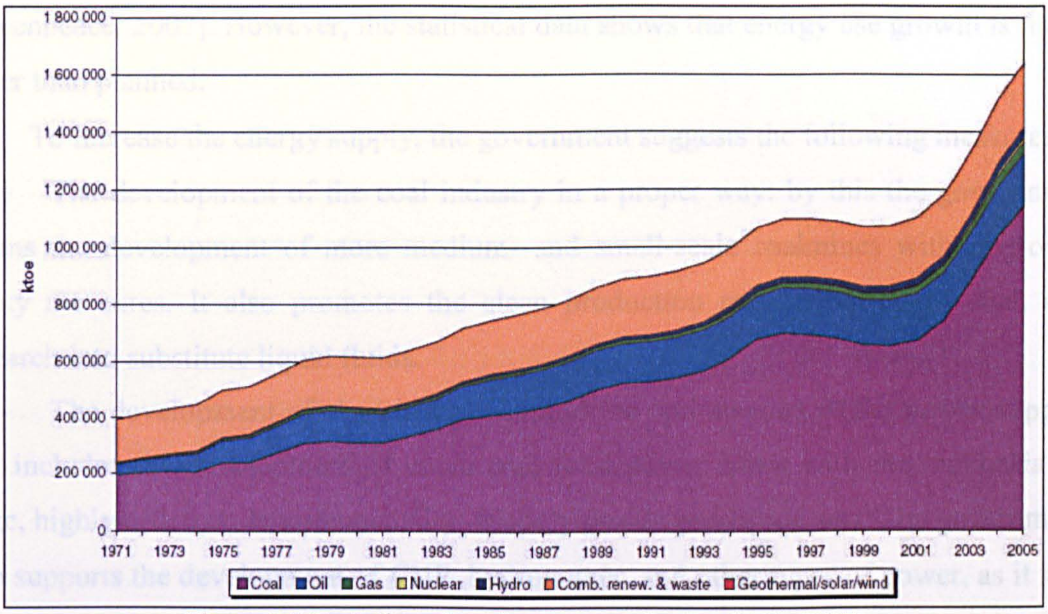

Figure 2-9 Evolution of total energy production [IEA, 2007]

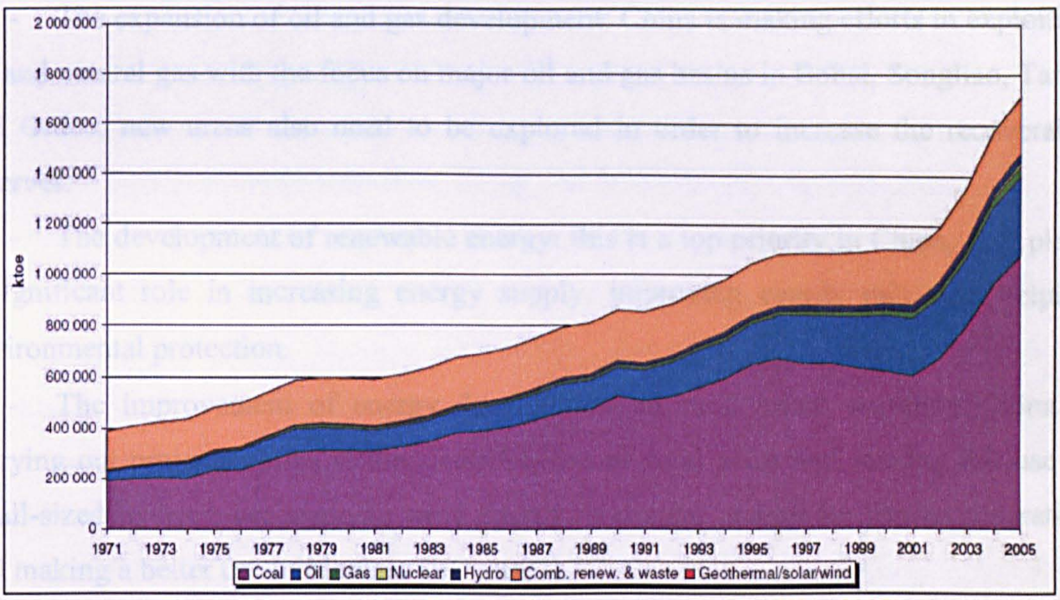

Figure 2-10 Evolution of total primary energy supply [IEA, 2007]

While coal still shows a high ratio in energy structure, the demand for clean energy is increasing. One of the main objectives of sustainable development in China is to keep the primary energy demand under 2,900 Mtce, and the share of coal in the energy consumption mix must be kept under 60%, whereas the amount of renewable energy should increase to at least 525 Mtce, or up to 100 GW of renewable energy generation [ERI, 2004]. This stimulates the development of the industry of electricity production and supply.

The Chinese government has set an energy supply target that is to double energy consumption from 1.3 bln tonnes of coal equivalent in 2000 to 1.83 bln toe in 2020

[Greenpeace, 2007]. However, the statistical data shows that energy use growth is much faster than planned.

To increase the energy supply, the government suggests the following measures:

- The development of the coal industry in a proper way: by this the government means the development of more medium- and small-scale coalmines with improved safety measures. It also promotes the clean production and utilisation of coal, and research into substitute liquid fluids.
- The development of electrical power and the optimisation of the power supply: this includes the development of clean coal-fired power bases with the emphasis on large, highly efficient, environmentally–friendly power generating sets. The government also supports the development of CHP, hydropower, and other types of power, as it will strengthen the distribution networks in western China.
- The expansion of oil and gas development: China is making efforts in exploiting oil and natural gas with the focus on major oil and gas basins in Bohai, Songliao, Tarim and Ordos; new areas also need to be explored in order to increase the recoverable reserves.
- The development of renewable energy: this is a top priority in China, as it plays a significant role in increasing energy supply, improving energy mix, and helping environmental protection.
- The improvement of energy development in rural areas: currently China is carrying out projects aimed at the electrification of rural areas and making full use of small-sized hydropower stations, wind energy, and solar energy for power generation and making a better use of biomass [SC, 2007].

2.1.4 Problems in energy sector

Though the energy sector is developing rapidly and is receiving a large amount of support from the government, there are still some problems remaining:

- The relationship between energy development and national economic development is not harmonised: since energy consumption per capita is still at a very low level, and the population of China is high, the demand for energy will show a big increase during the process of modernisation. However, the speed of the energy industry development does not match the speed of the national economic development.
- The current structure of energy production is not fit for the demand from economic development. The energy structure with the coal as the main part has not

changed fundamentally in China in recent years, though the demand for clean energy is increasing.

- The efficiency of energy use is low: the improvements in this area depend not only upon progress in technology, improvement in management and adjustment in the industrial structure, but also upon the elevation of national policies.
- A contradiction exists between demand and supply of energy in rural areas: 70% of the energy for the livelihood of the rural people is energy that destroys the forest vegetation in vast areas. Moreover, the electrification level is low in the countryside and there is about approximately 100 mln people without electricity.
- Serious environmental problems as a result of energy production [Wang, 2002].
- The economic development of China is a direct result of the large scale resource consumption.
- The production, distribution, and usage of energy are not connected making the energy consumption and distribution structure impractical [Liu, 2002].

Another big problem is price mechanism. Government subsidies mean that energy prices are generally lower than their social and scarcity costs, which does not favour environmental protection, energy conservation and reasonable utilisation, and sustainable development, as they do not send the right signal for companies and public to take action on energy savings. This means that the energy structure cannot be optimised as the relationship between the costs of different energy sources is unreasonable. According to the international standard of price relations calculated on the caloric values for different energy sources, the price relations of coal, oil and natural gas is about 1 to 1.5 to 1.35, whereas in China it is 1 to 4 to 3, which means that the natural gas price is lower compared to subsistence oil price. The same situation is found with the electricity pricing, as the price ratio of the price sold to the power grid over the retail price is disproportionally low. Also, China's dual pricing system effects price reform negatively. Although the coal price was deregulated on paper in 2002, it remains almost the same in reality. The gap between coal price for power and market price is still large. The authority also supervises oil prices by adopting price guidance. The natural gas price is also tow-tracked: one is planned price and another is self-sale price [RCSD, 2006].

Wang [Wang, 2002] gives the prospect on Chinese energy:

- Energy consumption will increase continuously in China: according to Wang's analysis, the total energy consumption of China in 2010 will be 2,050 mtce with the average yearly growth rate of 3.12%; electricity consumption will be 2,560,000 GWh in 2012 with an average yearly growth of 6.5%.

- Coal will still form the main part of the energy generation structure.
- There will be a big rise in the imports of crude oil and natural gas.
- The supply capacity of electricity will increase to meet the demand for it: the capacity for power generating units of thermal power will increase from 235 GW in 2000 to 414 GW in 2010; the capacity of power-generating units of hydropower will increase from 67.5 GW in 2000 to 100 GW in 2010; the capacity of power-generating units using other new energy, such as wind and solar, will increase from 0.5 GW in 2000 to 2 GW in 2010; the total capacity of power generating units will increase from 306 GW in 2000 to 536 GW in 2010; the total output of power could reach 2,513,000 GWh in 2010, which is close to demand for electricity consumption, as it can be seen on the Figure 2-11 below.
- Emissions will still increase from 780 mln tonnes in 2000 to 850 mln tonnes in 2010 [Wang, 2002].

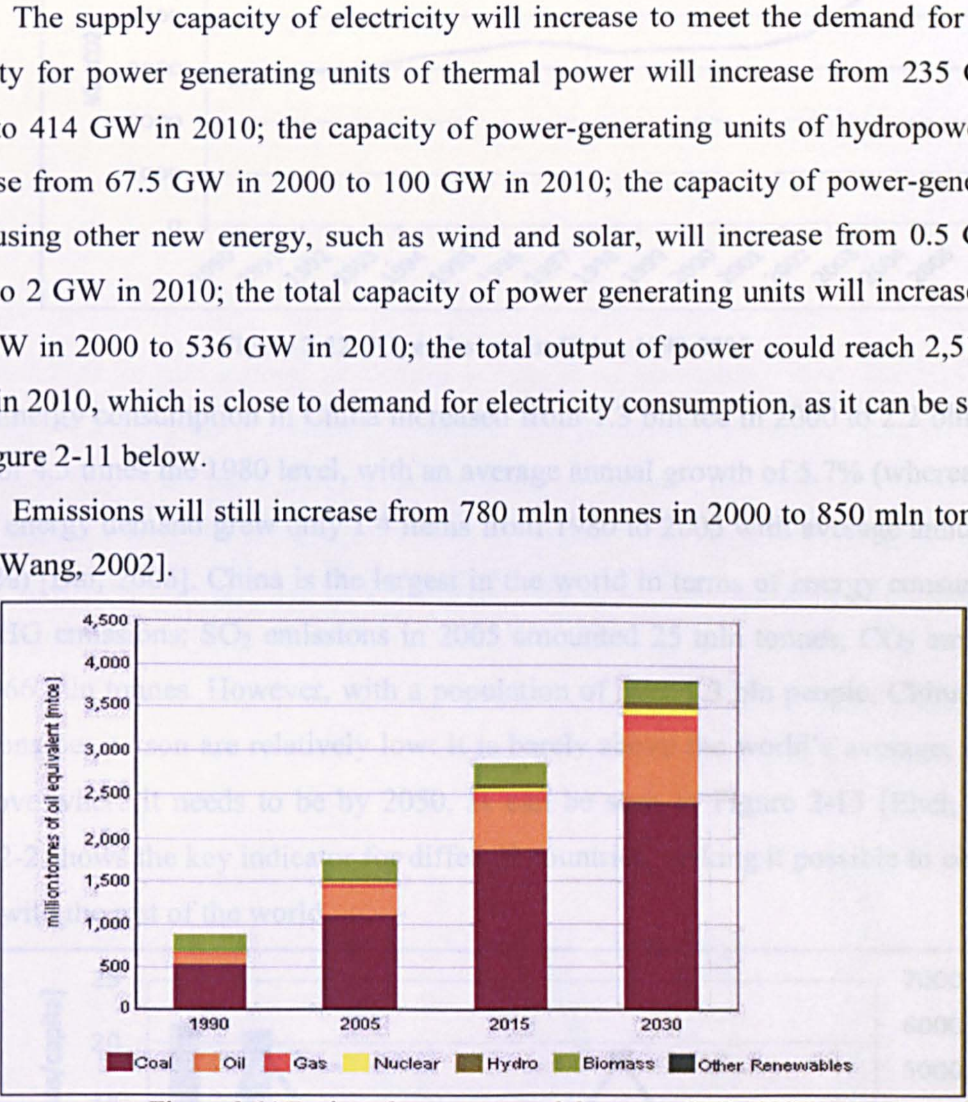

Figure 2-11 Projected energy growth by sector [IEA, 2007]

2.1.5 Emissions from energy production

As the energy use is growing, so are the GHG emissions. China's emissions of CO_2 have more than doubled from 1980 to 1997 [Bjorkum ,2005]. China's total GHG emissions in 1994 were 4,060 mln tCO_2e, with 3,070 mln tonnes of CO_2, 730 mln tCO_2e of CH_4 and 260 mln tCO_2e of N_2O. In 2004, China's GHG emissions were about 6,100 tCO_2e with 5,050 mln tonnes of CO_2, 720 mln tCO_2e of CH_4, and 330 mln tCO_2e of N_2O. This means that from 1994 to 2004, the annual average growth rate of GHG emissions was 4% with the share of CO_2 increased from 76% to 83%, as it can be seen in Figure 2-12 [NDRC, 2007].

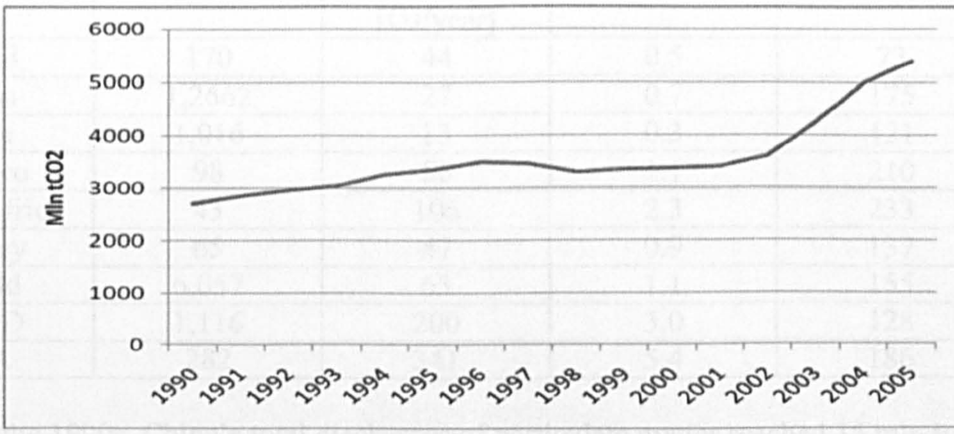

Figure 2-12 CO_2 emissions in China 1990-2005

Energy consumption in China increased from 1.3 bln tce in 2000 to 2.2 bln tce in 2005, or 4.3 times the 1980 level, with an average annual growth of 5.7% (whereas total global energy demand grew only 1.4 items from 1980 to 2005 with average annual rate of 1.6%) [Dai, 2006]. China is the largest in the world in terms of energy consumption and GHG emissions: SO_2 emissions in 2005 amounted 25 mln tonnes; CO_2 emissions were 966 mln tonnes. However, with a population of over 1.3 bln people, China's CO_2 emissions per person are relatively low: it is barely above the world's average, though far above where it needs to be by 2050, as can be seen in Figure 2-13 [Ebel, 2005]. Table 2-2 shows the key indicator for different countries, making it possible to compare China with the rest of the world.

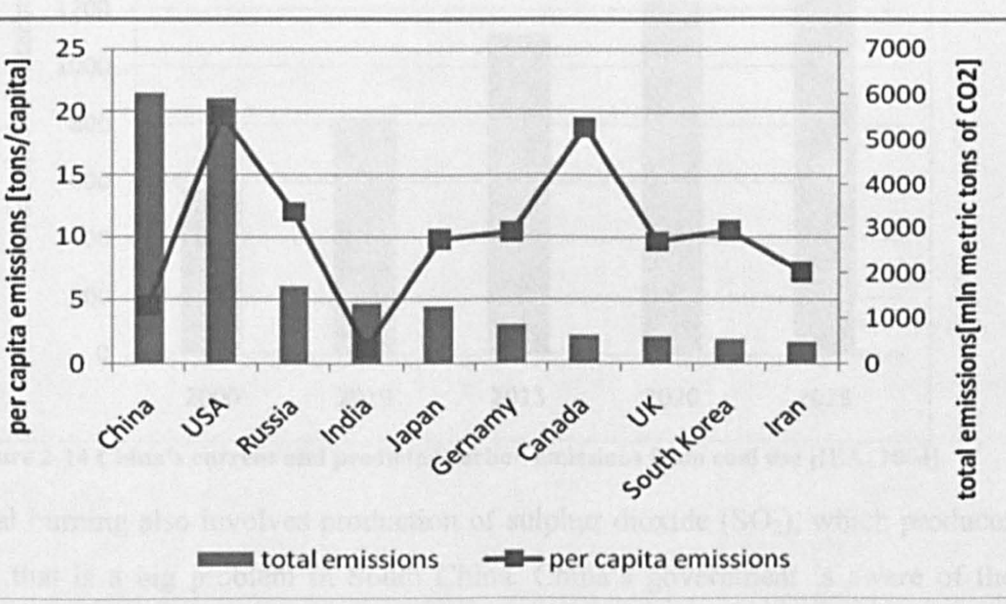

Figure 2-13 Total and per capita CO_2 emissions for selected countries 2006 [The Climate Group]

Table 2-2 Key indicators by country [Chandler et al, 2002]

Country	Population, [mln]	Primary energy per capita [GJ/year]	CO_2 per capita [tc/year]	CO_2/GDP [mln US$ in PPP]
Brazil	170	44	0.5	73
China	1,2662	27	0.7	175
India	1,016	13	0.3	121
Mexico	98	56	1.1	210
South Africa	43	106	2.3	233
Turkey	65	47	0.9	137
World	6,057	63	1.1	155
OECD	1,116	200	3.0	128
USA	282	341	5.4	186

By the 1990s, China's total discharges of particulate matter reached 15 mln tonnes, or as much as 20 mln tonnes, according to unofficial estimates [Chan, 2005]. Official figures show that China produces 15% of the global total of 100 mln tonnes; around 2/3 is generated by coal combustion. China's share of global CO_2 emissions in 1996 was 14.9% (second after the USA with 23.4% emissions). China's commercial energy use was already over one-half that of the USA (1,113 mln metric tonnes of oil equivalent) [Song, 1996].

As it has been mentioned earlier, coal is the main source of GHG emissions in China. The following figure 2-14 shows the growth of emissions from coal in China.

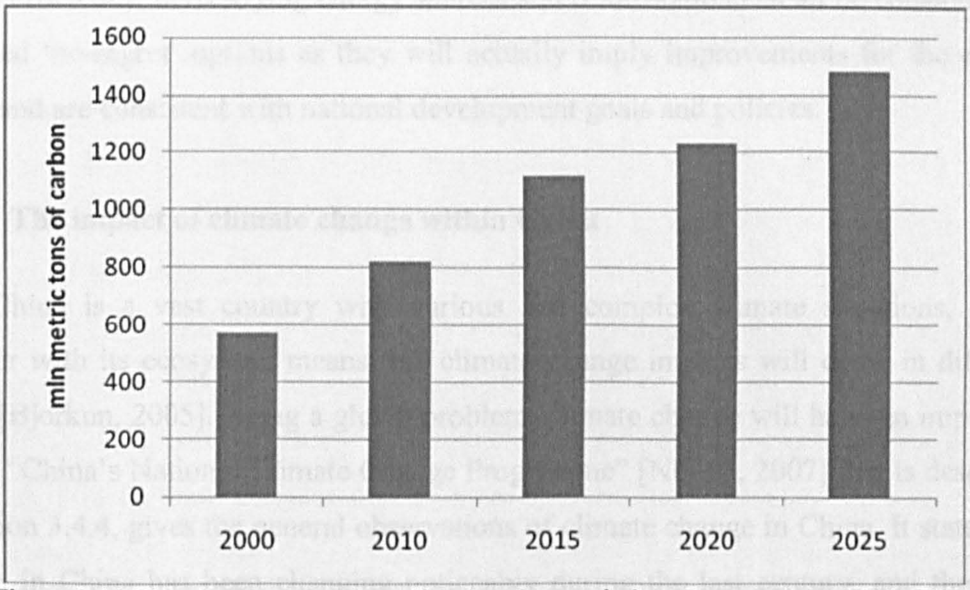

Figure 2-14 China's current and predicted carbon emissions from coal use [IEA, 2004]

Coal burning also involves production of sulphur dioxide (SO_2), which produces acid rain that is a big problem in South China. China's government is aware of the damage that the coal combustion does to the environment and health. In 1999, at the annual session of the Chinese National People's Congress, Premier Zhu Rongji recognised that 'the deterioration of the ecological environment remains a glaring problem', and pledged to 'improve the air quality in the capital and punish polluting enterprises' [in Economy, 2004]. However, there are powerful economic pressures for the continued increase in the coal consumption.

Zhang (1999) argues that without the effort made to reduce its energy intensity, CO_2 emissions in China in 1997 would be 50% more than they actually were (see Appendix E). There are two main strategies to reduce CO_2 emissions produced by fossil fuels: firstly, to improve energy efficiency, and secondly, to switch the energy supply from coal to alternative non-polluting energy sources. In the short term, the first strategy is the most cost-effective, however, although improving, energy efficiency in China is rather low, indicating a great potential for better energy efficiency measures. According to the 11th 5-year Plan, the Chinese government is going to reduce energy intensity by 20% in 2010 as compared to 2005 [NDRC, 2006].

It is obvious that coal will dominate in the Chinese energy sector for a long time; therefore, strategies to reduce emissions from the use of coal have to be considered. This is possible through various technologies such as coal washing, carbon capture, etc. Also, the development of alternative and renewable energy sources in China has a great potential, however, these sources are still not commercially profitable. Improving energy efficiency, diversifying energy sources and reforestation can all be considered as so-called 'no-regret' options as they will actually imply improvements for the energy sector and are consistent with national development goals and policies.

2.3 The impact of climate change within China

China is a vast country with various and complex climate situations, which together with its ecosystem means that climate change impacts will come in different forms [Bjorkun, 2005]. Being a global problem, climate change will have an impact on China. "China's National Climate Change Programme" [NDRC, 2007] that is described in section 3.4.4, gives the general observations of climate change in China. It states that climate in China has been changing noticeably during the last century, and the main evidence for it is the following:

- *Temperature.* Most of the temperature rise has been observed during the last 50 years with the average air temperature increasing by 0.5-0.8°C. The warming trends are more noticeable in western, eastern, and northern China, especially in winter: 20 consecutive warmest winters were experienced nationwide from 1986 to 2005.

- *Precipitation.* Though there was no obvious trend of change in annual precipitation in China, there is a considerable variation among the regions. The annual precipitation has steadily decreased since 1950s, but increased slightly from 1991 to 2000. The decrease in precipitation was mostly noticeable in northern China with the average of 20~40 mm/10a; on the other hand, the precipitation has increased dramatically in southern China by 20~60 mm/10a.
- *Extreme climate/weather events.* China has experienced changes in frequency and intensity of extreme climate/weather events in the last 50 years, and especially in the last decade. Droughts in the northern part of the country and floods in the middle and lower reaches of the Yangtze River have become more severe. In addition, earthquakes and extreme snowfalls have had a dramatic impact on the country's socio-economic development and people's standards of living. These and other natural disasters were unprecedented in scope of the affected area and for the mass of affected people.
- *Sea level.* In the last 50 years, the rate of sea level rise along China's coasts was 2.5 mm/a, and it continues to rise.

It is expected that the trend of climate change in China will further intensify in the future. Chinese scientists [NDRC, 2007] predict that the average nationwide temperature will increase by 1.3~2.1°C by 2020 and 2.3~3.3°C by 2050 compared with 2000 temperatures. Precipitation will increase by 2~3% by 2020 and 5~7% by 2050, mostly in the south-eastern coastal regions; however, the western part of the country is under risk of desertification. In addition, the glaciers in the Qinghai-Tibetan Plateau and the Tianshan mountains have already started to retreat and will continue to do so at an accelerated rate.

China's National Climate Change Programme [NDRC, 2007] outlines the following impacts of climate change on China:

- Impact on agriculture and livestock industry: an increased instability in agricultural production, changes in distribution and the structure of agricultural production and production conditions, increased potential for the acceleration of desertification, and an increased disease rate for domestic animals.
- Impact of forest and other natural ecosystems: a shift of geographical distribution of major forest types with some tree species being likely to reduce; increase

in forest productivity and output; increase in the frequency and intensity of forest fires and insect and disease outbreaks; acceleration of drying of inland lakes and wetlands; decrease of the areas of glaciers and frozen earth; reduction of snow cover; threat to biodiversity.

- Impact on water resources: a decrease in the mean annual runoff in some northern arid provinces and an increase in the already water-abundant southern provinces; water scarcity in Northern China; an expansion in the gap between water resources supply and demand.
- Impact on the coastal zone: a continuous rise in sea level; increase in typhoons and storms; hazards induced by coastal erosion; damage of some typical marine ecosystems.
- Impact on other sectors: increase in frequency and intensity of heat waves; stimulation of the emergence and spread of some diseases and increase in magnitude of other diseases; increase in extreme weather and climate events; increase in electricity consumption for air conditioning.

China faces a number of challenges when dealing with climate change. Firstly is the challenge to China's development. History shows that there is a positive correlation between per capita CO_2 emissions, per capita commercial energy consumption and the economic development level, which means that in order to achieve the development level of the industrialised countries, China will inevitably be confronted with growing energy consumption and CO_2 emissions. Therefore, China has to find a new and sustainable way of development. Secondly, its coal-dominated energy structure is a big challenge to its sustainable development and it will be difficult to decrease its carbon intensity. Thirdly, China mostly uses old technologies for energy production and utilisation and there is a large gap between developed countries and China in terms of energy exploitation, transmission and distribution, production, etc; out of date technologies still occupy a relatively high proportion of China's key industries. Moreover, China faces challenges on the conservation and development of forests and water resources, and adaptation to climate change in the agricultural sector and coastal regions, etc [Harris 2005]. The scale and vulnerability of China to the consequences of climate change makes it reasonable to believe that the costs of adaptation will be high. Adaptation to climate change includes securing the water and food supply and protection of the coastal area, which is challenging because of China's low per capita resources. The cost of climate change to China can be characterised as high. Areas with millions of people living there can be impacted by sea-level rise, and the decrease in agricultural and water output implies severe ramifications for China's population [Bjorkun, 2005].

2.4 Expected abatement costs, benefits and scenarios

China has about 9.4% of the world's installed electricity generation capacity, and over the next couple of decades is projected to be responsible for about 25% of the increase in global electricity generation, as Table 2-3 and Figure 2-15 shows [RCSD, 2006].

Table 2-3 Future energy consumption scenarios (BAU) [RCSD 2006]

	unit	2000	2005	2010	2020
Coal	10^8tonnes	14.5	19.2	22.8	31.8
Oil	10^8tonnes	2.3	3.1	4.1	6.5
Natural gas	10^8m^3	239	483	863	1701
Hydro, nuclear etc. primary electricity	10^8kWh	3930	7575	9227	15858
Energy consumption (equivalent calorific value)	10^8tce	14.4	19.6	24.4	36.2

Energy conservation, raising energy efficiency and replacing high coal-contained fossil energy with clean energy is a fundamental policy of the Chinese Government.

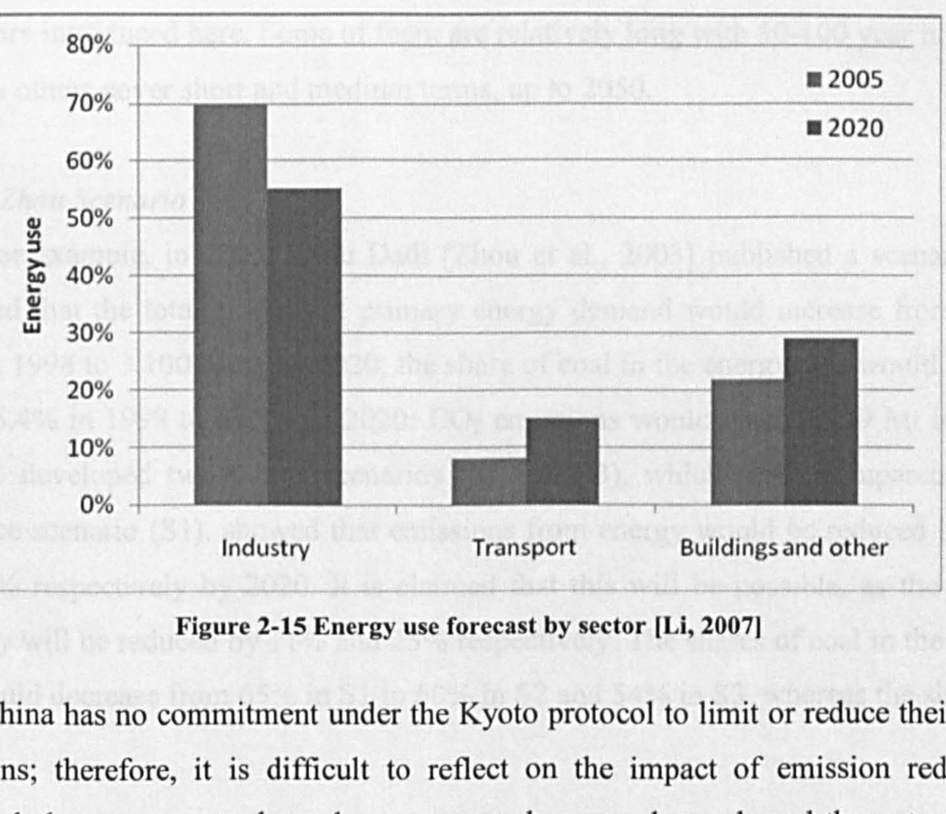

Figure 2-15 Energy use forecast by sector [Li, 2007]

China has no commitment under the Kyoto protocol to limit or reduce their GHG emissions; therefore, it is difficult to reflect on the impact of emission reduction. Expected abatement costs depend on prospected energy demands and the potential for fuel substitution [Rowlands 1995 in Bjorkun, 2005]. In the case of China, the potential cost of mitigation mainly depends on the restructuring of the energy sector, energy efficiency measures, and energy conservation.

There are two main strategies to reduce CO_2 emission from fossil fuels. The first option is to improve energy efficiency; the second is to switch the energy supply from coal to alternative energy sources. The first way is the most cost-effective in the short term [Fang et al.,1998].

As coal is the future of electricity production in China, strategies to reduce emissions from coal have to be considered. It is possible to improve the efficiency of the coal utilisation through various technologies, such as cleaner coal, carbon storage etc [Bjorkun, 2005]. China also has the potential to develop alternative energy sources, which will be discussed later in Chapter 4. Improving energy efficiency, diversifying energy sources and reforestation can all be considered as 'no-regret' options, as they will not just improve the energy sector but also the national development goal.

2.4.1 Scenarios

As mentioned previously, China's plan is to quadruple its 2000 GDP level by 2020. In order to see the consequences, many scenarios have been developed and their results are introduced here. Some of them are relatively long with 50-100 year horizons, whereas others cover short and medium terms, up to 2050.

2.4.1.1 Zhou Scenario

For example, in 2003, Zhou Dadi [Zhou et al., 2003] published a scenario that projected that the total amount of primary energy demand would increase from 1,368 Mtce in 1998 to 3,100 Mtce by 2020; the share of coal in the energy mix would decline from 75.4% in 1998 to 64.8% in 2020; CO_2 emissions would reach 1,899 Mt in 2020. He also developed two policy scenarios (S2 and S3), which when compared to the reference scenario (S1), showed that emissions from energy would be reduced by 13% and 33% respectively by 2020. It is claimed that this will be possible, as the energy intensity will be reduced by 11% and 25% respectively. The shares of coal in the energy mix would decrease from 65% in S1 to 60% in S2 and 54% in S3, whereas the shares of primary power[2] would increase from 6% to 7% and 10% respectively [Zhou et al., 2003]. The summary of Zhou scenarios is introduced in the Table 2-4.

Table 2-4 Comparison of energy demand and CO_2 emissions (MtC) [Zhou, 2003]

Scenarios	Variables	1998	2010	2020	Annual growth rate (5)	Changes based on S1 (%) in 2020
S1 Reference	PE (Mtce)	1,368	2,169.1	3,100	3.8	-
	Coal (%)	75.4	69.6	64.8		-
	CO_2 (MtC)	871.7	~1,350	1899.9	3.6	-
	Primary power (%)	2.7	5	6		-
S2 Policy scenario	PE (Mtce)	1,368	2,033.5	2,761.8	3.2	-11
	Coal (%)	75.4	67.3	59.7		-4.9
	Primary power (%)	2.7	5.4	7.2		1.2
	CO_2 (MtC)	871.7	~1,250	1659	2.97	-13
S3 Enhanced policy scenario	PE (Mtce)	1,368	1,869.3	2,318.7	2.4	-25
	Coal (%)	75.4	64.1	54.4		10.4
	Primary power (%)	2.7	6.3	10.2		4.2
	CO_2 (MtC)	871.7	~1,100	1,265.3	1.71	33

2.4.1.2 Development Research Centre Scenario

Similar to the first scenario, the Development Research Centre, a think tank under the State Council, has produced a report showing that in the reference scenario, the total annual primary energy demand would increase from 1,297 Mtce in 2000 to 3,289 Mtce by 2020; the share of coal in the energy mix would decline to 63.2% in 2020 compared to 70% in 2000; CO_2 emissions would reach 1,940 Mt by 2020 [RSCD, 2006]. Table 2-5 summarises the RCSD scenarios.

[2] In China, primary power includes hydro, nuclear, wind, solar, geothermal.

Table 2-5 Comparison of total demand for primary energy and its composition [RCSD, 2006]

		2000	2010	2020	Annual growth rate (%)	Changes based on S1 (%) in 2020
S1 Reference	PE (Mtce)	1,297	2,137	3,280	4.75	
	Coal (%)	69.9	66.7	63.2		
	Primary power (%)	2.3	2.9	3.3		
	Total CO_2 (MtC)	801	1,288	1,940	4.5	
	Industry and agriculture (%)	73.2	67.4	59.1		
	Transport (%)	10.7	12.8	16.1		
	Commercial/residential (%)	16.1	19.8	24.7		
S2 Policy scenario	PE (Mtce)	1,297	2,068	2,896	4.1	-12
	Coal (%)	69.9	66	61.7		-1.5
	Primary power (%)	2.3	3.4	4.1		0.8
	Total CO_2 (MtC)	801	1,234	1,716	3.9	-12
	Industry and agriculture (%)	73.2	67.4	57.9		
	Transport (%)	10.7	13	16.8		
	Commercial/residential (%)	16.1	19.6	25.2		
S3 Enhance Policy	PE (Mtce)	1,297	1,859	2,466	3.26	25
	Coal (%)	69.9	64.8	59.4		-2.8
	Primary power (%)	2.3	4.3	5.8		2.8
	Total CO_2 (MtC)	801	1,111	1,437	3	26
	Industry and agriculture (%)	73.2	67.1	57.1		
	Transport (%)	10.7	13	16.6		
	Commercial/residential (%)	16.1	19.9	26.3		

2.4.1.3 Li Scenario

Another scenario has been presented by Li [RCSD, 2006], who projected that the primary energy demand in China will be 2,947 Mtce by 2020 and it will be 4,249 Mtce by 2030, with the emissions going up to 2,575 MtC by 2030.

The following Figure 2-16 shows the comparison of the trend of the scenarios described above.

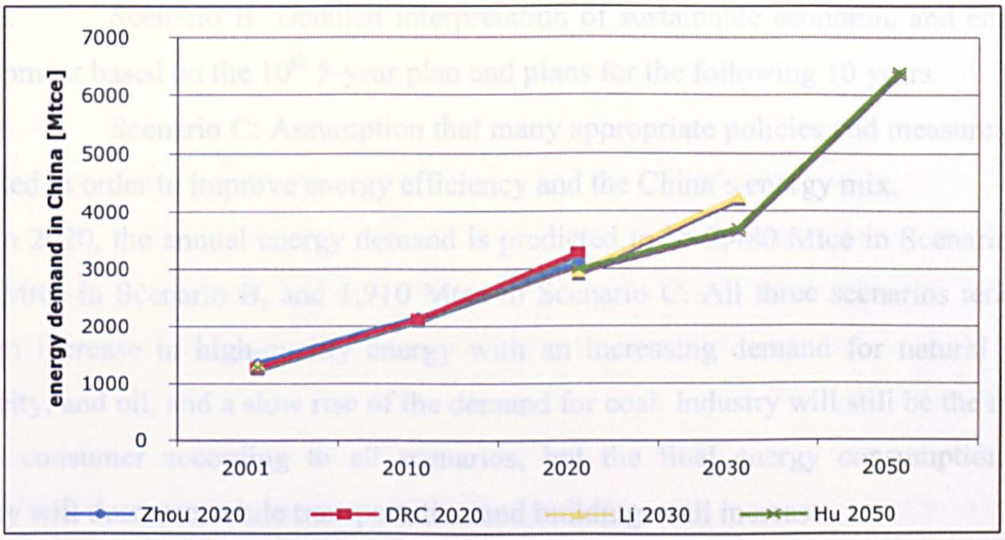

Figure 2-16 Comparison among projections

2.4.1.4 Liu Scenario

In the baseline scenario, projected by Liu, the primary energy consumption increases from 1,380 Mtce in 2000 to 6,600 Mtce in 2050 [Liu, 2009]. However, in the mitigation scenario the primary energy consumption is much lower – 4,760 Mtce by 2050, or 71% of the baseline scenario. As for the fossil fuels, they still take the dominant place in the baseline scenario; however, their share decreases from 90% in 2000 to 75% in 2050. Out of coal, oil, and gas, the former two continue to grow until 2040 and then stabilise. The consumption of natural gas steadily increases and overtakes oil consumption by 2050. The share of natural gas in primary energy consumption rises from 3.5% in 2000 to 21% in 2050. The shares of renewable energy sources also increase gradually. In the mitigation scenario, the primary energy structure is more optimised. The share of fossil fuels is reduced to 64% of total primary energy consumption. The share of natural gas increases to 27% by 2050, and the share of coal and oil together fall to 37% by 2050. The use of renewable energy resources grows rapidly, with wind and solar power accounting for 16% of primary energy consumption in 2050 [Liu, 2009].

2.4.1.5 Dai Scenario

Dai [Dai et al., 2006] has introduced another set of scenarios. Three scenarios were based on the following situations:

1. Scenario A: Restriction of investment in energy efficiency because of competition in the market; wide application of fuel technologies in the next 20 years.

2. Scenario B: Detailed interpretation of sustainable economic and energy development based on the 10th 5-year plan and plans for the following 10 years.

3. Scenario C: Assumption that many appropriate policies and measures are promoted in order to improve energy efficiency and the China's energy mix.

In 2020, the annual energy demand is predicted to be 2,480 Mtce in Scenario A, 2,250 Mtce in Scenario B, and 1,910 Mtce in Scenario C. All three scenarios tend to have an increase in high-quality energy with an increasing demand for natural gas, electricity, and oil, and a slow rise of the demand for coal. Industry will still be the main energy consumer according to all scenarios, but the final energy consumption by industry will decrease, while transportation and buildings will increase.

According to Scenario C, more non-fossil fuels will be used for power generation, whereas in Scenario A they will still dominate. The total energy consumption in 2020 in Scenario C is 2,470 Mtce, while in Scenario A it is 3,280 Mtce. However, even if non-fossil fuel develops fast, coal will still be a dominant energy source. In Scenario C, coal will be used for power and heat generation, but the commercial and residential sectors will use more of natural gas and oil. In this scenario, the annual coal demand in 2020 will be 210 Mt. In Scenario A, coal demand will be 290 Mt, which is double the current demand. Oil demand will reach 373 Mtoe in Scenario A and 287 Mtoe in Scenario C.

Electricity demand in the three scenarios is also different. Power demand in Scenario C is 430 TWh per year with the primary power from hydro, wind and nuclear. The installed capacity of all types will increase dramatically to 865 GW at the annual rate of 29 GW per year. All three scenarios take into account the development of hydro resources: in Scenario A, the capacity of hydro power will be 190 GW, in Scenario C it will be 240 GW with 40GW from small hydro power.

As for the annual CO_2 emissions, they will reach 1,940 MtC, 1,716 MtC and 1,437 MtC in scenarios A, B and C respectively. The annual energy consumption in the three scenarios will be 3,170 Mtce, 2,780 Mtce and 2,320 Mtce with the proportion of coal in the fossil fuel mix being 65%, 64% and 63%, respectively. If the relevant policies are not implemented, per capita annual CO_2 emissions will reach 1.33 MtC by 2020, which is two times higher than per capita emissions in 2000. Whereas with the implementation of the relevant policies, it will be less than 1 MtC annually. The emissions from buildings and transportation will increase dramatically, as the energy consumption increases. The share of the CO_2 from these two sectors in 2020 will be 25% compared to the current 7%.

Of the three scenarios, Scenario C presents the strongest optimisation of China's energy structure and suggests policies that would help to improve the energy mix (see Appendix F).

The reality has shown that all the scenarios are rather conservative, as in 2005, China's total energy consumption had already reached the levels projected for 2010. Even if the target of the 11^{th} Five-Year Plan to reduce energy consumption by 20% by 2010 compared to 2005 will be reached, the real total energy consumption is likely to be higher than it is projected. The main reason for this is the fast speed of China's economy. All the scenarios assume that the share of coal in the energy mix will decrease to about 3/5 by 2020 and then to ½ by 2030. However, this seems rather optimistic due to the following factors:

- The price of oil has grown rapidly within the past few years.
- Though a number of gas turbines were installed in Shanghai and Beijing, they are not operating due to the lack of, and therefore high price of, natural gas.
- China is investing in conversion of oil to coal because of oil shortage, which might have serious environmental consequences.
- Though the control of SO_2 has become stricter, the problem of desulphurisation requires more energy.
- The substitution of coal with nuclear is limited, mainly because of the huge investment, safety considerations and shortage of uranium reserves in China [RCSD, 2006].

Taking into account all the issues outlined above, the scenario analysis could well be underestimated for China.

2.4.2 China's capabilities in its choice of a less energy intensive future

As the scenarios in the previous section have shown, in order to reduce its GHG emissions and energy intensity, China has to choose a path for development where technological, financial, and institutional capacities play the key role in mitigation.

Technology in China varies dramatically: from advanced solar PV and zero energy buildings to what could be thought as primitive technologies, such as outdated small-scale coal fired power plants and wood and mud houses. China has the capacity to develop renewable energy sources and use its own technologies in energy use and conservation. However, the speed of technological development and adoption is uneven; primitive and outdated technologies are a large share of the total capacity and could be around for another 20-50 years. Though the government has published a medium and long-term science and technology development plan, it does not provide enough financial support for R&D; neither does the private sector invest enough. Moreover, regional differences make technological diffusion even greater, with coastal regions generally being more advanced in technologies compared to poorer, more remote inland areas [RCSD, 2006].

In terms of financial capacity, China is traditionally known for a tendency of high rate of savings and is attractive to foreign investors. International cooperation on energy, environment, and climate issues provides China with funding; however, the financial mechanisms that channel money into the energy and the climate change sector is not regulated properly. Many energy efficiency and energy development technology projects are long term and uncertain with respect to returns. Moreover, as the income in China is generally low, the market for high energy efficiency and new and renewable energy sources is not attractive [RCDS, 2006].

China's institutional capacity is theoretically very strong because of its government's strong administrative power over the planning and operation of the economy. A series of laws have being passed in order to promote energy conservation, and the development of renewable energy. Financial incentives are also employed. The problem here, is that normally, with a strong government, grassroots innovation is depressed [RCDS, 2006].

2.5 Summary

The thinking that drives China towards increased energy demand is its willingness to achieve rapid economic growth and moderately well off society. The recent increase in energy consumption is due to the acceleration of industrialisation and urbanisation, both of which require substantial amounts of energy intensive technologies. Moreover, irrational pricing contributes to a dramatic energy consumption increase. Artificially low energy prices and energy subsidies protect large state-owned and inefficient technologies from competition with more advanced ones.

According to the analysis of China's energy consumption structure, the dominance of coal in its energy mix is likely to remain in the future, though its shares will fall over the coming years. Currently, many of the new and renewable technologies are not competitive in China but this can be enhanced through the introduction of more effective policies.

Consumer and institutional behaviour can be a major constraint in mainly towards low carbon alternatives. Price liberalisation will reduce these market distortions.

Bearing all this in mind however, China's effort to increase energy efficiency and reduce energy intensity has been impressive. China has been undertaking efforts in developing hydropower, nuclear power, wind, solar and biomass energy sources. Legislation has been formulated on the promotion of energy efficiency, renewable energy, and clean fossil fuel technology.

Unfortunately, some policies have not been implemented. Reform is needed to create a positive investment climate to attract private capital to renewable energy that will give the opportunity to expand international cooperation in this field. Today, the Chinese government is working on the CDM project which is an effective way of attracting advanced international technologies and investments.

The abundance of cheap energy has had both positive and negative consequences in China. It is crucial for the development but detrimental for the environment. Energy policy is at the top of the agenda; energy security (meaning being reasonably priced, reliable and environmentally friendly) is therefore a key priority in China's development strategy.

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Chapter 3 - Energy efficiency policy making and implementation in China

3.1 General introduction to policy making in developing countries

This chapter will firstly introduce the policy making process in general. Then the policy making process in China will be discussed. After that, the main climate-related policies will be described and the role of China in climate change international negotiations will be analysed.

3.1.1 Process of policy making and policy instruments

Policy making is a very complicated process originating from political, economic, and institutional restraints. In the case of the developing countries, the economic aspect is the key one in the process of policy making, as often, the environmental aspect and economic aspect are seen as contradictory [Gamman, 1994]. Bureaucracy is a factor that might affect the policy making process. Imperfections in bureaucracy and institutional design affect policy making in a negative way, leaving space for political officials to 'bargain' in the policy process, which compromises the outcome of the policy. Another factor that has to be taken into account in policy making is the body that designs the policy. Often policies are designed on the national government level, but have to be implemented by local governments that often have insufficient funds and lack the responsibility [Andersson, 2006].

In order to implement a policy, an effective educational and enforceable policy instrument needs to be chosen. The most common policy instruments used for environmental policies are the following [Carter, 2001]:

- *Regulations:* they aim to act in a specific manner and are enforced by the government. They are the most common instrument and are believed to be effective, precise, and predictable.

- *Voluntary actions*: an instrument that is not ruled by law, but motivated by the desire of a more sustainable development. The main shortfall is that there is often a gap between the number of producers involved in voluntary actions and the number of producers that actually are taking actions to fulfil the agreement.

- *Government expenditure and funding programmes*: subsidies aiming at promoting a cleaner production strategy. This is a very expensive policy making instrument and it does not necessarily give a positive output; but if chosen carefully can balance outgoing and ingoing, such as increase in employment if the solar PV programme is implemented, etc.

- *Market based instruments* (MBI): designed to provide incentives and intended to prevent market failures. Many argue that this is the most effective policy instrument. There are four types of incentive policies implemented worldwide [Gleeston, 2001]:

1) Mandatory policies based on legal restraints or obligations. They consists of:

- relevant laws, regulations, and government mandates passed at any governmental level;
- regulatory and technological policies drawn up by relevant governmental departments;
- other mandatory regulations.

This type of policy is coercive and universal in its scope, and has a high degree of authority.

2) Economic policies cover a wide variety of policies and measures drawn up by government and fall into two categories:

- policies that provide economic incentives for rentable energy development: variety of subsidies, preferential pricing, income tax rebates, loans with interest allowance and loans at low interest rates;
- policies that provide economic deterrents and disincentives for the use of conventional energy resources, such as pollution charge systems, CO_2 and energy taxes.

Both these types influence the decision of enterprises by using market mechanisms to affect their income. These policies can provide a strong compulsion for enterprises to adapt their practices.

3) R&D policies: these relate to the attitude of the central government and the measures it takes to support R&D of renewable energy technologies. They usually do not provide direct, near term economic or other benefits, but are designed to produce scientific results and better long-term prospects.

4) Management policies and operating mechanisms: these cover a variety of strategic decisions and new measures that are introduced to make the management and operating mechanisms more efficient in promoting the development of renewable

resources. They can be characterised by their attempts to use a combination of market mechanisms and administrative management methods.

These incentive policies are summarised in table 3-1.

Table 3-1 Types of incentive policies

Mandatory policies	Laws		
	Codes		
	Regulations		
	Provisions		
	Guidelines		
	Governmental orders		
Economic policies	Incentive policies	Preferential investment policies	Interest allowance loans
			Loans at low interest rate/ with no interest
			Prolonged repayment period
			Accelerate depreciation
			Investment sharing
			Investment subsidy
		Preferential tax policies	Rebates on value-added import tax and surtaxes
			Rebates on value-added production tax and surtaxes
			Income tax rebate
			Export drawback tax
		Preferential pricing policies	Price subsidy
			Price balance sharing
	Deterrent policies	Drainage charge system	
		CO_2 tax	
		Energy tax	
R&D policies	Appropriate funds of financial enterprises		
	Appropriate funds of financial research expenses		
	Special research funds		
Management policies and operating mechanisms	Uniform management systems		
	Public bidding and fair competition		
	Special funds, rolling development		
	Standards and regulations		

3.1.2 Policy implementation

The policy implementation process has been clearly described by Mazmanian and Sabatier [in Najam, 1995] as "*those events and activities that occur after the issuing of policy directives, which include both the effort to administer and the substantive impacts on people and events*". In this particular project, only the analysis of the administration efforts has taken place. As the concept of implementation involves both the process and the result, it remains implementation even in the case of being unsuccessful [Najam, 1995]. Najam has tried to identify the key variables that influence the result of policy implementations. They were later summarised by Rosendal (1999) into the directions which implementation might take:

- Content of the policy: the goals and issues, and the ways they are discussed in the policy, and methods to solve the issues;
- Context through which the policy must go;
- Commitment of the ones who are responsible for carrying out the implementation of the goals and methods on various levels;
- Clients and coalitions whose interests are enhanced or threatened by the policy.

3.1.3 Energy efficiency policy making

There is a general agreement that for energy efficiency policy to be effective, it should combine regulatory instruments, financial incentives, and information provisions adapted for the country where it is implemented. Energy efficiency policy should not be restricted to energy policy only, but should be included as an integral part of governmental policies for industry, taxation, transport, environment, and social security. Undoubtedly, regulations and pricing are crucial in energy efficiency policy, but it will only achieve success if attitudes of the society are changed. This requires education and information, as well as encouragement of participation for all parts of the society [Andrews-Speed, 2009].

Usually, lack of reliable information, shortage of skills, and weak economic incentives are the main factors that make energy efficiency policy fail. Therefore, it is essential that governments focus on sectors where the impact is likely to be greatest and use the instruments that are likely to be effective [Andrews-Speed, 2009]

3.2 China's climate change policy

The traditional concept of harmony in Chinese culture is based on the harmonious relationships between man and nature. Confucianism, Taoism, Legalism and Buddhism all share the idea of "healthy respect for the importance and power of nature to shape mans' conditions". However, the truth is that in China (and not only there), the natural resources have been abused for centuries [Economy, 2004].

The first discussion on the global level about the environment was introduced to China in 1972 at the UN Conference held in Stockholm on the Human Environment. China's position at the conference was defensive, laying blame for the problems on the developed Western countries. However, China recognised its own environmental problems and in 1973 organised the national conference on environment. The conference concluded that China must pay immediate attention on its environmental problems and subsequently guidelines for environmental protection were set [Heggelund, 2007]. Environmental protection became a basic state policy in China in the early 1980s. Since then a large number of laws and regulations have been promulgated. Climate change mitigation is not just a domestic issue; it has a significant impact on the world energy and development situation. China has made great efforts in developing steps towards climate change mitigation and the promotion of energy conservation.

It is important to underline that environmental problems lay in the basis of climate-related problems, which energy efficiency issues are a part of.

3.2.1 Stages of China's climate change policy

Harris and Yu (2005) outline three stages in China's official participation in the climate negotiations: 1990-1992, 1992-1997, and 1997 until now.

3.2.1.1 Stage 1: Climate change becomes political agenda in China (1980s -1992)

At the end of the 1980s climate change became an important international issue attracting attention of public, media, scientists and governments all over the world [Chayes and Kim 1998 in Bjorkum, 2005]. At this stage, China initiated the coordination of its own climate change policy. In 1988, an inter-agency group was established by the Environmental Protection Commission with approval from the State Council; the National Climate Change Coordination Group was formed to facilitate the work of the formulation of China's position for international climate change negotiations. This group consisted of the State Science and Technology Commissions (SSTC), which was responsible for response strategies, the National Environment Protection Agency (NEPA), which was in charge of impact assessment, the State Meteorological Administration (SMA), which was in charge of scientific assessment and acted as the lead agency, and the Ministry of Foreign Affairs (MOFA), which lead the Chinese delegation during negotiations [Bjorkum, 2005].

China was also active in participating in international climate change negotiations. During the Intergovernmental Negotiating Committee (INC) negotiations in 1991, China strongly opposed the idea of targets and supported the general framework convention with no specific responsibilities. China was also successful in establishing a unified developing countries front in order to resist any singling out of developing countries commitments by the developed countries. From the very beginning of the international negotiations on climate change, China earned the reputation of a 'hard-liner' [Economy 1994 in Bjorkum, 2005]. The core elements of China's negotiation position were:

- emphasis on the major scientific uncertainties of climate change;
- focus on protection of national sovereignty;
- historical responsibility of the industrialised countries;
- the transfer of new and additional funding and technologies to developing countries [Hatch, 2003].

China together with other developing countries was able to influence the structure of the Convention, as can be seen in Article 3.1 of the Convention, which calls on the Parties to protect the climate system "*on the basis of equity and in accordance with their common but different responsibilities and respective capabilities. Accordingly the developed country Parties should take the lead in combating climate change and the adverse effects thereof*" [UN, 1992].

3.2.1.2 Stage 2: From Rio to Kyoto (1992-1997)

In 1992, China signed the UNFCCC and then ratified it in 1994. There were six more INC meetings between Rio and the first Conference of the Parties (COP), during which China emphasised that the implementation of the existing commitments should be the COP's major concern and underlined that China was not interested in negotiating until the Annex 1 Parties had implemented all their commitments [Bjorkun, 2005].

When parties gathered in Kyoto for the COP-3, China initially proposed that developed countries should have reduced their emissions of GHG[1] to 1990 levels by 2000, and then further by 7.5% by 2005, 15% by 2010 and 20% by 2020, with the total reduction of 35% by 2020 [Bjorkum, 2005].

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[1] CO_2, CH_4 and N_2O

In May 1998, China signed, and then in August 2002 ratified, the Kyoto Protocol that came into force on February 16^{th}, 2005. The Kyoto protocol divided all countries into two groups: developed Annex I countries, which are obligated to reduce their GHG emissions to approximately 5% below their 1990 level by 2012, and developing Annex II countries, which are not subject to these rules [UNFCCC, 1997]. At this stage, China's voluntary efforts had thus far been insufficient, especially in terms of implementation and enforcement. In response to the EU concern about the projected rise in its GHG emissions, Chinese officials noted that they could make a concerted effort to place environmental protection at the top of policy agenda. However, China generally was sceptical to Kyoto mechanisms. China and other developing countries objected to Article 17 on emissions trading stating that it would not reduce emissions, and proposed to delete it from the Protocol. In preparation for the implementation of the Kyoto protocol, the government set up an examination council for the Clean Development Mechanism (CDM) and promulgated the Interim Measures for Operation and Management of CDM. CDM is one of the three so-called flexible mechanisms under the Kyoto Protocol. It allows developed countries to invest in emissions reduction projects in developing countries to achieve emissions reduction credits. When it was first proposed in 1997, the CDM was met with scepticism in China, but received more positive attitude later on because China was able to see the opportunities to improve its energy efficiency and combat local pollution problems. Idea of the Joint Implementation (JI) was also met by China sceptically as China saw this instrument as created primarily for the developed countries benefit, as it helps them to avoid domestic actions [Freeston, 2005].

3.2.1.3 Stage 3: post- Kyoto China (1997 – currently)

The main issue during this stage was how to uphold the avoidance of developing countries commitments and how to relate to the Kyoto Mechanisms, especially the CDM [Harris and Yu, 2005].

During the COP-4 meeting in Buenos Aires, China together with India and other developing countries, rejected to the voluntary commitments idea and remarked that developed countries should change the pattern of production and consumption [Heggerlund, 2005]. After the next COP-5 meeting in Bonn, China started to discuss the rules and procedures to the practical implementation of CDM projects.

COP-7 agreed on the Marrakech Accord in November 2001. These are seen as the establishment of the CDM Executive Board, the clarification of project cycle and relevant stakeholders, and recognition of Certified Emissions Reduction (CERs) [Lin, 2004].

The CDM mechanism is the most important way for China in UN-led mitigation. The CDM's target is to encourage sustainable development in non-Annex 1 developing countries, and, therefore, to enable Annex 1 developed countries to invest in emissions reduction projects in non-Annex 1 countries, thus reducing the cost of compliance with their commitments. Examples of CDM projects in China are the building of hydroelectric and wind power facilities, destruction or replacement of GHGs in industries, fuel substitution, and waste heat recovery and utilisation in industry. The investing developed countries are issued Certified Emissions Reductions (CERs), which are the credits assisting them in complying with their Kyoto targets; one CER equals one tonne of CO_2 equivalent [Heggelund, 2009]. It is important to point out that CERs do not reduce the emissions and therefore "false credits" from non-additional projects would increase overall emissions [Wara, 2008].

Currently China is the biggest CDM host with 2,023 out of the 4,869 global projects. There will be issued 110 CERs with the 95 mln tonnes of reduced emissions in CO_2 equivalent. CERs are considered national property and are used in supporting activities on climate change. The main areas for CDM in China are energy efficiency, renewables, and methane recovery and utilisation [Heggelund, 2009]. The CDM mechanism will be discussed in details in Section 4.3.2.3.

The following COP meetings were also complex, and until now, there is no agreement on commitments. China did not leave the position it showed during the FCCC and has been very consistent throughout the 15 years of international climate change negotiations. Many targets for 2006 were not met, and as was acknowledged by the Chinese SEPA, the situation with water and air pollution become even worse. China's position on the Kyoto protocol stems from the Chinese government's mutually contradictory policies: maintaining record economic growth and expanding prosperity, and at the same time protecting the environment and preserving social stability.

3.2.1.3.1 Copenhagen meeting

It is important to discuss the most recent COP-17 meeting held in Copenhagen in December 2009. In May 2009, six months before the meeting in Copenhagen, the

NDRC issued "The Implementation of the Bali Roadmap: China's Position on the Copenhagen Climate Change Conference" [NDRC, 2009]. In this document, China outlines the main principles of the UNFCCC and its Kyoto Protocol, and gives the objectives of the Copenhagen Climate Change Conference. It is also emphasised in the Roadmap that it is important to enhance the "full, effective and sustained implementation of the UNFCCC" by the means of cooperation, mitigation, adaptation, technology development and transfer and financial support. The last section of the document states that the developed countries should further quantify their emissions reduction commitments (with the reduction of at least 40% below their 1990 level by 2020).

Just before the actual COP-17 meeting in December 2009, China announced its emissions cut target: "*China will cut CO_2 emissions per unit of GDP by 40-45% by 2020 from the 2005 level, increase the share of non-fossil fuels in primary energy consumption to around 15% by 2020, and increase forest coverage by 40 mln hectares and forest stock volume by 1.3 bln m^3 by 2020 from the 2005 levels* [BBC News Nov 26, 2009]. As can be seen, China's reduction is measured in carbon intensity, which differs from the traditional measurement of the emissions in tonnes. The meeting in Copenhagen was very controversial for China, and China was blamed by many governments for the failure of the meeting. As the summit did not achieve the results planned, there is still need for more negotiations on legally binding final agreements.

3.2.2 Strategies for addressing climate change

Addressing climate change is a very important part of China's policy making process. In doing this, China sticks to the following principles:

- Context of sustainable development: China's development should achieve a win-win outcome of pursuing economic development and addressing climate change.

- Common but different responsibilities: this is the core principle of the UNFCCC, according to which both developed and developing countries must adopt measures to mitigate and adapt to climate change, but due to the historical responsibility, developed countries should take a lead in reducing emissions.

- Equal emphasis on both mitigation and adaptation; these are the integral components of coping with climate change, and both must be treated with equal importance.

- The UNFCCC and Kyoto Protocol are the main channels for addressing climate change.

- Relying on science and technology innovation and technology transfer.

- Relying on public participation and international cooperation: dealing with climate change requires the participation of the whole society, as this is a challenge faced by the entire world [SC, 2008].

3.3 Current climate change related laws and regulations

3.3.1 Policy categories

Today, there are three categories of China's policies on the topic related to climate change mitigation: China's Central Government established the first two levels, and local governments (provincial, municipal, and county) established the third level with overall direction from the first two levels. The first level policies provide general directions and guidance; they also include country leaders' speeches and government standpoints on the global environment and development of renewable energy. The second level policies specify aims and development plans mostly with the focus on rural electrification, renewable-energy generation technology and fuel wood. The aim of these policies is to standardise the directions, focal points, and objectives of renewable energy development from different viewpoints. The third level policies include practical and specific incentives and managerial guidelines, and specific supporting measures for developing and using renewable energy [Christiansen, 1996]. Examples of the policies are given in Table 3-2.

Table 3-2 Example of different types of policies on different levels

First level	1983	Suggestions to reinforce the development of rural energy
	1992	China Agenda 21
	1992	Ten strategies on China's environment and development
	1995	SSTC Paper №4: China energy technology policy
	1995	Outline on new and renewable energy development in China, SPC, SSTC, SETC
	1995	Electric Power Law
	1996	Guidelines for the 9th 5-year Plan and 2010: Long term Objectives on Economic and Social Development of China
	1996	State Energy technology Policy
	1997	Energy Saving Law
	2003	Renewable Energy Promotional Law
Second level	1994	Brightness Programme and Ride the Wind Programme, formulated by SPC
	1995	New and Renewable Energy Development projects, in priority (1996-2010) China, by SSTC, State Power Corporation and SETC
	1996	9th 5-year Plan and 2010 Plan on energy conservation and new energy development by the State Power Corporation
	1996	9th 5-year Plan of industrialisation of new and renewable energy by SETC
	1998	Incentive policies for renewable energy technology localisation by SDPC and MST
	2001	10th 5-year Plan for new and renewable energy commercialisation development by SETC
	2003	Rural energy development Plan to 2020 for Western areas
Third level	1997	Circular of the communication and energy department of SPC on issuing the provisional regulations on the management of new energy capital construction projects
	1999	Circular of MST and SDPC on further supporting the development of renewable energy
	2001	Adjustment of VAT for some resource comprehensive utilisation products by MOF and State Tax Administration
	2001	Electricity facility construction in non-electrification townships in Western provinces of China or township electrification programme by SDPC and MOF

3.3.2 Policy-making bodies

China has a very large state apparatus with the complex division of labour and responsibilities. The following figure 3-1 represents the organisational structure for environmental protection in China.

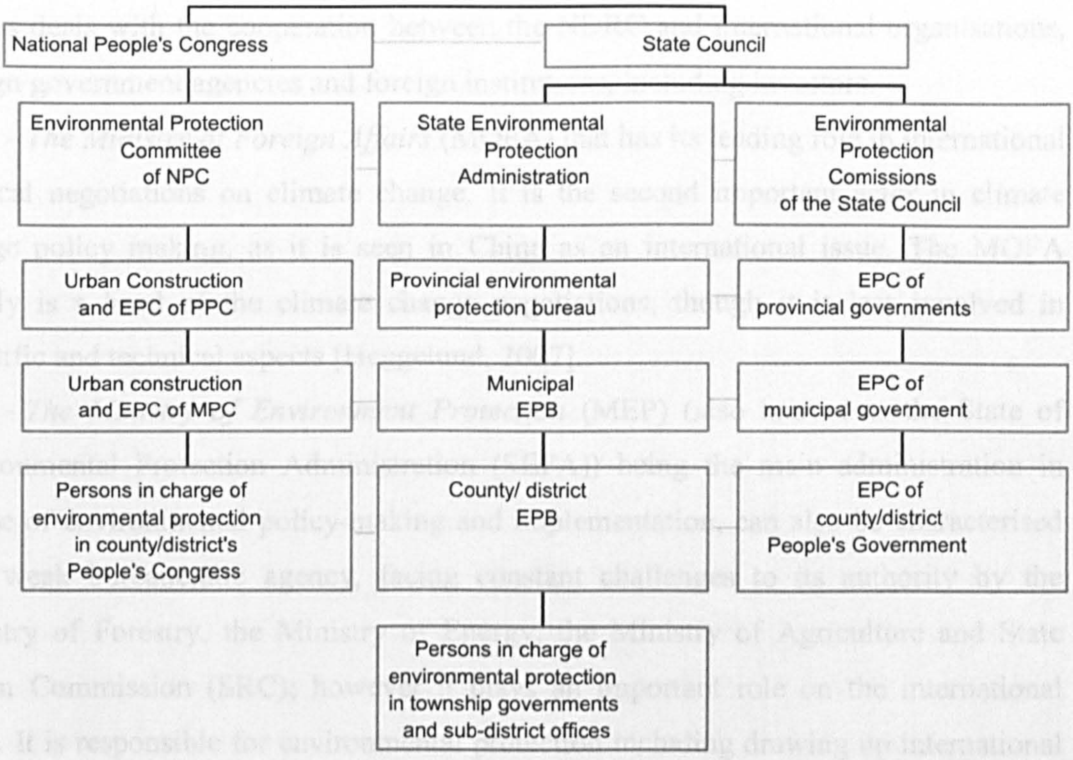

Figure 3-1 Organisation structure for environmental protection in China

As can be seen, the structure is very complex. In the 1990s, China saw climate change as a matter of science rather than energy, economy, and politics. Climate change issues were the responsibility of the CMA and other scientific agencies. However, gradually, climate change issues have shifted from being just science issues to being political and economic issues, and then they became the responsibility of the NDRC [Zhou, 2009]. This section outlines the central actors in Chinese climate change policy-making:

- *The National Coordination Committee on Climate Change* (NCCCC) was established in 1990 with the aim of promoting coordination among various relevant ministries and governmental bodies on climate change. The Climate Change Office functions as the secretariat to the NCCCC and practically has the responsibility for climate work in China. Different officials in the Office are responsible for the CDM, the Asia-Pacific Partnership (APP) for Clean Development and Climate, etc [Heggelund, 2007]. All the following ministries are the members of NCCCC.

- *The National Development and Reform Commission* (NDRC), who's highest priority is to maximize economic development and rapid expansion of energy suppliers, acts as a coordinator of China's climate change activities. The Department of Foreign Affairs deals with the cooperation between the NDRC and international organisations, foreign government agencies and foreign institutions, including investors.

- *The Ministry of Foreign Affairs* (MOFA) that has its leading role in international political negotiations on climate change. It is the second important actor in climate change policy making, as it is seen in China as an international issue. The MOFA usually is a head of the climate change negotiations, though it is less involved in scientific and technical aspects [Heggelund, 2007].

- *The Ministry of Environment Protection* (MEP) (also known as the State of Environmental Protection Administration (SEPA)) being the main administration in charge of environmental policy-making and implementation, can also be characterised as a weak bureaucratic agency, facing constant challenges to its authority by the Ministry of Forestry, the Ministry of Energy, the Ministry of Agriculture and State reform Commission (SRC); however it plays an important role on the international arena. It is responsible for environmental protection including drawing up international principles on global environmental issues, administering international cooperation on the environment, and participation and coordination of important international environmental events [Ho and Vermeer, 2006].

- *The China Meteorological Administration* (CMA) works to develop China's scientific capacity for climate monitoring and modelling, both through domestic support and international funding.

- *The Ministry of Science and Technology* (MST) deals with technical aspects of China's climate change mitigation being highly involved in technological transfer and scientific research. It also plays a crucial role in China's CDM participation; it has the broadest technical expertise about CDM in China and plays an important role in the development of CDM projects [Heggelund, 2007].

Other important bodies are the Ministry of Finance (MOF), the Ministry of Agriculture, the Ministry of Water resources, and the State Forestry Administration. China does not have separate energy ministry, though its establishment is currently being discussed mainly because such a ministry with clear mandate and authority can achieve efficient implementation of energy policy. Currently, an Office of the National Energy Leading Group established in 2005 and working under the NDRC is in charge of overall energy strategy, however its functions are not totally clear [Heggelund, 2007].

As can be seen, there are several ministries involved in the process of formulating China's position on climate change, and they all have a different degree of influence. The structure of these actors lacks a framework that would be able to provide the delegation of responsibilities among the numerous governmental bodies and institutions. All these actors are engaged not only in climate change policy-making but also in other policy areas, such as energy planning, economic development, China's foreign policy etc. The Chinese government expects these actors to endorse a proactive climate policy choice only to the extent that it does not conflict with that particular sector's other goals with higher priorities [Bjorkum, 2005].

The Chinese government also involves scientists in the process of decision-making, and they have been involved in different projects for several years now. Recently, twenty-eight Chinese experts were elected for the writing-up of the forth assessment report of the IPCC; Chinese scientists are also included into the COPs with their expertise increasingly aiding the negotiations. Economists from CAS, Qinghua University and Renming University have also been involved in climate change related work and been part of China's delegations to climate negotiations. These actors with different backgrounds are extremely important for China's policy-making process; however it is difficult to assess the influence that they have on the climate change arena [Heggelund, 2007].

Increasingly, information and knowledge are becoming more and more important as the basis for the policy making process. This means the information provided by research institutes, academies, agencies, and other think tanks. These think tanks can be independent bodies, as well as subordinate to commissions or ministries; however again, it is impossible to assess if they have the greatest influence on a climate change policy making process [Heggelund, 2007]. China has significantly increased its total R&D spending and it currently stands at 1.5% of GDP, which is about 40 bln USD. China has a great stock of human resources for science and technology and plans to spend 2.5% of GDP on R&D by 2020 [Bosetti et al., 2009].

3.3.3 Policy implementation problems

Although China has made good progress in achieving some of their policy targets, there are still many factors contributing to the poor performance of others. These factors are summarised in figure 3-2 below.

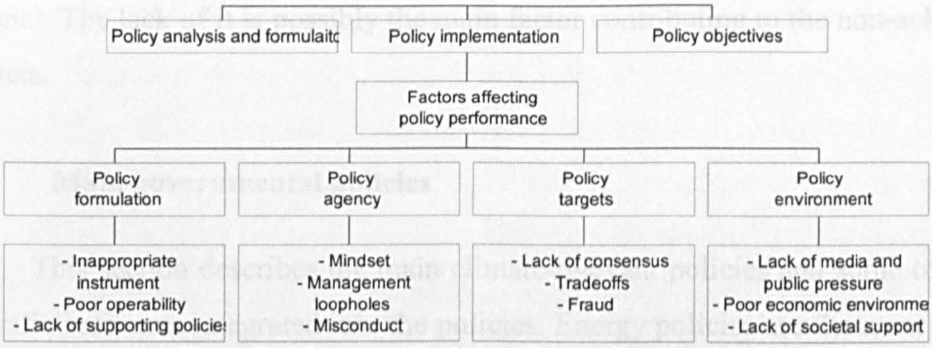

Figure 3-2 Factors affecting policy performance [ADB, 2007]

The most significant factors affecting policy performance are [ADB, 2007]:

- Inadequate attention of local government to environmental protection: under the Chinese administrative system, local governments are in charge of regulations, management, and protection. However the funding for environmental and climate change related policy implementation tends to be underprovided or not provided at all. There are also many cases where project approvals were granted in violation of environmental law enforcement. The main problem has been that the local government can be a shareholder if not an owner of the enterprises that it is supposed to be regulating. As a result of this factor, the second factor appears.

- Ineffective regulatory framework and weak supervision and enforcement: though there are various laws, regulations and standards that have been enforced in past 5 years, many of them are adopted from foreign countries without proper regard to the Chinese system. Some of the regulations lack enforceability; also there are often loopholes in them, as often the local government is responsible for the construction project as well as its monitoring and supervision. This often happens especially on a local level in small and medium cities. Moreover, most of the economic charges are too low, so it can make more economic sense to pay the charge.

- Overheated economy: when, between 2000 and 2002, the structural adjustments were implemented into the energy sector, the energy consumption decreased, however by 2003 the economy started to grow again with the high energy-consumption sectors growing by 10% throughout the year. The government has to pay more attention to creating institutional and regulatory levels with which it can influence economic development.

- Lack of cross-sectoral coordination: environmental and climate change related issues are responsibilities shared between multiple agencies, as it has been mentioned in section 3.2, therefore, under such an arrangement, strong cross-sectoral coordination is crucial. The lack of it is possibly the main factor contributing to the non-achievement of targets.

3.4 Main governmental policies

This section describes the main climate-relevant policies and some of the climate specific measures integrated into the policies. Energy policies are the most important in climate-related policies in China: they are central for the economic growth, and at the same time, energy in China is the main source of GHG emissions. China has implemented different measures in order to improve energy efficiency and decrease energy intensity (see Appendix G) [Richerzhagen and Scholz, 2007].

3.4.1 Agenda 21

In 1993, the Chinese Government took part in the Global Environment and Development Conference of the UN, after which the path towards development and utilization of clean energy was taken [Andrews-Speed, 2009]. It was emphasised again in the "Agenda 21 of China" to develop new and renewable energy. China had the following goals:

- To distribute the higher cost of wind energy beyond the normal price equally in the whole grid;
- To give favourable import customs duties on wind energy and solar energy products;
- To raise money from various sources;
- To establish a Task Force to organise and realise rural energy integrated construction of 100 counties [NDRC, 1992].

In 1995, the "Electricity Act of the People's Republic of China" was issued. This Act was the first to deal with energy resources: it showed that the Government encourages and supports the use of clean and renewable energy resources for electricity generation, and it emphasised the importance of developing and using renewable energy resources in construction of rural power generating capacity and agricultural power consumption [Heggelund, 2007].

3.4.2 Energy Conservation Law

The Energy Conservation Law of the PRC came into effect in January 1998. It includes six chapters covering general provisions, energy conservation management, rational utilisation of energy, technological progress of energy conservation and legal liability. The Law states that governmental authorities at all levels are requested to give investments for energy saving purposes and must strengthen the management for energy-using entities consuming over 7,000 tce annually. It also gives a list of energy efficient technologies and stipulates the measures in case of non-compliance, such as revoking a business licence [NDRC, 1998].

Currently a new Energy Law is to be enforced. A consultation process on its draft has been closed and presented to the Office of Law of the State Council and then will be submitted to the NPC for approval. This law is to be a basic law to guide and coordinate other laws in China's energy sector. It covers coal, oil, natural gas, renewable energy and nuclear energy as well as electricity, thermal power and petroleum products. This new law is planned to overlay specific energy laws, such as the Renewable Energy Law, Energy Conservation Law and the Electric Power Law and actions and measures associated with them. The purpose of the Law is to standardise the development, use and administration of energy; create a sustainable energy supply and service system; increase energy efficiency and security; promote the development and renewables of awareness of society in general [Energy Group, 2008].

3.4.3 Five-Year Plans

3.4.3.1 9th 5-year Plan

In March 1996, the 4th session of the 8th Congress of NPC adopted the outlines of the 9th Five-year Plan and long-term target till 2010. Sustainable development was introduced as an important strategy for the modernisation drive. Electricity generation was to be increased with coal as a primary source, but the exportation of petroleum and natural gas reserves and development of new energy resources were also to be encouraged. The importance of small hydro, wind, solar, geothermal, and biomass power were mentioned as well [NDRC, 1996].

The "China Electricity Law" 1998 reaffirmed and re-emphasized the strategic importance of renewable energy technologies for optimising usage of energy resources, reducing GHG emissions levels, and improving the environment [Heggelund, 2007].

3.4.3.2 11th 5-year Plan

The 11th Five-year Plan was approved by the 5th Plenary Session of the 16th NPC in 2006 [NDRC 2006]. It sets energy conservation targets for local governments and key central government departments. It also sets specific energy targets for electricity generation, some industrial processes, appliances, and transport. It contains a number of different measures that are designed to increase the share of renewable energy in China's energy portfolio [Zhou et al., 2009]. The main aims of the Plan are:

- The construction of 30 large-scale wind farms with the total capacity of 0.1 GW;
- The provision for grid-connected wind and biomass to reach 5GW and 5.5 GW respectively;
- The achievement by biomass and waste fuelled generation of more than 5.5GW by 2010 (see Appendix H for more detailed targets).

3.4.3.3 Medium and Long-term Special Planning for Energy Conservation

As the part of the 11th Plan, there is the *"Medium and Long Term special planning for Energy Conservation"*. It was promulgated in November 2004 with the main aim to promote energy conservation and energy intensity reduction [NDRC 2007]. The general target of the Plan for energy intensity is to reach 2.25 tce in 2010 and then 1.54 tce in 2020 per 10,000RMB [Wang, 2006]. According to the plan, the following are the main aspects of energy conservation and related safeguarding measures [RCSD, 2006]:

- Industrial restructuring: the main component of China's industrial policies is to reduce consumption of energy and other resources, improve the comprehensive utilisation efficiency of energy and resources, promote cleaner production, prevent and control industrial pollution.
- Structural adjustments: the internal structures of industries should be adjusted in a way that helps the energy conservation. Its pattern is "low input, low consumption, less emission and high efficiency" [SC, 2007].

- Command and control: to shut down all enterprises belonging to 15 small categories[2], new 5 small categories[3] and listed in catalogue of product and technologies to be eliminated; to stop and neaten enterprises that have no reasonable managing measures and cannot realise emissions criteria; to stop and threat those that have not finished their treatment task and are still discharging emissions above their permitted level criteria; to stop production in factories that do not implement an environmental impact assessment and do not reach environmental requirements etc.

- Standards and regulations of buildings: in 2005, an investigation carried out by the Ministry of Construction found that only 59% of buildings designed and awaiting construction and 23% of existing buildings follow correct building codes. The energy-saving design standard for public buildings was published in July 2005. During the 11th 5-year period, design standard of saving 50% energy must be implemented in new buildings, and as much as 60% for some big cities.

- Economic incentives: to establish a catalogue of energy-saving equipment; to provide subsidies of investment and capital or support of reduced interest loans to some key energy-saving projects discussed below in section 3.4.3.4, technological development, and demonstration projects. The target is to save 240 Mtce during the 11th 5-year period through ten key projects. Energy pricing is also critical [RCSD, 2006].

- Launching of energy-saving projects: currently China is carrying out ten key energy-saving projects, which involve petroleum substitution, CHP generation, surplus heat utilisation, and the construction of energy efficient buildings. The government is also encouraging the extensive application of high-efficiency and energy – saving products.

- Promotion of energy conservation in society: increase of public awareness and the culture of energy conservation. The energy conservation system is planned to be incorporated into the system of elementary and higher education and technical training. The use of mass media is also suggested to publicise and popularise more relevant energy conservation knowledge [SC, 2007].

In China where there is a top-bottom society, the government plays the key role to adjust economic structure, facilitate energy savings, and develop renewable energy through effective policy design and coordination among administration, law, and

[2] Small paper mills, small leather making, small dyeing material, small homemade coke, small galvanisation, small fulling and dyeing, small pesticide, small gold filtration, small oil refinery, small plumbing, small asbestos, small radialisation, small hydrodyrum refinery, small arsenic refinery.

[3] Small coal fired power, small glass making, small paper mills, small oil refinery, small steel mills.

incentives. The government acts as a choice editor through relationship with retailers and suppliers and catalyses action on energy conservation [RCSD, 2006].

3.4.3.4 The Key Projects

In 2005, *"Ten Key Projects"* were incorporated in the 11th Five-year Plan. These are important engineering technological measures, which are there to help to achieve 20% energy intensity reduction. These projects focus on reducing energy in industry and buildings; they include [Zhou et al 2009]:

1. Renovation of coal-fired industrial boilers using more than 50 Mtce per year;
2. District level CHP projects to save 35 Mtce per year;
3. Waste heat and pressure utilisation to save 1.35 Mtce per year;
4. Oil conservation and substitution to save 54.3 Mtce per year;
5. Motor system energy efficiency to save 2.46 Mtce per year;
6. Energy system optimisation;
7. Energy efficiency and conservation in buildings to save 100 Mtce per year;
8. Energy efficient lighting to save 3.56 Mtce per year;
9. Government procurement of energy efficiency products;
10. Monitoring and evaluation systems.

The saving of all these projects together is expected to be more than 250 Mtce annually, which is about 40% of 2010 target. In order for these projects to be implemented, provincial energy conservation centres were provided with financial support [Zhou et al., 2009].

3.4.4 National Climate Change Programme:

The National Climate Change Programme was implemented in 2007. It outlines the impact of climate change on China, and sets out a strategy to mitigate climate change and achieve sustainable development. This includes economic restructuring, energy efficiency improvement, vehicle emissions standards, participation in international R&D programmes, development, and utilisation of renewable energy etc. Many of these targets are from the 11th Five-year Plan (2006-2010) [NDRC, 2007].

The main objectives of the Programme are:

- To control GHG emissions and to enhance the capacity of adaptation to climate change by accelerating the transformation of their economic development pattern, strengthening policy on energy conservation and utilisation, speeding up R&D and enhancing public awareness. This also involves the optimisation of energy consumption though the development of renewable energy and nuclear power; the reinforcement of their industrial policies concerning metallurgy, construction materials and the chemical industry; control irrigation and fertilisation systems, and water conservation; increase forest coverage; monitor the trend of sea-level variation, etc.

- To enhance R&D by strengthening, further developing and improving basic research on climate change, and building up independent innovation capacity and promoting international cooperation and knowledge transfer.
- To raise public awareness and improve management by promoting more publicity, education and training; improving the inter-ministerial decision-making mechanism and developing a new mechanism, which would involve public participation.

For all the objectives to be addressed, the Programme suggests key areas that have to be a matter of priority. It also suggests major steps to aid mitigating climate change for each area. It mentions the key areas that have to adapt to climate change and emphasises the need for international cooperation [NDRC, 2007].

3.4.5 Scientific and Technological Actions on Climate Change

The Scientific and Technological actions were implemented in 2007 by the Ministry of Science and Technology and the NDRC. A document outlining gives these actions guidelines and sets targets for technological actions on climate change. It consists of five chapters outlining the current status of climate change and China's technological and scientific achievements in its mitigations. It also sets targets and key tasks for mitigating climate change and suggests measures that will help to enforce scientific and technological actions. The targets given in the Actions are divided into long-term (to 2020) and short-term (to 2010) [MST, 2007].

3.5 International cooperation

Since the 1980s, China has joined many international organisations and signed several international treaties. China's role in international politics and cooperation has increased dramatically since then. There are many forces that drive China to be more active in international carbon cooperation: including scientific knowledge and political consensus; international regime enhancement; information sharing and public awareness;

difference of technologies and their costs; trade liberalisation; TNCs expansion; and the issue of China's image [RCSD, 2006].

One of the ways in which China is showing its international cooperation on climate change mitigation is in the short term by coping with climate change through enhancing carbon management and improving energy efficiency, and in the long-term by reducing the GHGs and mitigating future climate change through financing the development of low carbon technologies. By no means, international cooperation always brings China benefits [Johnson, 2001]. The following figure 3-3 shows two-dimensional impacts for Chinese participation in international cooperation [RCSD, 2006].

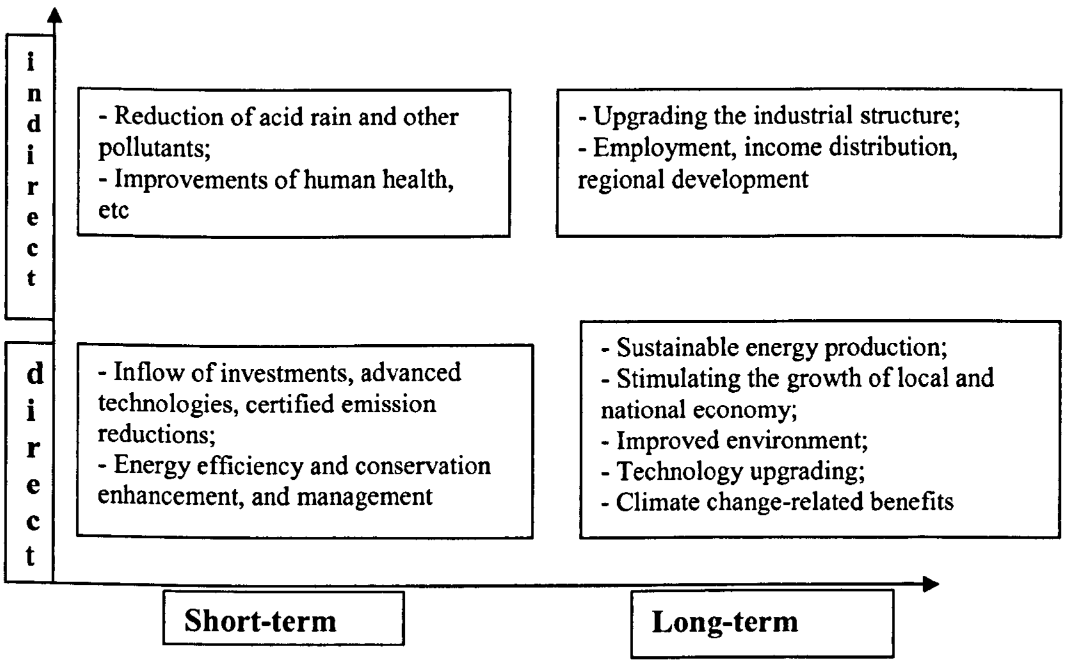

Figure 3-3 Two-dimensional impacts for China's participation in international cooperation

China, being one of the major contributors and also one of the potential victims of climate change, has become one of the main recipients of climate-related aid from bilateral and multilateral cooperation projects from the World Bank, the UNDP, the Asian Development Bank, and others [RCSD, 2006]. Moreover, China gets a lot of financial support from bilateral cooperation projects on climate change with the USA, Canada, Australia, Switzerland, and Norway. The largest bilateral projects are: EU-China Energy and Environment Partnership; Fossil Energy Protocol between the USA and China; and Climate Change Partnership of Australia and China.

Another important cooperation in the area of climate change is China – UN cooperation. China took its seat in the UN in 1971, and now undertakes a very important role in representing developing countries in the UN. The UNEP was established in the 1970s, and has had good relationships with China ever since. China has established foreign missions in the UNEP after the Stockholm conference, and the UNEP is playing an important role in establishing environmental institutions in China. It also contributes to strengthening SEPA's position within the Chinese government. The following are the main important points in China-UN cooperation [Heggelund, 2007]: training of personnel and policy making; public awareness; technical assistance; networking.

China also receives 17% of the total funding for climate change projects from the Global Emission Facility (GEF), 70% of which is used on energy efficiency projects and renewable energy projects, etc. In 2002 CDM projects were established in China; from 2002 to 2005 the total foreign investment for the development of 4 CDM projects[4] in China accounted for approximately 7.73 bln RMB (US $ 0.93 bln) [RCSD, 2006].

China can be characterised as a key actor in climate change discussions and negotiations as it has an influential position in the "Group of 77 and China". It is a rather heterogeneous group with largely different interests but acting united in climate change negotiations. China plays a major role in forming the position of the developing countries in these negotiations: this position being that it was the developed countries who played the largest part in emitting the GHG emissions that have caused the problems that the world is facing now; moreover, developed countries' technological and technical capacity to reduce emissions and mitigate climate change is much better then developing countries [Bjorkum, 2005].

It is important to remember that China is sceptical of international regimes to some extent. The country is cautious towards any policies that might affect its national sovereignty or questions that concern internal affairs of state [Heggelund, 2007].

3.5.1 Multilateral agreements

3.5.1.1 The Asia –Pacific Partnership (APP) on Clean Development and Climate

The APP is one of the climate change mitigation initiatives working outside of the UN. It is a seven countries pact with the aim to reduce emissions though technology and

[4] Xiaogushan Hydro Project in 2003; Huitengxile Wind Project in 2004; Zhaonan Wind Project in 2005; Daliangzi Hydro Project in 2005.

voluntary public-private partnership [Heggelund, 2009]. The APP countries are working with China in carbon-associated areas, and this has proved successful. There are some projects with multilateral banks that are involved with financing with incentives and the programmes identified by the task forces that expand the use of technologies and practices designed to promote objectives of the Partnership [RCSD, 2006]. International cooperation has a big impact on technology transfer due to the following reasons:

- strengthening innovation capacity (R&D): there are more than 400 RD&D centres in China set up by TNCs;
- enhancing technology integration and linkages: there is a possibility for China to acquire a complete package of technologies that is a mix of equipments, know-how and managerial skills;
- upgrading the overall technology levels/capacities;
- promoting private sector participation [RCSD, 2006].

In 2006, the APP issued its communiqué outlining that the "Partnership will be consistent with and contribute to our efforts under the UNFCCC and will compliment, but not replace, the Kyoto Protocol" [APP, 2006]. The APP has established main tasks forces that will focus on: renewable energy and distribution generation, power generation and transmission, and reducing energy consumption in the following industries: steel, aluminium, cement, coal mining, and building and appliance. There are also five projects listed as 'cross-cutting or other'. China is involved in all task forces, but not all projects, and is a co-chair of the Cleaner Fossil Energy Task Force and the Power Generation and Transmission Task Force [APP, 2009].

There are number of factors that explain why China is highly involved in the APP. The main motivation is the potential for the APP to contribute to China's energy security challenges as all task forces are related to energy production, energy intensive industries, or energy efficiency. Secondly, the APP focuses on technology that coincides with Chinese goals. Thirdly, the APP countries would like to mitigate climate change without giving up their development growth, which is very attractive to China. Fourthly, the APP provides a way for China to position itself on the global arena [Heggelund, 2009].

3.5.1.2 The Renewable Energy and Energy Efficiency Partnership (REEEP)

The REEEP is a global public-private partnership that structures policy and regulations for clean energy and provides financial support for these projects. The aim of REEEP is to accelerate the integration of renewables into the energy mix and to advocate energy efficiency as a way to improved energy security and reduce GHG emissions. China received support for more than 10 different projects with a total cost of around 700,000 Euros [Li, 2007].

3.5.1.3 International Carbon Sequestration Leadership (CSLF)

CSLF is a voluntary climate initiative of developed and developing countries, members of which are involved in technology cooperation in order to reduce emissions. It has been organised as a technical working group to develop technology and recesses for dealing with GHG emissions independent of other climate change activities. It carries out different projects and demonstrations, including projects on Carbon Capture and Storage (CCS), hydrogen, and low-carbon fuels for transportation, etc [Li, 2007].

3.5.2 Bilateral agreements

3.5.2.1 US – China Memorandum of Understanding on Biomass Development

In December 2007, a Memorandum of Understanding was signed between China and the USA. Its aim is to promote further research to propagate the greater use of biomass. The Memorandum outlines a large number of tasks for cooperative efforts between the two countries with the focus on the exchange of scientific, technical, and policy information on biomass production and its conversion into biofuel and bio-based products and chemicals [IEA, 2008].

3.5.2.2 Market Transformation programme – Partnership with the UK

An agreement on partnership was signed in 2006. The aim of this partnership is to harmonise and to cover product performance specification at a global level. Theoretically, this project would let China develop a more informed approach to product policy. It focuses on the efficiency of appliances [IEA, 2008].

3.5.2.3 The UK – China Action Plan on Climate Change and Energy

"The UK – China Action Plan on Climate Change and Energy" was outlined in December 2007. Its main objectives are to "*ensure climate security and secure, clean energy supplies at affordable prices by promoting a faster transition to a low carbon economy in China, and China's role in delivering an international framework*" [IEA, 2008]. This main target is made of seven objectives that are:

- encouraging China to engage positively in international negotiations;
- raising awareness and understanding of the need to adapt to climate change;
- persuading key national and regional political and industrial policy-makers and leaders of the need to address climate change;
- accelerating the delivery of key technology cooperation projects, including the Near Zero Coal Emissions project;
- persuading China to borrow for clean energy projects from the World Bank and the Asian development Bank, and to maximise its opportunities under the Environmental Transformation Fund;
- strengthening China's performance on improving energy efficiency;
- strengthening China's ability to better forecast future energy demand.

3.5.2.4 Memorandum of Understanding between the National Development and Reform Commission of the People's Republic of China, and the Department for Environment, Food and Rural Affairs on establishing a China-UK Climate change Working Group

The Memorandum was signed in London in December 2006 that is to run for five years, at the end of which the Working Group will meet again. The main aim of the Memorandum is to cooperate and share knowledge on climate change. The main areas covered by the Memorandum are [IEA, 2008]: science work; energy efficiency; energy technologies; approaches to adaptation; the use of flexible mechanisms, particularly CDM capacity building activities.

3.5.2.5 EU-China Energy and Environment Partnership

Annually, the EU supports several energy efficiency, renewable energy, and other carbon reduction based technical projects in China. The aim of the cooperation is to improve energy efficiency, enlarge the utilisation of renewable energy, develop natural gas markets, and encourage sustainable energy use [Li, 2007].

China also has bilateral agreements with Australia, Canada, Japan, and some separate EU countries.

3.6 Summary

Energy conservation and energy saving is one of the priority areas for Chinese government. There is already evidence that some of the governmental actions are having an effect. However, the main problem here is whether China will be able to stick to its commitments and not make their economic development a greater priority, above energy efficiency.

One commission and two ministries becoming more involved with think tanks and there is a trend that the number of actors in the policy making process will be increased. The policy making process in extremely complex in China and the agencies in charge do not always communicate well, which makes policies and regulation less efficient than they could be.

Climate–related and environmental aspects are now an integral part of China's Five-Year programmes, however, most of the policies are based on the desire to keep up with the economic growth and maintain it. Often the targets set are too ambitious, and sometimes the targets are a desirable by-product but not the main objective. China has the capacity to develop climate-related measures, and it has been proven already. However, lack of an enforcement and monitoring tools is a very big issue that needs to be overcome.

China actively participates in international efforts on climate change mitigation and takes part in multilateral, regional, and bilateral cooperation. However, China's principle position has not changed dramatically, and it is unlikely that the major policies will be reviewed is the near future.

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Chapter 4 - Renewable energy in China

4.1 Introduction

Internationally, renewable energy is divided into two categories: conventional renewable energy, which includes large-scale hydropower and biomass energy produced through conventional technologies, and new renewable energy, which includes small-scale hydropower, solar energy, wind, biomass, geothermal, ocean energy and organic solid wastes. In 2000, renewable energy accounted for 13.6% of the world's supply of primary energy and 19% of electric power [ERI, 2004]. China's renewable energy policy target is to reach 15.4% renewable energy share by 2020 and 27.5% by 2050. The policy instruments used to reach this target vary from the "Renewable Energy Law" to the political and financial support of R&D. The Chinese government pays a lot of attention on the development and applications of the renewable energy technologies. It not only pays attention to strategic positioning and specific goals and targets, but it also seeks to establish a policy system and institutional framework that aids the rapid development of the renewable energy industry [Wang, 2009]. Since the UN Environmental and Development Conference in 1992, the Chinese State Council has formulated a number of strategies to tackle its environmental and development problems. These strategies were adjusted to local conditions in order to develop and popularise solar, wind, geothermal and biomass energy. The first step on the way to the development of renewable energy technologies was done in the Agenda 21, mentioned earlier in Section 3.4.1. Since then, the development of renewable energy technologies has been listed as a priority field in every National Five-Year Plan, starting from the 6th Five-Year Plan in 1981.

Today, wind, solar and biomass are already relatively mature technologies and have a preliminary industrial base; research on geothermal, ocean and hydrogen energies are also in progress. However, the emergence of technical issues, such as grid connection, demand variability, etc. form obstacles for a deeper development of the industrialisation of these technologies.

There is still a big gap in renewable energy technology development in China compared to the developed countries. This is mainly due to the lower investments and skilled labour in this sector, although recently progress has been achieved in the research and demonstration of some certain technologies, such as wind and solar.

Renewable energy technologies in China have made good progress in the aspect of development and utilisation, and have attracted more and more attention from all over the world.

In this chapter, the development of the renewable energy technologies is described. It is important to understand their development, as in later chapters some of the technologies are used in the calculation of building energy consumption reductions. In addition, legislation for renewable energy is discussed, as well as the barriers and problems that renewable energy technologies face in China.

4.2 Overview of the renewable energy technologies market

4.2.1 Overview of the renewable energy development in China

In China, renewable energy plays a critical role in providing electricity services to more than 120 mln people who are currently not served by the electricity grid. The economic development of northern and western rural areas, which have abundant renewable resources such as wind and sun, is a priority of the Chinese government. Renewable energy will also benefit urban areas that suffer from high levels of GHG emissions. Moreover, renewable energy helps to reduce China's growing CO_2 emissions.

Renewable energy development goals in China cover three aspects: the developing of the rural energy infrastructure to eliminate energy poverty; the replacing of fossil fuels to optimise the energy structure; and developing and improving the renewable energy industry with respect to its own intellectual property rights [Shi, 2009].

Today, China produces about 1.5 mln tonnes of coal; to meet the electric power demand of the country, China plans to continue to rely primarily on coal. According to BAU scenarios, emissions from coal-fired power plant expansion are expected to increase 3.5 times by 2010 and may reach 5 times their current levels by 2020 [Greenpeace, 2007].

China has sufficient potential wind farm site to support at least 250 GW wind capacity. Solar radiation resources are also great, and could produce up to 1,200 MW electricity capacity from grid-connected PV and solar home systems. China would also be able to generate 700-900 MW in surplus power from bagasse, a waste product of the sugar industry. However, it seems that the renewable energy industry is not taking off at the speed it could and that there is very little progress in terms on MW installations [Greenpeace, 2007].

Table 4-1 summarises the current renewable energy capacity and introduces its expansion plan.

Table 4-1 China renewable energy capacity expansion plans (in MW) [NREL, 2005]

Renewable resource	Installed capacity (1994)	1994-2000	2001-2010	2011-2020	Total	National resource
Wind	30.4	1010	2130	5330	8500	250000
Solar	3.3	66	130	300	500	450-1200
Geothermal	30.4	76	94	130	330	500
Biomass	7.1	13	25	55	100	700-900
Ocean	6	34	160	200	400	9830

Today, modern renewable energy sources in China account for 7.5% of China's primary energy demand. Traditional biomass also plays an important role and accounts for approximately 12%. The share of renewable energy in electricity generation is 15%, with hydropower plants as the largest technology [Greenpeace, 2007].

The Chinese government target for 2020, shown in Table 4-2, is for renewable energy sources to make up 16% of the total primary energy mix. It is proposed that decentralised renewable energy systems, where power and heat are produced close to the point of final use, will play an important role in supplying electricity to rural populations in remote areas [Greenpeace, 2007].

Table 4-2 Government targets on renewable energy development (in GW) [CSEP]

	Installed capacity by 2005	Installed capacity by 2010	Installed capacity by 2020
Hydro	110	180	300
Wind	1.26	5	30
Biomass	2	5.5	30
Solar PV	0.07	0.3	1.8

According to the "Medium and Long Term National Planning of Renewable Energy Development" [NDRC, 2007], the target for the installed capacity of renewable energy generation is 30% of total generation capacity by 2020; of which hydro, wind, solar, and biomass generation should account for 300GW, 30GW, 1.8GW and 30GW respectively. Renewable energy supply will be 400-500 Mtce, or about 1/7 of primary energy consumption assuming the total primary energy consumption will be around 3.5 bln tce. However, the emergence of renewable energy will only slightly dent the overall dominance of coal in the near future in China [RCSD, 2006].

4.2.2 Wind power

China has approximately 250 GW of wind energy that is mainly situated in the northern part of China (Xinjiang, Inner Mongolia, Jilin, Liaoning, and Shandong) and the southeast coast of Hainan. The distribution of wind resources can be seen in Figure 4-1. The existing wind farms in these areas are of high development value and economic potentiality. By the end of 2006, China's wind capacity was ranked No.5 in the world [Wang, 2009].

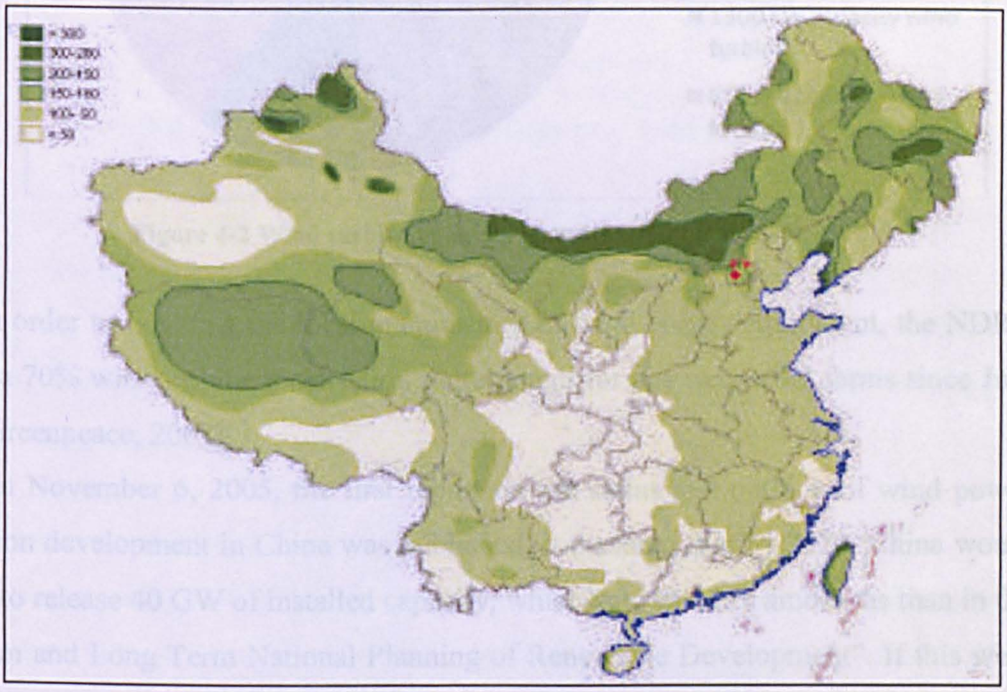

Figure 4-1 Distribution of wind resources [Li, 2006]

Wind power generation in China began in the 1970s when household micro-scale wind power generators of 100 W to 1 kW were first adopted in areas without a power supply for lighting and living [Li, 207]. In the 1990s, the development of China's grid-connected large-scale wind power began, and it has been developing rapidly during the "10th Five-Year Plan" period: from a total installed capacity of 350 MW in 2000 to 6 GW in 2007, with an average annual growth of 50% [Wang, 2009].

By the end of 2005 over 60 wind farms were built with a total installed capacity of 1.26 GW. The total installed capacity increased by 65% in 2005 and then 80% in 2006. China plans to install further 5 GW wind power by 2010 and 30 GW of wind power by 2020. Moreover, it is predicted that by 2020 the cost of wind power will be the same as that of coal power now. In 2030, the total capacity will reach between 150 to 200 GW, and wind power will become the third (after coal and hydro) power resource in China [Li, 2006]. China's installed wind turbine capacities can be seen in Figure 4-2.

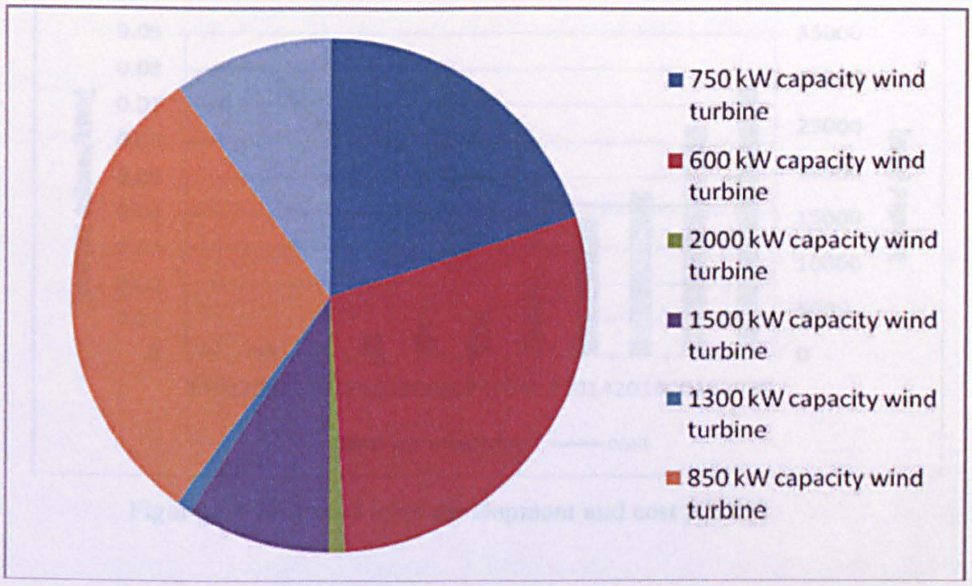

Figure 4-2 Wind turbine capacity range installed [Li, 2007]

In order to facilitate the local manufacture of wind energy equipment, the NDRC has set a 70% wind turbine localisation requirement for any new wind farms since July 2005 [Greenpeace, 2007].

On November 6, 2005, the first report on the status and outlook of wind power generation development in China was published. It declared that by 2020, China would be able to release 40 GW of installed capacity, which is even more ambitious than in the "Medium and Long Term National Planning of Renewable Development". If this were to be true, wind power would generate 80,000 GW annually to meet the demand of 80 mln people thereby avoiding 48 mtce [RCSD, 2006].

By the end of 2006, cumulative installed wind capacity had reached 2.6 GW with an annual growth of over 46%. The growing wind power market has encouraged domestic production of wind turbines: by the end of 2006 more than 40 companies were involved in manufacturing, and domestic production accounted for 41.3% of the annual market in 2006 [Li, 2007]. Figure 4-3 shows the projection on wind development and its cost.

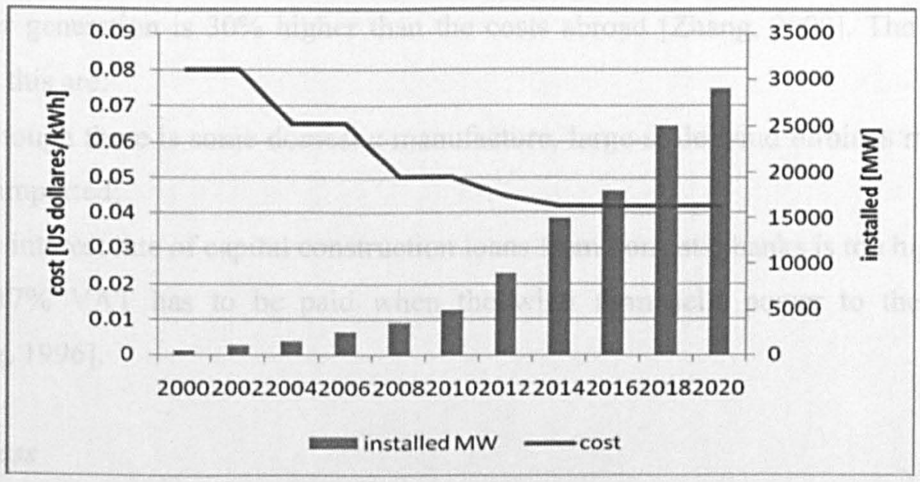

Figure 4-3 Projected wind development and cost [CSEP]

Examples of Chinese wind turbine manufacturers include Sinovel who produced more than 500 turbines of 1.5 MW-class in 2007; and GolWind who also produced and installed over 50 of its direct-drive 1.2 MW turbines. Since then, production capacity of supporting components improved dramatically which meant that supply bottlenecks began to ease [Wang, 2009].

4.2.2.1 Problems with wind power development in China

The advantages of wind power generation are the following: no fuel and pollution; short construction cycle and flexible scale; simple operation and maintenance; low cost; and little occupation of land. However, there are aspects that need to be improved, such as the cost/MW installed, power grid construction and reinforcement, more domestic wind power equipment manufacturers; the increase of unit power; and enhanced reliability [Li, 2006]. There are still defects in the design and manufacture of some spare parts and the production capacity is inadequate, much relying on imports. It is also recorded that wind turbine control systems and the electricity converters still have many problems [Wang, 2009].

In comparison with potential wind resource, the developed wind resource only accounts for 0.002% in China. There are two reasons for this. Firstly, people are not familiar with wind power and they do not get enough information about the advantages of wind power and the significance of using it. Secondly, wind power is not attractive for investors as the cost per kW and the commercial tariff for wind power generation in China is higher than those for thermal and hydro generation. The unit cost per kW for wind power generation is 30% higher than the costs abroad [Zhang, 2009]. The main reasons for this are:

- Although there is some domestic manufacture, large-scale wind turbines mostly have to be imported;
- The interest rate of capital construction loans from domestic banks is too high;
- A 17% VAT has to be paid when the wind farm sells power to the grid [Xianzhang, 1996].

4.2.3 Biomass

Here, biomass includes agricultural and forestry residues, crop stalks, oil plants, energy crops, methane and organic wastes. Major areas of biofuel crops are shown in Figure 4-4. Traditional biomass consists of agricultural and forestry residues that are burned directly for cooking and space heating in rural households; it is still the main source of energy supply for more than 35 mln Chinese living in areas where there is no access to the electricity [Zhang, 2009].

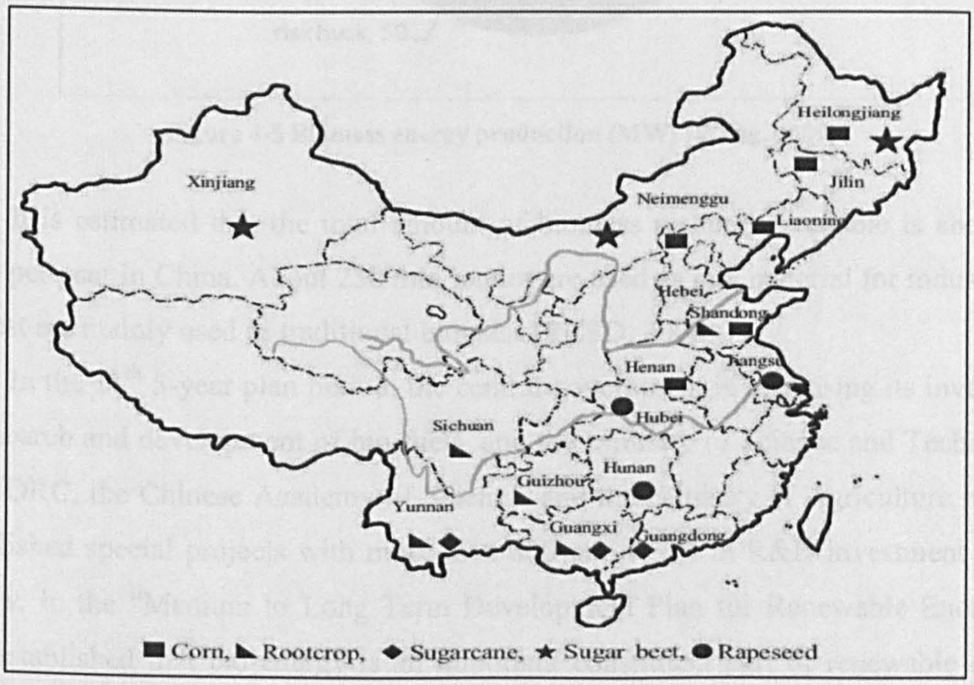

Figure 4-4 Major area of main biofuel crops

The annual energy use of crop stalks as a biomass energy resource is around 150 Mtce; forestry residue resources are around 200 Mtce; rapeseed, jatropha, sweet sorghum and other oil plants and energy crops can meet with raw materials demand of an annual output of 50 mln tonnes of liquid fuels; organic industrial waste and livestock organic waste can produce around 80 bln m^3 of biogas [Wang, 2009]. By the end of

2007, China's biomass power generation capacity was 3 GW [Wang, 2007]. The biomass energy production output can be seen in Figure 4-5. The annual production of ethanol and methane was 1.02 mln tonnes and 8 bln m³, respectively. The governmental target is to have modern biomass plants with an installed capacity of 5.5 GW by 2010 and 30 GW by 2020. For methane, the targets are 19,000 mln m³ and 44,000 mln m³, respectively [Greenpeace, 2007].

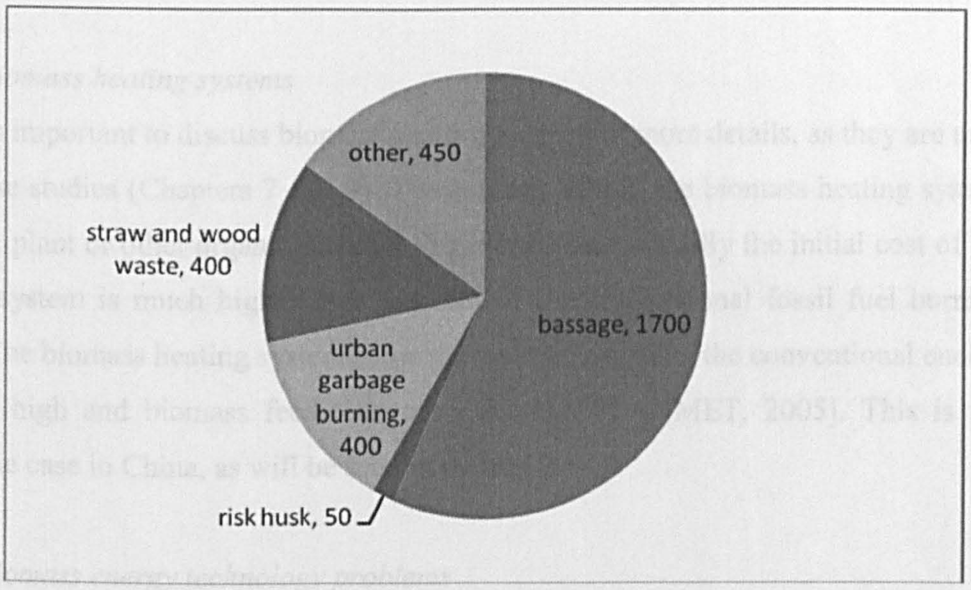

Figure 4-5 Biomass energy production (MW) [Wang, 2009]

It is estimated that the total amount of biomass resource available is about 500 Mtce per year in China. About 250 mln tonnes are used as raw material for industry and the rest are mainly used as traditional biomass [RCSD, 2006].

In the 11th 5-year plan period, the central government is increasing its investment in research and development of bio-fuels, and the Ministry of Science and Technology, the NDRC, the Chinese Academy of Science, and the Ministry of Agriculture have all established special projects with more than 800 mln RMB in R&D investment in bio-energy. In the "Medium to Long Term Development Plan for Renewable Energy", it was established that bio-energy is an important constituent part of renewable energy, and objectives for its development were set through to 2020 [NDRC, 2007]. By the end of 2007, 7500 biogas digesters for rural families and 5,000 livestock and poultry farms and industrial waste gas projects were built in China. Their annual output is 11 bln m^3 of biogas. Moreover the construction of four pilot projects that use grain as the raw material for the production of fuel ethanol and have an annual capacity of 1.02 mln tonnes, were approved. In 2006, China produced about 3.5mln tonnes of ethanol, of which fuel ethanol output was 1.3 mln tonnes – the third largest in the world. Output of bio-diesel from waste oils reached 60,000 tonnes in 2006 [Wang, 2009].

Progress has been made in ethanol, and butanol production technology using biological materials. Today, there are six national enterprises, which have completed construction on a kiloton-level ethanol production device, of which the largest can produce 3,000 tonnes [Wang, 2009].

4.2.3.1 Biomass heating systems

It is important to discuss biomass heating systems in more details, as they are used in the case studies (Chapters 7 and 9). The concept behind the biomass heating system is to burn plant or other organic material to generate heat. Usually the initial cost of the biomass system is much higher than the cost of the conventional fossil fuel burning system. The biomass heating system is the most attractive when the conventional energy costs are high and biomass feedstock costs are low [CANMET, 2005]. This is not usually the case in China, as will be seen in section 7.5.2.

4.2.3.2 Biomass energy technology problems

Although the market for biomass gasification power generation/heating and biomass briquette/pellet technology has matured, China's biomass liquid fuel technologies have not yet reached maturity and cannot meet the needs of large-scale industrial production. The main problems, such as high cost of cellulose enzyme production, old ethanol production technology, and high-energy consumption need further research. Moreover, the imperfect gasification purification system, the low-production capacity of fuel equipment, and other problems block the production scale [RCSD, 2006]. Another issue is that due to the biomass feedstock size, its delivery, storage and handling can be limited. Moreover, it is important to ensure the secure supply of the biomass. [CANMET, 2005]

4.2.4 Geothermal power

Geothermal power generation can be used in areas with a high temperature geothermal resource and local power demand (either electrical or thermal). In China, there are 5,500 possible geothermal sites and 45 geothermal fields with a total resource of 3,200 GW. Geothermal energy is extensively used for power generation, textiles, printing and dyeing, heating, medical care and health. The installed capacity today is

30.4 MW. The proven high temperature geothermal resources of China are mainly concentrated in Yanbajing of Tibet, the western part of Yunnan Province, and Taiwan, totalling 7,7 GW. The water temperature ranges from 140 to 330°C. The geothermal resources of low and middle temperatures are suited for direct utilization. Areas in the North and Northeast of China and in Fujian and Guangdong provinces have successfully applied geothermal energy in aquaculture, household heating, and tourism. [Greenpeace, 2007].

However, geothermal development has been relatively slow in China. One of the reasons is that the places with high temperature geothermal resources are mostly located in areas with large hydro resources, so the development of hydropower projects has taken precedence over geothermal projects [NREL, 2005].

China's largest geothermal installation is Tibet's Yanbajing geothermal plant with equipment imported from Italy and a capacity of 253 MW. It provides about 41% of the local town of Lhasa's power needs in the summer and up to 60% in the winter [Li, 2006].

4.2.4.1 Ground-source heat pump

It is important to discuss the background of GSHP here, as the system is used for the case studies discussion in section 8.5.2. GSHP applies to different systems that use ground, groundwater, or surface water as a heat source and sink. The principle of the GSHP is as follows: taking into consideration that 46% of the sun's energy heat reaches the planet is absorbed by the earth, this energy can be used for heating and cooling of the building. This form of solar energy's main benefit is that is does not need any transportation and is available on-site provided an open space is available. Because of the soils low thermal conductivity, it can transfer some heat from the cooling season to the heating season; the heat absorbed by the earth in summer effectively gets used in winter. The thermal fluctuations help in shifting the heating or cooling loads to the season where it is needed [CANMET, 2004].

GSHP provides low temperature heat by extracting if from the ground or a body of water and provides cooling by reversing this process. A heat pump is used to concentrate the free heat energy from the ground before distributing it in a building through conventional ducts. Heat pumps generally range from 3.5 to 35 kW in cooling capacity. GSHP does not create any combustion products directly but does require electrical input to move the heat, however since it draws additional free energy from the ground, it can produce more energy than it uses. Average GSHP efficiency is 200% to 500% over a season. GSHP is more efficient than air-source heat pumps as the temperature of the ground is more stable and moderate [CANMET, 2004].

The main problems with GSHP are high price and a buildings' limited availability of land for large earth connections [Hughes, 2008].

The research and practices of GSHP in China started much later than in developed countries, the first experiments and tests on the performance of GSHPs started at the end of the 1980s. The demand for GSHPs is rising rapidly in China as policy makers and the public have started to realise the benefits of GSHP projects. The first GSHP project was conducted in 1989 in Shanghai, where a closed vertical type ground heat exchanger was constructed. Since 2000, when incentive mechanisms and policies were established, the development of GSHPs became very rapid, as can be seen in Figure 4-6 [Yang, 2010].

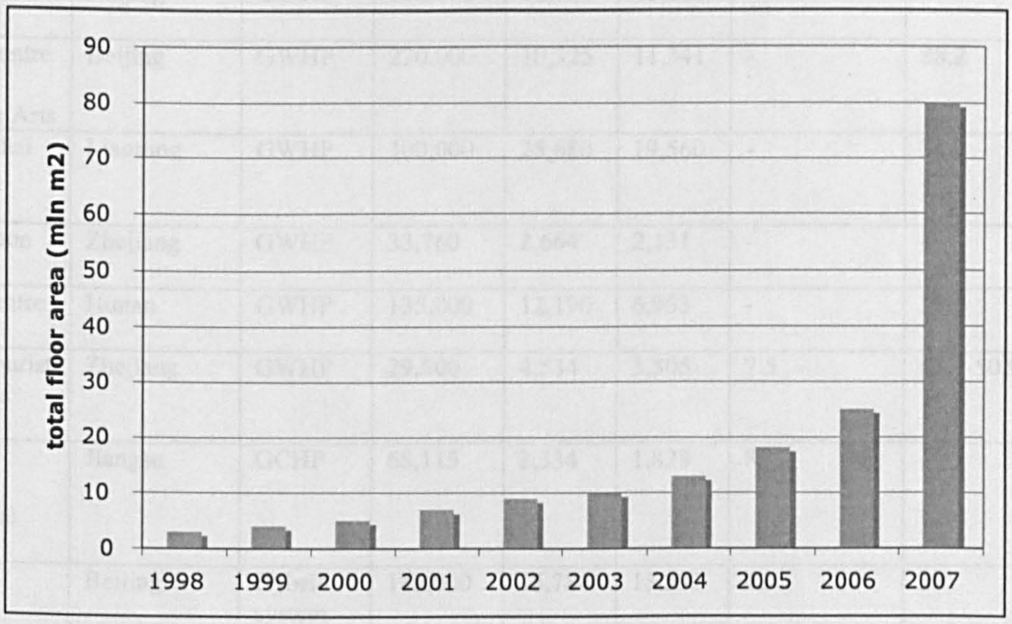

Figure 4-6 Total floor area of GSHP projects [Xu, 2008]

By 2005, the installed capacity of GSHP in China reached 631 MW with the annual energy use of 1824 GWh/year. GSHP are widely used in Beijing, Liaoning, Hebei and Shandong Provinces, which are situated in the "cold" or "hot summer and cold winter" climate zones and have abundant water resources [Yang et al., 2010]. The typical GSHP projects in China are listed in following table 4-3.

Table 4-3 Typical GSHP projects in China [Yang 2010]

Location	Province	Type	Floor area (m^2)	Cooling load (kW)	Heating load (kW)	Investment cost (mln RMB)	Annual operating cost (RMB/m^2)
Beijing Friendship Hospital	Beijing	GWHP	53,000	4,200	3,800	-	27
Qingdao Yingshentai International Commercial Port Building and Chengyang Trade Centre	Shandong	GWHP	84,400	6,751	4,051	29.9	19.4
Beijing Haidian Foreign Language School	Beijing	GWHP	50,900	4,581	4,717	-	35.9
Beijing Police Institute	Beijing	GWHP	178,000	16,000	15,000	-	-
National Centre for the Performing Arts	Beijing	GWHP	220,000	10,325	11,341	-	88.2
Dalian Xinhai Business District	Liaoning	GWHP	300,000	25,680	19,560	-	34
Dragon Moon Bay Hotel	Zhejiang	GWHP	33,760	2,664	2,131	-	-
Xingtan Centre Zone	Hunan	GWHP	135,000	12,190	6,953	-	19.6
Yinfeng Tourist Zone Xikou Fenghua	Zhejiang	GWHP	29,500	4,534	3,505	7.5	44.1-50.9
Nanjing Landsea International Block	Jiangsu	GCHP	68,115	2,334	1,828	8	-
Beijing Youyong software centre	Beijing	Hybrid system	185,000	15,784	13,391	42	32
Xi'an Gate of the City	Shanxi	Hybrid system	101,200	8,582	5,700	26	24.6
Ningbo Yinzhou Municipal State Taxation Bureau	Zhejiang	Hybrid system	19,000	2,400	1,600	9.6	36

Currently China has its own GSHP manufacturers, however, most of these companies are small or medium-sized, which indicates that the use of GSHP in China is still in the development stage.

4.2.5 Solar energy

China is rich with solar energy resources with 1.4×10^{16} kWh of solar radiation on the earth surface per year, equivalent to 170 bln tonnes of standard coal. Some areas receive an annual sunshine time exceeding 2,200 hours with a total radiation over 1389 kWh/m^2/year, which account for $^2/_3$ of the total land mass, offering great conditions for investments in solar energy development, as it can be seen from the Figure 4-7 below [Li, 2006].

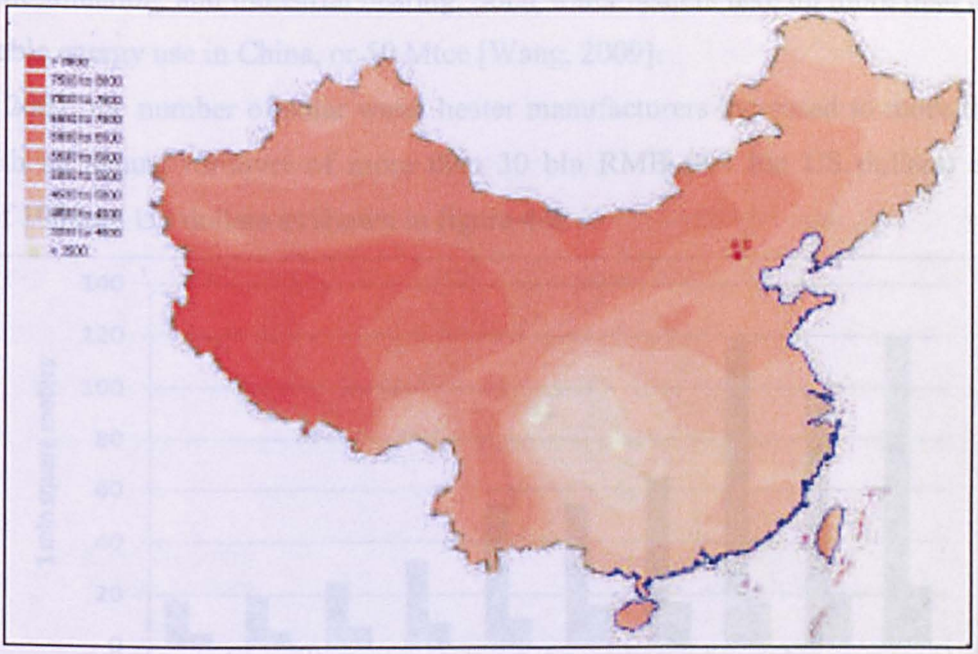

Figure 4-7 Solar energy resource distribution in China [Li, 2006]

4.2.5.1 Solar thermal

The most widely used solar energy technology is solar water heaters, which are mainly used to provide hot water in rural and small- and medium-sized urban life. China is the world's largest producer and consumer of solar hot water heaters, accounting for more than ½ of the world's output and consumption [Li, 2006]. By 2007, China's total area of solar heaters had reached 120 mln m^2, rising by 26% compared with 2006 [Wang, 2009].

No figures are currently available, but after 2008, the annual rate of growth and adoption of solar hot water heaters is expected to be 20% - 30%. If ¼ of China's population use solar hot water heaters, by 2020 the market will grow to 270 mln m^2. There are approximately 35 mln Chinese households owning solar hot water heater, and they spend 12%-20% less in power costs. The most significant city in terms of adoption of solar hot water heater in China is Rizhao (Shandong province) with 99% of city centre residents using them. In 2006, the value of solar hot water heater output was US $25mln; the cheapest solar hot water heater in China costs about US $150 [Li, 2007].

It is predicted that the carbon reduction from the use of solar power will mainly be delivered from solar thermal power until 2020. Recently, China has improved solar water heater technology in combination with building technology and completed a number of solar water heater and building integration projects. In addition to solar water heaters, China is also expanding the area of solar heating, refrigeration, air-conditioning, seawater desalination, and industrial heating. Solar water heaters take up more than half of renewable energy use in China, or 50 Mtce [Wang, 2009].

By 2007, the number of solar water heater manufacturers increased to more than 3,000 with an annual turnover of more than 30 bln RMB (4.4 bln US dollars) and exports of 100 mln US dollars as shown in figure 4-8.

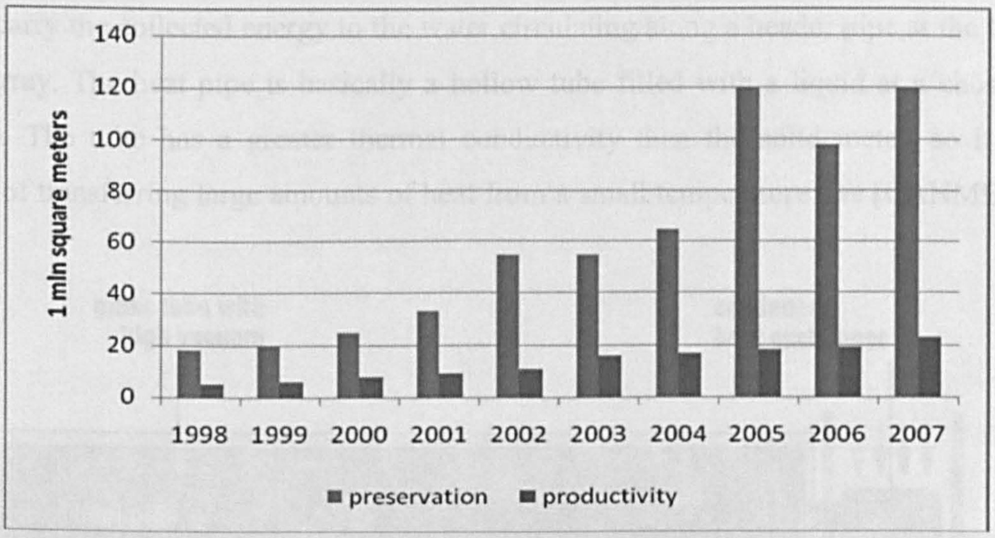

Figure 4-8 The capacity and scale of China's solar water heater production [Li, 2007]

China has also achieved a lot in the exploration of highly reliable, all weather, high-temperature solar collector systems and U-type all-glass vacuum tube collectors [Wang, 2009].

4.2.5.1.1 Types of Solar Water Heaters (SWH) systems

Different types of SWH are described further here, as it is important to understand the concept behind them for the further investigation and discussion in later chapters. The solar water collector used in the case study (Chapter 6) is SWH for service hot water.

Pumped SWH systems consist of solar collectors and a working fluid to transfer heat to the load. The system includes a pump that circulates the working fluid from the collectors to the storage tank, as well as control and safety equipment. Many systems also include a back-up immersion heater, which ensures that hot water needs are met during periods of insufficient sunshine [CANMET, 2004]. Solar energy is collected by the solar collector's absorber plates, which are applied with different coatings to improve the overall collection efficiency. Thermal fluid absorbs the energy collected. There are several types of solar collectors, the choice of which depends on the temperature of the application being considered and the climate [Boyle, 2004].

The modern evacuated tube collector, shown in figure 4-9, consists of a set of modular glass tubes with a heat pipe down the centre of each tube. Convective heat losses are suppressed by virtue of a vacuum in the tube. The collector uses a special heat pipe to carry the collected energy to the water circulating along a header pipe at the top of the array. The heat pipe is basically a hollow tube filled with a liquid at a chosen pressure. The tube has a greater thermal conductivity than the solid metal, so it is capable of transferring large amounts of heat from a small temperature rise [CANMET, 2004].

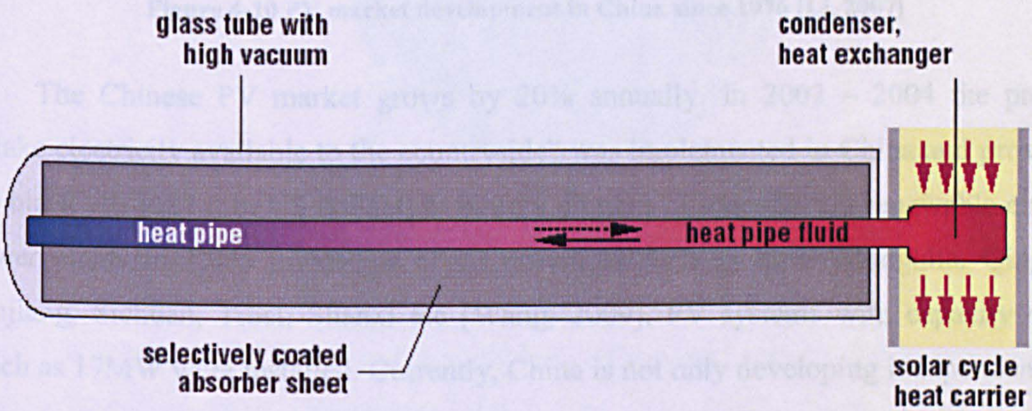

Figure 4-9 Plan view of an evacuated tube collector [CANMET, 2004]

Unglazed liquid flat-plate collectors are made of a black polymer and do not have a selective coating; neither do they include a frame and insulation at the back. These collectors are usually simply laid on a roof or wooden support. These collectors are very cheap and are good at capturing the sun; however, their thermal losses can be high, especially in windy locations [CANMET, 2004].

For glazed flat-plate collectors, a flat–plate absorber is covered with a selective coating and is fixed in a frame between single or double layers of glass with an insulation panel at the back. Because of the glazing, which gives the greenhouse effect, much of the solar energy is prevented from escaping, which makes them efficient, so they can be used in moderate climates [CANMET, 2004].

4.2.5.2 Solar PV

The major renewable energy generation technology in China is solar PV. Solar PV modules are used in industry as well as commerce; they also provide electricity to remote rural areas and urban lighting applications. China's installed capacity of PV systems by the end of 2006 was over 100 MW, around 50% of which are used to supply electricity to the residents of remote rural areas, as can be seen in Figure 4-10 [Li, 2007].

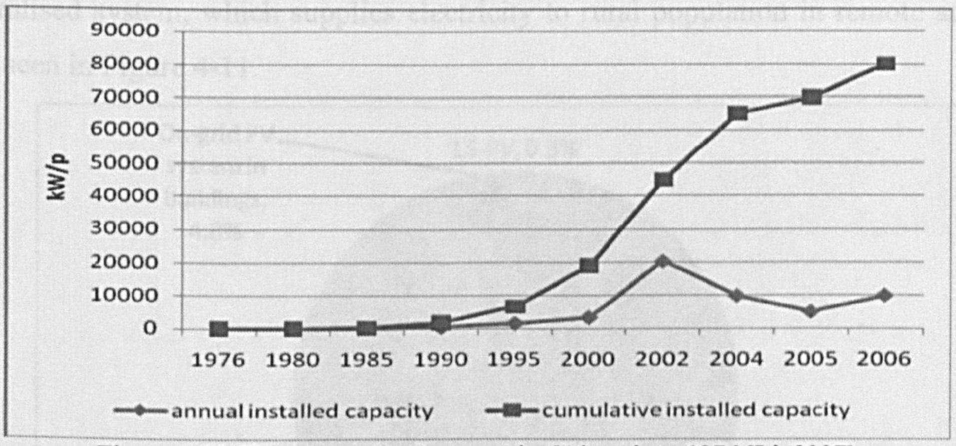

Figure 4-10 PV market development in China since 1976 [Li, 2007]

The Chinese PV market grows by 20% annually. In 2002 – 2004 the project "Make electricity available to the countryside" was implemented in China and provided 4.7 bln RMB (687 mln US dollars) to build a number of independent renewable energy power plants in 1,065 townships of 12 provinces such as Inner Mongolia, Qinghai, Xinjiang, Sichuan, Tibet, Shanxi etc [Wang, 2009]. PV systems with capacity of as much as 17MW were installed. Currently, China is not only developing independent PV systems in remote areas without accessing power grid; China has also begun the demonstration of roof-mounted grid-connected PV systems. The industrial and commercial PV markets are also relatively stable [Li, 207]. The annual production capacity for urban PV lighting systems is over 10MW, of which 55% come from decentralised PV power generation systems for residents in remote area [Wang, 2009]. The market breakdown for 2006 is shown in Table 4-3.

Table 4-4 China's PV market breakdown in 2006 [Li, 2007]

Market sector	Installed capacity/MWp	Market share/%
Rural electrification	33	41.3
Communication and industrial application	27	33.8
Solar PV appliances	16	20
On-grid PV system in buildings	3.8	4.8
Large scale power station in desert	0.2	0.3
TOTAL	80	100

For solar heating, the annual production capacity has reached 15 mln m² and the total coverage has reached 80 mln m². Solar power plays a very important role in decentralised system, which supplies electricity to rural population in remote areas, as can be seen in Figure 4-11.

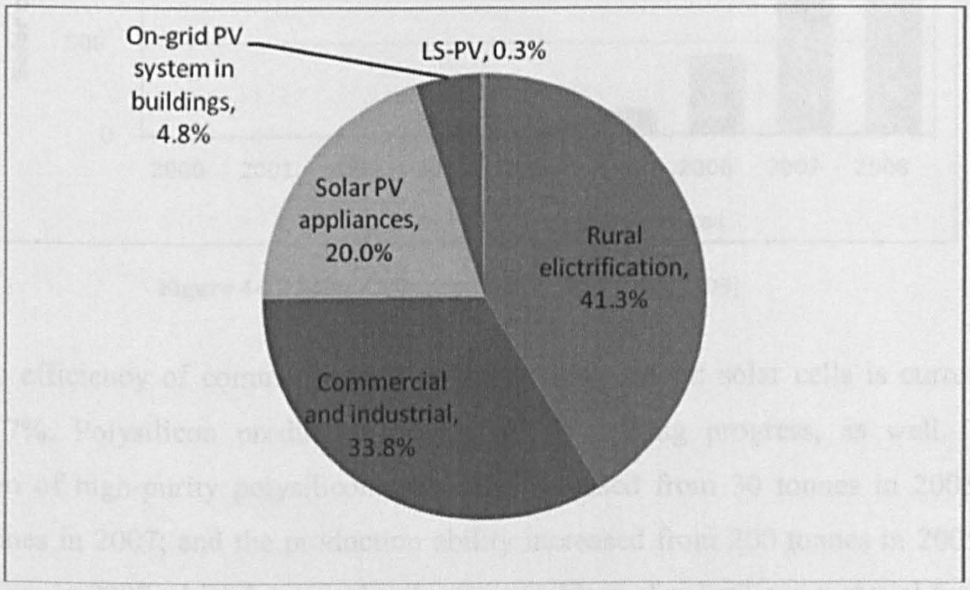

Figure 4-11 Market shares of PV power in China [Li, 2007]

The targets for 2010 are to have 300 MW of installed capacity of solar PV power and 1,800MW by 2020 [Greenpeace, 2007]. The target for 2020 and 2050 is to reach 270 mln and 500 mln m^2 with the potential to conserve 120 TWh in 2020 and 300 TWh in 2050. The CO_2 emission reduction will be 29 mln tonnes in 2020 and 72 mln tonnes in 2050 [Li,2007].

By the end of 2006, the cumulative installed capacity of solar cells reached 40 MWp. The market for PV power generation is currently mainly composed of communications, industrial applications, rural off-grid supply, grid connected systems and small solar products. PV is expected to have large promotion and popularisation in China by 2010, and installed capacity will reach 50 MWp by then [Shi, 2009].

Solar cell production is expanding gradually: the number of manufacturers of solar cells is growing and solar cell production has risen from 150 MW in 2005 to 1,100 MW in 2007, making China the world's biggest solar producing country [New energy, 2008]. The progress in manufacturing of PV cells can be seen in Figure 4-12 below.

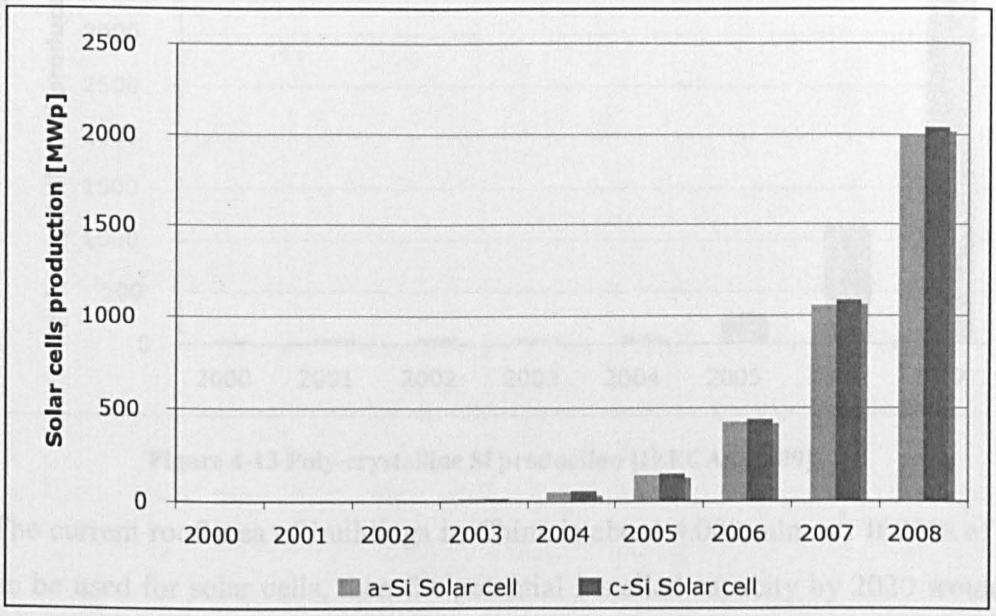

Figure 4-12 Solar Cells production [IEECAS, 2009]

The efficiency of commercialised polycrystalline silicon solar cells is currently around 17%. Polysilicon production technology is making progress, as well. The production of high-purity polysilicon materials increased from 30 tonnes in 2005 to 1,100 tonnes in 2007; and the production ability increased from 200 tonnes in 2005 to 5,000 tonnes in 2007 which has eased a shortage problem of polysilicon material for the production of solar cells [Wang, 2009]. This can be seen in Figure 4-13.

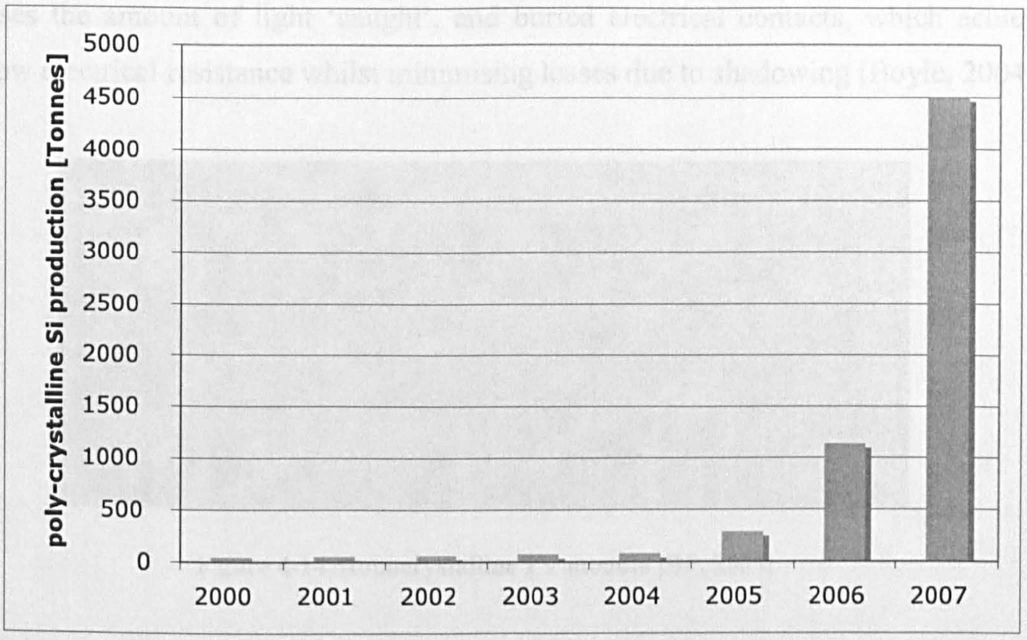

Figure 4-13 Poly-crystalline Si production [IEECAS, 2009]

The current roof area of buildings in China is about 4,000 mln m^2. If 20% of this area can be used for solar cells, then the potential installed capacity by 2020 would be 100 GWp [Ng, 2009].

4.2.5.2.1 Types of PV modules

To make the PV modules that are currently produced in China, crystalline silicon wafers or advanced thin film technologies are used. In the crystalline silicon wafers, single crystal silicon (mono-Si), polycrystalline silicon (poly-Si) or ribbon silicon (ribbon-Si) are made into solar cells, which are then assembled into modules. A typical crystalline silicon module consists of a series circuit of 36 cells, encapsulated in a glass and plastic package for protection from the environment. Typical conversion efficiencies for common crystalline silicon are in the 11-15% range. As for the thin film technology, there are four types: cadmium telluride (CdTe), copper indium deselenide (CIS), amorphous silicon (a-Si) and film silicon (thin film-Si). Thin film modules are made directly on the substrate, so the intermediate solar cell fabrication step is not required, which substantially decreases the manufacturing costs although conversion efficiencies are also reduced to around 6-10% [CANMAT, 2004].

The monocrystalline PV modules, shown in Figure 4-14, have an efficiency of around 16% and use the 'laser-grooved buried-grid' cell technology. Amongst the features of these cells are their use of a pyramid-shaped texture on the top surface that increases the amount of light 'caught', and buried electrical contacts, which achieve very low electrical resistance whilst minimising losses due to shadowing [Boyle, 2004].

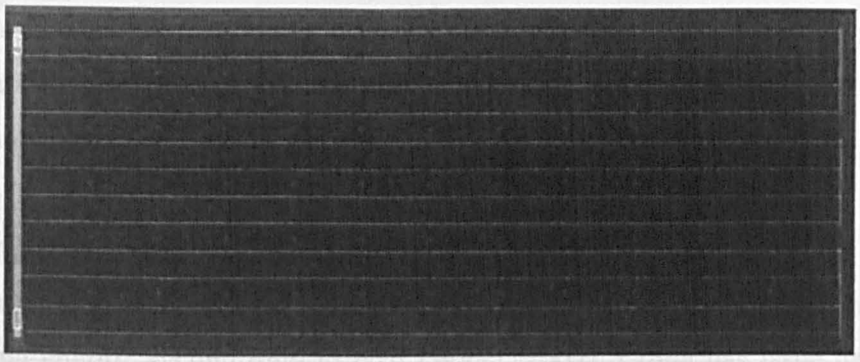

Figure 4-14 Monocrystalline PV module [BP, 2009]

Polycrystalline silicon consists of small grains of monocrystalline silicon. Polycrystalline cells are easier and cheaper to manufacture when compared to monocrystalline cells. However, they are less efficient as light-generated charge carriers can recombine at the boundaries between the grains within the polycrystalline silicon. These cells reach efficiencies of 10 to 14% [Boyle, 2004].

4.2.5.3 Solar energy technology problems

Although the Chinese PV industry capacity has increased substantially in recent years, there is lack of follow-up technologies. There is also a gap with other countries in the exploitation of thin-film solar cells and other new cells, high-performance crystalline silicon cells and system integration technology [Wang, 2009]. Moreover, PV development in China experiences the following problems:

- Backward techniques: the manufacturing technology is old and energy consumption during manufacture is about 1.5-2 that of the world's most advanced one.
- The cost of solar PV is extremely high, making the technology prohibitive.
- Small production scale [Li, 207].
- Shortage in quality control.
- Lack of technological standards and criteria [IEECAS, 2009].

There are also problems in the integration of PV technologies in buildings, large-scale PV power station construction, efficiency and reliability, data performance monitoring and data communication in the power plant, etc. There is a need to support the large-scale application of new solar cells and the reduction in the cost for PV power generation as well as the further expansion of the domestic PV market [Wang, 2009].

As for solar water heaters, the main technology used is the vacuum tube solar collector (around 90% of all solar collectors). In most other countries, flat-panel solar waters heaters are more widely used, as they can bear strong pressure and are highly efficient, and are easily integrated with buildings [Wang, 2009].

4.2.6 Hydropower

Hydropower resources account for around 40% of the China's reserves of conventional energy, second only to coal [Wang, 2007]. China has large quantities of rivers, more than 50,000 of which cover a basin area over 100 km^2, and 3,886 of which have hydropower potential over 10 MW [Huang, 2009]. Existing potential hydropower sites are found throughout the whole China although 70% are in the western more mountainous region, as can be seen in figure 4-15. They are mainly found along the following rivers: Yangtze River, Jinsha River, Yalong and Dadu River, Wujiang River, Hongshui Rive, Langcang River, Nujiang River and Yellow River [Wang, 2009].

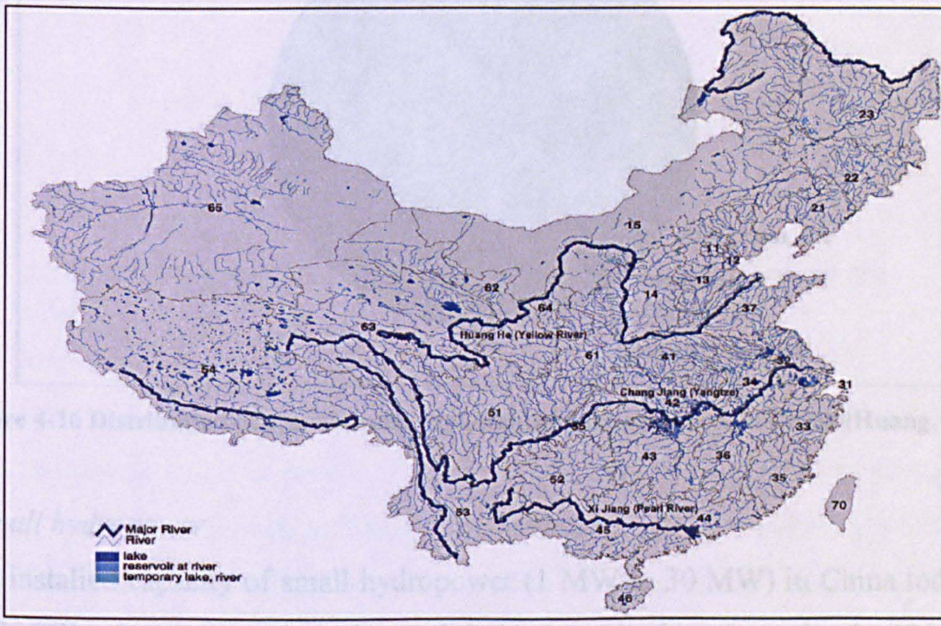

Figure 4-15 Main rivers in China [NREL, 2005]

By the end of 2007, the total installed hydropower capacity reached 145 GW, or 19% of total power generation capacity. This accounts for 433 TWh/year, or 13% of total annual generation [Wang, 2009]. The 11th Five-Year Plan has proposed the construction of 400 hydropower plants for rural electrification, listed in table 4-5 [NDRC, 2006].

Table 4-5 Hydropower development projects [Huang, 2009]

Project	Province	River	Installed capacity [MW]	Average energy generation [TWh/year]
The Three Gorges	Hubei	Yangtze	18,200	84.86
Wujiangdu	Guizhou	Wujiang	1,250	4.06
Longtan	Guangxi	Hongshuihe	6,300	18.7
Gongboxia	Qinghai	Yellow River	1,500	5.14
Shuibuya	Hubei	Qingjiang	1,840	3.92
Xiaowan	Yunnan	Lancangjiang	4,200	18.89
Sanbanxi	Guizhou	Qingshuijiang	1,000	2.43
Pubugou	Sichuan	Daduhe	3,300	14.43
Goupitan	Guizhou	Wujiang	3,000	9.53
Xiluodu	Sichuan	Jinshajiang	12,600	64
Laxiwa	Qinghai	Yellow River	4,200	10.233
Jinping-1	Sichuan	Yalongjiang	3,600	16.62
Pengshui	Chongqing	Wujiang	1,750	6.3

The following figure 4-16 shows the hydro resources that are economically exploitable in each region.

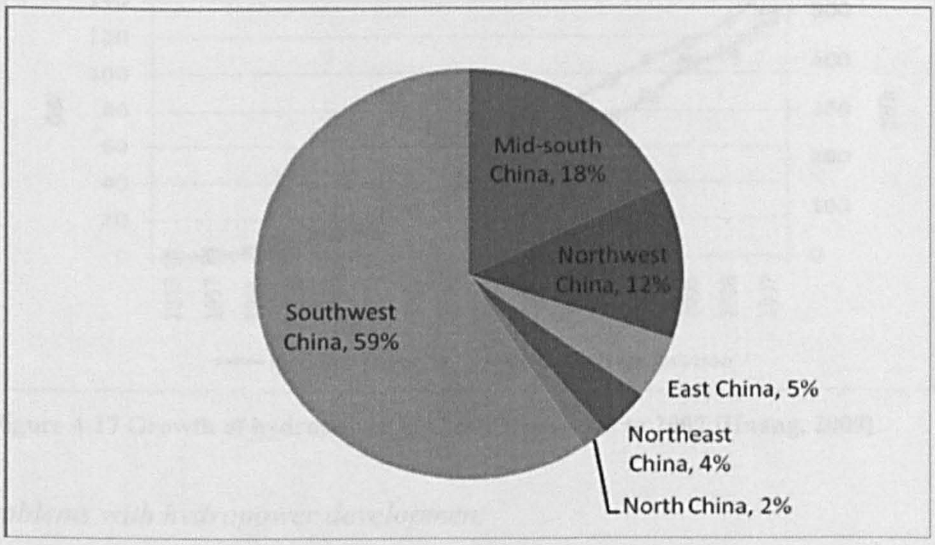

Figure 4-16 Distribution of economically exploitable hydro resources in China [Huang, 2009]

4.2.6.1 Small hydropower

The installed capacity of small hydropower (1 MW to 30 MW) in China today is less than 50GW, whereas its technically exploitable capacity is estimated to be 128 GW, giving an average energy generation of 450 TWh/year. It is widely distributed in more than 1,600 mountainous counties. Southwest China has the richest hydropower resources, and so does Mid-West China; North China has the least amount of hydro resources [Huang, 2009].

By the end of 2005, small hydro projects had an installed capacity of 38 GW with an annual average energy generation of 130 TWh, or about 32.9% of the total hydropower generation capacity in 2005. More than 40,000 small hydropower plants have been built and 653 rural counties were connected to these. The development level of small hydropower is higher than that of large and medium-scale hydropower. Moreover, 15 small hydropower sites are under construction, with an installed capacity of around 1 GW [Huang, 2009].

China is considered to be the world leader in the design, engineering, management, and facilities manufacturing fields of hydropower. It has the ability to manufacture 700 MW of hydro turbines per year [Li, 2006].

Hydropower will continue to play an important role in China's power supply and its growth will be significant, as can be seen in Figure 4-17. According to national targets, the capacity of hydropower will reach 180GW in 2010 and 300 GW in 2020, or about 30% of total installed power capacity at that time [Li, 2006].

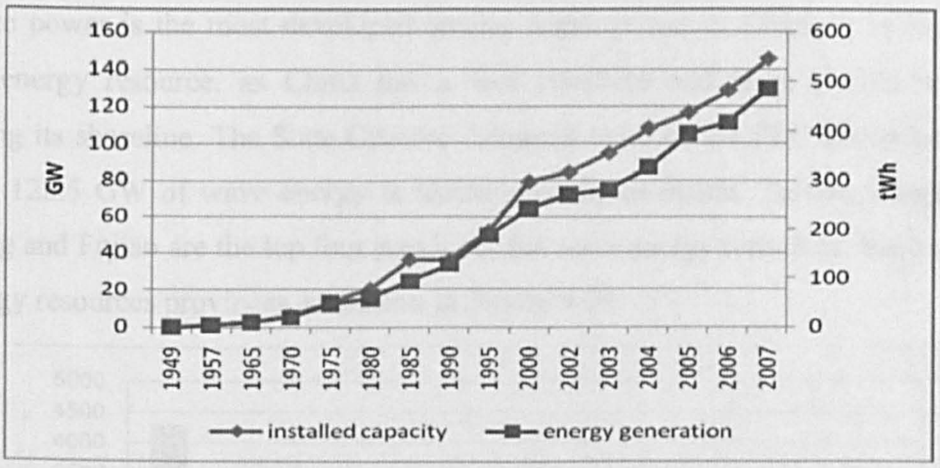

Figure 4-17 Growth of hydropower in China from 1949 to 2007 [Huang, 2009]

4.2.6.2. Problems with hydropower development

Hydropower development does have its disadvantages. The temporal and spatial distribution of precipitation is very uneven in China. This is a major disadvantage for the development of hydropower, as it makes the river flow vary dramatically within one year from the flood season to the dry season. Uneven precipitation may also lead to continuous dry or wet years [Huang, 2009].

Another big problem is the resettlement and the negative impact on the environment. Hydropower projects cannot be done without constructing dams and reservoirs, which causes the submergence of lands and resettlement. This also brings negative impacts on the ecosystem [Huang, 2009].

4.2.7 Ocean power

China's ocean contains abundant ocean energy resources, such as tidal energy, wave energy, oceanic flow energy, temperature difference energy, salt difference energy etc. According to rough estimations, the theoretical reserve of China's tidal energy is around 190 GW with the total installed capacity of developable resources of 21 GW and average power generation of 61.9 TWh/a, among which 90% are distributed in Zhejiang and Fujian. The average theoretical reserve of wave energy resources is 12.9 GW, which are distributed very unevenly, but mostly in Zhejiang, Guangdong, Fujiang and Shandong. None of the ocean energy resources has reached their maturity stage yet, as the development has only started recently [Zhang, 2009].

4.2.7.1 Wave power

Wave power is the most developed among ocean power in China; it is also an abundant energy resource, as China has a vast coastline and large pacific waves approaching its shoreline. The State Oceanic Administration of the PRC has estimated that about 128.5 GW of wave energy is technologically available. Taiwan, Zhejiang, Guangdong and Fujian are the top four provinces for wave energy resources; the top ten wave energy resources provinces are shown in Figure 4-18.

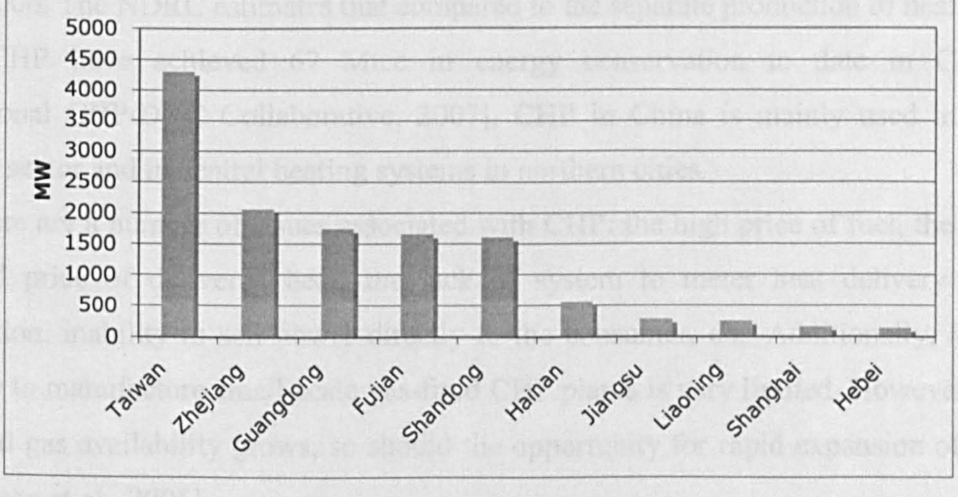

Figure 4-18 Top ten wave energy resources provinces [Zhang et al., 2009]

The research and development of wave energy in China started in the late 1970s; up to now, the main types of wave energy converters are shoreline Oscillating Water Column (OWC) power plants, floating OWC buoys and pendulous wave power plants. In 2001, a 100 kW shoreline OWC demonstration plant was put in operation at Zhelang town (Guangdong province). It is the only large scale project integrated to an electric grid in China today. The power system is designed to deliver a peak power of 100 kW at a significant wave of 1.5 m [Zhang et al., 2009].

Though the development of the wave energy started a relatively long time ago and some achievements have been made in the study of wave energy utilisation, wave energy technologies in China are still far from maturity. The existing wave energy devices are deficient in many aspects, especially high cost, low efficiency, poor reliability, poor stability, and small scale [Zhang et al., 2009].

4.2.8 Combined heat and power (CHP)

When using biomass, CHP can be considered as a renewable energy technology. Boyle argues that the small-scale generators (such as the CHP generator) could cut the need for large scale electricity grids and provide back up for other types of generators (such as wind generators) [Boyle, 2004].

China sees CHP as an energy-efficient and sustainable energy supply option. As a result of governmental promotion, the CHP market in China is rapidly developing. Currently, China is second in the world and installed CHP capacity increased from 10 GW in 1990 to 80 GW in 2006. The annual growth rate from 2000 to 2005 was 18.5%. The share of the CHP capacity in thermal generation increased from 11.3% in 1990 to 18% in 2006. The NDRC estimates that compared to the separate production of heat and power, CHP have achieved 67 Mtce in energy conservation to date in China [International CHP/DHC Collaborative, 2007]. CHP in China is mainly used in the industrial sector and in central heating systems in northern cities.

There are a number of issues associated with CHP: the high price of fuel, the low controlled price of delivered heat, the lack of system to meter heat delivery and consumption, inability to sell power directly to the consumer, etc. Additionally, local capability to manufacture small-scale gas-fired CHP plants is very limited. However, as the natural gas availability grows, so should the opportunity for rapid expansion of the CHP [Sinton et al., 2005].

4.3 Renewable energy policies and standards

Proper formulated renewable energy policies provide the biggest support to the development of the renewable energy technologies implementation. The Chinese Government realised how important the development and the utilisation of the renewable energy is many years ago. In 1980, the State Council issued several Recommendations on Promoting the Development of Rural Energy, making renewable energy a part of the plans for the development of rural electrification. In 1994, the Ministry of Power issued several recommendations on the Construction and Management of Wind Farms, establishing a firm foundation for the development of wind power in China. In 1999, several policy recommendations on promoting the development of renewable energy were issued. In 2003, the Government started to formulate the Promotion Law for Renewable Energy Development and Utilisation. The main goals of these documents were: to confirm the important role of renewable energy in China's national strategy; to remove barriers to the development of the renewable energy market; to create market space for renewable energy; to set up a financial guarantee system; to raise public awareness. After that, the China Renewable Energy Law was issued in 2005 [Li, 2006].

The State Planning Commission, State Science Commission, State Economic and Trade Commission together with financial, banking and tax departments consult with each other and outline the relative favourable policies on financing, investment, credit and tax for renewable energy. The main aims of these consultations are:

- To increase the financial investment and aid, especially for R&D;
- To enlarge the credit scale and provide low-interest loans;
- To establish rewards, cost compensations, tax reduction, and exemption [New Energy 2008].

The State Council proposed that in 2007 "200 demonstration and promotion projects shall be launched for the large-scale application of renewable energy in construction"; as a result, the Ministry of Construction and the Ministry of Finance worked out the concept of 'demonstration, policy support, technical guidance, plus industrial matching' that was received by the whole country [Greenpeace, 2007].

Some provinces and cities were a basis for research and investigation of local renewable energy resource conditions and the potential to be used in building construction. The 11^{th} Five-year Plan developed for renewable energy the following measures: standards and norms set for extension and application; research and development and the integration of some technological products; economic incentive policies established [Ng, 2009].

4.3.1 Laws, regulations and policies

In terms of renewable energy laws, regulations and administrative stipulations, the process can be said to have been initiated with the implementation of the Electricity Law of the PRC in 1995. Then, in 1997 it was continued with the Energy conservation Law and in 2000, the Air Pollution Prevention Law of the PRC. These documents have played an important role in stipulating the exploitation and use of renewable. The State Department has issued a series of administrative regulations and systems, such as the Administration of Joint Networks Wind Power Generation; Further Support on the Development of Renewable Energy, Contents of State Encouraged Industries, Products and Techniques; 1996-2010 New Energy and Renewable Energy Development Principles; 2000-2015 New Energy and Renewable Energy Development Principles; Comprehensive Working Programmes on Energy Saving and Emissions Reduction [Zhang, 2009]. The aims of the programmes towards the development of the renewable energy are introduced in table 4-6.

Table 4-6 Targets set in the Renewable Energy Development Programme 2000-2020 [Huang, 2009]

Renewable energy	2000	2005	2010	2020
Converted to standard coal [mln tonnes]	298	10th five-year programme does not include small hydropower and biomass energy	390	600
Hydropower installed capacity [mln kW]			190	300
Of which: small hydropower installed capacity [mln kW]	19.855		27.88	75.00
Biomass power installed capacity [mln kW]	0.05		5.50	30.00
Wind power installed capacity [mln kW]	0.3-0.4	1.2 grid-connected	10 grid-connected, 0.75 non-grid connected	30.00
Solar power installed capacity [mln kW]	To build off-grid solar PV power station in 9 counties without access to electricity in Tibet	Cumulative amount to reach 53 MW	0.3	1.8
Annual biomass solid fuel utilisation [mln tonnes]			1	50
Annual biogas utilisation [mln m^3]	2,260	Number of large biogas digesters to reach 2,000 mln m^3 in 10th five-year plan period	19,000 mln, including 4,000 mln large biogas digesters	44,000
Annual utilisation of biodiesel [mln m^3]			0.2	2
Annual utilisation of biofuel ethanol [mln tonnes]			3	10
Solar heat collector [mln m^2]	Equivalent to 1.23 mln tsc	10th five-year plan: 64	150	300
Of which: rural areas			50	100
Geothermal heat	0.88 mln tonnes of standard coal	20 mln m^3	Heat supply: 30 mln m^3; hot water supply: 0.6 households (1.21 mln tonnes of standard coal)	12 mln tonnes of standard coal
Hydrogen energy			5000m^3 / day	
Marketable firewood forest base [mln ha]	6.4		13.4	
Tidal wave power installed capacity [mln kW]				0.1

4.3.1.1 Renewable Energy Law

On 28th February 2005, The Renewable Energy Law was passed in the 14th session of the 10th NPC Standing Committee. The Chinese Renewable Energy Law came into effect on 1st January 2006 with a specific aim of "increasing energy supply, improving energy structure, guaranteeing energy safety, protecting the environment and realizing the sustainable development of economy and society" [NPC, 2005]. This Law puts forward a comprehensive renewable energy policy. The introduction of the Law has meant that a number of policies and instruments for China's renewable energy development and utilisation have been institutionalised. These policies instruments include indicative renewable energy targets, renewable energy planning, entry of renewable energy products to the market, grid connection of renewable power generation project, feed-in tariff of renewable power generation, fiscal and taxation measures, renewable energy technology R&D and diffusion, and renewable energy education and training.

The Law defines China's Feed-in Tariff guiding principles. It formulates concrete measures for the implementation of the approach. Before the Renewable Energy Law was implemented, some directives regarding feed-in tariff had already been enacted in China: Directive on Renewable Energy power generation; Directive on renewable Power Pricing and Incremental Cost Sharing. A premium of 0.25 Yuan/kWh (0.037 US dollar) is available for biomass power generation projects. However, the wind power pricing is still decided through public bidding [NPC, 2006].

Taxation measures are also recognised in the Law. It requires the relevant government departments to formulate fiscal and taxation measures such as tax and/or tariff relief and preferential loans to support China's renewable energy industry development. For example, wind farms have received a 50% reduction in VAT (VAT in China equals 17%) [NPC, 2006].

The Law is also targeting the removal of barriers of the entrance of renewable energy power into the energy markets. The Directive on Renewable Energy Power Generation, issued by the NDRC, is the Law's implementing regulation, and it states that the grid has to give priority to the access of renewable energy sources [Greenpeace, 2007].

After the passing of the Law, relevant supporting regulations and laws were issued. Among them, investigations on renewable energy resources, total goal, programmes on exploitation and use, industrial development content, electricity pricing policy, cost sharing, special capital, and financial support [Zhang, 2009].

Under this law, the government set a target that 15% of all energy is to come from renewable sources by 2020 [NPC, 2006].

In December 2009, China passed amendments to the Law. One of the main points of these amendments was that 25% of the energy used in new buildings should be from renewables. Even though it is too early to talk about the impact of these amendments, it shows China's willingness to develop and expand its renewable energy capacity.

4.3.1.2 Medium and Long-term Development Plan for Renewable Energy in China

The Medium and Long-term Development Plan for Renewable Energy in China was enforced in August 2007. The aim of the Plan is to increase the speed of renewable energy development, promote energy conservation, and reduce pollutants for climate change mitigation. The priority sectors are hydropower, biomass energy, wind energy, and solar power. It gives guidelines and targets for development until 2020. The installation capacity of renewable energy generation is expected to reach 30% of total generation capacity, with renewable energy supply of 400-500 Mtce, accounting for about 1/7 of primary energy consumption assuming that total primary energy consumption to be around 3.5 bln tce [RCSD, 2006].

The main principles of this Plan are [NDRC, 2007]:

- To coordinate renewable energy development and deployment with economic, social, and environmental objectives.
- To ensure mutual promotion of the market (demand) and industrial development (supply).
- To combine short-term utilisation with long-term technology development.
- To combine policy incentives with market mechanisms.

The Plan suggests the establishment of the following policies:

- To establish a sustainable and stable market demand with favourable pricing policies, Mandatory Market Shares (MMS) policies, government investments, government concession programmes, etc.
- To improve the renewable energy market environment.
- To set renewable power tariffs and cost-sharing policies.
- To increase fiscal input and tax incentives.
- To accelerate technology improvement and industry development.

The national targets in the Plan are presented in the Table 4-4 below.

Table 4-7 National targets [NDRC, 2007]

Energy source	2005	2010	2020
Hydro	115 GW	190 GW	300 GW
Wind	1.3 GW	5 GW	30 GW
Solar PV	0.07 GW	0.3 GW	1.8 GW
Solar thermal	80 mln m^2	150 mln m^2	300 mln m^2
Biomass	2 GW	5.5 GW	30 GW
Ethanol	0.8 mln tonnes	2 mln tonnes	10 mln tonnes
Biodiesel	0.05 mln tonnes	0.2 mln tonnes	2 mln tonnes

4.3.2 Financial policies

Although there is no comprehensive financial incentive system for the development of the renewable energy in China, local and central governments are providing economic incentives (especially subsidies), particularly for R&D on key technologies, investment in renewable village power systems in remote rural areas, exemption on VAT or custom duties and pricing policy in favour of renewable energy. For example, favourite tax rates applied to some renewable energy have been reduced from average 17% to 8.5% for wind power, 13% for biomass, and 6% for small scale hydropower [RCSD, 2006]. The main economic incentive policies are the following:

- Reduction of import duties: most of them were reduced to 23%; at present there are preferential measures for wind power and PV equipment so that import duty on parts for wind turbines is around 3%, and around 12% for PV equipment.

- Preferential VAT rates: preferential VAT rates are not valid for the national level; however, there are some provinces (Hebei, Liaoning, Jilin, and Guangdong) where the VAT rate for wind power is only 6%. In Xinjiang, foreign-owned and JV wind power enterprises are able to obtain a preferential VAT rate once they have been in operation for more than 10 years.

- Loans with interest allowance: in 2001, the State Economic and Trade Commission introduced a policy that provides loans at low interest rates with the aim of promoting the development of nationwide wind power projects. The interest allowance is available for between 1 and 3 years depending on local conditions.

- Subsidy policies: central government subsidies are mainly used for R&D funding, whereas provincial subsidies are mostly used for the popularisation and installation of small-scale wind power systems and solar PV systems [Li, 2006].

4.3.2.1 Feed-in tariff (FIT)

Feed-in tariffs are one of the incentives for renewables widely used increasingly throughout the world. Studies have shown that it enables investors to reduce their investment risks on potential renewable energy projects [Ng, 2009]. Currently China has set a fixed FIT for new onshore wind power plants. There are four categories of plants that can apply for FIT. Areas with more favourable wind resources have a lower FIT, and areas with lower wind resources have FITs that are more generous. The tariffs per kWh vary from 0.51 RMB to 0.61 RMB, depending on the category of the plant [Chan, 2009]. China also plans to put in place a solar FIT by 2011.

4.3.2.2 Mandatory Market Share

MMS is a regulation requiring 5% and 10% of all primary energy to come from renewable energy in 2010 and 2020 respectively. China is starting up this programme by launching 'wind concession programmes' – long-term supply contracts with new wind energy facilities. Two provinces (Fujian and Sichuan) are already piloting MMS programmes: Fujian will build 400 MW of wind facilities by the end of 2010 to implement the first phase of its MMS programme. Guangdong, Jiangsu, Jilin, and Inner Mongolia have auctioned wind development rights to private developers, contracting some US $600 mln in new wind installations. Moreover, China has announced 4270MW of new wind facilities by 2010 with a potential investment over US $4 bln [Shi, 2009].

4.3.2.3 Clean Development mechanism (CDM)

CDM is one of the three Kyoto mechanisms, which was briefly described in Chapter 3 section 3.2.1.3. There are a big variety of possible CDM projects, mainly in the areas of energy efficiency improvement, renewable energy development, coal-bed methane, power generation, and forestry. The total GHG reduction potential in China is estimated to be around 777 mln tonnes of carbon dioxide equivalent, including 545 mln tonnes reduction coming from energy efficiency, 138 mln tonnes from renewable energy sources, 67 mln tonnes from coal-related methane, and 27 mln tonnes from fuel switching and new technologies for power generation. The current Chinese government priorities in CDM projects are renewable energy, energy efficiency, and use of clean methane (natural gas) as can be seen from Table 4-8.

Table 4-8 CDM activities

	Area	Project title	Outline
Renewable energy projects	Wind	Huitengxile 25.8MW project	514291 CERs over 10 Year Crediting period from 2004, Uses AM0005, Validated, Imminent submissions to UNFCCC website
	Wind	Mingmen 49MW project	800000CERs, 10-year crediting period from 2005, uses A0005, PDD under development
	Hydro	Yunnan 32MW project	500000 CERs per year, 10 year crediting period from 2005, new methodology, PDD under development
	Biomass	GIEC rice husk gasification project	39901 CERs per year, 10 year crediting period from 2008, new methodology, PDD under development
	Tidal	Yalu River 300MW	840000 CERs per year, 10- year crediting period from 2008, new methodology, development phase
	SWH	Lijiang	726000 CERs, 10year crediting period from 2003, new methodology, PDD under development
	Landfill	Nanjing, 1.5MW	60000 CERs, 10 year crediting period, to use approved consolidated methodology, trying to raise underlying finance
Energy efficiency	Waste heat recovery and use for power	Taishan Cement works 13.2Mw project	150000 CERs per year, 10 year crediting period from 2005, new methodology.
	Waste gas to power	Shanghai ESCO Power plant project	47000 CERs per year, 10 year crediting period from 2000, similar to Jindals methodology
	District heating	Haerbin DaoLi District heating project 1	To be drafted
Coal mine methane	CMM to power	Jincheng	2900000CERs per year, 10 year crediting period, follow the methodology of Hegang CBM for power project, PDD under development
	CMM to power	Nanshan 1.8MW	62400 CERs per year, 10 year crediting period new methodology, NM0066
	CMM to furnace	Yangquan 1	>600000 CERs per year, 10 year crediting period, PDD under development now, requires new methodology
	CMM to power and flared excess	Panshan 4MW, Huainan	27800 CERs per year, 10 year crediting period, new methodology,

The ongoing and planned future efforts on climate change mitigation and GHG emissions reduction point towards a potential for achieving it through the CDM [RCSD, 2006].

In June 2004 under the NDRC, the Designated National Authority (DNA) was established, and the State Council adopted and issued Interim Measures for Operation and Management of CDM Projects in China. This forms the basis for China's CDM projects. According to these measures, more than 10 Chinese governmental organisations are involved in CDM-related affairs. The approval procedure is rather complicated: the applications are sent to the NDRC, which forwards them to an expert review. If the proposal passes the assessment, which lasts for around one month, then the project proposal is sent to the CDM Board, which appraises the proposal and makes a joint decision. If the proposal is rejected, it undergoes revision before being resubmitted. If the Board approves the proposal, the DNA issues a letter of authorisation, which has formal endorsements from the MFA and the MST [Heggelund, 2007]. The mechanism is summarised in Figure 4-19 below.

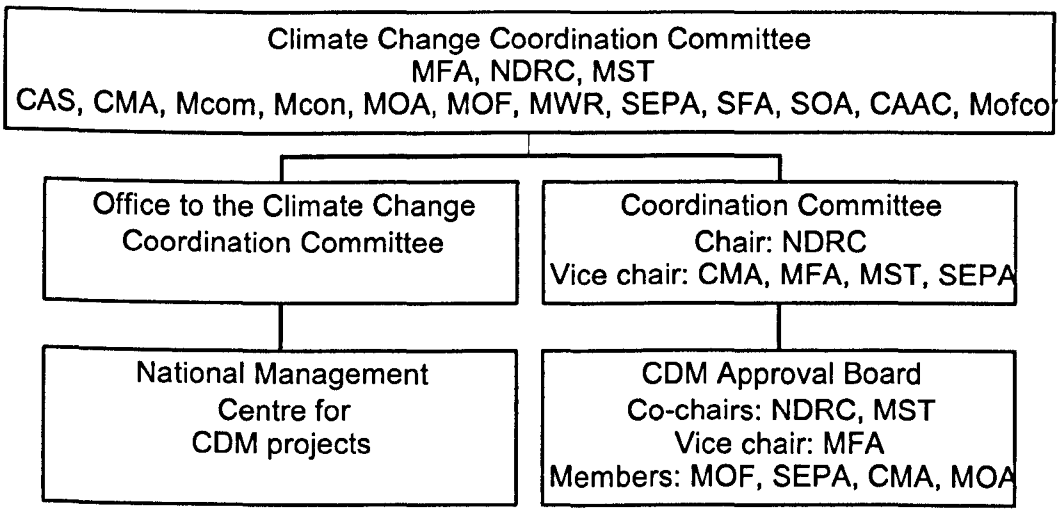

Figure 4-19 CDM projects approval mechanism in China [Heggelund, 2007]

From the time it was established, the procedure has been quite efficient and rapid with the process being also fairly transparent. However, as the Interim Measures were not clear in some areas, they were replaced by the "Measures for operation and management of CDM projects in China" in October 2005. The revised measures announced a tax of 2% on the project in priority areas and afforestation. Heavier taxes were announced of 65% for HFC (hydroflourocarbon) projects and of 30% for N_2O projects. The eligibility of the organising company is the key to the CDM projects protection; China does not want companies to be involved in the project for the profit benefits only. According to Chinese officials, if the company is wholly foreign owned, the benefits merely go from the enterprise in China to the headquarters abroad, with less benefit for China. In addition, Chinese companies are less competitive than foreign companies in the CDM market; therefore, if all companies in China should be made eligible for the CDM projects, Chinese companies would not be able to have any CDM projects. However, Chinese officials are aware of the need for flexibility, so, according to Principle 51, a percentage of an enterprise should be Chinese-owned. The flexibility of China's CDM mechanism is still an issue and not specifically underlined in the CDM measures [Heggelund, 2007].

By 31st December 2006, 255 projects had been successful in obtaining their registrations, and other projects had been sent a letter of approval, as can be seen in Table 4-9.

Table 4-9 Projects approved by DNA of China (as of December 31, 2006) [CDM in China]

Project type	Number of projects	Estimated average GHG reduction (tCO_2e/y)
Energy saving and efficiency improvement	29	7,436,363
Renewable energy	179	21,893,127.95
Methane recovery and utilisation	26	15,022,050
HFC23 (chemical pollutants reduction)	8	51,093,068
N_2O decomposition	3	14,726,343
Afforestation and reforestation	1	20,020
Fuel substitution	9	6,491,107
TOTAL	255	116,682,079

Recently, the National CDM Management Centre was established as a part of the Energy Research Institute. Under the guidance of the Climate Change Office in the NDRC, it operates on the project level and assists the office with receipt of materials for CDM project applications, organises experts, and keeps a database of projects; it is the Centre's responsibility to make sure that government CDM policies are followed [Heggelund, 2009].

China Renewable Energy Industrial Association (CREIA) made an estimation that until 2020 the major renewable technologies for CDM projects will likely be wind power, small hydropower, biomass power, and LFG utilisation. From 2005 to 2010, the capacity of newly installed projects will reach 25 GW with the reduction of 37 mln tonnes of CO_2 emissions. From 2010 to 2020, these technologies may reach 55 GW in capacity with 101 mln tonnes in reduction of CO_2 emissions [Li, 2006].

Though the whole CDM runs smoothly, there is still room for the improvement and the reduction of administrative costs. The main problem is that most of the CDM projects are research projects and not always adapted to real projects. This causes some complications, such as project design document development, and makes the validation and certification complex [Li, 2006].

4.3.2.4 Wind Power Concession Programme

The wind power concession programme was implemented in 2006. The Chinese Government is selling tenders to domestic and international companies in order to bid for large-scale potential projects (100-200 MW). The success of the bidders depends on the price per kWh of the proposed wind electricity and the share of domestic components utilised in the wind farm. After 30,000 full-load hours, the bidder will receive the average local feed-in-tariff on the power market at that time. Two projects have already been sold. The NDRC expects to award about 20 projects by 2010 contributing to the overall aim to reach 30 GW-installed capacity in 2020. [IEA, 2008]

4.4 Barriers and suggestions

Undoubtedly, China has achieved great progress in research, development and utilisation of renewable energy technologies. However, there is still a gap when compared with the world level [New Energy, 2008]. The following are barriers to implementation of strategies for the promotion of the renewable energy technologies:

- An absence of long term financing mechanism for renewable energy projects;
- A divergence between private costs and social costs of electric power in measuring project benefits;
- A concern about integrating renewable energy into electric grid [Kelly, 1996];
- A lack of a consistent policy system encouraging long-term development of renewable energy;
- A lack of necessary renewable energy resource survey and assessment;
- A weak industry infrastructure for renewable energy technology development;
- A lack of market mechanism for renewable energy promotion [Li, 2007];
- Absence in the state energy consumption plan;
- Low investment input [New Energy, 2008];
- A lack of innovation in regional policy;

- Inadequate investment in the technical research and development [Zhang, 2009].

As can be seen, the main barriers for the development of renewable energy in China are related to costs, market share and policy issues. Renewable energy has higher costs compared to traditional energy sources, and this is the biggest barrier to renewable energy's wider implementation and distribution. Comparison of costs shows that small-scale hydropower is 1.2 times than the cost of coal-burning power, biogas is 1.5 times, wind power is 1.7 times, and PV is 11 to 18 times higher [Ng, 2009].

Despite the emergence and rapid development of commercially successful solar-module manufacturing enterprises, a large share of their products are exported to the EU [Ng, 2009].

The market for renewable energy is small and uncertain; therefore, the reduction in production costs and the improvement of technological reliability are very important for the expansion of the market. The government has a great impact on attracting investments and expanding renewable energy.

Most of China's renewable energy technology is still in the process of research and development rather than industrialisation. There is a need to establish a series of technical experiments and demonstration projects that will help to analyse and investigate the various renewable resources. In addition, complete sets of equipment and design and manufacturing should be formed. Furthermore, regulations should be set to provide a solid foundation for the large-scale development of China's renewable energy [Wang, 2009]. Specifically the following should be done:

- The unification of the decision-making: there are many State Council energy departments in charge of different part of the decisions made towards renewables. This weakens the coordination function of the State Council Department in charge of energy. The body, which makes effective implementation of a state's renewable energy strategies, policies and principles, should be integrated.

- The development of guidelines for the all-round renewable energy technology development. For competitive, mature technologies, mandatory policies should be used; for solar power generation, more R&D should be done; for wind power generation, a foundation for large-scale generation should be provided.

- The strengthening of renewable energy capacity building R&D: renewable energy courses should be offered in the main universities; renewable energy research teams should be integrated into a national renewable energy centre. Moreover, research and industry should work closer together.

- A gradual involvement: China has a basis for the mass production of renewable energy equipment and has the potential to be the world's largest renewable energy manufacturer; therefore, China should gradually develop into a renewable energy development and utilisation power.
- The promotion of industrial integration and industrial base: there is a need for creating a good environment for accelerating the industrialisation of renewable energy technology results and products and focusing on the regions with the greatest renewable energy resources. The construction and development of an industrial base should be established as close as possible to the raw materials or consumer market [Wang, 2009].
- The improvement of the effectiveness of policy completeness and policy grouping: in China, renewable energy is promoted in remote and poor areas, with high social efficiency but low economic efficiency; thus, renewables need more encouragement and support from national and regional levels of the government.
- Enhancing the policy innovation in policy regions: development of renewable energy must be based on regional situations and local conditions;
- The development of the process of management: there is a problem of the unsmooth transmission to lower level units, which causes trouble in the function of the renewable energy policy. To avoid this, the renewable energy offices, which are in charge of the policy implementation, should be organised on different levels; moreover, the monitoring offices should be set up to monitor policy conveying and implementation [Zhang, 2009].

China has formally issued a long-term planning for renewable energy development along with China's renewable energy development goals and objectives. In the next 15 years, the investment of more than 2 trl RMB (195,5354,030 USD) is needed to achieve these objectives. Moreover, with the completion of existing strategies and aims, it will be necessary to develop new strategies and aims [Wang, 2009].

4.5 Summary

Renewable energy is undoubtedly the inevitable choice for sustainable economic growth and sustainable development. In order to promote and support the growth of renewable energy, the Chinese government has issued a series of policies on renewable energy development, including laws, regulations, economic encouragement, technical research, and development [Zhang, 2009]. However, the current market for renewable energy in China is very small and has too many uncertainties. It is crucial for cultivating and expanding the market to reduce production costs and improve technological reliability.

Currently there are a number of significant policy challenges to the wider use of renewables. Government policies have a very big impact on attracting private sector investments and determining the pace of expansion of renewable energy. To scale up the use of renewables, the following measures should be taken:

- Creation of supportive policy, legal, and institutional frameworks;
- Securing of public sector commitment, including for R&D and procurement policies;
- Promotion of private sector involvement and stronger alignment between policy timeframes and timelines for investments;
- Support for the establishment of national renewable energy industries including small and medium enterprises;
- Provision of access to affordable financing, including micro-finance, and consumer credit mechanisms [RCSD, 2006].

The source driving China towards an increased energy demand can be explained by its willingness to achieve rapid economic growth and a moderately well-off society. The recent increase in energy consumption is due to the acceleration of industrialisation and urbanisation, both of which require substantial amounts of energy intensive products. Moreover, irrational pricing also contributes to dramatic energy consumption increases. Artificially kept low price and energy subsidies protect large state-owned and inefficient technologies from competition with advanced ones.

According to the analysis of China's energy consumption structure, the dominance of coal in the energy mix is likely to continue in the future, though its shares will be lowered over the years. Currently, many new and renewable technologies are not competitive in China and competitiveness can be enhanced through the introduction of more effective policies.

Consumer behaviour and institutions can be the major constraints to the use of low-carbon alternatives. Price liberalisation will reduce market distortions.

Already China's effort to increase energy efficiency and reduce energy intensity is impressive. China has been undertaking efforts to develop hydropower, nuclear power, wind, solar and biomass energy sources. Legislation has been made on the promotion of energy savings, renewable energy, and clean production. The government pursues a positive approach through making a series of laws, regulations, and policies. The Renewable Energy Law shows how important renewable energy is seen for China's future energy security. The government provides economic incentives and subsidies for R&D, for investments in rural areas and exemptions on VAT in favour of renewable technologies. In addition, the CDM mechanism plays an important role in attracting international technologies and investment. Unfortunately, some policies have not yet been implemented. Reform is needed to create a positive investment climate to attract private capital to renewable energy that will give the opportunity to expand international cooperation in this field.

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Chapter 5 – Buildings energy consumption and building energy efficiency

5.1 Introduction

China has the largest population in the world. Since its one child family planning policy was initiated in the 1980s, the population growth has been kept relatively low. However, as Figure 5-1 shows, the urbanisation process is accelerating in China. This process has a large impact on China's energy consumption as nearly 60% of the population is expected to live in urban areas by 2030 (compared to today's 45%) [SSB, 2006]. The high speed of urbanisation is also accompanied by an increase in the need for more employment opportunities, higher consumption pattern, infrastructure construction, etc.

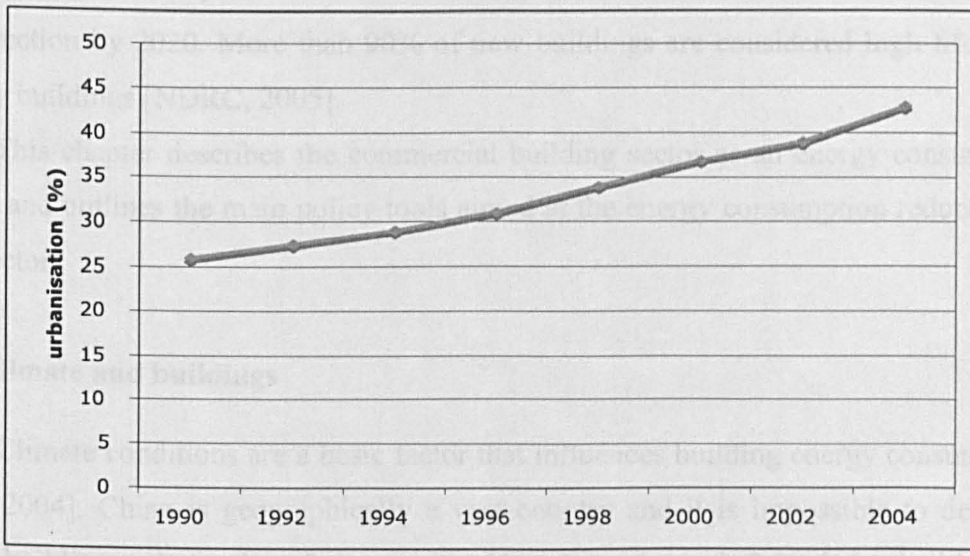

Figure 5-1 Urbanisation trend in China [SSB, 2006]

As can be seen in Figure 5-2, China's construction speed is impressive. China has the largest construction area in the world with about 2 bln m^2 of new buildings completed annually. Currently about 80% of these are categorised as high-energy buildings. The World Bank estimates that by 2015 about half of the world's new building construction will take place in China [LBNL, 2008].

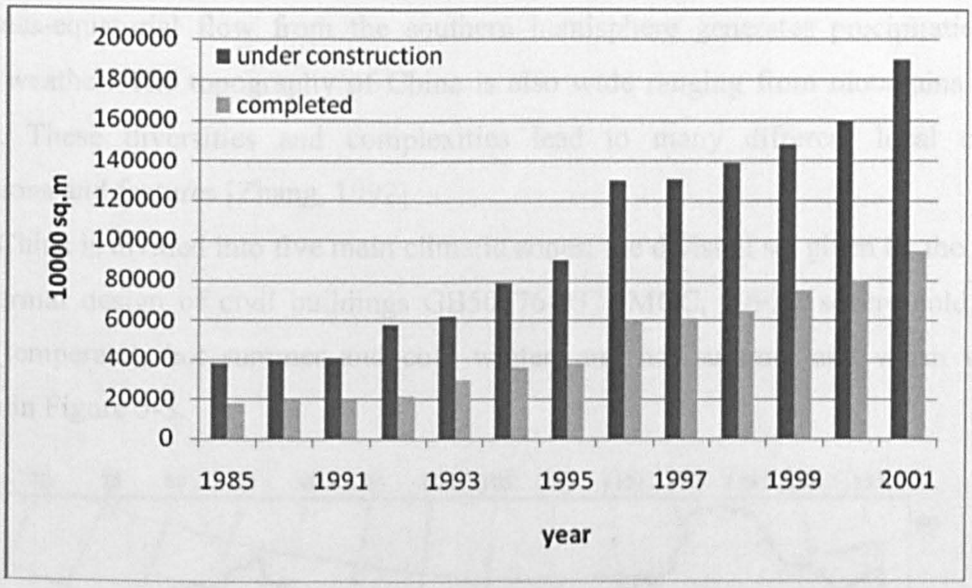

Figure 5-2 Floor construction in China [NDRC, 2005]

China's Ministry of Construction estimates that China will add 4 bln m^2 in new construction by 2020. More than 90% of new buildings are considered high life-cycle energy buildings [NDRC, 2005].

This chapter describes the commercial building sector as an energy consumer in China and outlines the main policy tools aimed at the energy consumption reduction in this sector.

5.2. Climate and buildings

Climate conditions are a basic factor that influences building energy consumption [ERI, 2004]. China is geographically a vast country and it is impossible to design a single building code for the whole country. China's total area is 9.6 mln km^2 with about 98% of the land stretching from latitude of 20°1' N to 50°1' N, from subtropical zones in the south to temperate zones in the north including warm-temperate and cold-temperate. Maximum solar altitudes vary greatly and there is a large diversity in climates, and especially in temperature distributions in winters [Zhang, 1992].

China is located on the south-eastern part of the Eurasian continent towards the Pacific Ocean, so the air masses of either continental or maritime origin affect the climate. Climate conditions are ruled by monsoons throughout the year: in winter, monsoons form in mid-Siberia and Mongolia and bring cold and dry air masses; in summer, monsoons form from the subtropical anticyclone in the Northwest Pacific and the cross-equatorial flow from the southern hemisphere generates precipitation and warm weather. The topography of China is also wide ranging from mountains to flat plains. These diversities and complexities lead to many different local climate conditions and features [Zhang, 1992].

China is divided into five main climatic zones; the division set given by the "Code for thermal design of civil buildings GB50176-93" [MOC, 1993]: severe cold, cold, mild (temperate), hot summer and cold winter, and hot summer and warm winter, shown in Figure 5-3.

Figure 5-3 China's climate zones division [MOC, 1993]

The zoning is based on the monthly average temperatures of the coldest and hottest months of the year (January and July, respectively), and the number of days with the daily average temperature below 5°C and above 25°C.

Climate plays an important role in influencing the energy efficiency of the building. The most import variables that must be considered when talking about energy efficiency of buildings are those that affect the indoor thermal comfort and the heat transfer through a buildings fabric and via ventilation: temperature (dry bulb and wet bulb), solar radiation (global, direct and diffuse) and wind conditions (speed and direction) [Bobenhausen, 1994]. The climate determines the amount of solar radiation and outside temperature that a building is exposed to; it also influences the amount of energy that is used for the heating and cooling of a building, and the amount of energy used for lightning [Haase et al., 2002].

5.3 Buildings as energy consumers

Today, buildings play a very important role in the energy demand sector as they account for more than ¼ of China's total primary energy consumption, and are likely to increase to 35% by 2030 with the GHG produced in the building sector accounting for approximately 25% of China's total emissions [Fridley et al., 2008].

Many efforts have been made since 1986 when the first building code was introduced in China; however the building sector is still much less efficient than those in other parts of the world, and as can be seen in Figure 5-4, buildings energy consumption in growing.

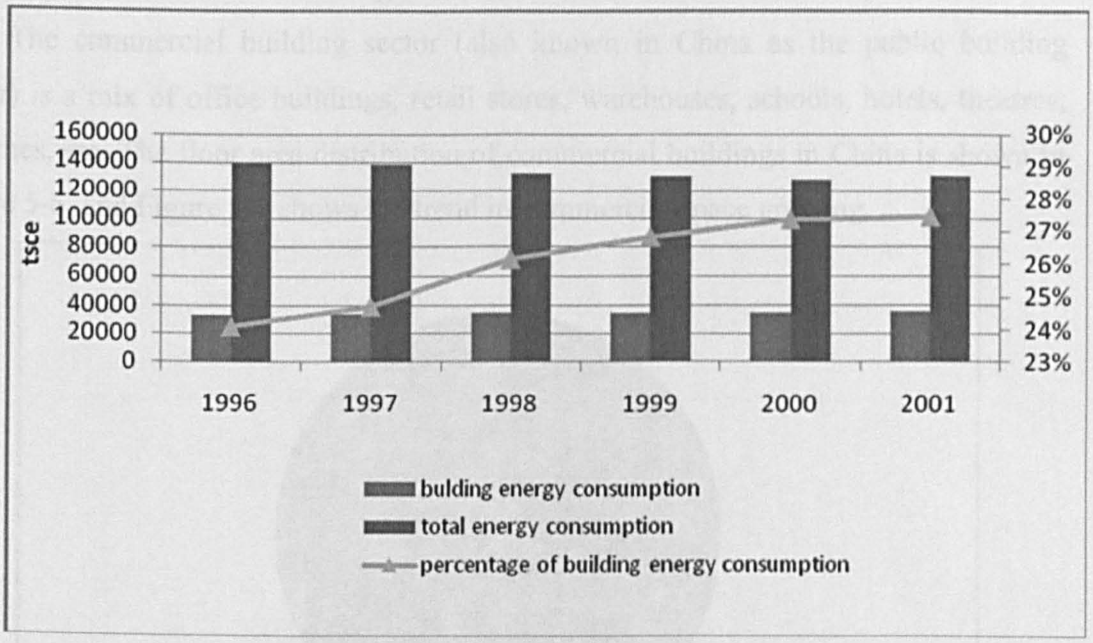

Figure 5-4 Building energy consumption [Yao, 2005]

Although the Chinese government has issued many standards and codes in order to improve energy efficiency of buildings, little effect has appeared less than 6% of newly constructed buildings comply with these standards [Kang and Wei, 2005]. Energy consumption per building in China is 2-3 times higher than that of the developed countries with similar climatic conditions (as is shown in Figure 5-5), and buildings are less comfortable as a result of poor thermal performance and too little insulation in most of China's buildings.

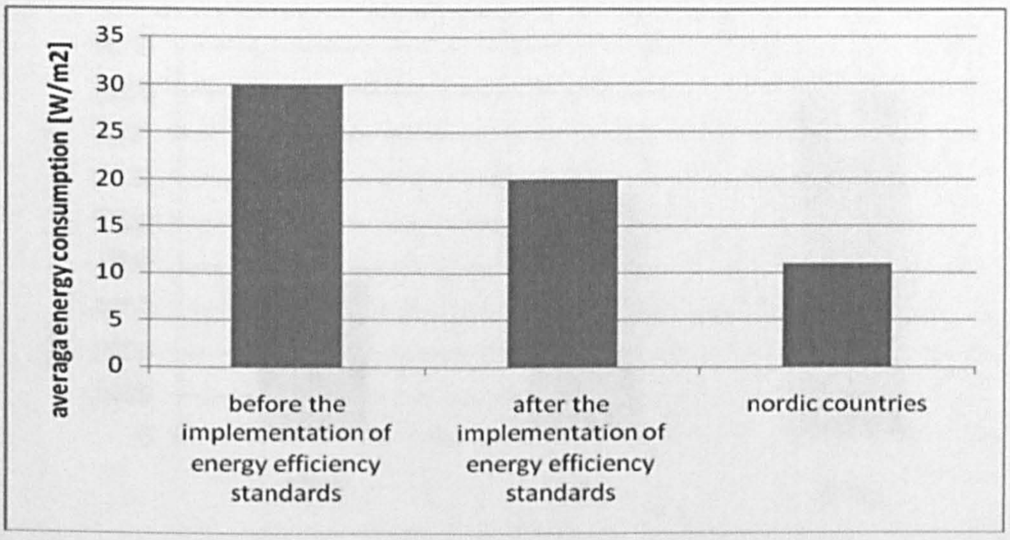

Figure 5-5 Building energy consumption comparison, China and Nordic countries [Li, 2009]

5. 3.1 Types of commercial buildings

The commercial building sector (also known in China as the public building sector) is a mix of office buildings, retail stores, warehouses, schools, hotels, theatres, churches, etc. The floor area distribution of commercial buildings in China is shown in Figure 5-6, and Figure 5-7 shows the trend in commercial space growing.

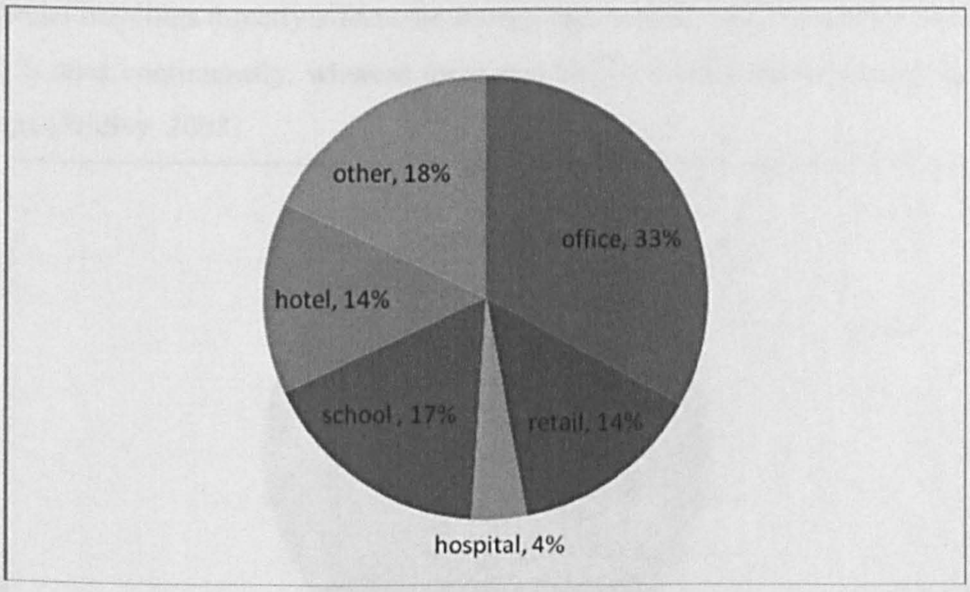

Figure 5-6 Floor area distribution among commercial buildings in China [LBLN, 2008]

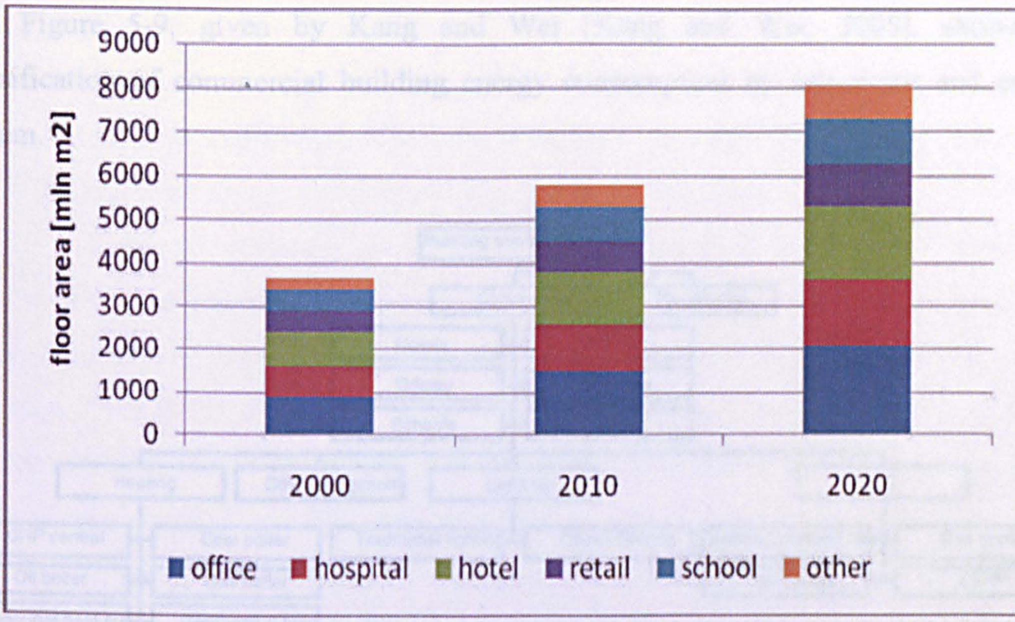

Figure 5-7 Commercial floor space growth [LBLN, 2008]

The commercial buildings sector main characteristic is its energy demand, especially for space heating, air conditioning, and lighting as is shown in Figure 5-8. The energy intensity of commercial buildings depends on the building's construction and energy using activities within the building. The type of the occupants of the commercial buildings directly affects the energy use, as well; i.e. in hospitals and hotels, energy is used continuously, whereas there is a steady weekly use of energy in office buildings [Fridley, 2008].

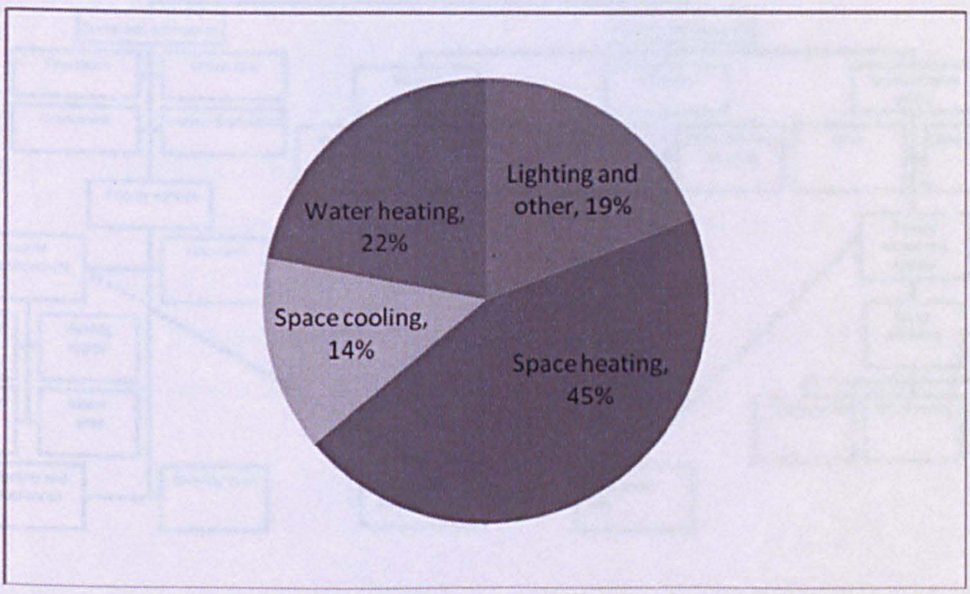

Figure 5-8 Energy distribution in commercial buildings [Zhou et al., 2007]

Figure 5-9, given by Kang and Wei [Kang and Wei, 2005], shows the classification of commercial building energy consumption by sub-sector and energy system.

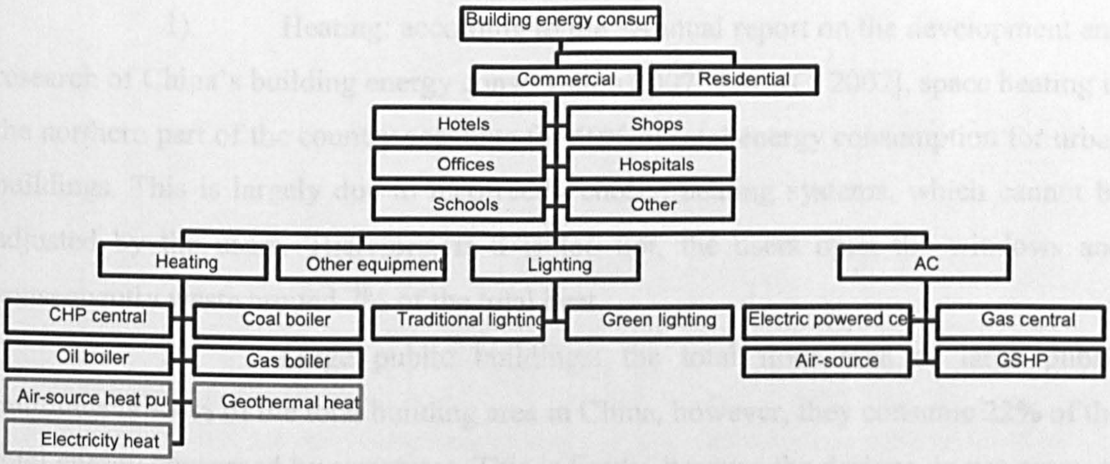

Figure 5-9 Classification of commercial building energy consumption by sub-sector and energy system [Kang and Wei, 2005]

5.3.2 Main energy consuming areas

The energy consumption of a building is a complex scheme influenced by both internal and external factors. Kang [Kang and Wei, 2005] provide a breakdown of these factors, which are reproduced in figure 5-10, and discussed next.

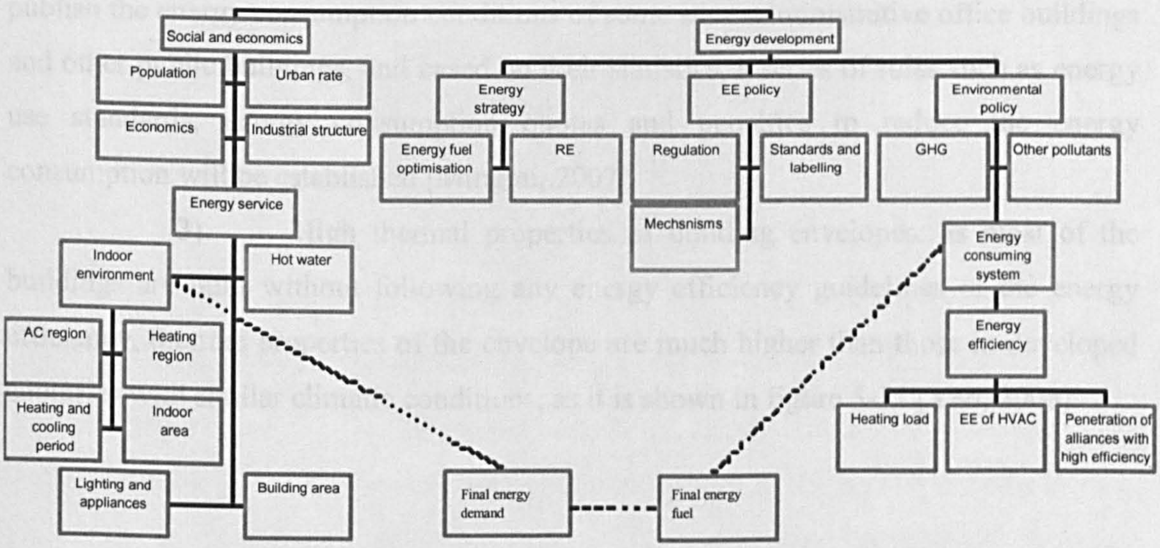

Figure 5-10 Factors affecting building energy consumption

Kang and Wei show the different factors on which energy consumption depends. Figure 5-10 also shows that the level of building energy efficiency depends on the degree of technical improvements and the energy efficiency policies that are employed.

The top three energy consumers in buildings in China are:

1) Heating: according to the "Annual report on the development and research of China's building energy conservation 2007" [BERC, 2007], space heating in the northern part of the country accounts for 40% of total energy consumption for urban buildings. This is largely due to incorrectly chosen heating systems, which cannot be adjusted by the users. Therefore, if it is too hot, the users open the windows and consequently waste around 7% of the total heat.

2) Large public buildings: the total floor area of large public buildings is ~ 4% of the total building area in China, however, they consume 22% of the total energy consumed by structures. This is firstly, because the designs do not promote energy conservation: many large public buildings have huge glass screen walls without any shading or insulating materials that cause great energy losses through large summer cooling loads and winter heating loads. Secondly, the energy conservation awareness of the building users is limited [Ming'ai, 2007]. The MOC has started doing a statistical analysis of energy consumption in state administrative office buildings and large public buildings in 32 provinces, municipalities, and autonomous regions. The MOC plan to publish the energy consumption conditions of some state administrative office buildings and other public buildings, and based on their statistics, a series of rules such as energy use standards, energy consumption quotas and penalties to reduce the energy consumption will be established [Ming'ai, 2007].

3) High thermal properties of building envelopes: as most of the buildings are built without following any energy efficiency guidelines of the energy efficiency, thermal properties of the envelope are much higher than those in developed countries with similar climatic conditions, as it is shown in figure 5-11 [Yao, 2005].

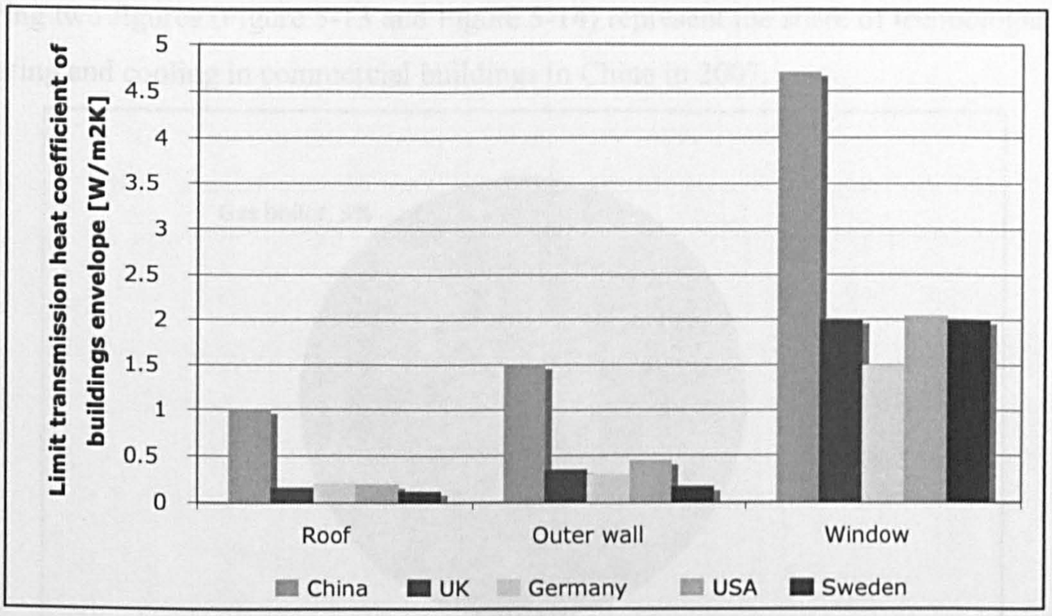

Figure 5-11 Comparison of limit transmission heat coefficients of buildings envelopes

In terms of primary energy consumption by fuel, coal is the dominant secure for energy use in the commercial buildings sector in China. This can be seen in Figure 5-11.

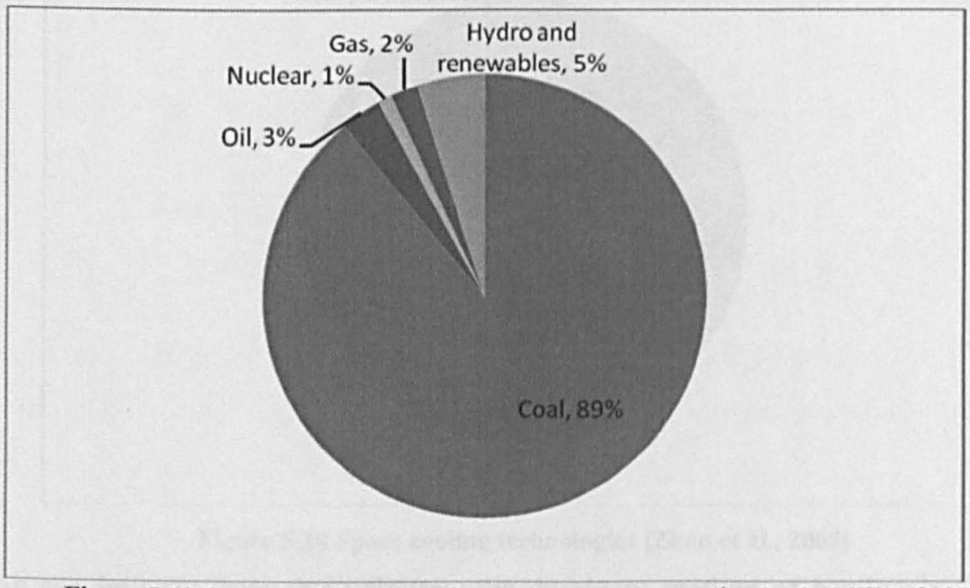

Figure 5-12 Commercial sector primary energy consumption by fuel [IEA, 2007]

An important role in energy improvements in commercial buildings is played by energy technologies. Consumers' choices generally follow the market criteria of cost, performance, accessibility and availability of one or another technology. However, government can influence the decision by introducing more energy efficient technologies using incentives, subsidies, and regulations [Zhou et al., 2007]. The following two figures (Figure 5-13 and Figure 5-14) represent the share of technologies for heating and cooling in commercial buildings in China in 2007.

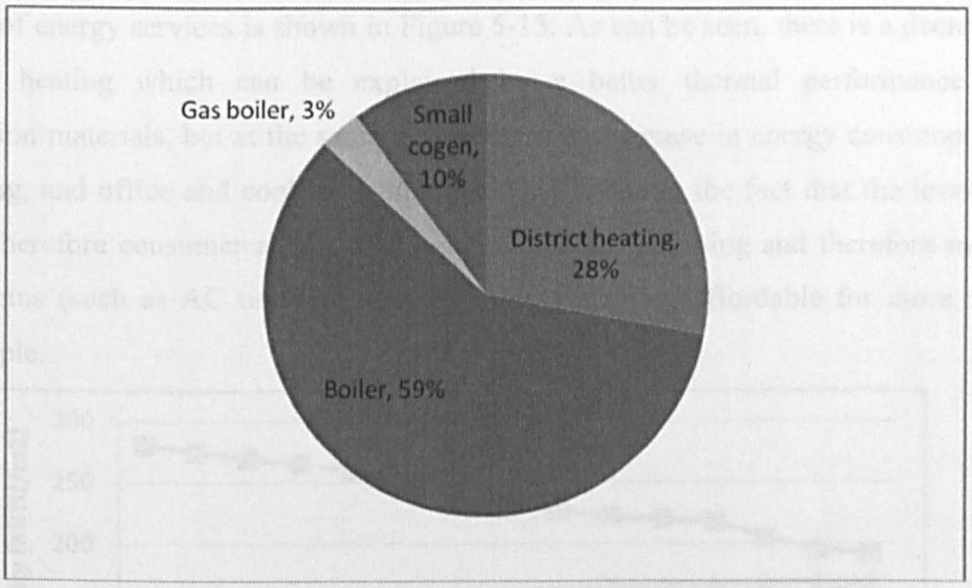

Figure 5-13 Space heating technologies [Zhou et al., 2007]

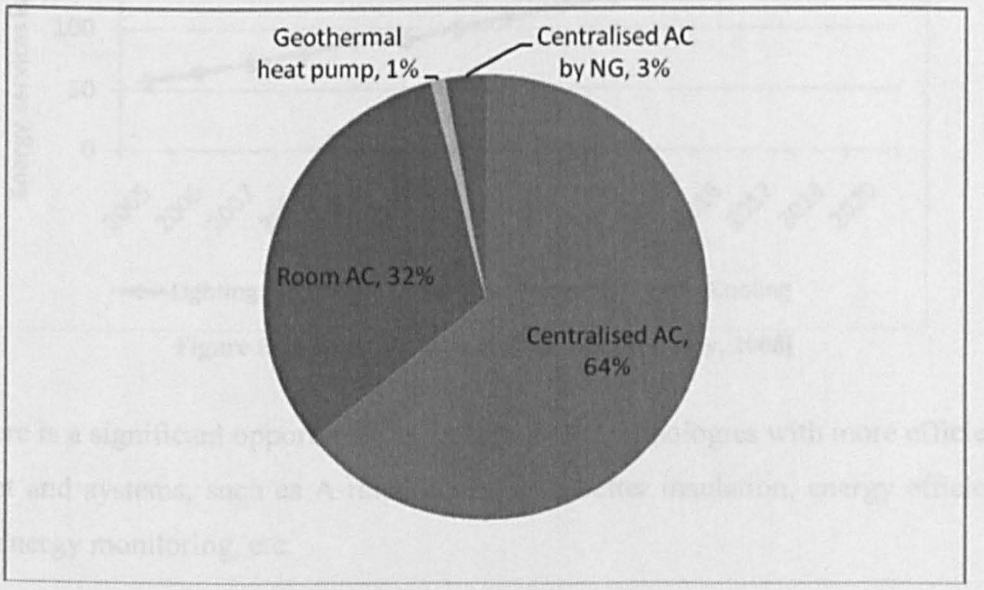

Figure 5-14 Space cooling technologies [Zhou et al., 2007]

As can be seen from these figures, the dominant method of heating is by coal boiler, followed by district heating, which uses coal as the primary resource. As for the cooling technologies, the dominant in centralised AC, whereas geothermal AC with higher efficiency (see Appendix I) has virtually insignificant share [Zhou et al., 2007]. Thermal performance and heating systems must be improved if China wants to mitigate GHG emissions. However, Chinese experts expect that with the decline of winter-time heating intensity due to temperature rises and buildings having better thermal performance, the summer-time cooling intensity will rise. As Chinese commercial sector continues to grow, the use of lighting and office equipment are expected to increase the energy demand as well [Yao et al., 2005]. The recent and predicted intensity of energy services is shown in Figure 5-15. As can be seen, there is a decrease in space heating which can be explained by a better thermal performance of construction materials, but at the same time there is an increase in energy consumption by lighting, and office and cooling equipment. This is due to the fact that the level of life and therefore consumer ability of the population is increasing and therefore more luxury items (such as AC units, printers, etc) are becoming affordable for more and more people.

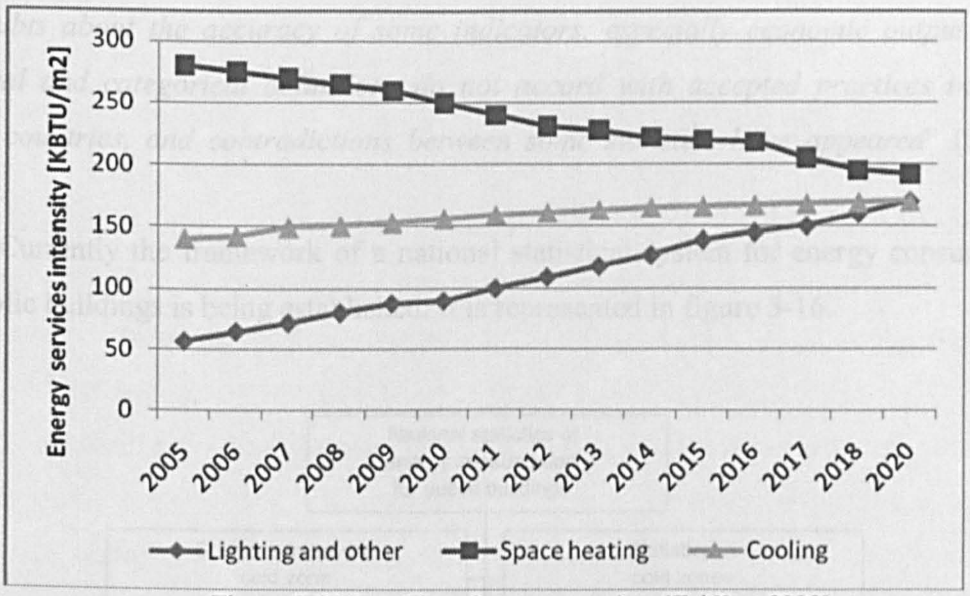

Figure 5-15 Intensity of energy services [Fridley, 2008]

There is a significant opportunity to replace these technologies with more efficient equipment and systems, such as A-rated equipment, better insulation, energy efficient lighting, energy monitoring, etc.

5.3.3 Statistics for energy consumption

In China, building energy consumption is seen as a part of the consumption sector of the national energy statistics; this sector is divided into many and mingled with other types of energy consumption in statistical departments. However, the national statistical system of energy consumption for public buildings in China does not work properly and improvements are needed in order to get the actual consumption data and put forward the countermeasures for the ongoing energy efficiency work in buildings. Many commercial buildings are shown in statistics as industrial, agricultural, etc, which changes the statistical data about the energy consumption [Chen et al., 2008]. Information on energy demand by end-use is also limited, which leads to an inadequate ability to capture the potential for energy efficiency improvements and the impact of energy efficiency policies and programmes. Moreover, China uses a different classification system than other OECD countries for energy reporting, therefore the sectoral breakdown has been questioned [Zhou, 2008]. Sinton (2001) says: "*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*" [Sinton, 2001].

Currently the framework of a national statistical system for energy consumption of public buildings is being established. It is represented in figure 5-16.

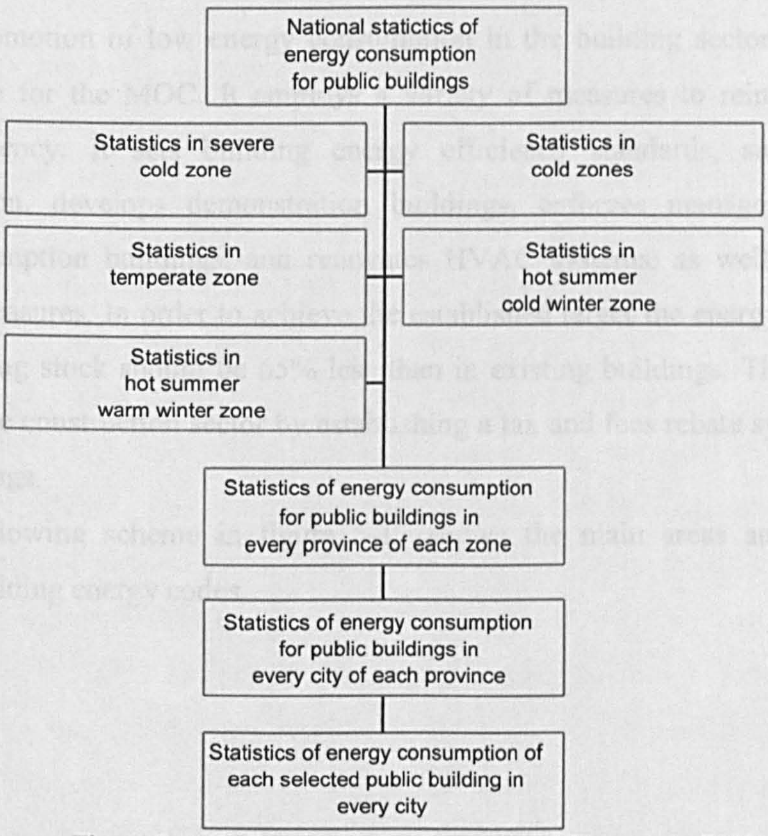

Figure 5-16 National statistics framework [Chen et al., 2008]]

The establishment of a national statistical system of building energy consumption in China will create the ability to conduct the statistics gathering in a uniform way throughout the country that will help to bring into effect policies aimed at energy efficiency improvements of commercial buildings.

5.4 Building energy efficiency standards and codes

Standards are the tool of the policy implementation. China has two sets of national building energy standards: one for residential and one for commercial buildings. Both of them are the responsibility of the MOC. The common target of the standards is to reduce energy consumption by 50% compared to building energy consumption in 1980s (or by 65% in developed cities like Beijing and Shanghai, as they are supposed to set the example for other cities). This number might look substantial but in reality the standards fall short of international standards and most are less stringent than their EU counterparts. These standards are rather narrow in scope and lack a strong regulation framework to incorporate energy efficiency in construction. [Yao, 2005].

The promotion of low energy consumption in the building sector is one of the main agendas for the MOC. It employs a variety of measures to reinforce building energy efficiency. It sets building energy efficiency standards, supervises their implementation, develops demonstration buildings, enforces management of high energy consumption buildings, and renovates HVAC systems, as well as other less significant measures. In order to achieve the established target the energy consumption in new building stock should be 65% less than in existing buildings. The government encourages the construction sector by establishing a tax and fees rebate system for low-energy buildings.

The following scheme in figure 5-17 shows the main areas and compliance options of building energy codes.

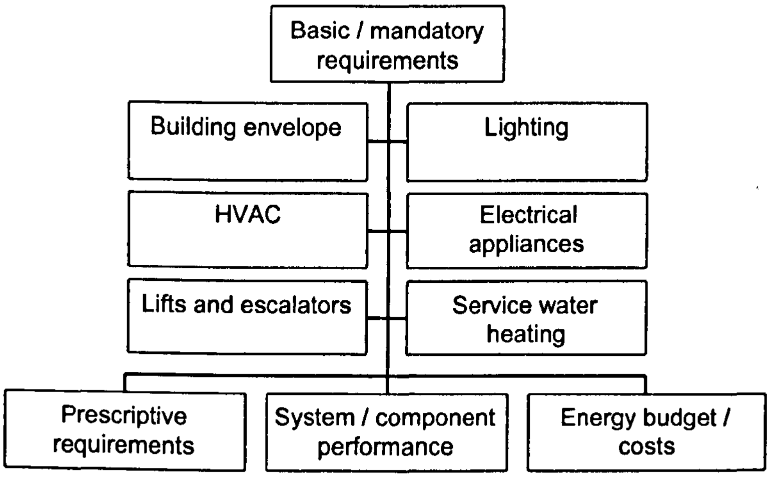

Figure 5-17 Main area and compliance options for building energy codes [Yong et al., 2003]

The basic/mandatory requirements are fundamental and must be satisfied, whereas the perspective requirements, system/component performance, and energy budget/cost are the options to meet the code's other criteria [Yong et al., 2003].

In 2005, the Central Government also began building inspection programmes that monitor the implementation of the building energy efficiency (BEE). Under these programmes, design institutions, developers, and construction companies will lose their licences/certificates if they do not comply with the regulations. Since then, the MOC conducts inspection-based surveys on energy efficiency in the main Chinese cities. The key of the inspection is the monitoring of the implementation of the building standard. Selected cities are required to submit a complete inventory of building projects. Survey teams randomly inspect 12 of them: they examine six projects drawings and conduct an on-site inspection for the remaining six projects [Shui et al., 2009]. The problem with this inspection is that it takes place in major cities only, whereas it is known by not only the academics, but also stated by the Chinese government, that the implementation of the codes and standards remain problematic in small provincial cities [Zhou, 2009].

Monitoring was officially pronounced in the National Building Energy Standard, which was enforced in 2008 by the MOC. This Standard covers both new and existing residential and commercial buildings. It also follows the Design Standard, which will be described in section 5.4.2, and states that the punishment provisions for non-compliance energy consumption activities and buildings will be issued. The penalties the companies may face are 200,000 – 500,000 RMB (29,429-73,573 USD), and the penalties the design institutes that violate the rules are 100,000 – 300,000 RMB (14,715-44,144 USD). Monitoring should be provided by the local government consumption department, but the Standard does not underline the procedure or a check list for the inspection [MOC, 2007].

Another way to improve energy efficiency in the building sector is an application of 'feebates' for energy hook-ups. Under this system, one either pays a fee or receives a rebate when connected to gas or electric systems. The amount paid or received depends either on the size of subscription or on the efficiency of one's buildings. The fees pay for the rebates that make the system cost neutral and economically and politically attractive. The main difference between codes and standards, and 'feebates' is that the codes and standards do not offer any incentive to exceed the requested efficiency level, whilst feebates drive continuous improvement: the more efficient you are, the bigger rebate you get [Yong, 2003].

The implementation of energy efficiency standards is not as easy as it might first appear. It is a complex system involving the cooperation of many departments. Today, this system faces the following problems [Yong, 2003]:

- The government confuses its function., as there is no clear division of responsibilities among the government bodies when in comes to energy efficiency issues.
- The Chinese energy efficiency standards lag behind international standards, mainly because of a lack of energy efficient technologies.
- There is a lack of governmental financial support and private investment.
- There is a lack of awareness [Yong, 2003].

The main problem of the energy efficiency standards for energy consumption is the unwillingness or inability of local governments to enforce detailed regulations that would suit local conditions, and to enforce national regulations through inspections and penalties. Local governments have encouraged the speed of construction, but this has forced wasteful construction of the buildings, which are excessively large and grandiose, but mostly under-used [Andrews-Speed, 2009].

Moreover, construction companies lack guidelines and training for energy efficiency in construction, and even with the appropriate design, there is the potential for communication breakdown design and construction. The buyers of the buildings also generally lack clear guidance of labelling of both building and appliances use within their buildings [Yao et al., 2005].

In order to enforce and implement energy efficiency standards, China needs to construct an appropriately designed institutional framework and an integrated policy needs to be formulated in order to combine the energy infrastructure quality, building energy efficiency, and public policies. All these will benefit the fast-growing urbanisation process and the huge number of buildings that are planned to be constructed in the next few decades.

5.4.1 Energy efficiency standards and energy labelling system in China

Energy efficiency standards (EES) are a procedure or regulation specifying energy performance of products. EES usually fall into three categories:

1) directive standards;
2) Minimum Energy Performance Standards (MEPS);
3) class-average standards.

All EES promulgated in China are mandatory national standards and belong to MEPS; among them the core indices are the limited values of energy efficiency, and the lowest threshold requirement for marking products, such as equipment. EES also include energy efficiency grading criteria and target-limited values of energy efficiency. Additionally, EES specify the classification of various production methods, indices, and parameters of energy efficiency, testing methods, and product checking and inspection rules [Li, 2006]. The EES structure can be seen in Figure 5-18.

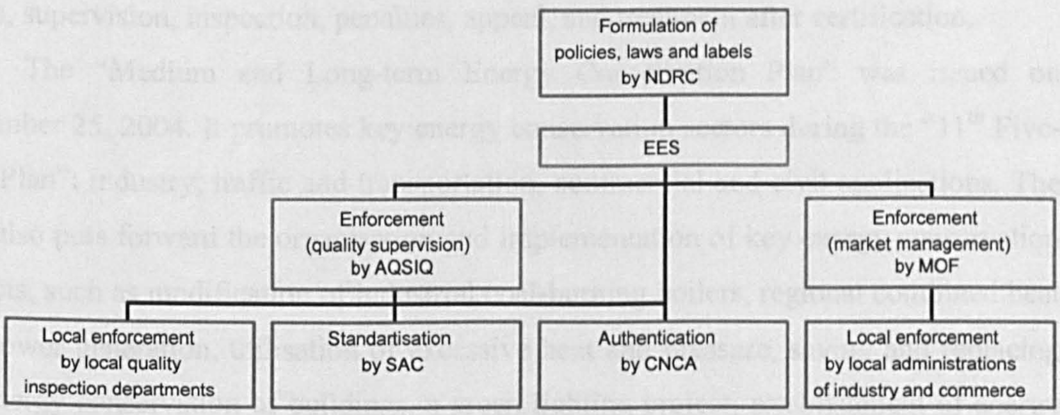

Figure 5-18 Energy efficiency standards structure

Though China has introduced a voluntary energy-conservation product-certification system and a mandatory energy-labelling system, it has not yet established a comprehensive framework of standard enforcement and monitoring, so the impact of EES is not reasoned [SSB, 2006]. Research on EES in China started in the 1980s, and currently China has implemented 25 EES that cover 24 kinds of products in 5 categories (see Appendix J for more details).

Today, China has an established framework of standardisation. The following are the main regulations implemented:

- The "Standardisation Law" was implemented on April 1, 1989; it stipulates development, implementation, supervision, and related to standardisation laws. It also specifies the punishment on products, which fail to meet compulsory standards of the production, sales, and imports.
- The "Management Method of National Supervision and Random Inspection of Product Quality" came into effect on March 1, 2002. National supervision and random inspection is one of maintaining product quality by the State. Regular supervision and random inspections are conducted every quarter, and irregular supervision and inspections are conducted according to the status of the product quality.
- The "Energy Conservation Law" came into effect on January 1, 1998. It regulates energy conservation management, energy utilisation, improvement of energy conservation technologies, and legal liabilities.
- The "Management Method of Energy Conservation Product Certification" was published in 2002. Product certifications adopt the principal of voluntarism. The method stipulates certification conditions, procedures, certificated, usage of energy conservation marks, supervision, inspection, penalties, appeal, and treatment after certification.
- The "Medium and Long-term Energy Conservation Plan" was issued on November 25, 2004. It promotes key energy conservation sectors during the "11^{th} Five-Year Plan": industry, traffic and transportation, commercial and civil applications. The Plan also puts forward the organisation and implementation of key energy conservation projects, such as modification of industrial coal-burning boilers, regional combined heat and power generation, utilisation of excessive heat and pressure, saving and replacing oil, energy conservation of buildings, a green lighting project, establishment of energy conservation monitoring and a technical service system, etc [Li, 2006].

Another important document in terms of building energy efficiency is the "China Buildings Programme Strategy", issued in 2005. Its main goal is to promote building energy efficiency through appliance energy efficiency standards and building codes. It states that it is possible to do so using the following actions [MOC, 2005]:

- To reduce energy consumption of appliances and equipment through standards and labels. Currently, China has developed six mandatory energy efficiency standards for refrigerators, AC units, fluorescent lamps, washing machines, TV sets, and gas appliances; two further standards for power supply units and natural gas water heaters are under development.
- To develop residential and commercial building energy codes in Central and South China and develop policies that ensure the implementation of these codes.

The main problems of EES in China are:

- The laws and regulation system is not complete; punishment degree is not strict enough. Though the "Standardisation Law" stipulates supervision of mandatory standards implementation and legal liabilities, the mandatory standards implementation is still poor. Little observation of laws and inaccurate law enforcement are prevalent, which gives an opportunity for illegal manufacturing, which leads to a poor quality of products.
- Market supervision mechanisms are not complete. There is no government or market supervision overseeing whether manufacturers comply with the mandatory limited values of energy consumption; therefore, manufacturers often exaggerate their energy efficiency. Though the State has started to conduct the supervision process, it is still too weak.
- Incentive mechanisms are insufficient. In order to meet the requirements of EES, enterprises need to make technical improvements, which would cause an increase of costs. Currently, consumers in China pay more attention on the price rather than on energy efficiency of the product. Therefore, taking into account that no favourable policies are provided, enterprises are not willing to manufacture the energy efficient products because of the high price doing so.
- A lack of public knowledge. As the government policies and publicity programmes are not adequate, the public does not recognise energy conservation and product certification [Li, 2006].

5.4.2 Introduction to the "Design Standard for Energy Efficiency of Public Buildings" GB50189-2005

More attention is paid on this particular Standard, as this is the only standard focusing on energy efficiency of commercial buildings. It has been used for evaluation in later sections of this thesis.

China adopted building energy standards gradually, starting with an energy design standard for residential building in the heating zone of northern China in 1986. Then the standard for tourists' hotels was implemented in 1993. One of the latest EES, implemented by the MOC is the "Design Standard for Energy Efficiency of Public Buildings" GB50189-2008 (herein referred as the Standard). Currently, it is the only standard covering the efficiency of commercial buildings [MOC, 2005]. The Standard has been developed by the China Agency of Building Research and the Building Energy Efficiency Professional Committee of China Construction Industry Association, which covers 21 organisations all over the country. The MOC is in charge of the interpretation of mandatory articles, and the China Academy of Building Research has provided detailed technical support [Hong, 2009].

As the Standard has only been issued recently, little academic work has been done on analysing it. The most substantial work among the ones found is by Hong (Hong, 2008), who is comparing the Standard with the ASHRAE Standard. The results of Hong's paper are similar to the results presented in this section. Another body of work has been done by Shui et al (2009); however, these works mostly focuses on the residential standards and only briefly mentions the Standard and discuss just some of its parts.

The Standard was implemented on July 1, 2005 as a replacement for the "Energy Efficiency Standard of Thermal Engineering and Air-Conditioning for Tourist Hotels" GB20189-1993 [MOC, 1993]. It is a mandatory national model energy standard, which is applicable to local governments and construction commissions. The aim of the Standard is to reduce the energy use of public buildings by 50% in comparison to the buildings constructed in 1980s. The Standard covers new construction, expansion, and retrofit of commercial buildings. It also covers the building envelope and HVAC systems. The structure of the Standard is outlined in Table 5-1.

Table 5-1 Structure of the Standard

Chapter	*Description*
Chapter 1	General provision
Chapter 2	Terminology
Chapter 3	Indoor thermal environment and design indices for building energy efficiency
Chapter 4	Building and building thermal design
4.1	General provision
4.2	Design of the building envelope
4.3	Tradeoffs in the thermal characteristics of the building envelope
Chapter 5	Energy efficient design of the HVAC systems
5.1	General provision
5.2	Heating
5.3	Ventilation and air-conditioning
5.4	Air-conditioning, heating and cooling sources
5.5	Monitoring and control
Appendices	
A	Calculation of the building external shading coefficients
B	Tradeoff calculations of the envelope thermal performance
C	The economical insulation thickness of indoor cold and hot water pipes for a building's air-conditioning system
Glossary	Explanation of the meaning of the words used in the Standard

The Standard specifies minimum insulation requirements and construction materials for different climate zones based on the zones defined in the "Thermal design code for civil buildings" GB50176-93 [MOC, 1993]. It recommends energy efficiency for HVAC systems, and provides design guidelines for energy efficiency requirements. Moreover, it covers the monitoring and control of buildings. In addition to the Standard, the three already existing national standards have to be taken into account when interpreting the Standard: there are Lighting Standard GB50034-2004; Chiller rating system GB19577-2004; Packaged air-conditioning unit-rating system GB19576-2004 [MOC, 2005].

The Standard also specifies the temperatures inside a building: for summer, the temperature in air-conditioned space is not allowed to be lower than +26°C; in winter, the temperature is not to be higher than 20°C. However, the indoor temperature is not specified according to climate zones, and is given only as general guidelines. In its appendix, the standard specifies how the internal temperature should change throughout the day during the cooling and heating season (see Appendix K). The requirements specified in the Standard for a particular type of space are given in the following table 5-2:

Table 5-2 Internal temperatures required by the Standard during the heating season

Room type	Temperature C°
Bank	18
Shop	18
Canteen	18
Security office	20
Computer room	16
Corridor	14
Business centre	18
Hotel room	20
Meeting room	18
Waiting room	18
Office	20
Archive	14
Karaoke room	16
Beauty salon	20

Air change rate per space volume lies between 0.1-0.2 m^3/s during the winter season, and 0.15-0.3m^3/s during the summer season. The fresh air requirement set out in the Standard is 30 m^3/h person. However, indoor design temperatures are not mandatory and may vary depending on building type and space type.

The mandatory requirements are those for roofs, opaque walls, floors, vertical fenestration, and skylights. The Standard also provides recommendations for the inside surface temperatures of thermal bridges in exterior walls and roofs, exterior window shading, natural ventilation, the operable area for exterior windows and transparent curtain walls, air infiltration and insulation of entry doors, and air tightness of exterior windows and transparent curtain walls. Only the mandatory requirements were taken into account for the case studies simulation, which will be described in more detail in Chapters 6, 7, 8, and 9.

The five climate zones (severe cold, cold, temperate, hot summer cold winter, and hot summer warm winter), described in Section 5.2 are used in the Standard when talking about building envelope criteria: insulation levels depend on climate zone the building is situated in. Table 5-3 presents the insulation requirements provided by the Standard.

Table 5-3 Building envelope requirements

Building envelope component	U-value [$W/m^2 °C$]
Outer wall	0.45-1.5
Roof	0.35-0.7
Floor	0.45-1.0
Window (single gazing)	1.7-3.0

The lighting requirements, provided in Table 5-4, are referred to the existing national standard GB50034-2004 for Lighting Design of Buildings. It covers the minimum requirements of interior lighting design for commercial, industrial, and residential buildings. There are no mandatory requirements for daylighting and exterior lighting is not mentioned either.

Table 5-4 Lighting requirements for building space types

Space	Maximum LPD (W/m^2)
Typical office room	11
Conference room	11
CEO office room	18
Guest room	15
Lobby	15
Classroom	15
Laboratory	11

As it has been mentioned before, the aim of the Standard is to reduce the energy consumption by 50%. The benchmark for this is the 1980s typical commercial buildings, characteristics of which are introduced in the following Table 5-5.

Table 5-5 Typical 1980s commercial building characteristics

Components	Severe cold climate zone	Cold climate zone	Hot summer cold winter climate zone	Hot summer warm winter climate zone
Outer walls U-value ($W/m^2 {}^\circ C$)	1.28	1.7	2	2.35
Roofs U-value ($W/m^2 {}^\circ C$)	0.77	1.26	1.5	1.55
Windows U-value ($W/m^2 {}^\circ C$)	3.26	6.4		
Lighting LDP (W/m^2)	25			
Heating	Coal—fired boiler, 55% efficiency			
Cooling	Water-cooled chillers, COP 4.2 for centrifugal chillers, COP 3.8 for screw chillers			

The Standard, however, does not make the aim of 50% reduction compulsory and states that the energy savings may vary from climate to climate. The average savings from the envelope and HVAC should be 13-25%, and from lighting about 7-18%.

As most of the buildings constructed in 1980s in cold and severe cold climate zones are provided with space heating, the Standard mentions this as well. It recommends using district hot water heating system in the Severe Cold climate zone only. As for the Cold climate zone, the Standard recommends for new construction to make a comprehensive economic and technical analysis (including building class, number of heating days, energy consumption, etc) before choosing district heating. The Standard does not regulate district heating efficiency.

The Standard also states that HVAC systems should have monitoring and control equipment, which should include such features as parametric testing, operating conditions display, automatic adjustment and control, automatic switch response to operating conditions, energy metering and a central monitoring and control system. The digital controls for all-air systems in buildings are recommended for buildings with a floor space more than 20,000 m^2.

The Standard also provides an appendix where the recommended percentage of the use of equipment, lighting, and occupancy for each hour of the day is provided (See Appendix L).

5.4.2.1 Problems of the Standard

Though the Standard plays an important role in the development of energy efficiency in commercial buildings, as with the many standards in China, the enforcement of the Standard is still a problem, especially in small and medium sized cities, mainly because of the lack of awareness and governmental support. The Standard also lacks some major features [MOC, 2005; Hong, 2009], such as:

- The incorporation of lighting and HVAC energy efficiency requirements.
- No regulation on external lighting and service water heating.
- No whole building performance compliance method and no specific regulations on compliance tools.
- No separated criteria for different construction classes of building envelope.
- No checklist for inspection.
- No life-cycle cost analysis.
- No list of sanctions and fines in case of non-compliance.
- Renewable energy technology is not incorporated.

5.4.2.2 Suggestions for the improvement

In his work, Hong (2009) suggests the following improvements, outlined in Table 5-6, which need to be made in order to exceed the Standard performance.

Table 5-6 Energy measures for exceeding the Standard performance

Components	Energy measures	Saving potential	Applicable climate zone
Envelope	Additional insulation	Cooling/heating	Hot, cold
	Use of cool roofs	Cooling	Hot
	Optimisation of building shapes	Cooling/heating	Hot, cold
	Use of high performance windows with low U-values	Cooling/heating	
	Lower WWR; avoidance of west and south facing windows in hot regions	Cooling/heating	
	Lower skylight-roof ratio	Cooling	Hot
	Use of exterior shading	Cooling	
Lighting	Use of dimming and occupancy sensors	Lighting/ cooling	All regions
	Use of daylighting techniques; reduction of electrical lighting	Lighting/cooling	
	Use of energy efficient lamps	Lighting/cooling	
HVAC	Use of natural ventilation	Cooling	Temperate
	Use of appropriate HVAC systems, zoning and controls	Cooling/heating	All regions
	Use of radiant cooling and heating systems	Cooling/heating	
	Use of air-side and water-side economisers	Cooling	Temperate
	Use of variable speed drives for fans and pumps	Electricity	All regions
	Use of high efficiency boilers	Heating	Cold
	Use of high efficient chillers	Cooling	Hot
	Use of reset controls to adjust air supply and chilled water temperature etc	Cooling/heating	All regions
	Use of demand control ventilation	Cooling/heating	Cold, hot
	Use of heat recovery	Cooling/heating	Hot, cold
	Use of CHP systems	Electricity, heating	Cold
	Use of geothermal	Cooling/heating	All regions
RE	Use of PV	Electricity	
	Use of SHW	Heating	

This Standard will be evaluated in detail in Chapter 10 and further suggestions for its improvements will be introduced.

5.5 Building energy performance

Building energy performance is the key element in the assessment of building environmental sustainability and is based on a number of components (though the local context has to be considered): emissions to air; GHG production; releases to water; contamination of land; waste management; use of non-renewable resources; use of renewable natural sources [Hui, 2001].

One of the ways of improvement of energy efficiency is through the construction of exemplar green buildings (one of them is shown in figure 5-19), which are emerging in China now, mainly driven by the government concerns about pollution, resource depletion and energy deficits, and the desire for international recognition [Langer and Watson, 2004].

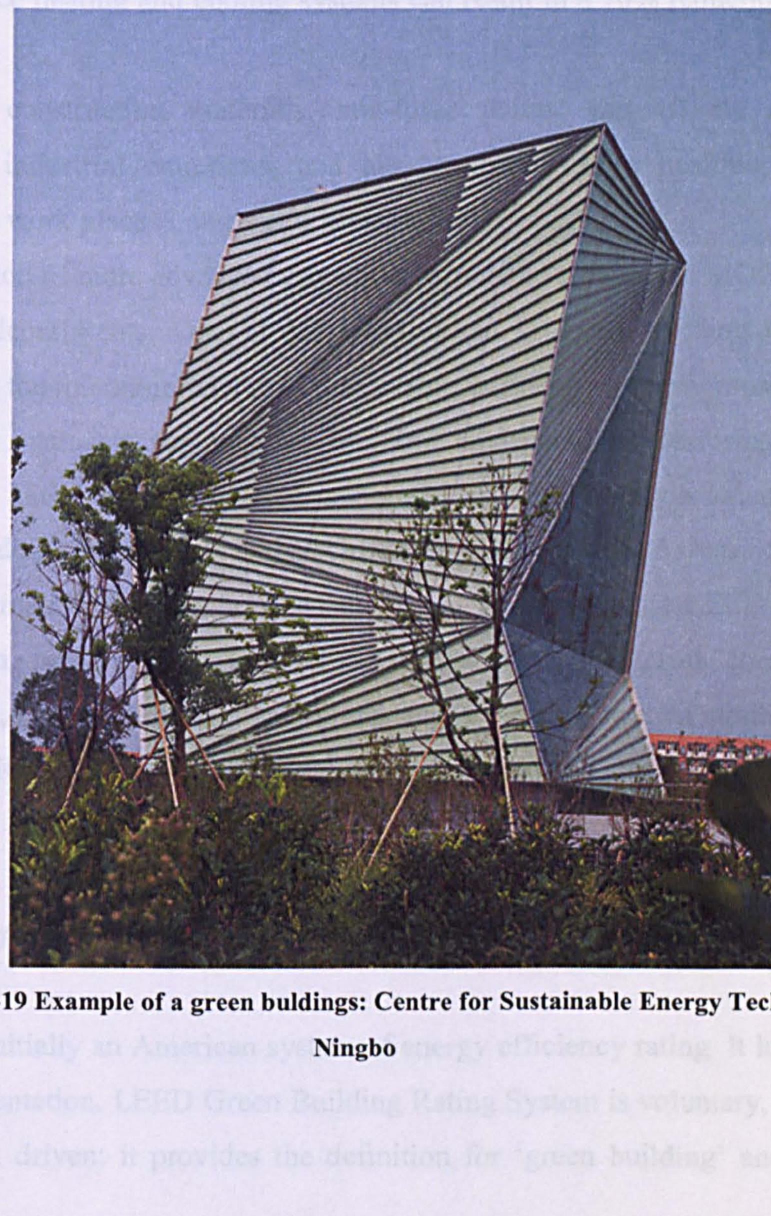

Figure 5-19 Example of a green buldings: Centre for Sustainable Energy Technology in Ningbo

Compared to conventional buildings, green buildings consume less water and energy, preserve natural resources, and provide excellent indoor environmental quality that is achieved through the integration of four elements:

- Architectural design features: the maximization of natural daylight and natural ventilation, which results in energy saving and productivity, as well as comfort optimisation;
- Landscaping: the reduction of water use by 70-80% can be achieved by the combination of the proper selection of plants and site design and rainwater retention and onsite water purification systems;
- Electrical and mechanical systems: the combination of energy-efficient lighting with high-performance windows, well-insulated walls and roofing, and high performance heating and cooling systems can result in a 70% reduction of energy use;
- 'Green' construction materials: non-toxic paints, carpets, etc can reduce embodies industrial emissions, and also contribute to a healthier and more productive work place [Langer and Watson, 2004].

The adoption of more advanced green practises is the aim for the MOC, the SEPA and the other departments. One of the ways found is green building certification systems, such as the internationally used Leadership in Energy and Environment Design (LEED). LEED evaluates and certifies building environmental performance in site selection, water and energy efficiency, materials, and indoor environmental quality. Another system designed in China is the "Green Olympic Building Assessment System" (GOBAS). The main difference between these two systems is that LEED focuses on post-construction performance, whereas GOBAS requires interim completion of planning, design, construction, and operations stages. Another system similar to LEED issued by the MOC recently is the "Evaluation Standard for Green Buildings" GB/T 50378-2006.

5.5.1 Energy performance rating systems

5.5.1.1 LEED

LEED is initially an American system of energy efficiency rating. It has different areas of implementation. LEED Green Building Rating System is voluntary, consensus-base and market driven; it provides the definition for 'green building' and evaluates environmental performance from a whole building perspective over a building's life cycle.

The rating system includes five categories: sustainable sites; water efficiency; energy and atmosphere; materials and resources; indoor environmental quality. LEED can measure the rating for new as well as existing buildings, both residential and non-residential, as is shown in Figure 5-19 [LEED, 2005].

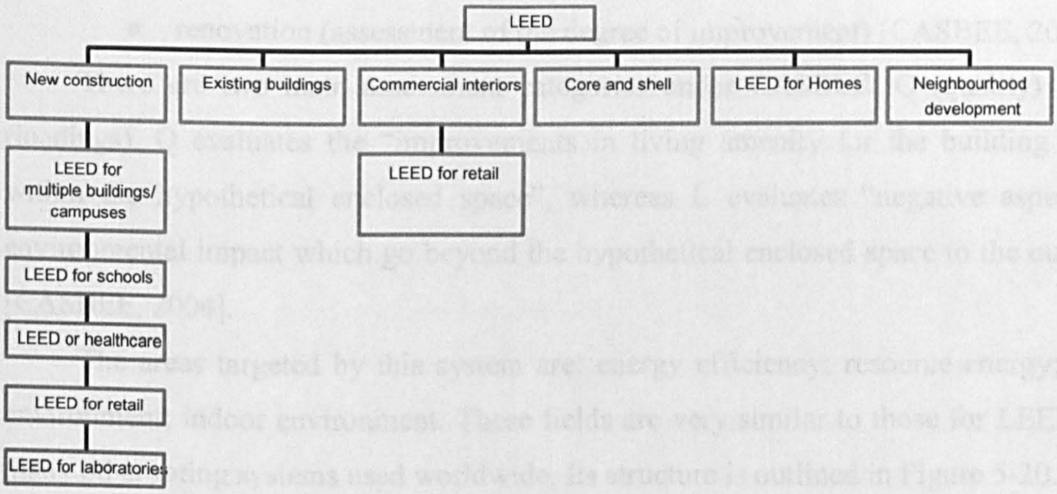

Figure 5-20 LEED structure

It is a performance-oriented system where credits are earned for satisfying each criterion; the number of total credits earned is an indicator to different levels of green building certification [LEED, 2005].

5.5.1.2 Evaluation Standard for Green Buildings

The Evaluation Standard for Green Buildings GB/T 50378-2006 was issued in June 2006 by the MOC to encourage buildings to go beyond the minimum energy efficiency requirements. This standard is very similar to LEED. The MOC collects building energy consumption data, assesses energy performance based on standards, and issues the three-star building certification to qualifying buildings. The local government is in charge of the issuing of lower level one/ two- star certification [LEED, 2005].

5.5.1.3 Green Olympic Building Assessment System

GOBAS was created by the Tsinghua University and funded by the Beijing Science and Technology Committee. It is based on Japanese CASBEE and has some features of LEED as well [LEED, 2005]. This system is composed of four assessment tools corresponding to a building life-cycle:

- pre-design;
- new construction (allows rising of the BEE value; makes assessments based on the design specification and the anticipated performance);
- existing building (an assessment based on the operation record for at least one year after completion);
- renovation (assessment of the degree of improvement) [CASBEE, 2004].

There are two main assessment categories under CASBEE: Q (quality) and L (loadings). Q evaluates the "improvements in living amenity for the building users, within the hypothetical enclosed space", whereas L evaluates "negative aspects of environmental impact which go beyond the hypothetical enclosed space to the outside" [CASBEE, 2004].

The areas targeted by this system are: energy efficiency; resource energy; local environment; indoor environment. These fields are very similar to those for LEED and many other rating systems used worldwide. Its structure is outlined in Figure 5-20.

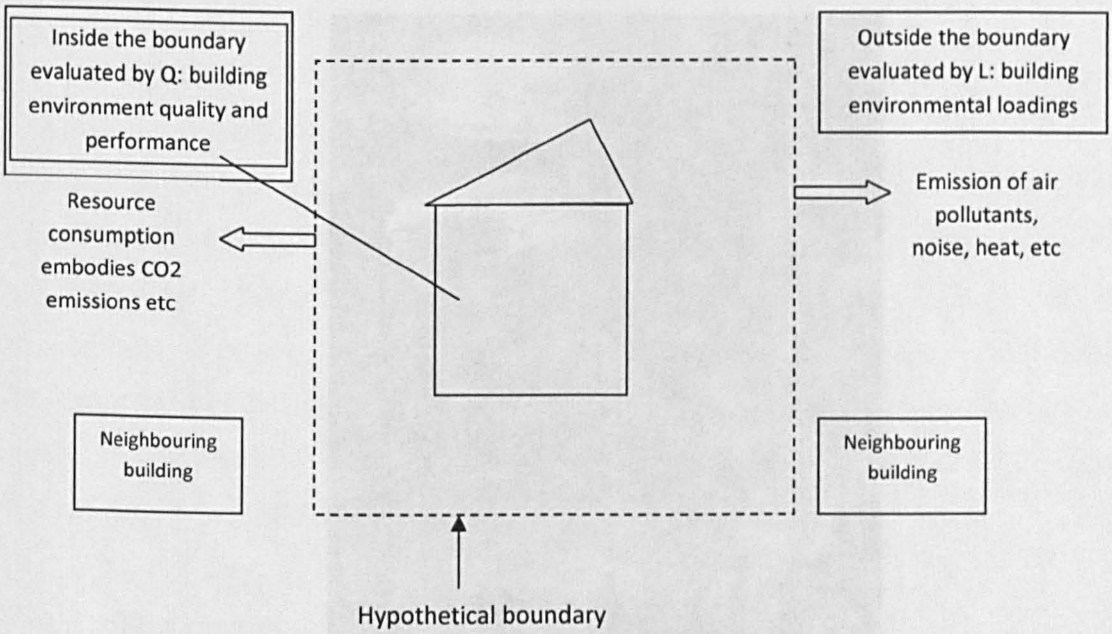

Figure 5-21 GOBAS structure

However, although the market is expanding, green buildings are still rare in China. It is difficult to give the exact number of buildings adopting green technologies in China; however, it is known that as of July 2009, there were 30 buildings that had achieved green building certification under LEED. Another 10 buildings had been certified under other standards, and more than 210 buildings attempted to receive the standard after construction was complete. Taking this number into account it is estimated that the total floor space of green buildings was less than 1% of China's new construction in 2009 [Crachilov et al., 2009].

5.5.2 Eco-cities

The development of eco-cities has emerged as a way to address sustainability in urban environments. Girardet [Girardet, 2004 in Hald, 2009] explains "*a sustainable city enables all its citizens to meet their own needs and to enhance their well-being, without degrading the natural world or the lives of other people, now or in the future*". According to White [White, 2002 in Hald, 2009], an eco city is "*a city that provides an acceptable standard of living for its human occupants without depleting the ecosystem and the biochemical cycles on which it depends*".

Many eco-cities have been appearing in China; some of them are more like eco-communities, whereas others are large-scale. An example is Dongtan Eco-City, located on Chongming Island at the mouth of Yangtze River not far from Shanghai.

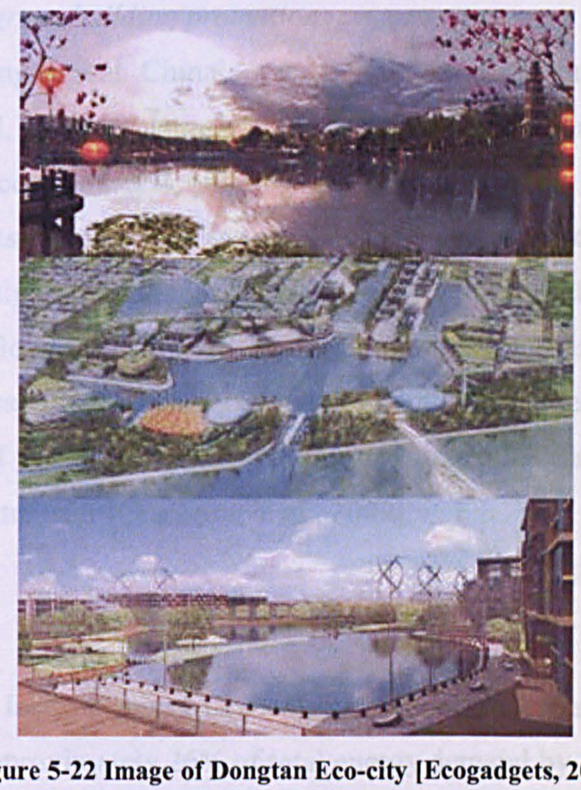

Figure 5-22 Image of Dongtan Eco-city [Ecogadgets, 2010]

The project has received investment from both UK and Chinese governments, as the design of the city was provided by the company Arup with their headquarters in

London. The plan for city functioning is the following: all energy is in the form of electricity, heat and fuel is to be provided by renewable means; buildings will achieve energy conservation by specifying high thermal performance and using energy efficient equipment and systems. Transport energy demand is to be reduced by eliminating the need for motorised journeys and the use of energy efficient vehicles. Energy supply comes from the local grid and electricity and heat is produced by four different means: a CHP plant running on biomass from rise husks, which are the waste product of rice mills; a wind farm situated nearby; biogas extracted from the treatment of municipal solid waste and sewage; and PV cells and micro wind turbines. It is also planned to collect 100% of all waste and recover 90% of it. The buildings combine traditional and innovative technologies, so that their energy consumption is to be reduced by 70%. According to the plan, Dongtan city will accommodate 500,000 people by 2050 [Hald, 2009].

Other eco-city projects under development in China are Huangbaiyu in Liaoning Province, Rizhao in Shangdong Peninsula, and Tianjin.

5.5.3 Challenges for green building promotion

The main challenges that China's green building development is facing are financial, technological, and regulatory. A decreased market value due to the low awareness: potential occupants and building developers lack the knowledge of the capital costs and benefits of green building solutions. As the awareness is low, investors are not willing to pay higher initial cost, even though it would result in lower resource expenditures over the long-term. Moreover, in the Chinese building market foreign designers and builders can play only a very limited role due to Chinese regulations. This results in distortions of competition and complicates green building implementation, resulting in a low skills transfer [Crachilov et al., 2009].

5.6 Future trends

Energy Research Institute gives three different energy demand scenarios where buildings account for approximately 26% of total energy demand by 2020 [ERI, 2003]:

1) The green growth scenario: energy demand in buildings is below 327 mtoe that is 27% lower than Business as Usual;

2) The reference scenario: buildings account for 28% of final energy consumption, that is 282 mtoe by 2015, and 401 mtoe by 2030;

3) The policy scenario: buildings account for 26.7% of final energy consumption, or 312 mtoe in 2020, and 401 mtoe in 2030.

The limitation of the above energy forecast is that they neglect renewables, though the place of the renewable energy in China is rather big as it accounts for about 7% of total energy production.

Jiang and Hu give a scenario of China's building sector energy demand and emission trend [Jiang and Hu, 2005]: their baseline scenario predicts that coal will steadily be replaced by gas, and electricity will represent 42% in 2020 and 48% in 2030 of the final consumption. Energy demand in buildings would increase to 417 mtoe in 2020 and 666 mtoe in 2030. Under the policy scenario with the active implementation of efficiency improvement policies and the upgrading of appliances efficiency, energy demand is predicted to reduce by 17% and by 28% in 2020 and 2030 respectively; and there is still some room for further reductions with the implementations of more advanced technologies. According to their reference scenario, buildings would account for 28% of final energy consumption in 2030.

Another scenario projection is introduced by Zhou and Lin (2008). As commercial floor area is increasing steadily in China, the Ordinary Effort Scenario suggests that it will grow from 8 bln m^2 in 2000 to 21.2 bln m^2 in 2020. As the consumers' demand for comfort is growing, penetration of all major building energy end-uses will increase dramatically by 2020. For space heating, it will reach 55% (compared to 35% in 2000), and the cooling will increase by 40 %. As the Chinese government implements many energy efficiency standards, incentives and subsidies, Zhou's and Lin's model shows that a 35% demand-abatement potential compared to BAU scenario can be achieved, mainly driven by sizable energy efficient opportunities for space heating and water heating. The energy mix of the commercial sector will also change, with the share of on-site use of coal dropping from 49% in 2003 to 12% in 2020, whereas the share of electric power will triple to 47%, and natural gas will reach 19% (compared to 2003 when it was just 2%) [Zhou and Lin, 2008].

The majority of scenarios project that solid fuel will be substituted step-by-step with electricity in buildings over the upcoming decades. They also point out that the largest potential of energy saving is in space heating: improvement of space heating energy efficiency by tightening the building code should lead to the reduction of 112mtoe energy use in 2020, or 100Mt of CO_2 that might be avoided. The full implementation of the DSM policy of electricity consumption may lead to the reduction of 347Mt of CO_2 in 2030, and the active development of renewable energy in electric production allows a further 390Mt of CO_2 reduction by 2020.

All the scenarios provide the analysis of the energy demand in building sector in China and predict that it would have a dramatic increase. However, the results of these projections are different, though all of them justify the necessity of acting immediately on efficiency improvement in building stock [Li, 2008].

5.7 Barriers

Many studies (IPCC, 2007; Deringer et al., 2004; Westling et al., 2003) discuss barriers to energy efficiency in policies towards buildings (see Appendix M). The number of them is large, however the main barriers for energy efficiency improvement in commercial buildings are:

- Technical barriers: standards should be suitable for local climate conditions; design and materials (such as energy efficient construction materials, envelope insulation, and ventilation options) should be promoted as an important contribution to energy-saving and climate change mitigation.

- Institutional barriers: cost-effective methods should be promoted to attract the interest of consumers and supplement the implementation of energy efficiency in buildings. Consumers are not eager to save the energy while compromising their comfort, therefore reasonable price signals should be sent to them.

- Trend of energy use in buildings in China: the statistics do not count renewable sources in the energy balance of buildings energy consumption. The awareness of renewable energy use should be promoted amongst commercial building users.

- CO_2 abatement measures: technical solutions, such as renewable energy technologies, are not used properly: CO_2 mitigation in buildings needs to identify the most effective and cost-effective measures to address the problem of climate change; cost effectiveness and relevance should be considered as primary criteria in assessing the mitigation policies [Li, 2008].

5.8 Summary

Commercial buildings in China are less energy efficient than in developed regions. Chinese energy efficiency standards for commercial buildings are different from those in the other countries. The whole process of standardisation was started later than in developed countries. However, after the 1980s the standards have been developing rapidly and systematically, and today there are design standards, testing standards, management standards, and building energy consumption standards.

What is lacking is the public awareness and educational campaigns aimed at building energy saving and conservation are far from adequate. More attention must be given to energy saving in total, especially in the development and manufacture of new materials.

The increased construction costs associated with energy efficient buildings that use advanced technologies give developers little incentive to comply with energy codes. To promote energy efficiency compliance in buildings in China, carrot and stick policies should be adopted, as a strict command and control system can supervise and enforce the compliance rate in new constructions with the market incentives encouraging developers to exceed the standards of building codes and create a market opportunities for new efficient technologies at the same time.

The improvement of building energy efficiency is the quickest, cleanest and the most effective way of creating energy savings and extending services supply to buildings [Li, 2008]. However, to make full use of these improvements, China has to create more market incentives, tighten the energy efficiency requirements in new buildings, accelerate the retrofitting process; promote high-performance appliances and renewable energy; develop progressive high efficient energy supply technologies; diversify the investments in energy efficiency in buildings; integrate energy development in urban planning; institutionalise the energy performance assessment system, and promote public awareness and R&D.

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Chapter 6 - Case Study Analysis: Huazhou Hotel, Kunming

6.1 Introduction

6.1.1 Methodology

In order to appreciate what energy savings difference can be achieved if the energy efficiency standard was implemented into the building construction, four case studies in different climate zones were assessed. For each of the four case studies introduced in chapters 6, 7, 8 and 9 two scenarios are presented. The first scenario represents the real operation of the building. The second scenario represents the building operation based on the Standard for Energy Efficiency of Public buildings GB500189-2005. In addition, for each of the case studies, possible renewable technologies have been suggested. Case studies were selected based on their location: they represent different climate zones. Another factor was that all case study buildings are commercial buildings.

The same calculation methods were been used for all case studies. The aim of the calculations was to see if the Standard is able to achieve its aim of energy consumption reduction (see section 5.4.2). The example of the calculations is presented in Appendix N.

6.1.1.1 Building heating and cooling load

All calculations were done in Excel 2007. The following equations were used for the calculation of the heat gain and heat loss of each building, and for the amount of CO_2 emissions. The equations used are provided by the ASHRAE (2005). All calculations have been done separately for each room of a building taking into account the windows facing direction when calculating solar gains. The example of the calculations for winter month for Kunming case study is presented in the Appendix N.

In order to be able to calculate the building heating and cooling loads, firstly, the building heat losses were calculated.

To calculate the fabric heat loss the following equation 6-1 is used,

$$Q_f = \Delta T \times A \times U \qquad \textbf{Equation 6-1}$$

where Q_f is a fabric heat loss , ΔT is the average temperature difference in winter, A is area of the surface, and U is a U-value of that particular surface. Q_f is calculated for each surface of the room, that are four walls, roof (ceiling), floor, and window. However, it equals 0 for all the floors except Level 1 (ground floor) (for floor) and Level 17, which is the top level (for roof), as in any other case they are not influenced by any outer conditions, as the temperatures in the rooms above and below are similar to the internal temperature in the room evaluated. The total fabric heat loss is a sum of the fabric heat loss of each external surface. To find the temperature difference, equation 6-2 is used,

$$\Delta T_{winter} = T_{in} - T_{out}$$ **Equation 6-2**

where T_{in} is internal temperature, and T_{out} is external temperature. The equation changes for summer time (in this case, from April to September):

$$\Delta T_{summer} = T_{out} - T_{in}$$ **Equation 6-3**

To calculate the ventilation heat loss, the following equation was used,

$$Q_v = \frac{V \times N \times \Delta T}{3}$$ **Equation 6-4**

where Q_v is ventilation heat loss, V is volume, N is air exchange rate, and $^1/_3$ is heat loss in W or J per second.

To calculate the infiltration loss, the following equation was used,

$$Q_i = \rho \times V \times D_i \times C_p \times \Delta T$$ **Equation 6-5**

where Q_i is infiltration loss, ρ is density of air, V is flow rate, D_i is infiltration rate, and C_p is the specific heat of air.

To calculate the total space heat loss, the following equation was used,

$$Q_{sp} = Q_f + Q_v + Q_i$$ **Equation 6-6**

where Q_{sp} is total space heat loss.

Secondly, heat gains possible in the buildings were calculated. Heat gains from people, equipment, and lighting and solar heat gain were calculated to find out the cooling load.

To calculate the heat gain from people, equation 6-7 was used.

$$Q_p = N_{people} \times q_{person}$$ **Equation 6-7**

Here Q_p is the heat gain from people, N_{people} is number of people occupying the room, and q_{person} is the heat gain from one person according to his/her activity (for example, 70 W from a person doing a light office work).

To calculate the heat gain from the equipment, equation 6-8 was used,

$$Q_e = N_{equip} \times q_{equipment}$$ **Equation 6-8**

where Q_e is the heat gain from equipment (PC, PC monitor, TV, printer, scanner), $N_{equipment}$ is the number of appliances in the room, and $q_{equipment}$ is the heat gain from one piece of the equipment. As different types of equipment have different heat gain rates, the heat gain is calculated for each type of equipment and then summed up together.

To calculate the heat gain from lighting, the following equation was used,

$$Q_l = N_{lux} \times 0.001496 \times A$$ **Equation 6-9**

where Q_l is heat gain from lighting, N_{lux} is amount of lux produced by the light used in the room, *0.001496* is a constant allowing to convert lux into Watts, and A is the room area.

To calculate the solar heat gain, equation 6-10 was used,

$$Q_{solar} = S \times I \times A_g$$ **Equation 6-10**

where Q_{solar} is solar heat gain, S is solar gain factor, I is solar radiation intensity, and A_g is glazed area. Solar gain factor was specifically chosen for each month of the year for a particular location and was also specified according to the facing direction of window.

The sum of all heat gains gives the total heat gain.

$$Q_t = Q_p + Q_e + Q_l + Q_{solar}$$ **Equation 6-11**

In order to see monthly space heating or cooling requirements for the period, the following equation is used.

$$E_{sp} = (Q_{tloss} - Q_{tgain}) \times H_m$$ **Equation 6-12**

where H_m is the hours per month.

As one of the case study buildings is provided with hot water, it was also important to calculate the hot water energy consumption in order to find out the amount of energy used for its heating. In order to calculate monthly hot water consumption, equation 6-13 was used,

$$E_{hw} = M_a \times C_p \times \Delta T$$ **Equation 6-13**

where E_{hw} is hot water energy consumption, M_a is amount of water consumed per person per day, C_p is specific heat for water, which equals 4.186 J/gmK, and ΔT is the temperature difference between the outlet temperature of hot water and the temperature of the hot water source.

6.1.1.2 Electric energy consumption

As the aim of the calculations is to find out the real building operation energy consumption, the electric energy consumption of different sectors of each building was calculated.

In order to see the electric energy consumption of the lighting per month, the following equation was used,

$$EEC_l = N_l \times N_{Watt} \times N_h \times N_d \qquad \textbf{Equation 6-14}$$

where EEC_l is lighting electric energy consumption, N_l is the number of light bulb/tubes, N_{Watt} is the amount of Watts consumed by the light bulb/tube, N_h the number of hours the lighting was used per day, and N_d is the number of days the lighting was used per month.

In order to see the electrical energy consumption of the equipment per month, the following equation was used,

$$EEC_e = N_{equipment} \times N_{Watt} \times N_h \times N_d \qquad \textbf{Equation 6-15}$$

where EEC_e (calculated separately for printers, photocopiers, TV, and PC) is the equipment electrical energy consumption, $N_{equipment}$ is the number of equipment items, N_{Watt} is the amount of Watts consumed by the particular piece of equipment, N_h is the number of hours the equipment was used per day, and N_d is the number of days the equipment was used per month.

In order to find out the amount of electrical energy consumed by air source heat pumps, the following equation was used:

$$EEC_a = \frac{E_{sp}}{CoP} \qquad \textbf{Equation 6-16}$$

where CoP is the coefficient of performance (different for heating and cooling).

The sum of the each of the above calculated electrical energy consumptions provides the total electrical energy consumption of the building.

6.1.1.3 Payback period calculation

In order to evaluate the cost effectiveness of the Standard, it was decided to calculate the payback period of the energy efficiency measures.

In order to calculate the simple payback period the following equation has been used,

$$SP_{yr} = \frac{\pounds_{invest}}{\pounds_{sav/yr}} \qquad \textbf{Equation 6-17}$$

where SP_{yr} is the simple payback period, $£_{invest}$ is the initial investment cost of an energy conservation investment, $£_{sav/yr}$ is the savings achieved by the energy conservation investment per year. However, the simple payback period does not represent value for money, the discounted payback period needs to be calculated. In order to calculate the discounted payback period, firstly, the discount factor has to be calculated,

$$DF = \frac{1}{(1+d)^n} \qquad \textbf{Equation 6-18}$$

where DF is the discount factor, d is the discount rate as a decimal, and n is the future year being evaluated. The use of a discount factor allows us to find out the present value of money savings realised in the future, as presented in equation 6-19,

$$PV = FV \times DF \qquad \textbf{Equation 6-19}$$

where PV is the present value of savings, which will be derived in some future year n, and FV is a future amount of money savings. Then the discounted payback period can be found out by comparing the total investment with the accumulated savings, which are calculated using equation 6-20,

$$£_{as} = (£_{sav/yr} * DF) + £_{as}{}^{n} \qquad \textbf{Equation 6-20}$$

where $£_{as}$ is accumulated savings and $£_{as}{}^{n}$ is accumulated savings in previous year. The year when the total investment is equal or smaller than the accumulated saving states for the number of years of the discounted payback period.

As the Standard have the requirements for glazing, the price for the installation of the new improved glazing with the required U-value has been taking into account when calculating the payback period.

As the Standard does not provide information about which insulation material or which type of glazing is to be used in order to achieve the energy consumption reduction, materials were chosen from the "Spon's Architects and Builders Price Book 2007" [Langdon 2008]. Preference was given to materials produced in China, as it allows a reduction in transportation costs and embodied energy. As both the original and proposed U-values are known, it is possible to find the required extra thermal resistance using Equation 6-21 and therefore allowing the thickness of the new insulating material to be calculated using Equation 6-22,

$$R_e = R_1 - R_2 \qquad \textbf{Equation 6-21}$$

where R_e is extra thermal resistance required, R_1 is the target total thermal resistance, and R_2 is the existing total thermal resistance.

$$d_m = R_e \times k$$ **Equation 6-22**

Here d is the thickness of the proposed insulated material, and k is k-value of the proposed insulated material.

The simple payback for the renewable energy technologies theoretically can also be calculated using Equation 6-17. However, as the renewable technology requires scheduled check-ins and maintenance, the expected annual savings are calculated using the following equation,

$$£_{savyear} = (£_{Kwh} \times TE_{Kwh}) - £_{oper}$$ **Equation 6-23**

where $£_{Kwh}$ is the cost per unit of electricity, TE_{Kwh} is the annual electricity/heat generated by the renewable energy technology, and $£_{oper}$ is the annual operation and maintenance costs .

In this analysis, no fuel escalation has been taken into account concerning the current economic situation of fluctuating oil prices. It can be argues that over time oil prices will increase, further reducing payback period and increasing cost-effectiveness.

6.1.2 Case study location

Case Study One is a hotel in Kunming, the central city of the Yunnan Province situated in Southern China.

Figure 6-1 Yunnan province location [Lam 2008]

Kunming is known as a 'spring city' and according to climatic division, it is a part of the temperate climate zone. This area has a long summer and mild winter; the yearly and daily temperature range is very small. The coldest month average temperature is

5 °C, the summer daily average temperature varies from 25 to 29 °C for about 100-200 days annually. Figure 6-2 shows the solar radiation and temperature for Kunming.

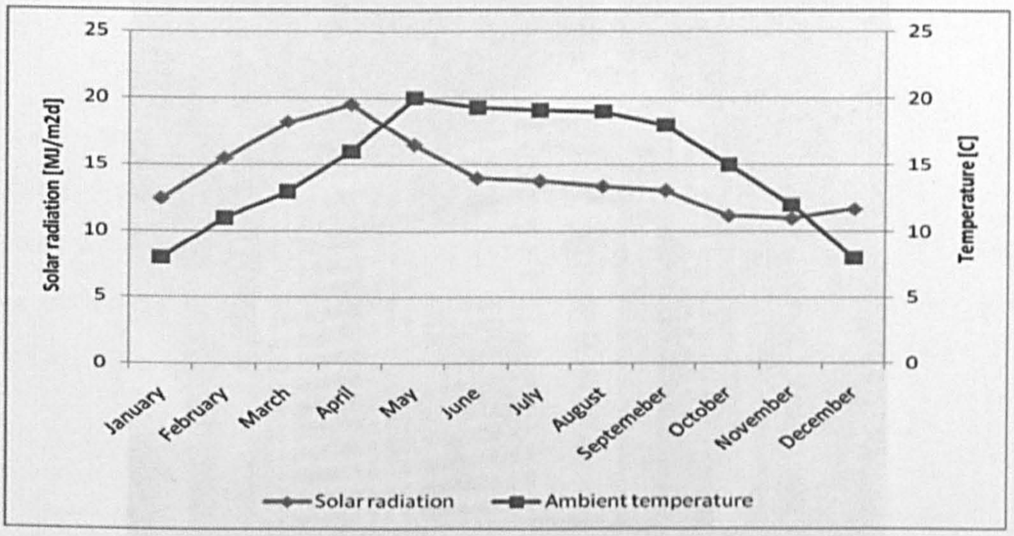

Figure 6-2 Daily horizontal solar radiation and ambient temperature of Kunming

This area has the most precipitation in China. Elevation angle is big, and so is solar irradiation. The following table 6-1 gives the main climatic conditions for Kunming.

Table 6-1 Main climatic characteristics for Kunming [Lam, 2008]

			Dry-bulb temperature °C				Rel. humidity %		Sunshine
Lat. (north)	Lang. (east)	Elev. (m)	Annual average	Annual diff.	HMA	CMA	HMA	CMA	Hours
25°01'	102°41'	1891.4	14.7	12.1	19.8	7.7	83	68	2470.3

6.1.3 Hotel description

Huazhou hotel is located in Yunnan Province, Kunming (225 Huan Cheng East Road). Figure 6-3 presents a visual image of the hotel.

Figure 6-3 Image of the hotel [www.chinaforgroups.com]

It is a four-star hotel situated in the city's international business district. The hotel is an 18-storey building with 212 guest rooms, 13 restaurants, 12 karaoke rooms and 5 shops. The top three floors are used for the offices of the hotel administration. Two underground levels are used as a car park. The total floor plan area of the building is 20,000 m^2. Area per floor is ~1,000 m^2. In the case study analysis, corridors, toilets, and other common areas were not taken into account, as they are not included in the hotel's heating/cooling distribution system. Underground levels (car park) are also not included for the same reason.

6.1.3.1 Building components

Materials with the following U-values are used in the building:

Floor: covered with carpet, with U-value=2.08 W/m^2 $^{\circ}$C, and covered with linoleum, with U-value= 0.05 W/m^2 $^{\circ}$C.

Roof: pitched with felt, 100 mm insulation, with U-value=0.3 W/m^2 $^{\circ}$C;

Glass: single glazed, with U-value= 5W/m^2 $^{\circ}$C;

Outer wall: 12 inches thick concrete block, with U-value= 1.89 W/m^2 °C;
Inner wall: brick plaster, with U-value 2.2 W/m^2 °C. The windows-wall ratio is 20% (with the visible transmittance of the widows not less than 0.4).

6.1.3.2 Temperature

Table 6-2 represents the internal and external temperatures. It shows the internal and external average temperatures for each month and different spaces. The average difference between day and night temperature is 10.5 °C. The infiltration air rate level per space volume in the rooms is 0.6 m^3/s.

Table 6-2 Monthly average internal and external temperature

Space	**Temperature °C**												**Light**
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	**(lux)**
Bank	16	16	18	20	24	26	27	28	26	24	19	18	500
Shop	14	14	16	18	22	24	26	27	24	22	17	16	300
Dining room	13	13	15	17	20	22	24	25	22	20	16	14	200
Security office	16	16	18	20	24	26	27	28	26	24	19	18	300
Computer room	16	16	18	20	24	26	27	28	26	24	19	18	500
Business centre	16	16	18	20	24	26	27	28	26	24	19	18	300
KTV	14	14	16	18	22	24	26	27	24	22	17	15	100
Beauty salon	16	16	18	20	24	26	27	28	26	24	19	18	500
Hotel room	16	16	18	20	24	26	27	28	26	24	19	18	200
Meeting room	15	15	17	19	23	25	26	27	25	23	18	17	300
Waiting room	15	15	17	19	23	25	26	27	25	23	18	17	300
Office	16	16	18	20	24	26	27	28	26	24	19	18	300
Archive, storage room	14	14	16	18	22	24	25	26	24	22	17	16	200
Corridor	8	9	11	18	21	22	23	24	20	15	10	9	-
External temperature	1.5	2.9	3	10	23	25	24	24	22	15	7	3	-

6.1.2.3 Occupancy

The number of total hotel employees is 200 people. The hotel management states that occupancy is on average 80%. It is estimated that the guest room are occupied for

16 hours during the day 25 days a month. As it was mentioned before, the hotel is situated in a business centre of Kunming; therefore it is a popular place to stay among business people.

6.1.4 Current energy systems

6.1.4.1 Air source heat pump

The air source heat pump that is used in the building is a packaged rooftop unit WFR190Z produced by the Chinese company "Bright Air Conditioning". The heat pump is used for both heating and cooling purposes. Its image can be seen in Figure 6-4.

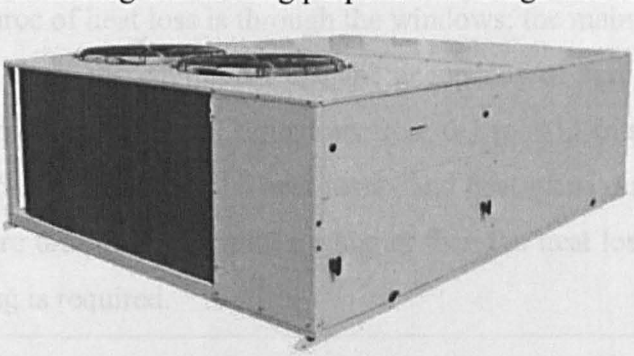

Figure 6-4 WFR190Z rooftop unit [Quaschning, 2004]

It is designed for outdoor installation and can be used for both residential and commercial applications. It uses a direct expansion heat exchanger and a one-piece heat pump with an optional electric heater. The following table 6-3 gives the air source heat pump specifications:

Table 6-3 Air source heat pump specifications[Quaschning, 2004]

Electrical capacity (kW)	190-203.6
Electrical efficiency (%)	85
Heating capacity (kW)	168.5
Cooling capacity (kW)	203.6
Electrical input	360V/3Ph/50Hz
Grade of heat (°C)	60
Dimensions (m)	5800 ×2230 ×1810
Weight (kg)	2460

6.1.4.2 Hot water boiler

All hotel rooms are en-suite and provide hot water throughout the day. No water meter is used in the case study buildings, therefore ASHRAE Handbook has been used for the estimation. According to ASHRAE, a hotel building's average requirement during summer months for hot water is 45 litres/unit; during winter months the requirement in 68 litres/unit [ASHRAE, 2009].

Hot water is supplied instantaneously using a gas boiler with an efficiency of 85%. The outlet temperature of the hot water on average is 60°C; the temperature of the water source is on average 17°C.

6.2 Scenario One: Real building operation

6.2.1 Heat losses and heat gains

The main source of heat loss is through the windows; the main source of heat gain is the exhaust heat from the equipment and the occupancy of some of the rooms. To calculate the heat loss and heat gain, Equations from 6-1 to 6-11 in section 6.1.1.1 have been used. Figure 6-5 shows Level 16 heat losses and heat gains during December. As can be seen in figure 6-6, the heat gains are higher than the heat losses in rooms 3 and 12, therefore cooling is required.

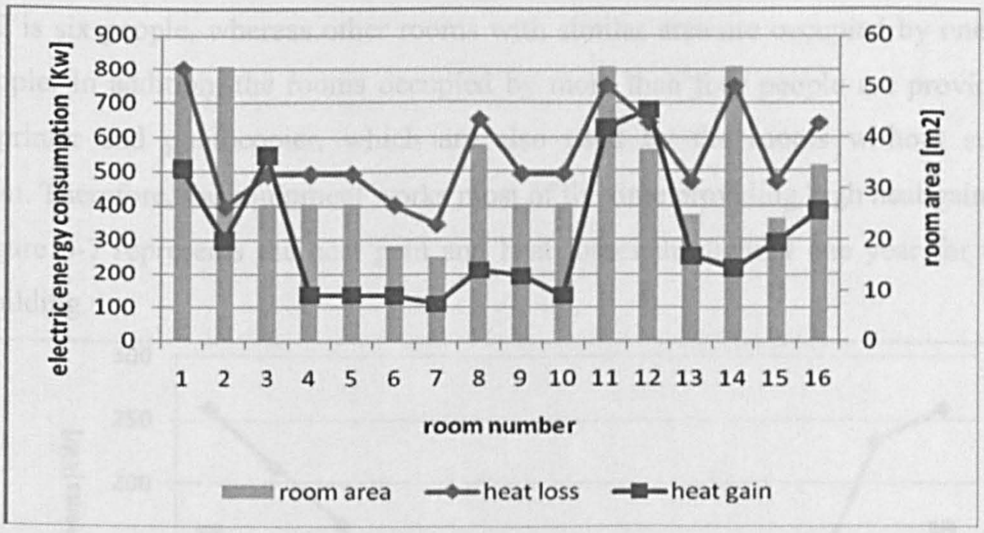

Figure 6-5 Heat losses and heat gain for the level 16 in December

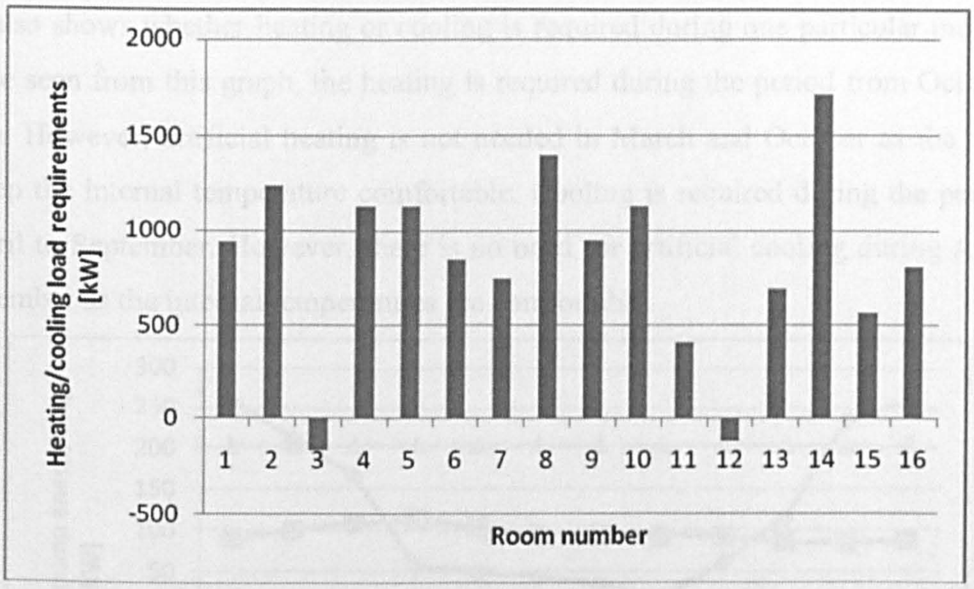

Figure 6-6 Heating and cooling load requirements for the Level 16 in December

This can be explained by the fact that Rooms 3 and 12 have relatively small floor area (27 m^2 and 37 m^2). However, the occupancy of Room 3 is five people, and of Room 12 is six people, whereas other rooms with similar area are occupied by one to three people. In addition, the rooms occupied by more than four people are provided with a printer and photocopier, which are also used by the rooms without such equipment. Therefore, the equipment works most of the time providing high heat gains.

Figure 6-7 represents the heat gain and heat losses throughout one year for the whole building.

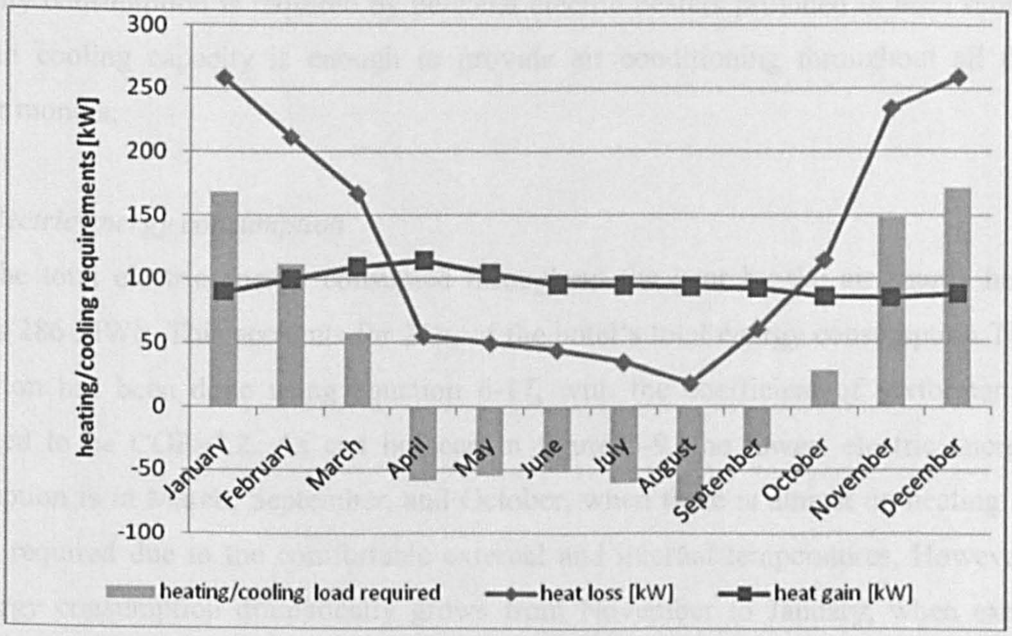

Figure 6-7 Monthly heating and cooling requirements

It also shows whether heating or cooling is required during one particular month. As can be seen from this graph, the heating is required during the period from October to March. However, artificial heating is not needed in March and October as the heat gains keep the internal temperature comfortable. Cooling is required during the period from April to September. However, there is no need for artificial cooling during April and September as the internal temperatures are comfortable.

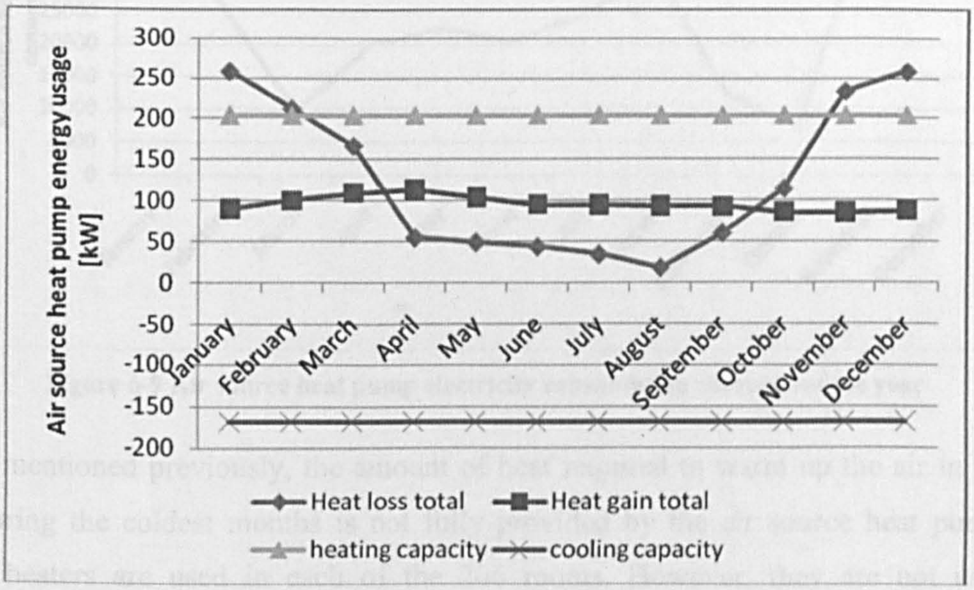

Figure 6-8 Air source heat pump capacity requirements

As can be seen in figure 6-8 above, the air source heat pump capacity to provide heat is not enough during the coldest months of November to January. Therefore extra electricity consumption is required by personal electric heaters provided in each room. The unit cooling capacity is enough to provide air conditioning throughout all the summer months.

6.2.2 Electric energy consumption

The total electric energy consumed throughout the year by the air source heat pump is 286 MWh. This accounts for 26% of the hotel's total energy consumption The calculation has been done using equation 6-17, with the coefficient of performance calculated to be COP=2.2. As can be seen in figure 6-9, the lowest electric energy consumption is in March, September, and October, when there is almost no heating or cooling required due to the comfortable external and internal temperatures. However, the energy consumption dramatically grows from November to January, when extra heating is required. This can be explained by the fact that the external temperatures fall rapidly; also poor thermal insulation causes a large amount of heat losses.

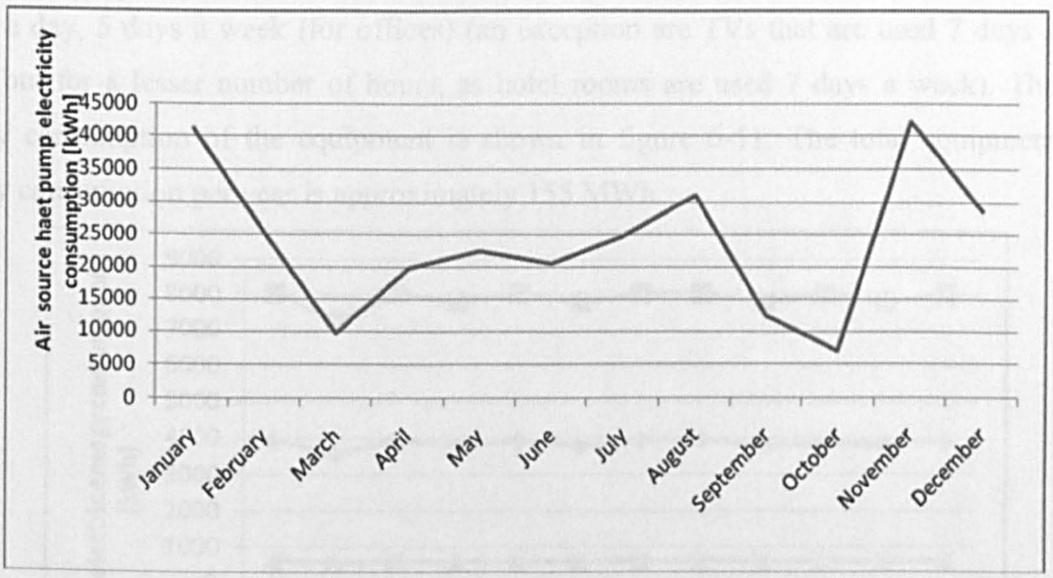

Figure 6-9 Air source heat pump electricity consumption throughout the year

As mentioned previously, the amount of heat required to warm up the air in the rooms during the coldest months is not fully provided by the air source heat pump. Personal heaters are used in each of the 206 rooms. However, they are not used constantly; the estimated amount of time is 3 hours a day during the coldest months. The electric heater energy consumption is 900W and therefore the total energy consumption of the electric heaters is approximately 39 MWh, which is 4% of total energy consumption. The following figure 6-10 shows the amount of energy used by the electric heaters throughout the year.

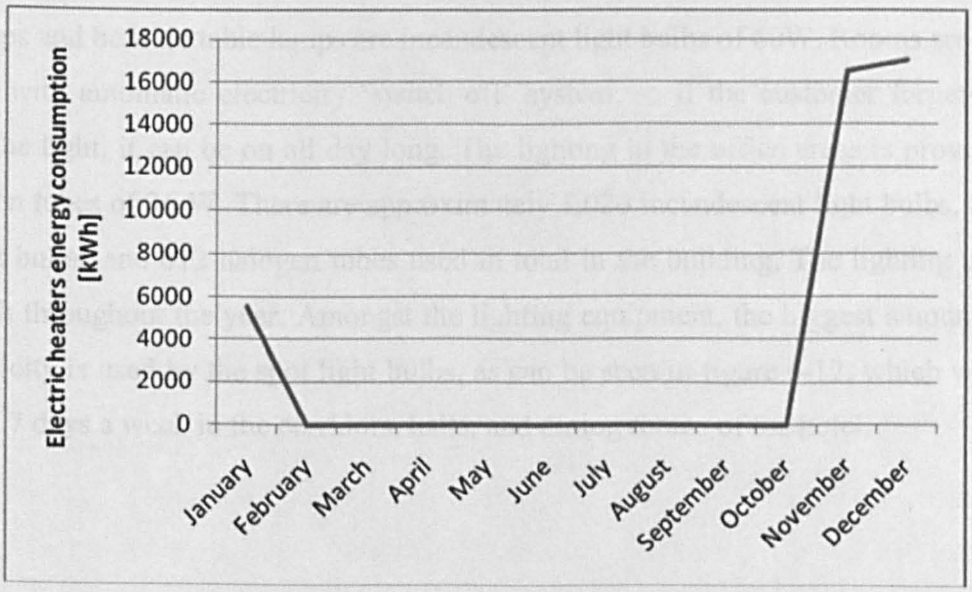

Figure 6-10 Electric heaters electric energy consumption

As for the energy consumption of the equipment, it accounts for 14% of the total energy consumption. This is mainly due to the fact that the equipment is used only 8 hours a day, 5 days a week (for offices) (an exception are TVs that are used 7 days a week but for a lesser number of hours, as hotel rooms are used 7 days a week). The energy consumption of the equipment is shown in figure 6-11. The total equipment energy consumption per year is approximately 155 MWh.

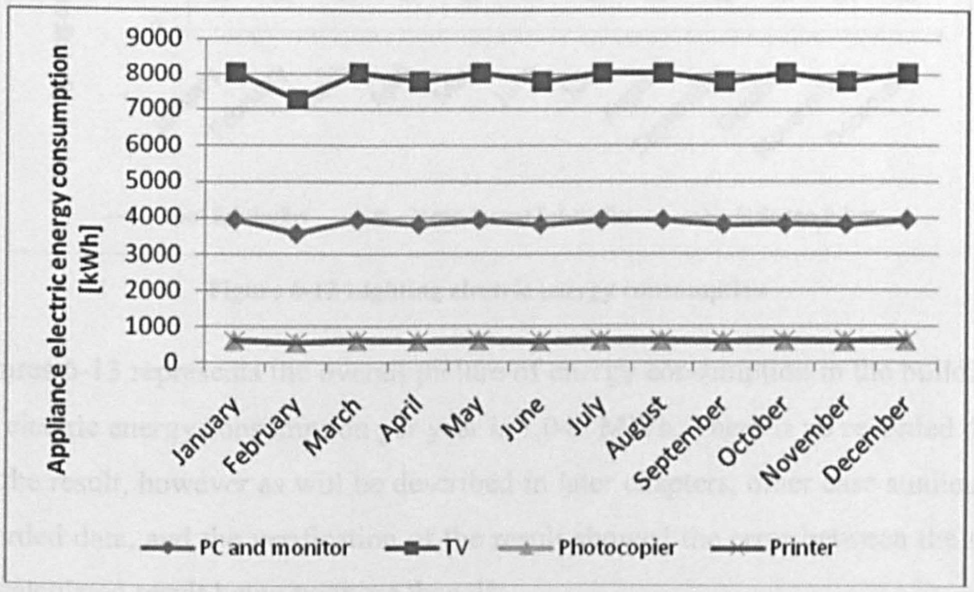

Figure 6-11 Equipment electric energy consumption

The biggest energy consumer (53%) in the building is lighting. This can be explained by the fact that lighting is used 24 hours a day throughout the year in corridors and halls. The bulbs used for the lighting of these areas are highly inefficient as they are spot light bulbs with an energy consumption of 50W; the bulbs used for table lamps and bedside table lamps are incandescent light bulbs of 60W. Rooms are not provided with automatic electricity 'switch-off' system, so if the customer forgets to turn off the light, it can be on all day long. The lighting in the office areas is provided by halogen tubes of 36 W. There are approximately 1,020 incandescent light bulbs, 850 spot light bulbs, and 612 halogen tubes used in total in the building. The lighting uses 567 MWh throughout the year. Amongst the lighting equipment, the biggest amount of the electricity is used by the spot light bulbs, as can be seen in figure 6-12, which work 24 hours, 7 days a week in the corridors, halls, and dining rooms of the hotel.

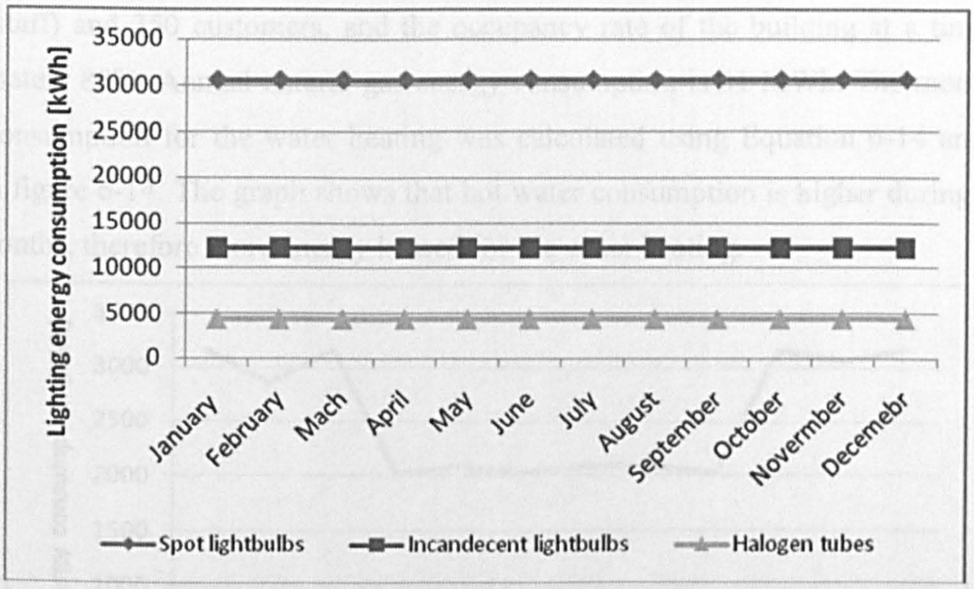

Figure 6-12 Lighting electric energy consumption

Figures 6-13 represents the overall picture of energy consumption in the building. The total electric energy consumption per year is 1,047 MWh. There is no recorded data to verify the result, however as will be described in later chapters, other case studies do have recorded data, and the verification of the result showed the error between the real data and calculated result being no more than 4%.

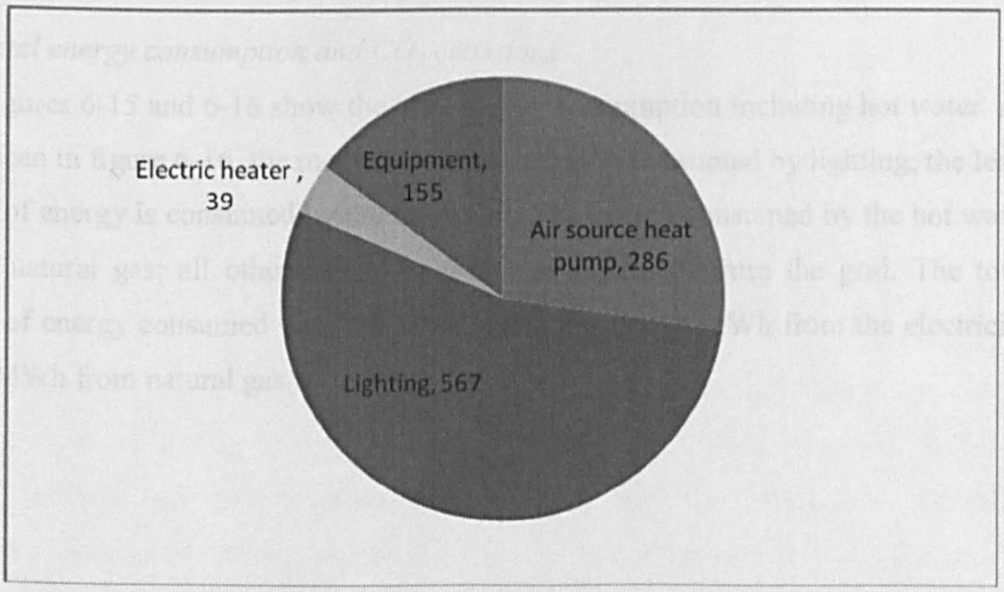

Figure 6-13 Total electric energy consumption [MWh]

6.2.3 Natural gas energy consumption

Natural gas is used for the hot water heating, which is used for showers and hand washing. The hot water supply is instantaneous to every room of the hotel, and also to the toilets on the office floors of the building. The occupancy of the building is 200 people (staff) and 350 customers, and the occupancy rate of the building at a time is approximately 80%. Annual natural gas energy consumption is 31 MWh. The monthly energy consumption for the water heating was calculated using Equation 6-14 and is shown in figure 6-14. The graph shows that hot water consumption is higher during the colder months, therefore more energy is used for the water heating.

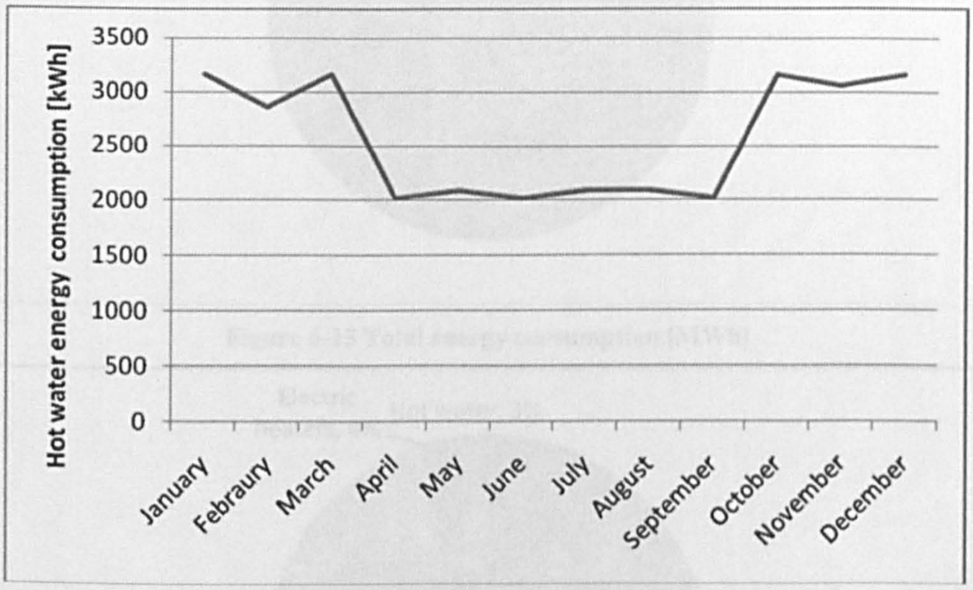

Figure 6-14 Hot water energy consumption

6.2.4 Total energy consumption and CO_2 emissions

Figures 6-15 and 6-16 show the total energy consumption including hot water. As can be seen in figure 6-16, the most amount of energy is consumed by lighting; the least amount of energy is consumed by the hot water. The energy consumed by the hot water is from natural gas; all other energy is from the electricity from the grid. The total amount of energy consumed is 1,078 MWh, including 1,047 MWh from the electricity and 31 MWh from natural gas.

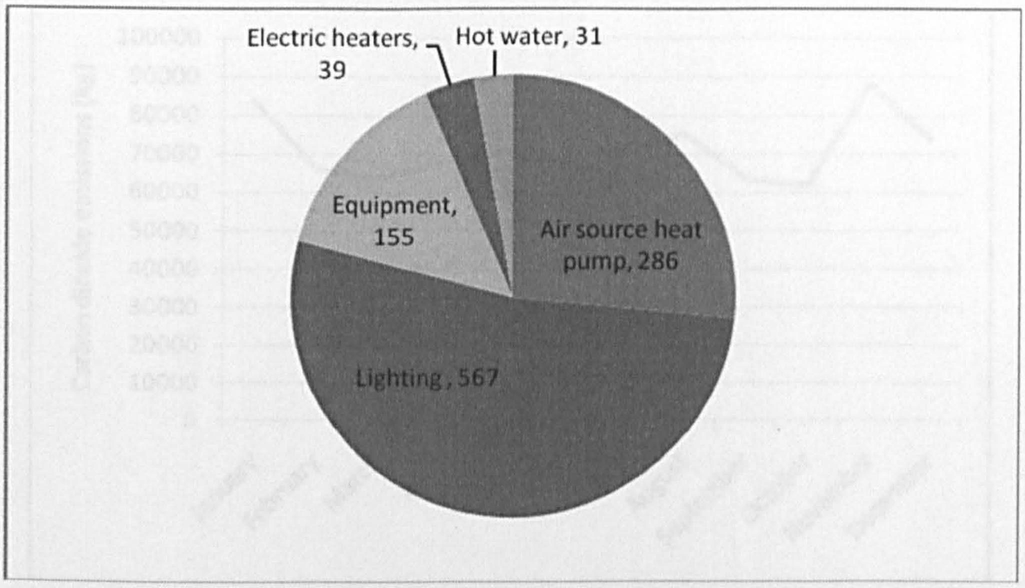

Figure 6-15 Total energy consumption [MWh]

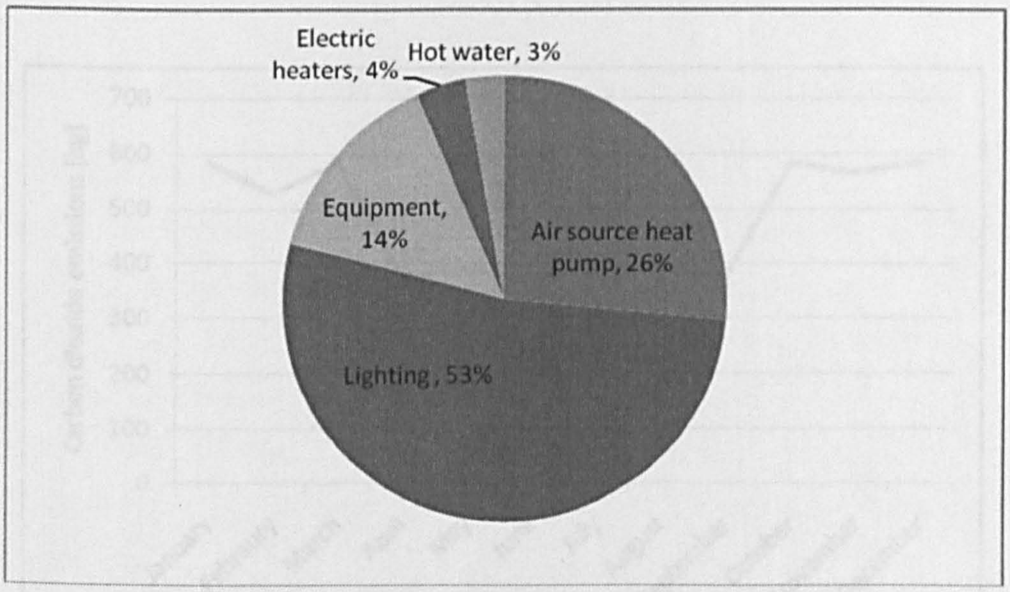

Figure 6-16 Shares in total energy consumption

As would be expected, the highest CO_2 emissions are during the months when the biggest amount of heating or cooling is required (see figure 6-17), whereas the lowest amount is emitted during the months of March, April, September and October, when the temperature is comfortable, therefore the air source heat pump's energy consumption is low.

CO_2 emissions from natural gas, shown in figure 6-18, are much lower comparing to those from electricity. The largest amount is emitted during the winter months, when more hot water is required.

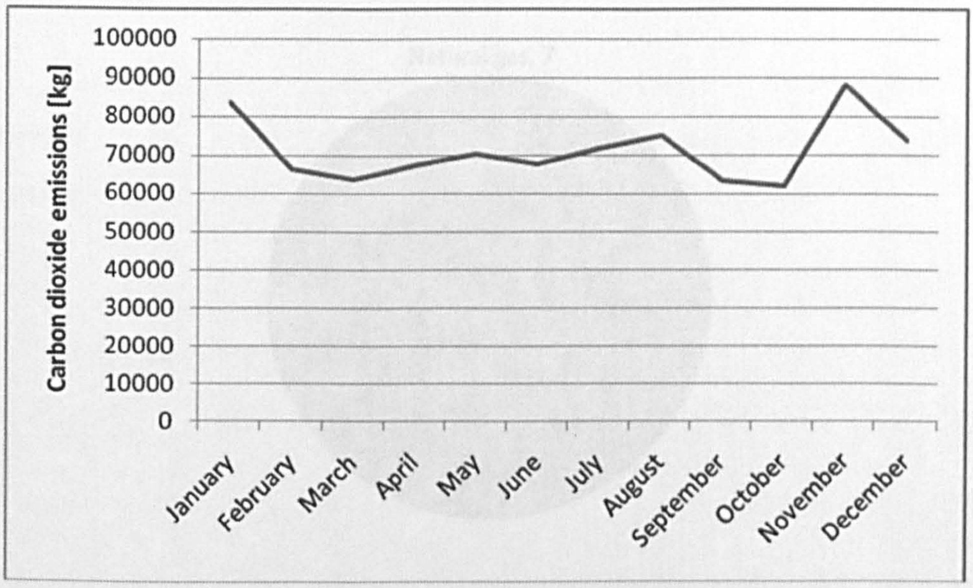

Figure 6-17 CO_2 emissions from electricity

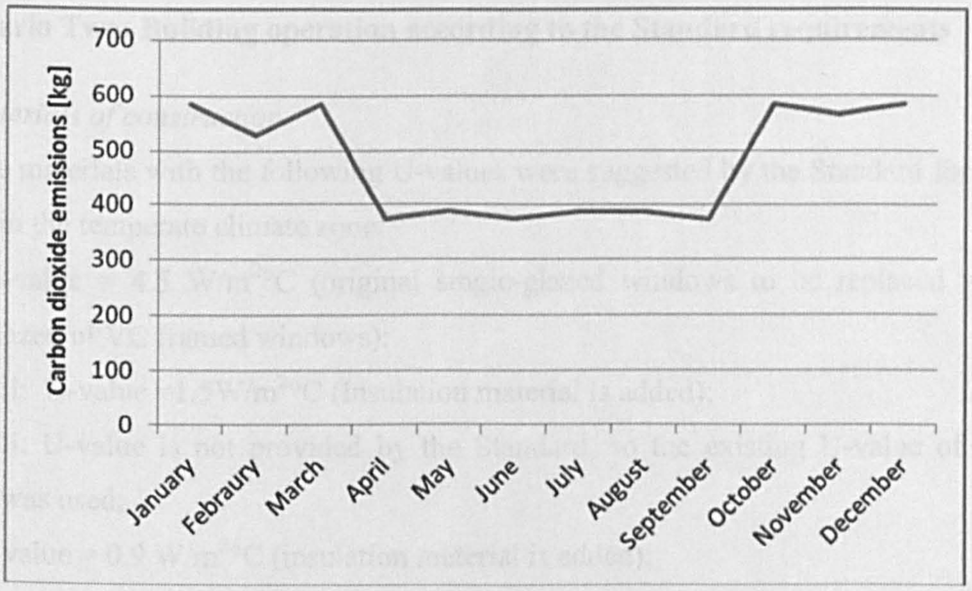

Figure 6-18 CO_2 emissions from natural gas

The total amount of the CO_2 emissions is calculated to be 569 tonnes. Figure 6-19 shows that 562 tonnes are emitted from electricity, and the rest (7 tonnes) is from natural gas.

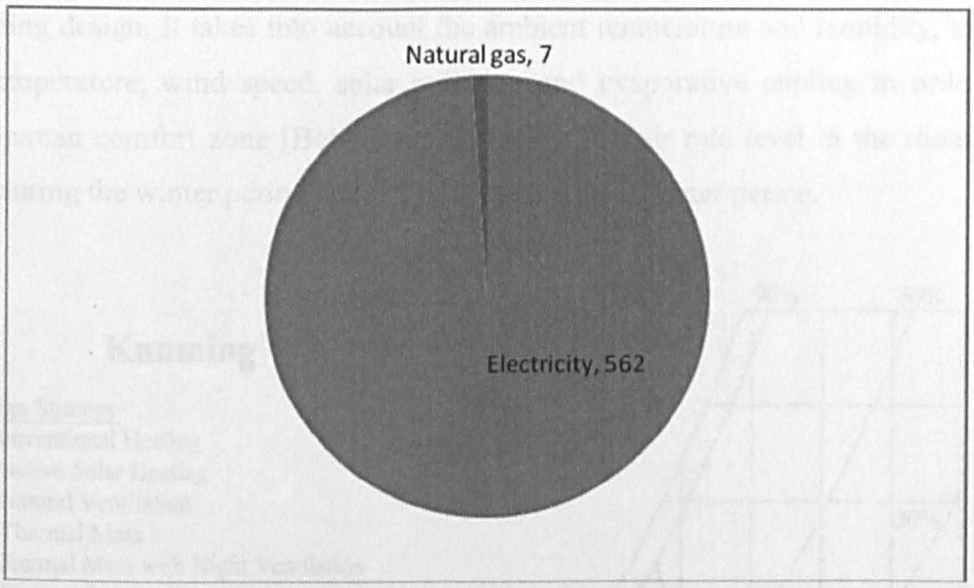

Figure 6-19 Total CO_2 emissions [tonnes]

6.3 Scenario Two: Building operation according to the Standard requirements

6.3.1 Materials of construction

The materials with the following U-values were suggested by the Standard for the building in the temperate climate zone:

Glass: U-value = 4.5 W/m^2°C (original single-glazed windows to be replaced with double glazed uPVC framed windows);

Outer wall: U-value =1.5W/m^2°C (Insulation material is added);

Inner wall: U-value is not provided by the Standard, so the existing U-value of 2.2 W/m^2°C was used;

Floor: U-value = 0.9 W/m^2°C (insulation material is added);

Roof: U-value = 0.35 W/m^2°C (insulation material is added). As the roof U-value suggested by the Standard is the same as the roof material used in the hotel, the real material has not been changed for the calculations.

6.3.2 Temperatures

The room temperatures for each category of room were changed according to the temperature limits given by the Standard and mentioned in section 5.4.2; also, the comfort temperatures, shown in figure 6-20, were taken into account. As can be seen from the bioclimatic chart for Kunming, the comfortable temperature range is from 20 to 26°C. Bioclimatic chart was developed in order to incorporate the outdoor climate into building design. It takes into account the ambient temperature and humidity, mean radiant temperature, wind speed, solar radiation and evaporative cooling in order to indicate human comfort zone [Bobenhausen, 1994]. The air rate level in the rooms is 0.2 m^3/s during the winter period and 0.3 m^3/s during the summer period.

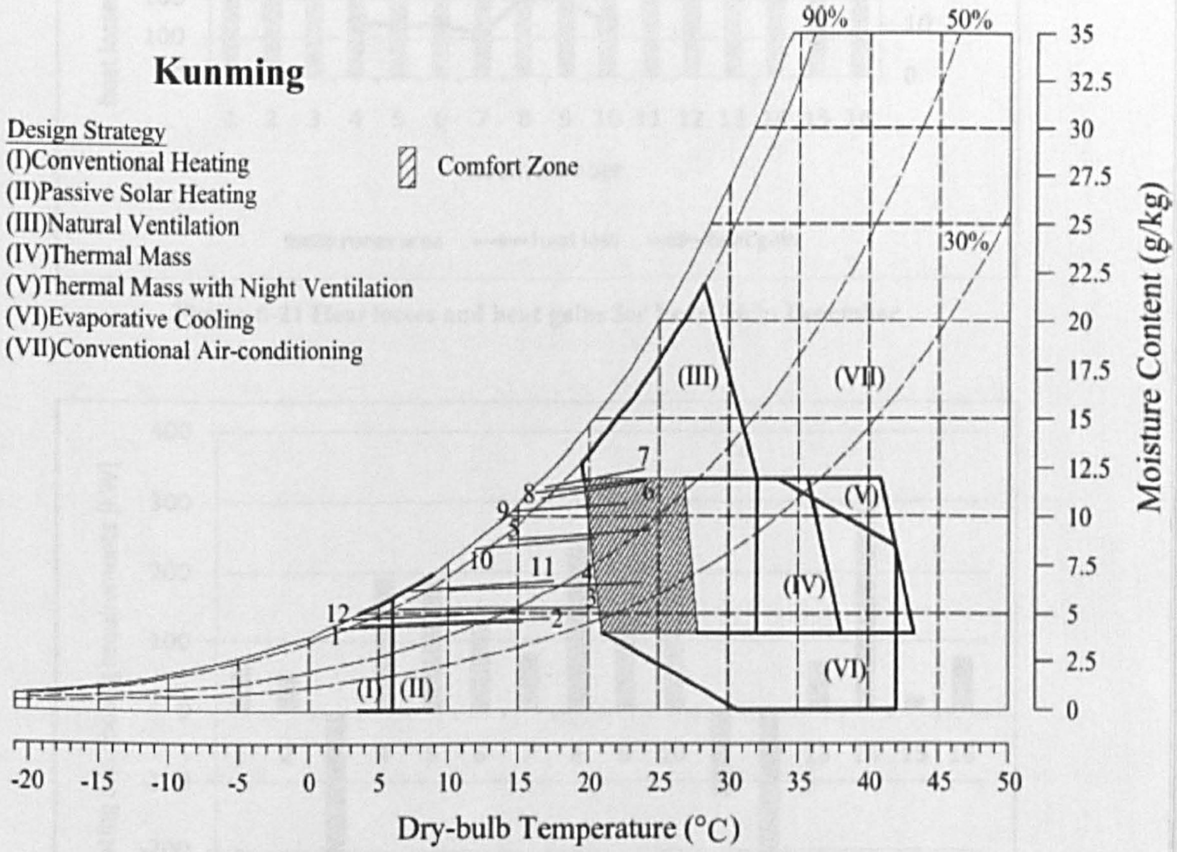

Figure 6-20 Bioclimatic chart for Kunming [Lam, 2005]

6.3.3 Heat losses and heat gains

Heat losses and heat gains were calculated for each room of each floor but the results are obviously too large to show here. Therefore, the following figures 6-21 and 6-22 are an example of the heat losses and heat gains experienced in the rooms on Level 16 during the month of December.

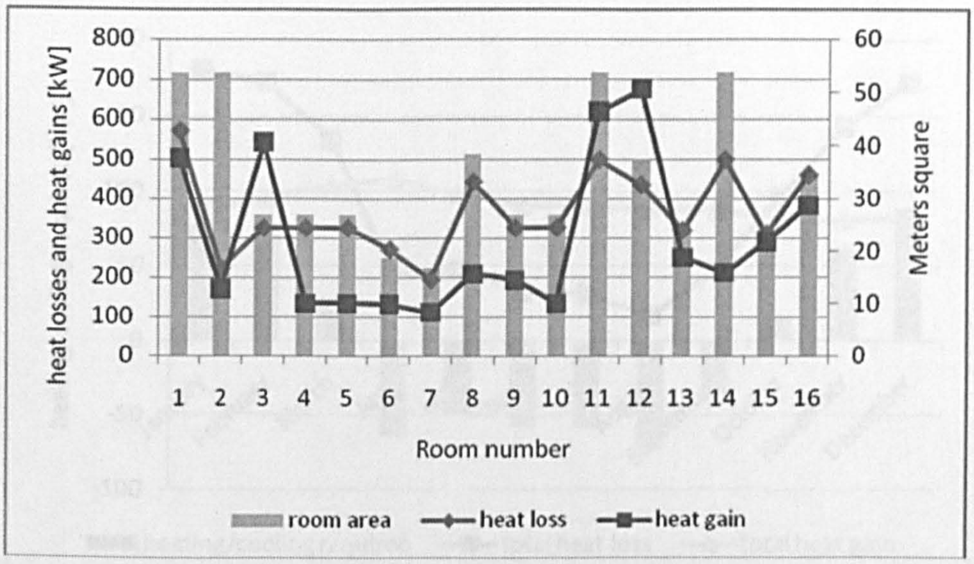

Figure 6-21 Heat losses and heat gains for Level 16 in December

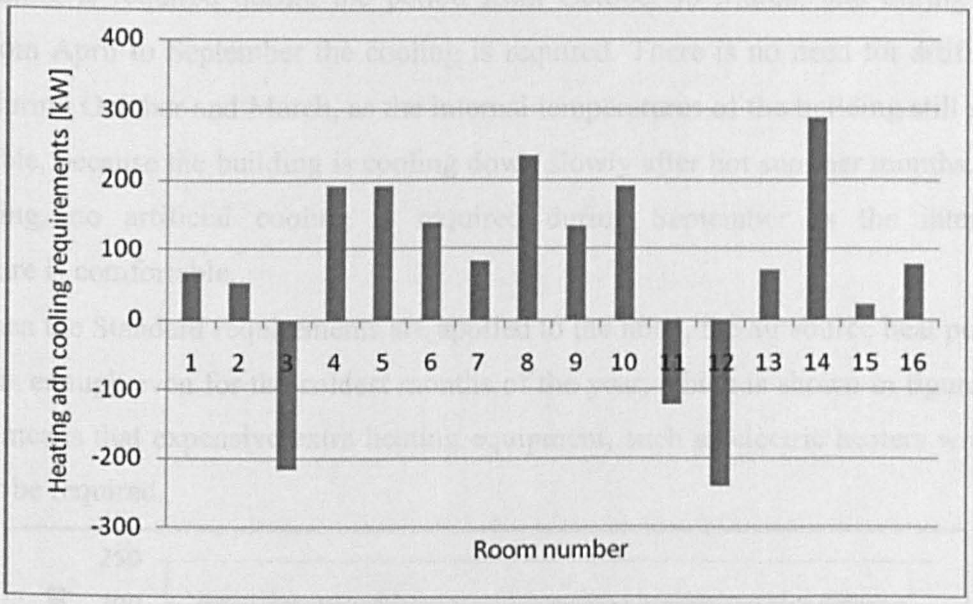

Figure 6-22 Heating and cooling requirements for Level 16 in December

Even though the U-values of the surfaces were improved by employing the Standard, the situation with heat gains in some of the office rooms has not changed when compared to the Scenario One but got worse due to the fact that the U-value of the construction material was improved; therefore the heat loss was decreased, whereas heat gain was not changed, as none of the equipment or people occupying the space were removed. In addition, the level of lighting heat gains was not changed.

Figure 6-23 shows the heat losses and heat gains throughout the year for the whole building.

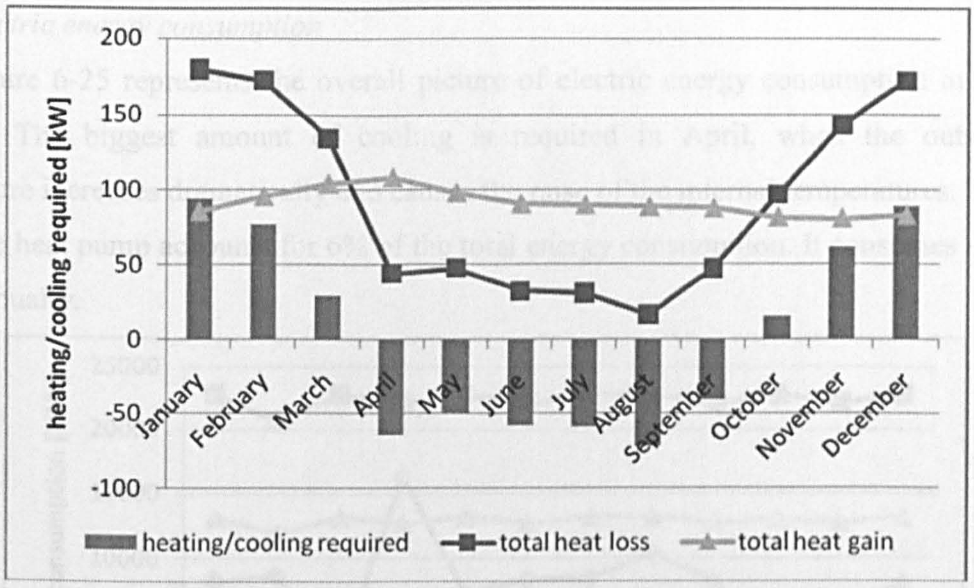

Figure 6-23 Monthly heating and cooling load requirements

Heating is required during the period from October to March; and during the period from April to September the cooling is required. There is no need for artificial heating during October and March, as the internal temperatures of the building still stay comfortable, because the building is cooling down slowly after hot summer months. As for cooling, no artificial cooling is required during September as the internal temperature is comfortable.

When the Standard requirements are applied to the hotel, the air source heat pump capacity is enough even for the coldest months of the year, which is shown in figure 6-24. This means that expensive extra heating equipment, such as electric heaters would no longer be required.

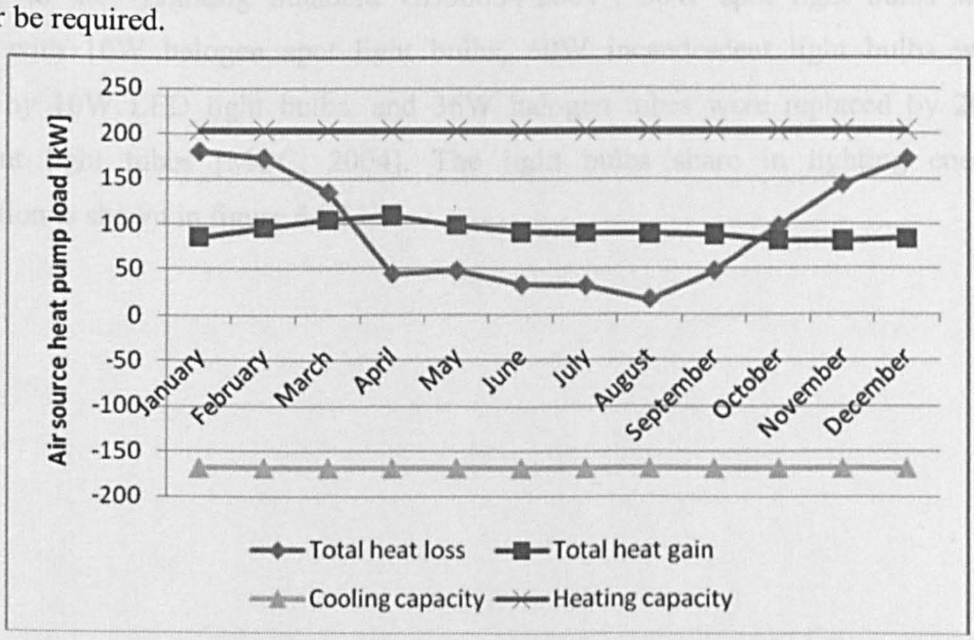

Figure 6-24 Air source heat pump heating and cooling capacity

6.3.4 Electric energy consumption

Figure 6-25 represents the overall picture of electric energy consumption in the building. The biggest amount of cooling is required in April, when the outside temperature increases dramatically and causes the raise of the internal temperatures. The air source heat pump accounts for 6% of the total energy consumption. It consumes ~94 MWh annually.

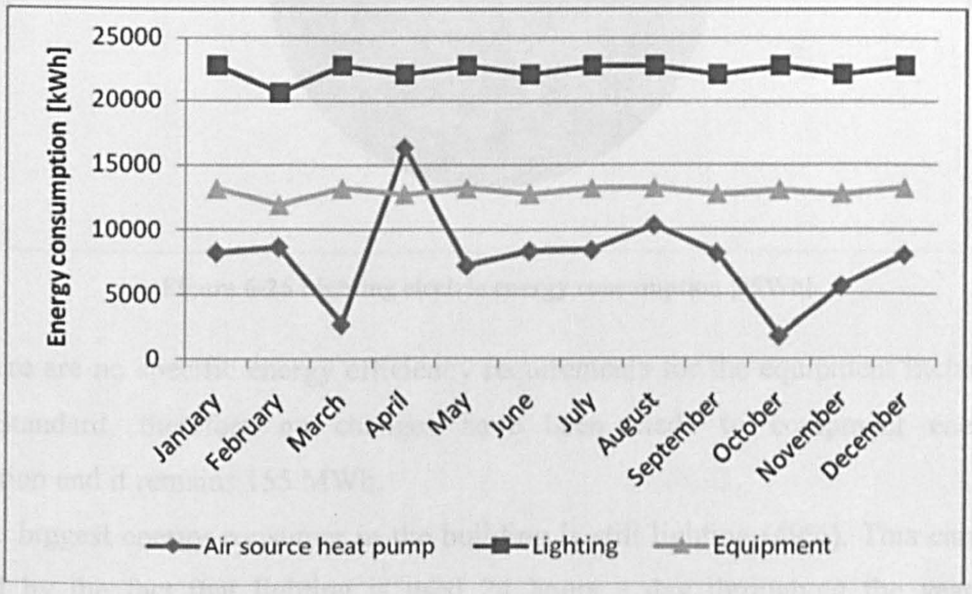

Figure 6-25 Electric energy consumption

Lighting is the biggest energy consumer with a consumption of 269 MWh, and accounts for 49% of the total energy consumption. The lighting equipment was changed according to the "Lighting Standard GB50034-2004": 50W spot light bulbs were replaced with 10W halogen spot light bulbs, 60W incandescent light bulbs were replaced by 10W LED light bulbs, and 36W halogen tubes were replaced by 20W fluorescent light tubes [MOC, 2004]. The light bulbs share in lighting energy consumption is shown in figure 6-26.

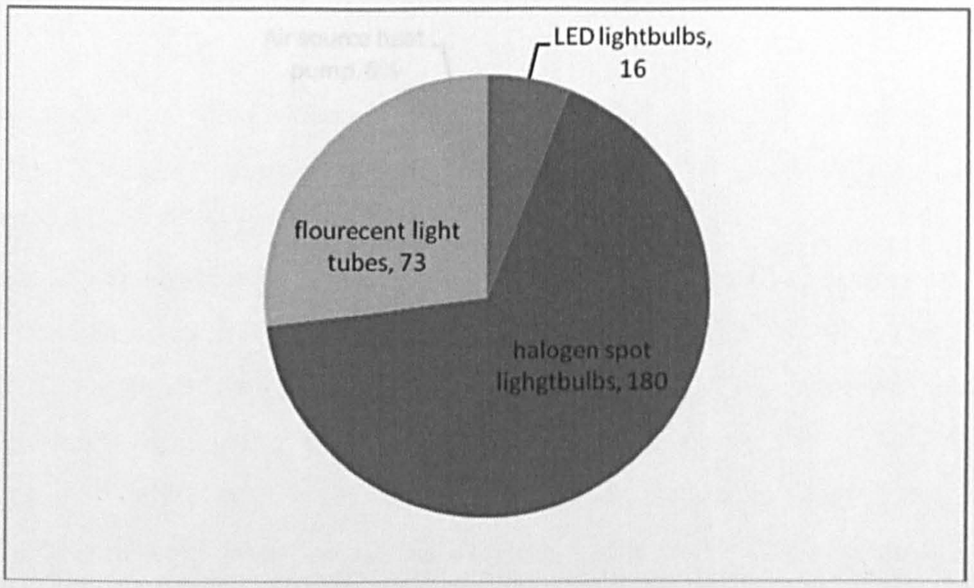

Figure 6-26 Lighting electric energy consumption [MWh]

There are no specific energy efficiency requirements for the equipment included in the Standard, therefore no changes have been made to equipment energy consumption and it remains 155 MWh.

The biggest energy consumer in the building is still lighting (49%). This can be explained by the fact that lighting is used 24 hours a day throughout the year in corridors and halls. However, all the lighting equipment was changed to the low-energy bulbs mentioned in the GB50034-2004.

6.3.5 Natural gas consumption

There are no requirements listed in the Standard for the hot water, therefore no changes have been made. The natural gas consumption is similar to the real building operation natural gas consumption and accounts for 31 MWh.

6.3.6 Total energy consumption and CO_2 emissions

The following figure 6-27 shows the shares in the total energy consumption including hot water.

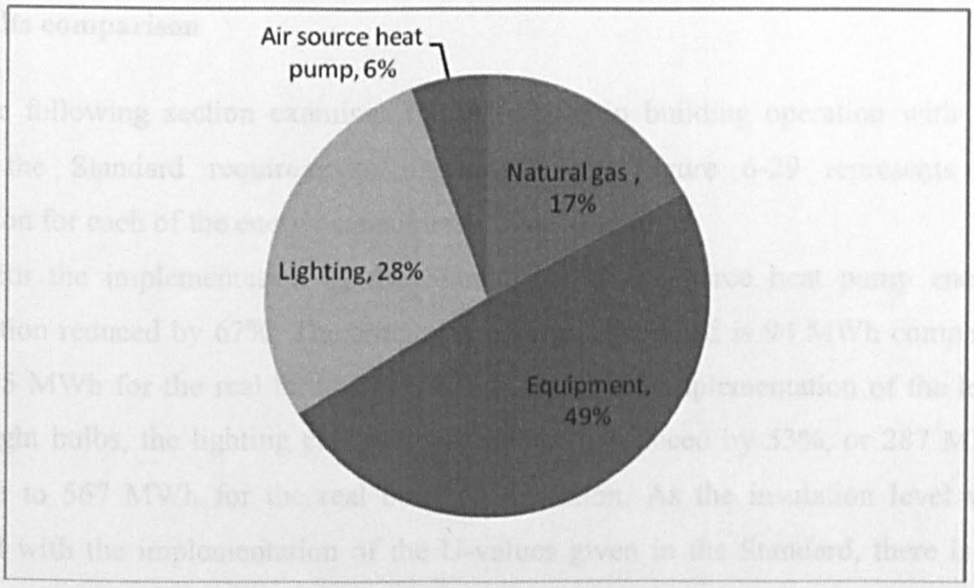

Figure 6-27 Total energy consumption [%]

The total amount of energy consumed is 549 MWh, including 518 MWh from electricity and 31 MWh from natural gas. The total amount of CO_2 emissions is 284 tonnes, as can be seen in figure 6-28. In this scenario, 98% of the emissions produced are from electricity and 2% are from natural gas.

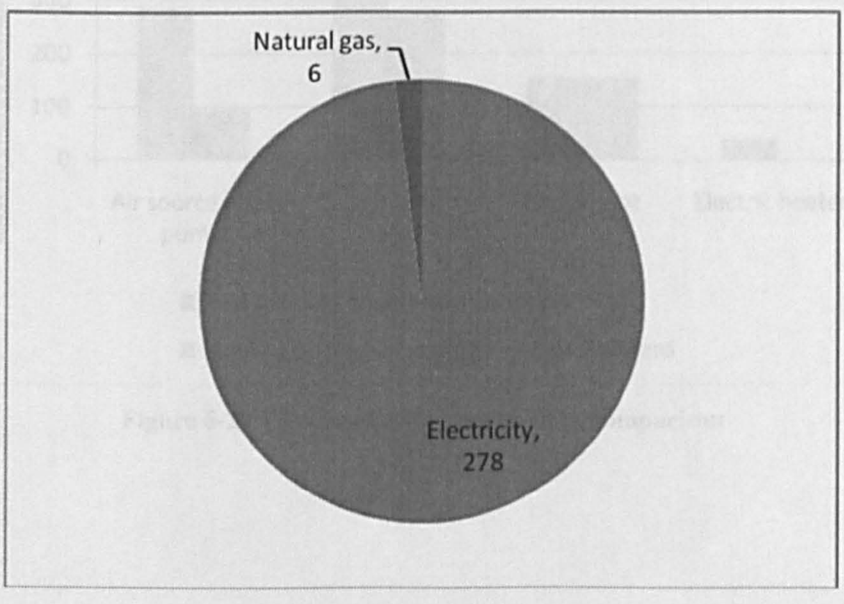

Figure 6-28 Total CO_2 emissions [tonnes]

6.4 Results comparison

The following section examines the difference in building operation with and without the Standard requirements implementation. Figure 6-29 represents the comparison for each of the energy consumers in the building.

With the implementation of the Standard, the air source heat pump energy consumption reduced by 67%. The amount of energy consumed is 94 MWh compared to the 285 MWh for the real building operation. With the implementation of the low-energy light bulbs, the lighting energy consumption is reduced by 53%, or 287 MWh compared to 567 MWh for the real building operation. As the insulation level was improved with the implementation of the U-values given in the Standard, there is no need for extra heating during cold months, therefore no electric heaters need to be used. The total electric energy consumption reduced by 51%, as it can be seen in figure 6-30, therefore the Standard has reached its aim of a 50% reduction in energy consumption.

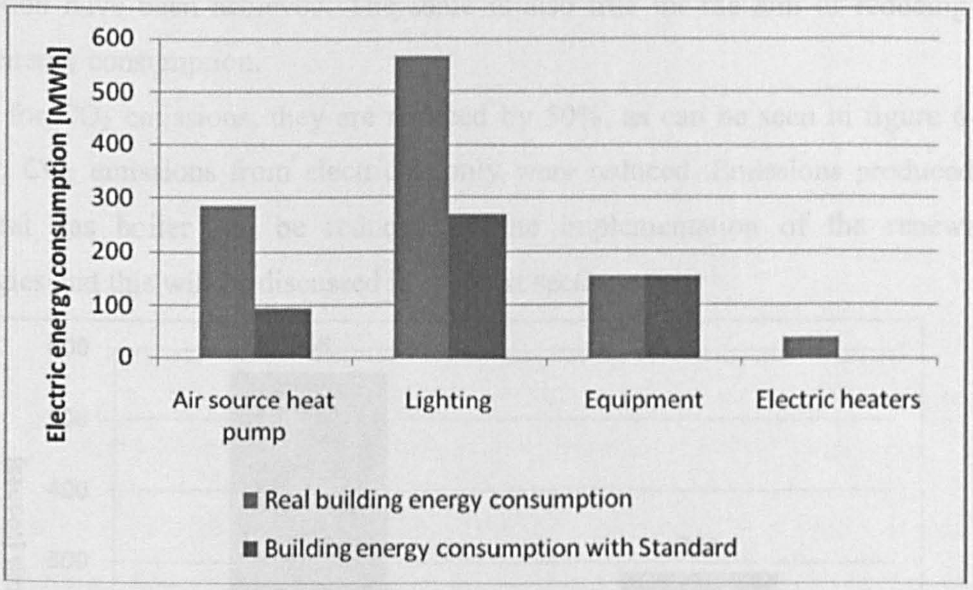

Figure 6-29 Electric energy consumption comparison

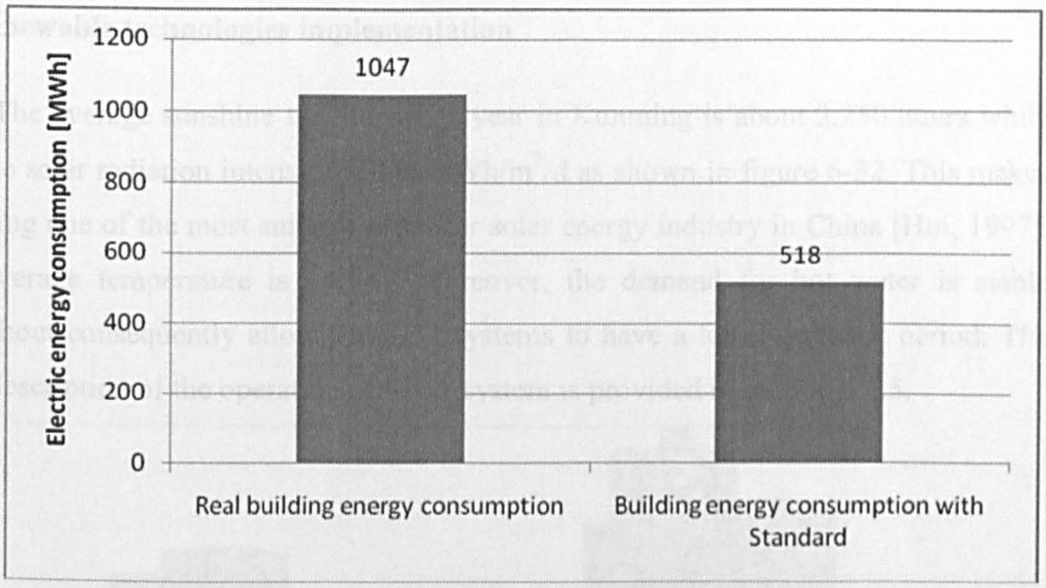

Figure 6-30 Total energy consumption from grid comparison

The specific targets to reduce the envelope heat loss and HVAC energy consumption have been achieved. The same is also true for the aim of reducing the lighting energy consumption.

As for CO_2 emissions, they are reduced by 50%, as can be seen in figure 6-31. However, CO_2 emissions from electricity only were reduced. Emissions produced by the natural gas boiler can be reduced by the implementation of the renewable technologies and this will be discussed in the next section.

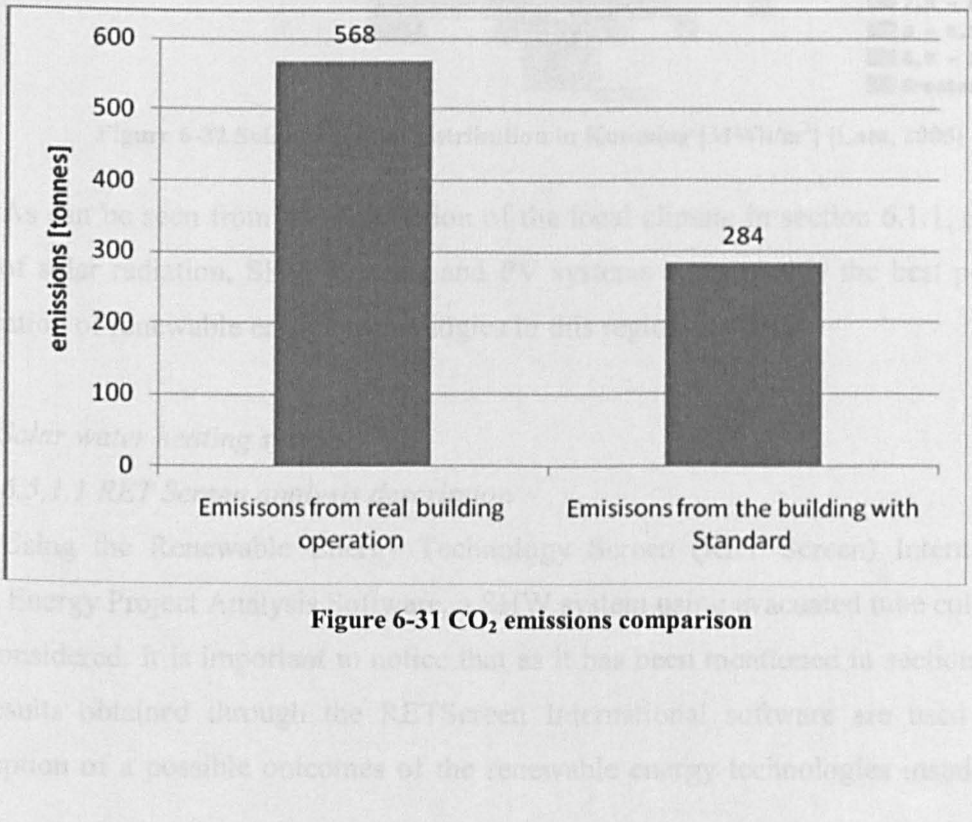

Figure 6-31 CO_2 emissions comparison

6.5 Renewable technologies implementation

The average sunshine for the whole year in Kunming is about 2,250 hours while average solar radiation intensity is 3.99 kWh/m^2/d as shown in figure 6-32. This makes Kunming one of the most suitable areas for solar energy industry in China [Hui, 1997]. The average temperature is 14.5°C. Moreover, the demand for hot water is stable throughout consequently allowing SHW systems to have a lower payback period. The short description of the operation of SHW system is provided in section 4.2.5.

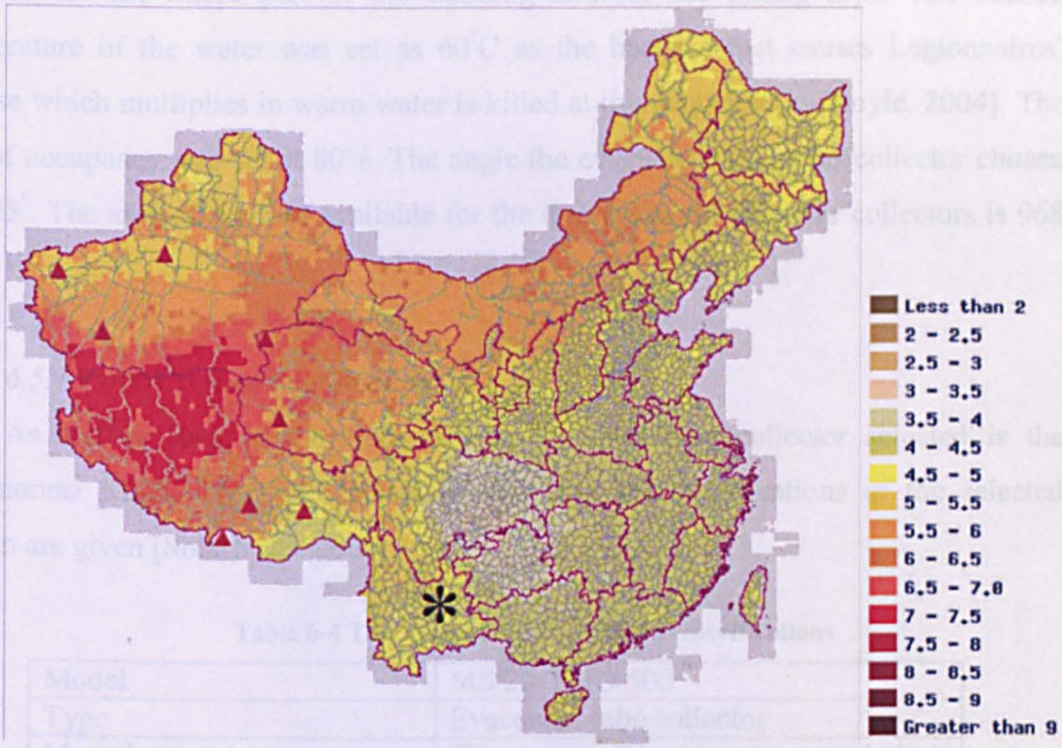

Figure 6-32 Solar radiation distribution in Kunming [MWh/m^2] [Lam, 2005]

As can be seen from the description of the local climate in section 6.1.1, and the level of solar radiation, SHW systems and PV systems are probably the best possible application of renewable energy technologies in this region of China.

6.5.1 Solar water heating system

6.5.1.1 RET Screen analysis description

Using the Renewable Energy Technology Screen (RET Screen) International Clean Energy Project Analysis Software, a SHW system using evacuated tube collectors was considered. It is important to notice that as it has been mentioned in section 1.3.3, the results obtained through the RETScreen International software are used as an assumption of a possible outcomes of the renewable energy technologies installations and cannot be treated as precise outcomes. This is relevant to all four case studies completed in this project. The evacuated tube collectors system was chosen, as during the simulations in the software, it gave the best output with the least amount of space used. This particular type of SHW technology was described in section 4.2.5. The system was sized to provide all of the buildings hot water requirements (RETScreen simulation sheet is provided in Appendix O).

339 rooms are provided with showers and hot water taps; the hot water is also required for the office part of the building and for the dining area. The desired temperature of the water was set as 60°C as the bacteria that causes Legionnaires' disease which multiplies in warm water is killed at this temperature [Boyle, 2004]. The rate of occupancy was set at 80%. The angle the evacuated tube solar collector chosen was 25°. The area of the roof available for the installation of the solar collectors is 968 m^2.

6.5.1.2 SHW system specification

As can be seen in the Appendix O, the evacuated collector selected is the Thermomax MS20–TMO500. Below in table 6-4 the specifications of the selected system are given [Solarfeeds, 2009].

Table 6-4 Thermomax MS20-TMO500 specifications

Model	MS 20-TMO 500
Type	Evacuated tube collector
Manufacturer	Thermomax Kingspan Renewable Ltd.
Dimensions	
Total length	1.961 m
Total width	1.417 m
Gross area	2.779 m^2
Aperture area	2.135 m^2
Absorber area	2.040 m^2
Weight empty	49 kg
Technical data	
Minimum flowrate	120 l/h
Nominal flowrate	160 l/h
Maximum flowrate	300 l/h
Fluid content	3.1 l
Maximum operating pressure	5 bar
Types of mounting	Construction for sloping roof
	On flat roof with stand
Hydraulic connection	Copper pipe, nominal diameter 22 mm

The area of the SWH system suggested by RETScreen was 736 m^2 where 265 evacuate tubes can be fitted. This will be fitted on the roof. The roof area is 968 m^2 , so it is sufficient for this amount of tubes. This allows for provision of 100% of the hotel's hot water requirements, as presented in Appendix O. The system is expected to operate throughout the year and no antifreeze is required, as temperatures do not fall below $0^{\circ}C$.

6.5.1.3 CO_2 emissions reduction after the installation of the SHW system

The installation of the SHW system covers the requirement for the hot water in the building throughout the year. Figure 6-33 shows that if the system is to be installed, but the Standard requirements are not implemented, then the buildings CO_2 emissions are reduced by 3%. If the Standard is implemented and the SWH is installed, then the building CO_2 emissions can be reduced by 52% (see Appendix O).

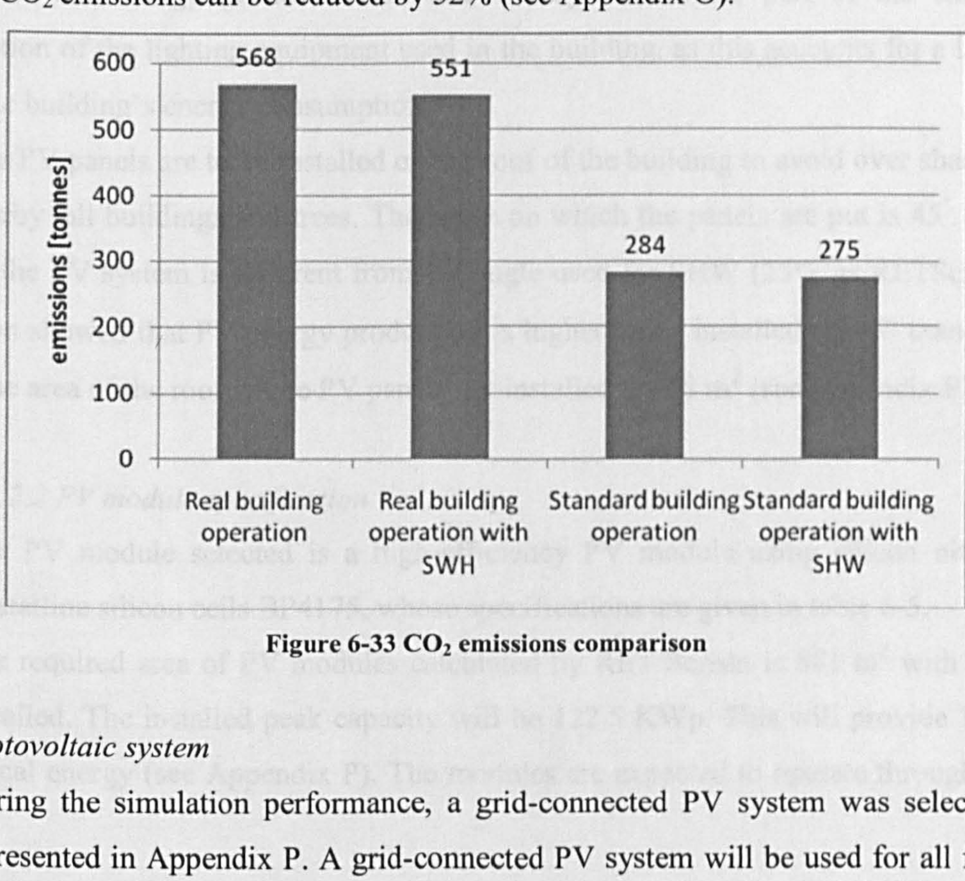

Figure 6-33 CO_2 emissions comparison

6.5.2 Photovoltaic system

During the simulation performance, a grid-connected PV system was selected. This is presented in Appendix P. A grid-connected PV system will be used for all four case studies. The choice can be explained by the fact that a grid-connected PV system can potentially reduce the cost for energy production and generator capacity, it also has environmental benefits through reduced CO_2 emissions. Grid-connected PV systems can be considered to be a form of distributed generation, whereby the generator is located at or near the site of electrical consumption, which reduces both energy and capacity losses in the utility distribution network. Furthermore, its use will avoid or delay upgrades to the transmission and distribution network because the average daily output of the PV system corresponds with the utility's peak demand period.

Different types of the PV cells are described in section 4.2.5. The monocrystalline PV module was chosen for this installation. The same type of PV modules will be used for all the case studies. The monocrystalline PV module chosen is manufactured by BP Solar who operate in China, thereby reducing the cost of transportation, and associated CO_2 emissions.

6.5.2.1 RET Screen analysis description

Using RETScreen, the grid-connected monocrystalline PV system was chosen, as it showed itself as the most efficient with the least amount of space required during the simulation. The energy produced from the PV system covers part of the energy consumption of the lighting equipment used in the building, as this accounts for a large part of the building's energy consumption.

The PV panels are to be installed on the roof of the building to avoid over shading from nearby tall buildings and trees. The angle on which the panels are put is 45°. The angle of the PV system is different from the angle used for SHW (25°), as RETScreen simulation showed that PV energy production is higher when installed on 45° than 25° angle. The area of the roof where PV panels are installed is 968 m^2 (see Appendix P).

6.5.2.2 PV module specification

The PV module selected is a high-efficiency PV module using silicon nitride monocrystalline silicon cells BP4175, whose specifications are given in table 6-5.

The required area of PV modules calculated by RET Screen is 881 m^2 with 700 units installed. The installed peak capacity will be 122.5 KWp. This will provide 12% of electrical energy (see Appendix P). The modules are expected to operate throughout the year.

Table 6-5 BP4175 specifications

Model	**BP 4175**
Configuration	Framed module with output cables and polarised Multicontact connectors
Performance	
Rated power (P_{max})	175W
Power tolerance	±5%
Nominal voltage	24V
Electrical characteristics	
Maximum power	175W
Voltage at Pmax (V_{mp})	35.7V
Current at Pmax (I_{mp})	4.9A
Warranted minimum Pmax	166.5W
Short-circuit current (I_{sc})	5.4A
Open-circuit voltage	44.0V
Temperature coefficient of I_{sc}	(0.065±0.015)%/°C
Temperature coefficient of V_{oc}	-(160±10)mV/°C
Temperature coefficient of power	-(0.5±0.5)%/°C
NOCT (Air 20°C; Sun 0.8kW/m²; wind 1m/s)	47±2°C
Maximum series fuse rating	15A (S, L)
Maximum system voltage	600V
Mechanical characteristics	
Dimensions	1595×790×50mm
Weight	15.4 kg
Solar cell	72 cells (125×125) in a 6×12 matrix connected in series
Output cables	RHW AWG#12 cable with polarised waterproof DC rated Multicontact connectors
Diodes	IntegraBus™
Construction	Front: high-transmission 3mm tempered glass; back: tedlar; encapsulated: EVA
Frame	Bronze anodised aluminium alloy type
Qualification parameters	
Temperature cycling range	-40°C to +85°C
Humidity freeze, damn heat	85%RH
Hailstone impact	25mm at23 m/s
Front loading	113psf
Static load front and back	50psf

6.5.2.3 CO_2 emission reduction after the installation of the PV module

As can be seen from Appendix P, the installation of the PV module allows for a reduction of the electrical energy consumption from the grid by 12%, or 10% of CO_2 emissions, as figures 6-33 and 6-34 show. The figures 6-34 and 6-35 also show that if the Standard requirements are implemented and the PV modules are installed, then the energy consumption is reduced by 56% with 68% of emissions reduction.

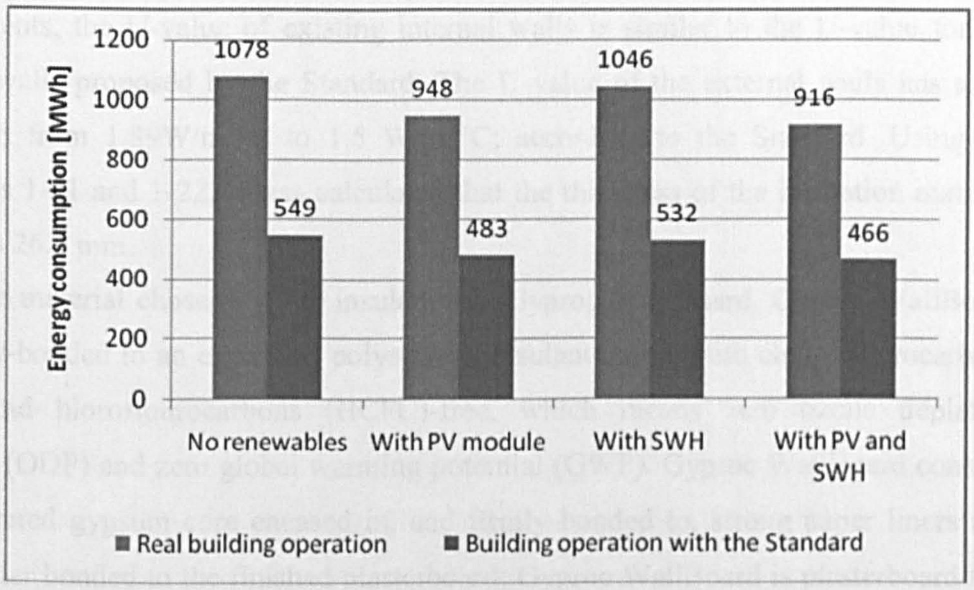

Figure 6-34 Grid energy consumption reduction comparison [MWh]

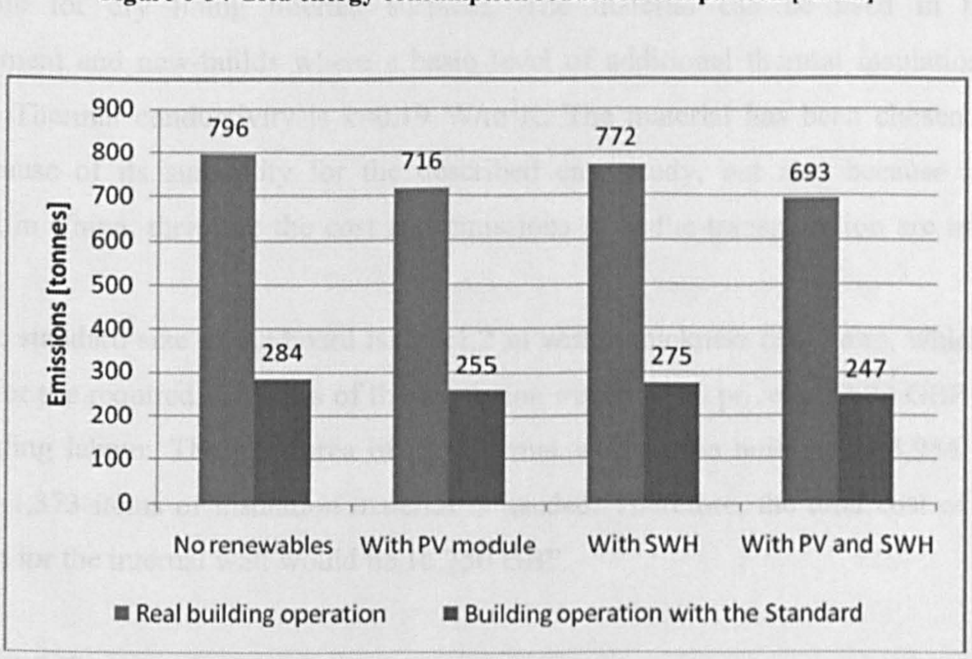

Figure 6-35 CO_2 emissions reduction comparison [tonnes]

6.6 Payback period

6.6.1 Materials payback period

Using the equations in section 6.1.1.3, the simple payback period for walls, roof, floor insulation and windows replacement, suggested by the Standard used in Scenario Two has been calculated.

6.6.1.1 Wall insulation price

Only external walls are to be insulated, because, according to the Standard requirements, the U-value of existing internal walls is similar to the U-value for the internal walls proposed by the Standard. The U-value of the external walls has to be decreased from 1.89W/m^2°C to 1.5 W/m^2°C; according to the Standard. Using the Equations 1-21 and 1-22, it was calculated that the thickness of the insulation material needed is 26.6 mm.

The material chosen for the insulation is Gyprog WallBoard. Gyproc WallBoard is factory-bonded to an expanded polystyrene insulant that is both chloroflourocarbons (CFC) and hloroflourocarbons (HCFC)-free, which means zero ozone depletion potential (ODP) and zero global warming potential (GWP). Gyproc WallBoard consists of an aerated gypsum core encased in, and firmly bonded to, strong paper liners and then further bonded to the finished plasterboard. Gyproc WallBoard is plasterboard that is suitable for dry lining internal surfaces. The material can be used in both refurbishment and new-builds where a basic level of additional thermal insulation is required. Thermal conductivity is k=0.19 W/m^{2}K. The material has been chosen not only because of its suitability for the described case study, but also because it is produced in China, therefore the cost and emissions from the transportation are much lower.

The standard size of the board is 2.4×1.2 m with a thickness of 30 mm, which is suitable for the required thickness of the insulation material. Its price is 12.22 GBP per m^2 including labour. The total area of the internal wall of the building is 3,954 m^2, therefore 1,373 items of insulation material is needed. Therefore, the total cost of the insulation for the internal wall would be 16,750 GBP.

6.6.1.2 Floor insulation price

The ground level floor has to be insulated in order to reach the thermal property advised in the Standard. The U-value has to be reduced from 2.08 W/m^2°C to 0.9 W/m^2°C. According to the Equations 6-21 and 6-22, the thickness of the insulation material needs to be 18 mm.

The insulation material chosen for the ground level floor is a floor insulation board called Celotex FR4000. It is manufactured from rigid PIR using blowing agents with low GWP and zero ODP. Thermal conductivity of the material is k=0.022 W/m^{2}K.

The standard size of the board is 1200×2400 mm with thickness varying from 25 mm to 200 mm. 347 boards are needed for the buildings ground floor insulation. The price is 8.68GBP per m^2, including the price of labour, which brings the total cost of the floor insulation to 8,680 GBP.

6.6.1.3 Roof insulation price

There is no roof insulation needed for this case study, as the original U-value of the roof complies with the U-value required by the Standard.

6.6.1.4 Glazing replacement costs

The windows used in the case study building are uPVC single-glazed windows with a U-value of 5.0 $W/m^2{}^\circ C$, which has to be reduced to 4.5 $W/m^2{}^\circ C$, according to the Standard. In order to achieve the proposed U-value, the windows are to be replaced by single-glazed hardwood windows. Together with the installation work, the price per m^2 is 318GBP (Spon's 2007). The current area of the glazing in the building is 772 m^2, which brings the total cost of the glazing replacement to 120,314 GBP.

6.6.1.5 Total payback period calculations for materials and glazing

The price per kWh is 0.04 GBP, therefore with an energy consumption of 1,078 MWh, the price paid annually is 43,114 GBP. If the Standard is implemented and the energy consumption is reduced to 549 MWh, then the amount spent on energy consumption will be reduced to 21,952 GBP. The amount of money that can be saved with the implementation of the Standard is therefore 21,162 GBP.

The total amount of money, which is spent on the implementation of the Standard (insulation materials and glazing replacement) is 145,771 GBP. Using Equation 6-18, the simple payback period has been calculated. The results of the calculation show that the simple payback period for the implementation of the Standard into the case study building is 7 years. However, simple payback period does not reflect the value for money, therefore the discounted payback period has been calculated using Equation 1-20. When investing in the improvement of energy efficiency of the building, the discount rate in China is 6% interest (http://chinagreenbuildings.blogspot.com/), therefore it is possible to calculate the discount factor, using Equation 1-19. Figure 6-36 shows the accumulated savings during the discounted payback period. The results show that if the Standard is to be implemented then the discounted payback period of the investment will be around 9 years.

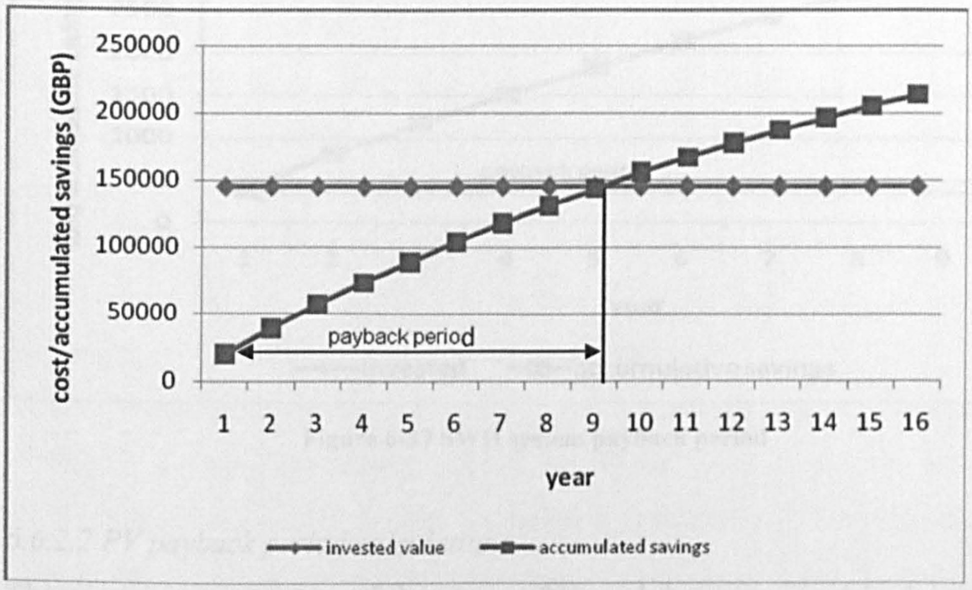

Figure 6-36 Insulation and glazing payback period

6.2 Renewable energy technology payback period

6.6.2.1 Solar water heater payback period calculations

As previously mentioned in section 4.2.5, evacuated tube collectors were selected for this SHW system. According to RET Screen, the total price of the SWH is 2,380GBP. The average installation cost can be estimated at around 30% of the cost of the material [Nahar, 2002], a value of 717GBP. Therefore, the total upgrade cost is 3,097 GBP. The maintenance cost is assumed to be 5% of cost of the solar heater [Nahar, 2002], or 119.5 GBP/year.

The amount of energy used for water heating is 31 MWh/year, or 2,784 m^3. Cubic meters are used as in China the price for natural gas is given per m^3 rather than per kWh. One m^3 of natural gas costs 0.2 GBP (based on an exchange rate of October 15th, 2009). This brings the total cost of water heating by natural gas to 557GBP.

As it has been mentioned in previous section, the interest rate for the installation of the renewable energy technology is 6% and this has been taken into account when calculating the payback period. Using Equation 6-18, the expected annual savings have been calculated to be 437 GBP. Knowing this, it was possible to calculate the payback period using Equation 6-23, and the results show that the discounted payback period of the installation of the SWH system is 9.5 years, as is highlighted in figure 6-37.

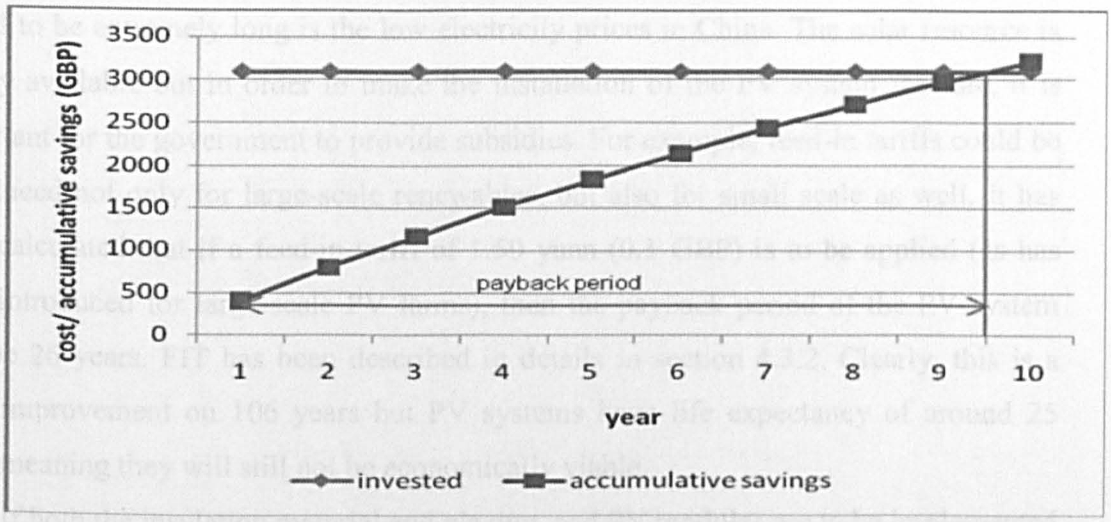

Figure 6-37 SWH system payback period

6.6.2.2 PV payback period calculations

The economic parameters of the chosen PV module is presented in the table 6-6 below. As the data on Chinese prises is not available, these values were used when calculating. It is possible that the prices might be cheaper in China, which would decrease the payback period. However, as it will be se shortly, the payback is not economically feasible, so the decrease in price has to be dramatic to make a difference for the payback period, which does not seem to be possible.

Table 6-6 PV module economics [University of Strathclyde, 2008]

Item	Price per item (in GBP)	Total price for the Case Study (in GBP)
BP Solar mono-si 4175 module	352 (per framed unit)	246,048
Inverter	100	900 (1 inverter per 10 m^2)
Miscellaneous equipment	200	200
Installation	20% of the module cost	49,210
TOTAL COST		**296,357**
Annual maintenance (includes 4 visits per year and parts if required)	500	500

Installed PV modules cover 12% of the total electric energy consumption, or 66 MWh (in the case of the Standard implementation scenario). Price per kWh used for calculations is 0.05 GBP. Using Equation 6-23, the expected annual savings have been calculated. This accounts for 2,793 GBP. The simple payback period was calculated to be 106 years, which is not economically beneficial even before taking into account the interest rate and calculation of the discounted rate. The main reason for the payback period to be extremely long is the low electricity prices in China. The solar resource is clearly available but in order to make the installation of the PV system feasible, it is important for the government to provide subsidies. For example, feed-in tariffs could be introduced not only for large-scale renewables, but also for small scale as well. It has been calculated that if a feed-in tariff of 1.50 yuan (0.1 GBP) is to be applied (as has been introduced for large-scale PV farms), then the payback period of the PV system will be 26 years. FIT has been described in details in section 4.3.2. Clearly, this is a huge improvement on 106 years but PV systems have life expectancy of around 25 years meaning they will still not be economically viable.

If both the insulation material and glazing, and PV modules are to be implemented in the building, the total investment needed is 442,480 GBP. This brings the total discounted payback period to 18.5 years, as shown in figure 6-38. If both insulation and SWH are to be installed, the total investment needed is 148,151 GBP with the discounted payback period of 4.5 years, as can be seen in figure 6-39 below.

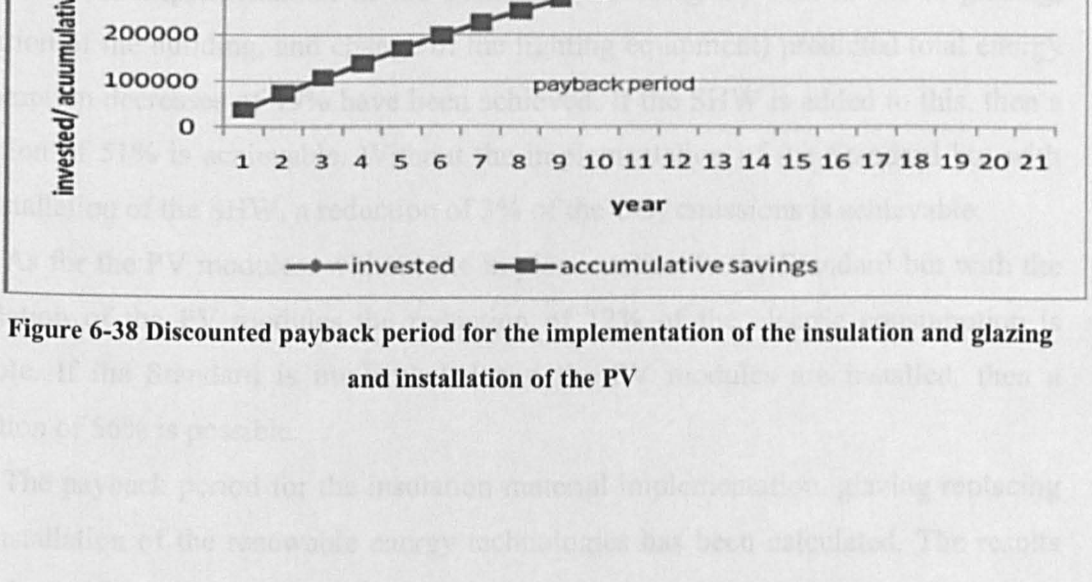

Figure 6-38 Discounted payback period for the implementation of the insulation and glazing and installation of the PV

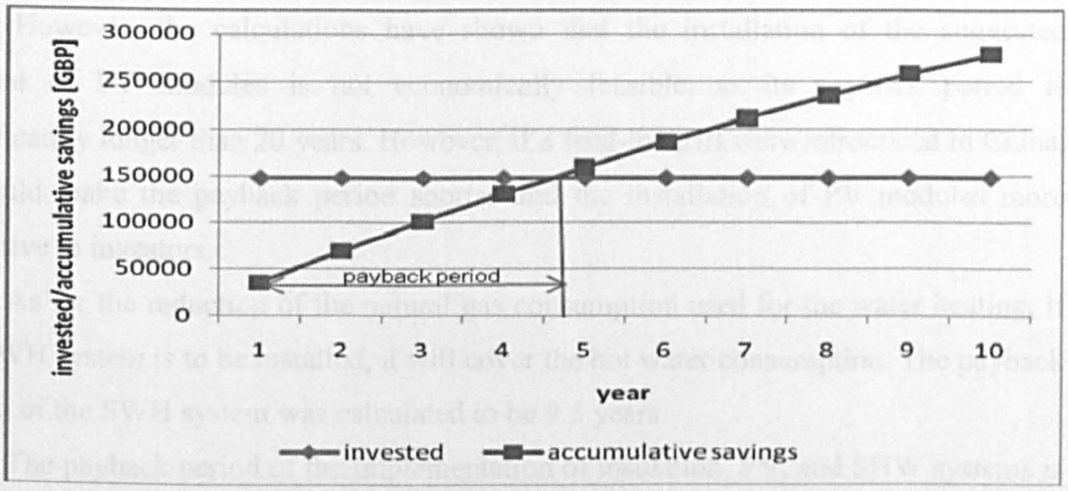

Figure 6-39 Discounted payback period for the implementation of insulation and glazing and installation of SWH

6.7 Summary

As the analysis has shown, the main problem of this case study building is the large heat losses during the winter period and big heat gains during the summer period. This is due to the fact that the insulation of the building is not up to the Standard. Moreover, the lighting equipment used in the building is not energy efficient and results in high energy consumption.

With the implementation of the Standard (including the renovation of glazing, insulation of the building, and change of the lighting equipment) predicted total energy consumption decreases of 49% have been achieved. If the SHW is added to this, then a reduction of 51% is achievable. Without the implementation of the Standard but with the installation of the SHW, a reduction of 3% of the CO_2 emissions is achievable.

As for the PV modules, without the implementation fo the Standard but with the installation of the PV modules the reduction of 12% of the electric consumption is possible. If the Standard is implemented and the PV modules are installed, then a reduction of 56% is possible.

The payback period for the insulation material implementation, glazing replacing and installation of the renewable energy technologies has been calculated. The results have shown that with for the implementation of the Standard (insulation material and glazing), an investment of 145,771 GBP is needed. With an interest rate of 6%, it will be returned in 4 to 5 years time.

For the further reduction of electric energy consumption, the installation of PV modules was simulated, which allow a reduction in electrical energy consumption of

12%. However, the calculations have shown that the installation of the suggested amount of PV modules is not economically feasible, as its payback period is significantly longer than 20 years. However, if a feed-in tariff were introduced in China, it would make the payback period shorter and the installation of PV modules more attractive to investors.

As for the reduction of the natural gas consumption used for the water heating, if the SWH system is to be installed, it will cover the hot water consumption. The payback period of the SWH system was calculated to be 9.5 years.

The payback period of the implementation of insulation, PV, and SHW systems is 8 years, taking into account the FIT.

The main reason for the payback period of the renewable energy technologies being so long is the low cost of electricity and hot water. For the PV modules to be economically feasible, either interest rates have to be 0%, or the installation has to be supported by government incentives. A smaller amount of the PV panels can be seen as a possibility; however, it will not reduce the electric energy consumption dramatically.

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Chapter 7 - Case Study Analysis: Development Office Building, Beijing

7.1 Introduction

7.1.1 Case study location

Case study Two is Development Office Building in Beijing. Figure 7-1 shows Beijing location. Beijing is the capital of China and is an administrative separate to any of the Chinese provinces.

Figure 7-1 Beijing location

It is located in the "Cold climate zone" according to climatic zones divisions introduced in section 5.2. Beijing climate is defined as continental monsoon with four distinctly recognisable four seasons.

The average temperature throughout the year is 11.8 °C with January as the coldest month (average temperature is -8°C) and July as the hottest month (average temperature is +30°C). Figure 7-2 shows the solar radiation and the average temperature for Beijing. Table 7-1 represents the main climatic characteristics for Beijing.

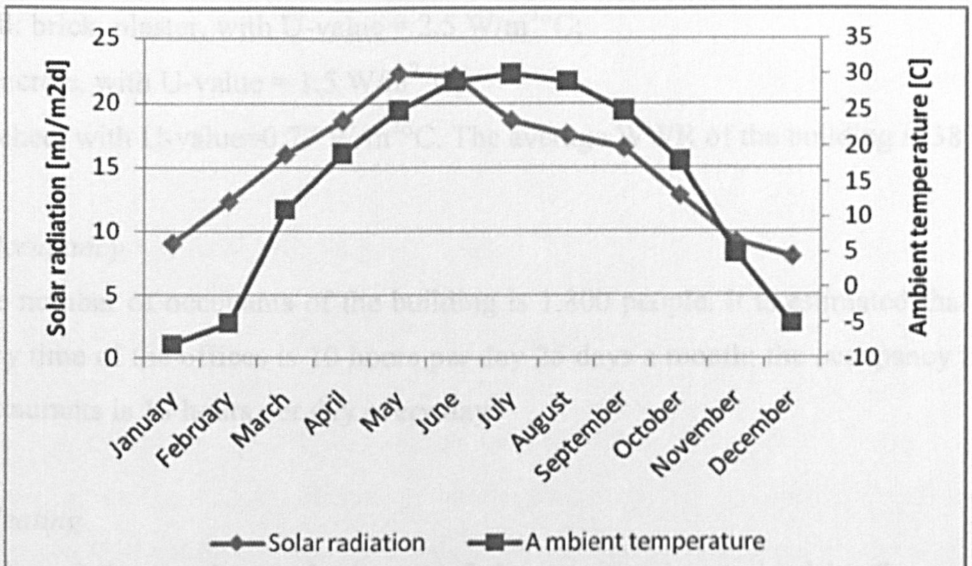

Figure 7-2 Horizontal solar radiation and average temperature for Beijing

Table 7-1 Main climatic characteristics for Beijing [Lam, 2007]

Lat. (N)	Long. (E)	Elev. (m)	Dry-bulb temperature °C				Rel. humidity (%)		Sunshine (hours)
			Average annual	Annual diff.	HMA	CMA	HMA	CMA	
39°48'	116°28'	31.5	11.5	30.4	25.8	-4.6	78	45	2780.2

7.1.2 Building description

The Development Office Building is situated in Beijing, 5 Sanhuaibei East Road. It is a typical office building built in the 1980s. It is an office building and is used by more than 10 different companies. It has a total floor area of 54,990 m^2 with 22 floors, 20 levels above the ground and 2 levels below ground. The lowest level is used as a car park. The 1st level is used for Japanese and Chinese restaurants, the Bank of China, ChinaAir company office and a shop. The 2nd level is used as a restaurant. All the levels from 3rd to 22nd are used for offices with the exception of level 13. Level 13 is used for storage; this can be explained by the superstition that number 13 brings bad luck; therefore, companies do not wish to have their offices on the 13th level.

7.1.2.1 Materials of construction

Construction materials with the following U-values are used in the building:

Glass: double glazed, with U-value = 3.26W/m^2°C;

Outer wall: concrete block and plaster, with U-value = 1.7 W/m^2°C;

Inner wall: brick, plaster, with U-value = 2.5 W/m²°C;

Floor: concrete, with U-value = 1.5 W/m²°C;

Roof: pitched, with U-value=0.77 W/m²°C. The average WWR of the building is 38%.

7.1.2.2 Occupancy

The number of occupants of the building is 1,800 people. It is estimated that the occupancy time of the offices is 10 hours per day 25 days a month; the occupancy time of the restaurants is 13 hours per day every day.

7.1.2.3 Heating

Beijing, being in the northern part of the country, is provided by the central district heating brought into the building 24 hours a day everyday from November 15th to March 15th. The efficiency of district heating is around 65%. The occupants do not have an opportunity to regulate the internal temperatures, as thermostats are not installed.

7.1.2. 4 Cooling

TRANE cooling system shown in Figure 7-3 is used in the building to provide cooling during summer. Its COP is 1.8. Individual AC units in each office also support the cooling system.

Figure 7-3 TRANE cooling unit [solarshop.com]

7.1.2.5 Hot water

No hot water is provided for this building. This is a typical situation for commercial building in China.

7.2 Scenario One: Real building operation

The total energy consumption of the building has been taken from the meter readings. Obtaining accurate meter reading has proved difficult in China and so the meter readings from this building have been used to calculate the level of error for the other case studies, as exactly the same methodology has been used in each case. Comparison of this building meter readings with the energy consumption calculations outlined in the methodology (section 6.1.1) and used for all the case studies showed only a 3% error, which would not affect the results of this investigation dramatically. Also the purpose of the calculations was to see the electric energy consumed by lighting, equipment and cooling system separately, as the meter reading provided the total energy consumption only.

7.2.1 Temperature

Temperatures vary from room to room depending on the type of room. For this building, there was not a big variety of rooms. The following table 7-2 provides the internal temperatures throughout the year. The data was provided by the estate manager of the building and is average for each month and space. The infiltration air rate in the rooms is 0.3 m^3/s throughout the year.

Table 7-2 Internal temperatures and lighting level

Space	Room Temperature												Lighting (lux)
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Corridor	12	13	14	15	18	20	22	23	21	19	14	13	-
Office	25	25	20	21	23	27	28	28	26	22	20	25	300
Bank	25	25	20	21	23	27	28	28	26	22	20	25	300
Canteen	25	25	20	21	23	27	28	28	26	22	20	25	200
Storage	20	20	16	17	20	22	23	23	21	19	17	20	50
Waiting area	25	25	20	21	23	27	28	28	26	22	20	25	200
Shop	23	23	18	19	21	25	26	26	24	20	18	23	500

7.2.2 Heat losses and heat gains

The main source of the heat losses during the winter months is because the temperature inside the room cannot be regulated, it actually gets too hot sometimes, and the occupants open the windows which cause the biggest overall heat loss for the building. As for the heat gains, the main reason is equipment, as almost every office room is provided with a photocopier and a printer that produce high heat exhausts (400 W and 160W respectively).

Figure 7-4 represents the heat gains and heat losses throughout the year for the whole building. It also shows if heating or cooling is required during a particular month. As can be seen from the graph, heating is required from November to March. The heating is central district heating provided constantly by the local coal-fired power station from November 15th to March 15th. As in March and November the external temperatures are still cold after the district heating is off, the individual AC units provide any required heat. Cooling is needed from April to October and is provided by the TRANE cooling system with a COP of 1.8 and individual AC units with COP of 2.5.

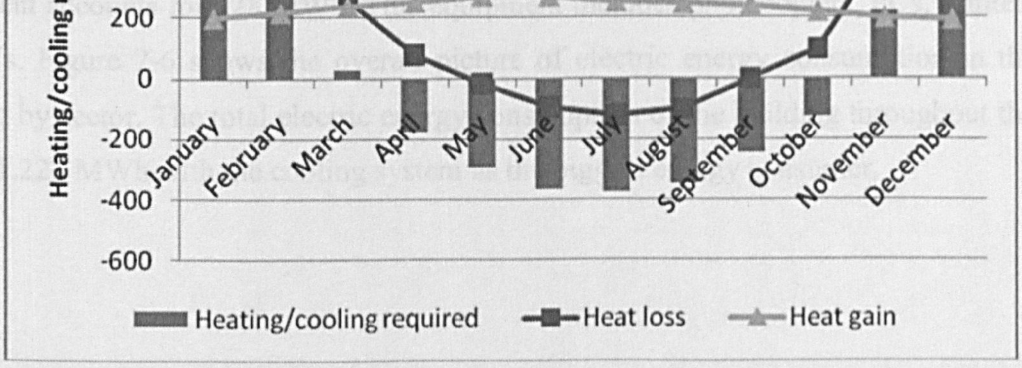

Figure 7-4 Yearly heating/cooling requirements

7.2.3 Electric energy consumption

Figure 7-5 shows the electric energy consumed by the cooling system, lighting, equipment, individual AC units, and other (including kitchen appliances for the restaurants, vacuum cleaners, washing machines, etc).

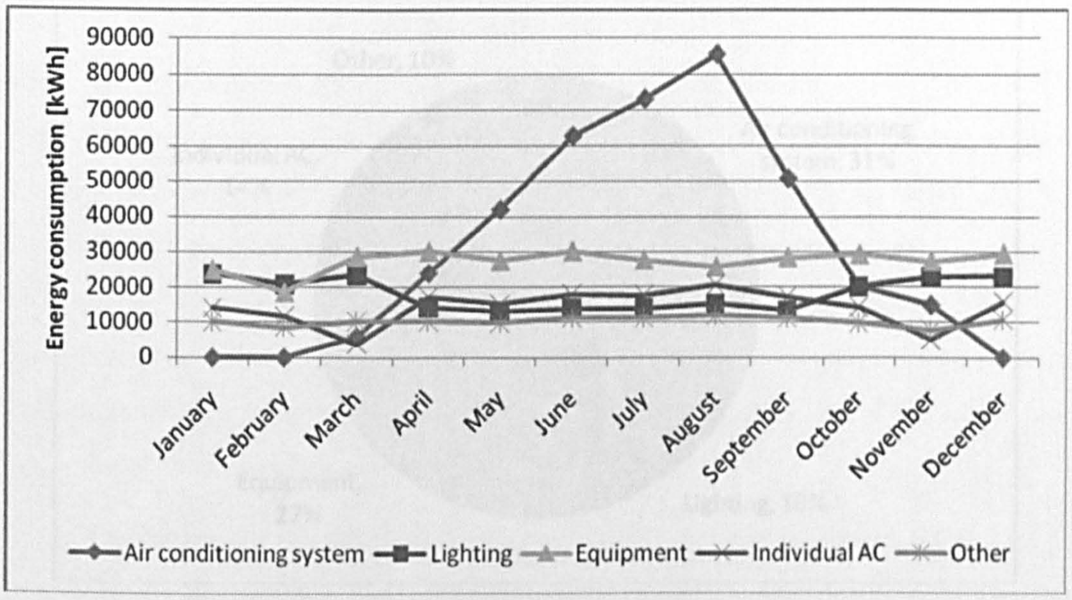

Figure 7-5 Electrical energy consumption

The annual total energy consumed by the cooling system is 380 MWh. It is the largest energy consumer in the building, though it is not used from December to February. The lowest energy is consumed by the system in March, when the cooling amount is low. However, its energy consumption reaches its peak in July and August when the external temperatures are the hottest. As has been mentioned before, cooling as well as heating is also provided by the individual AC units. Their total energy consumption is 172 MWh. The electric energy consumption of the lighting is 219 MWh. All the lighting is provided by halogen tubes. The electric energy consumption of office equipment accounts for 328 MWh. This equipment includes photocopiers, PCs, printers and TVs. Figure 7-6 shows the overall picture of electric energy consumption in the building by sector. The total electric energy consumption of the building throughout the year is 1,223 MWh with the cooling system as the biggest energy consumer.

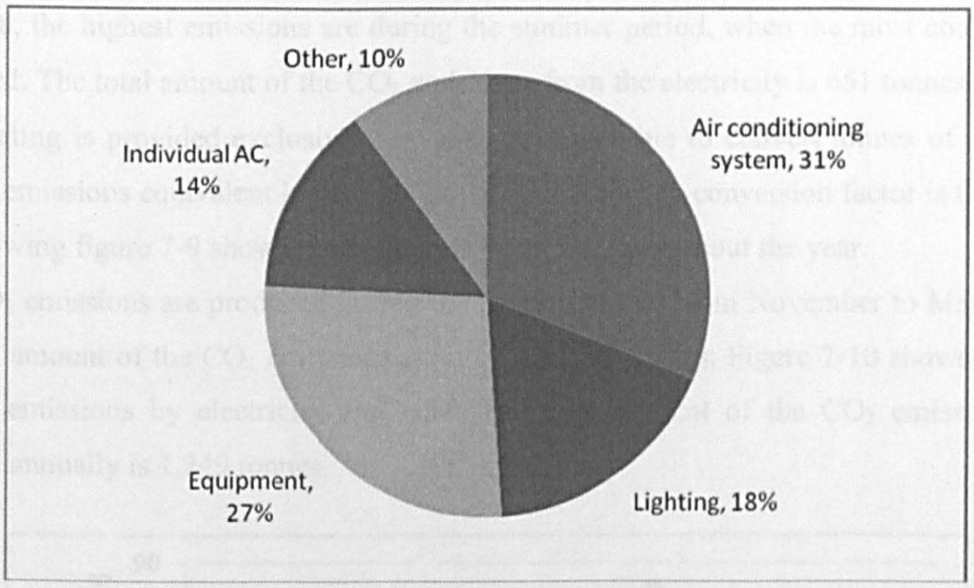

Figure 7-6 Share of the electric energy consumption

7.2.4 Coal consumption

The central district heating is used from November to March and is supplied by a coal-fired power station. Figure 7-7 represents the coal energy consumption during the year. The coal energy consumption has been calculated in MWh using data from the calculation of heating load along with equation 6-13. The amount of heating needed is 585 MWh.

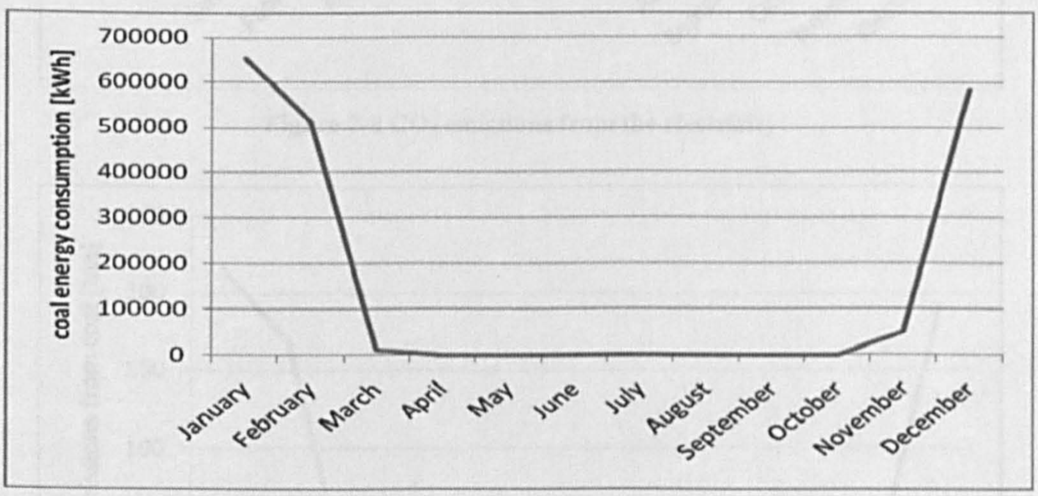

Figure 7-7 Coal energy consumption

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7.2.5 CO_2 emissions

All the electricity used in the building is from the grid. The following figure 7-7 represents the amount of the emissions produced for each month. As can be seen in figure 7-8, the highest emissions are during the summer period, when the most cooling is required. The total amount of the CO_2 emissions from the electricity is 651 tonnes.

Heating is provided exclusively by coal. It is possible to convert tonnes of coal into CO_2 emissions equivalent knowing that the coal emission conversion factor is 0.33. The following figure 7-9 shows the emissions from coal throughout the year.

CO_2 emissions are produced during the heating season from November to March. The total amount of the CO_2 emissions from coal is 598 tonnes. Figure 7-10 shows the share of emissions by electricity and coal. The total amount of the CO_2 emissions produced annually is 1,249 tonnes.

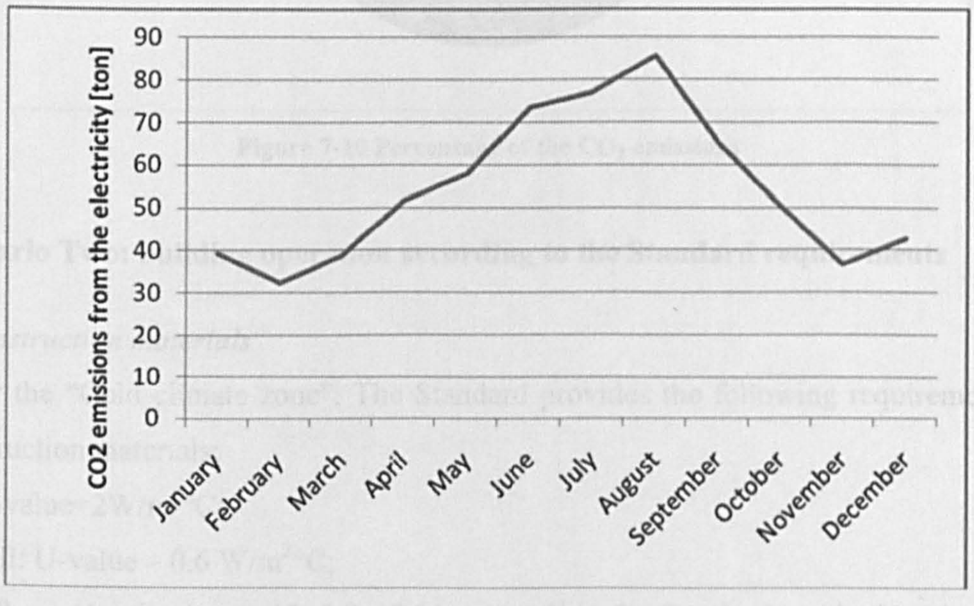

Figure 7-8 CO_2 emissions from the electricity

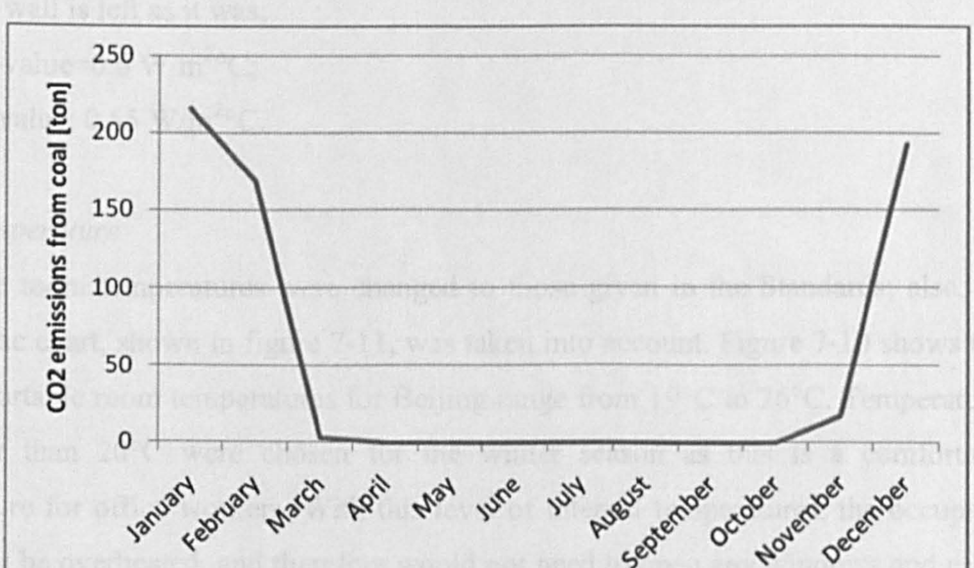

Figure 7-9 CO_2 emissions from coal

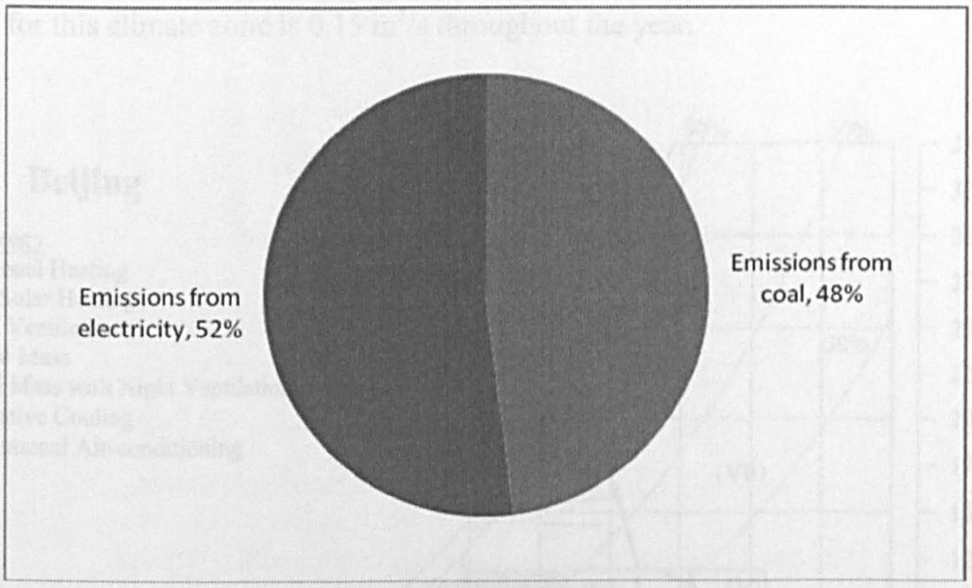

Figure 7-10 Percentage of the CO_2 emissions

7.3 Scenario Two: building operation according to the Standard requirements

7.3.1 Construction materials

For the "Cold climate zone", The Standard provides the following requirements for construction materials:

Glass: U-value=2W/m^2°C;

Outer wall: U-value – 0.6 W/m^2°C;

Inner wall: no U-value is specified for the inner wall in the Standard, so the U-value of the inner wall is left as it was;

Floor: U-value=0.6 W/m^2°C;

Roof: U-value: 0.55 W/m^2°C.

7.3.2 Temperature

The room temperatures were changed to those given in the Standards; also, the bioclimatic chart, shown in figure 7-11, was taken into account. Figure 7-10 shows that the comfortable room temperatures for Beijing range from 19°C to 26°C. Temperatures no hotter than 20°C were chosen for the winter season as this is a comfortable temperature for office workers. With this level of internal temperatures, the occupants would not be overheated, and therefore would not need to open any windows and cause the massive heat losses previously mentioned. For the summer season, temperatures no higher than 26°C were chosen. The air change rate by room volume suggested by the Standard for this climate zone is 0.15 m^3/s throughout the year.

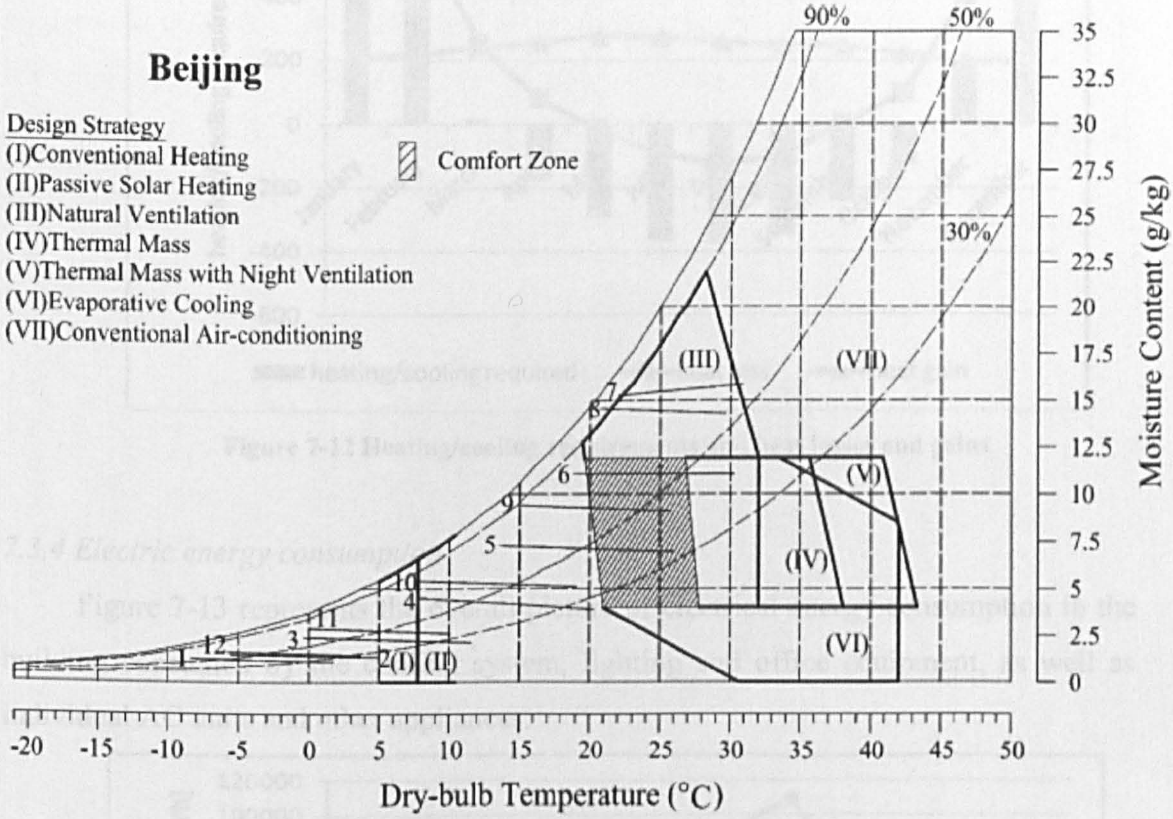

Figure 7-11 Bioclimatic chart for Beijing

7.3.3 Heat losses and heat gains

As the U-values and the internal temperatures have been changed, heat losses have decreased. However, this caused an increase in heat gains which was good for the cold months of March and November, when the central heating is off for the 15 days of the month, but caused an increase in the cooling requirement during the summer months. The following figure 7-12 represents the heat losses, heat gains, and the heating and cooling requirements of the building throughout the year. The graph highlights that heating is required from November to March. As has been mentioned, the heating is provided by the local power station. The cooling is required from April to October with the maximum cooling required in June, July, and August. Because of the increased heat gains, the extra cooling is also needed.

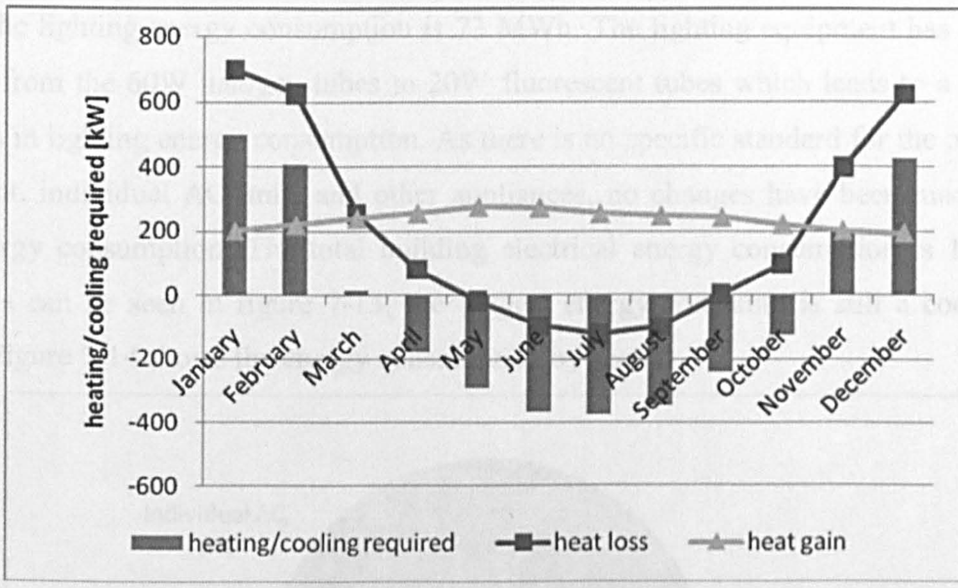

Figure 7-12 Heating/cooling requirements and heat losses and gains

7.3.4 Electric energy consumption

Figure 7-13 represents the overall picture of electrical energy consumption in the building consumed by the cooling system, lighting and office equipment, as well as individual AC units and other appliances.

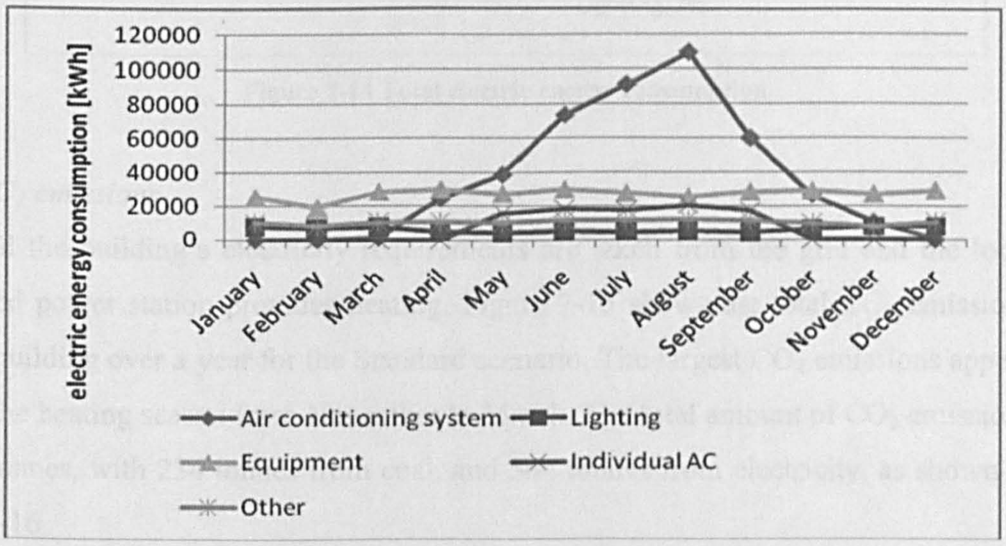

Figure 7-13 Electric energy consumption

The largest energy consumer is still the cooling system. The energy consumption of the cooling system is 436 MWh, with the largest amount of energy consumed from May to September. Extra cooling is provided by the individual AC units during summer months, however due to less heat losses during the winter period, no extra heating is needed in March and November. The individual AC units' energy consumption is 89

MWh. The lighting energy consumption is 73 MWh. The lighting equipment has been changed from the 60W halogen tubes to 20W fluorescent tubes which leads to a 33% reduction in lighting energy consumption. As there is no specific standard for the office equipment, individual AC units and other appliances, no changes have been made to their energy consumption. The total building electrical energy consumption is 1,051 MWh. As can be seen in figure 7-13, the biggest energy consumer is still a cooling system. Figure 7-14 shows the energy consumption by sector.

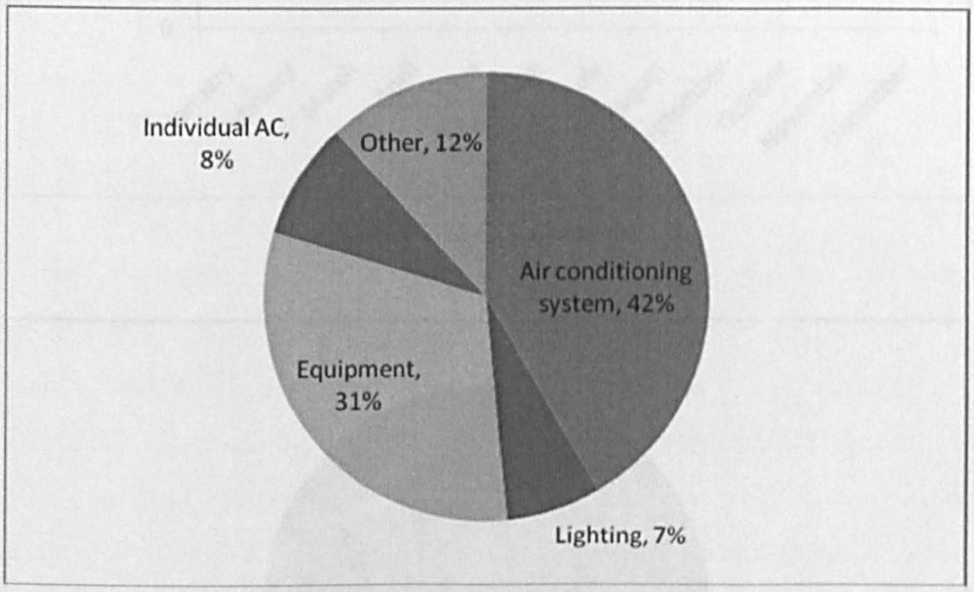

Figure 7-14 Total electric energy consumption

7.3.5 CO_2 emissions

All the building's electricity requirements are taken from the grid and the local coal-fired power station provides heating. Figure 7-15 shows the total CO_2 emissions for the building over a year for the Standard scenario. The largest CO_2 emissions appear during the heating season from November to March. The total amount of CO_2 emissions is 798 tonnes, with 234 tonnes from coal, and 564 tonnes from electricity, as shown in figure 7-16.

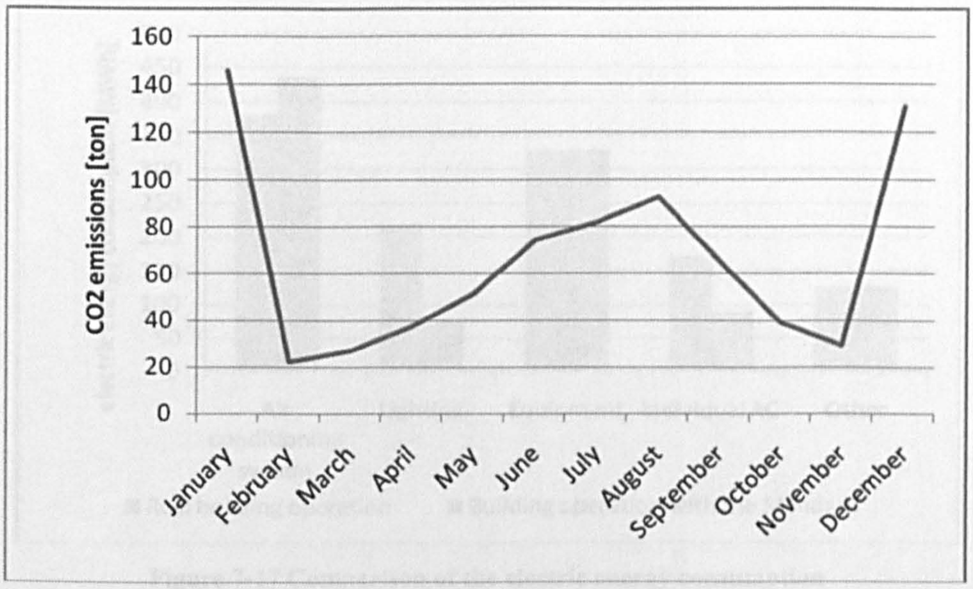

Figure 7-15 CO_2 emissions

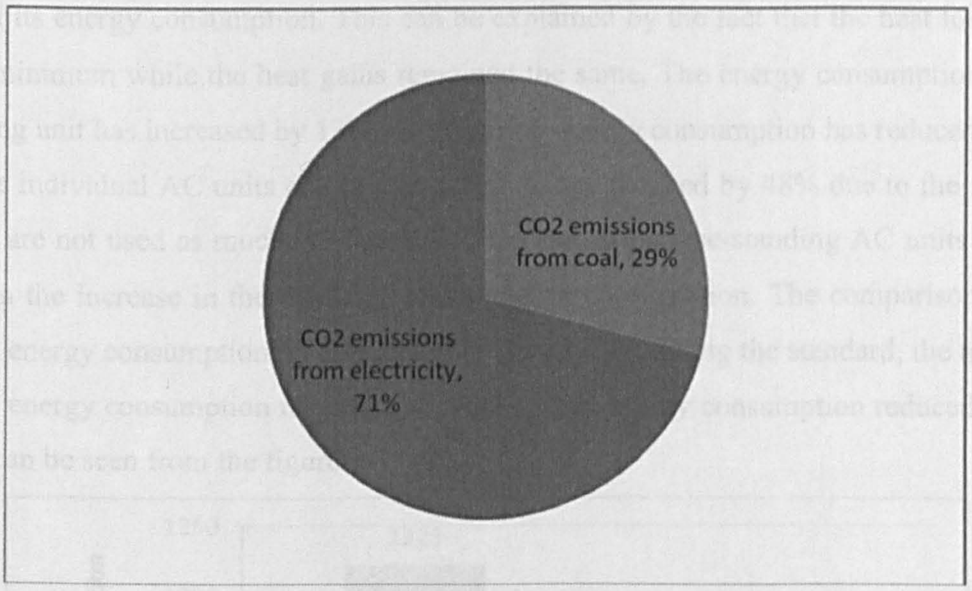

Figure 7-16 Share of the CO_2 emissions

7.4 Results comparison

Figure 7-17 shows the difference in the electric energy consumption with and without the implementation of the Standard requirements.

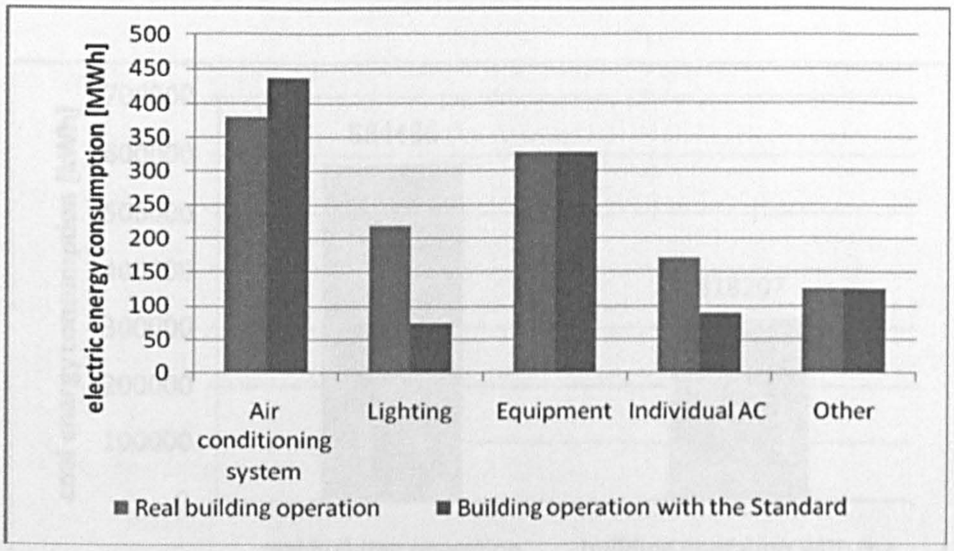

Figure 7-17 Comparison of the electric energy consumption

With the implementation of the Standard, the cooling system has actually increased its energy consumption. This can be explained by the fact that the heat losses became minimum while the heat gains remained the same. The energy consumption of the cooling unit has increased by 13%. The lighting energy consumption has reduced by 67%. The individual AC units energy consumption has reduced by 48% due to the fact that they are not used as much. The savings from not using free-standing AC units are more than the increase in the cooling system energy consumption. The comparison of electrical energy consumption is represented in figure 7-18. Using the standard, the total electrical energy consumption is reduced by 14%. Coal energy consumption reduced by 46%, as can be seen from the figure 7-19.

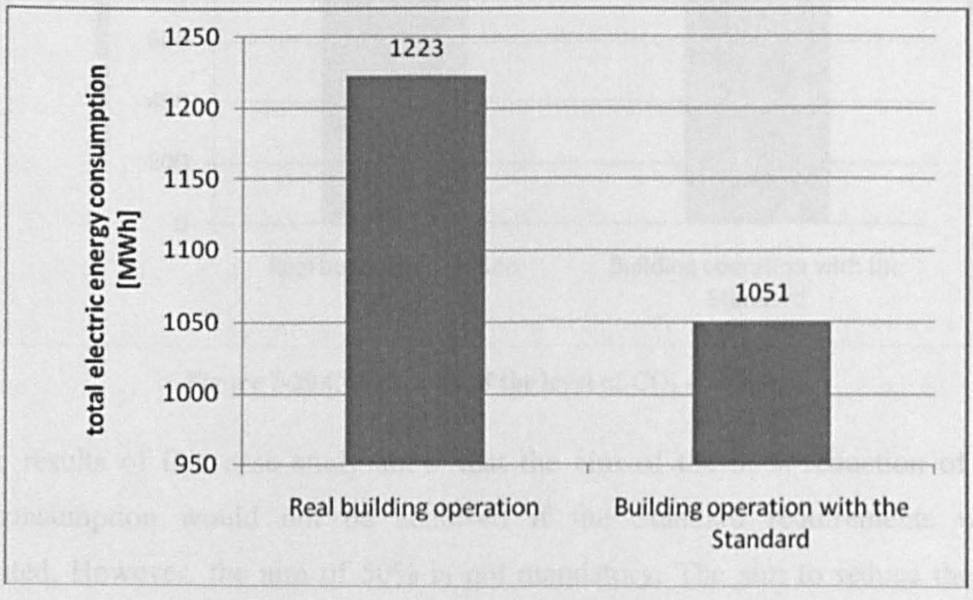

Figure 7-18 Comparison of the total grid energy consumption

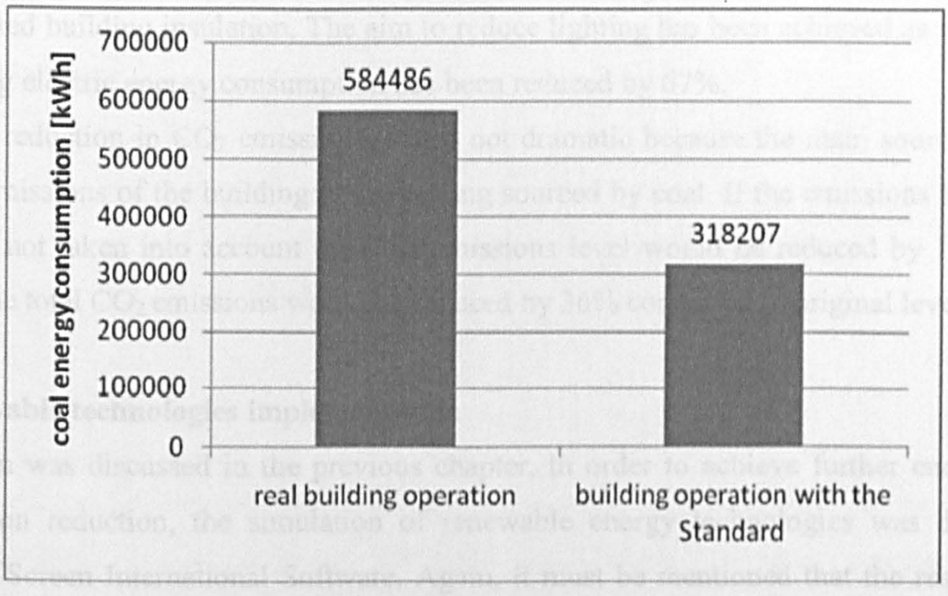

Figure 7-19 Coal energy consumption

As figure 7-20 shows, the level of CO_2 emissions is reduced by 36%, mainly because the heat losses were reduced and therefore the amount of heat required is reduced. This caused a reduction in the amount of coal required for the space heating during the winter months.

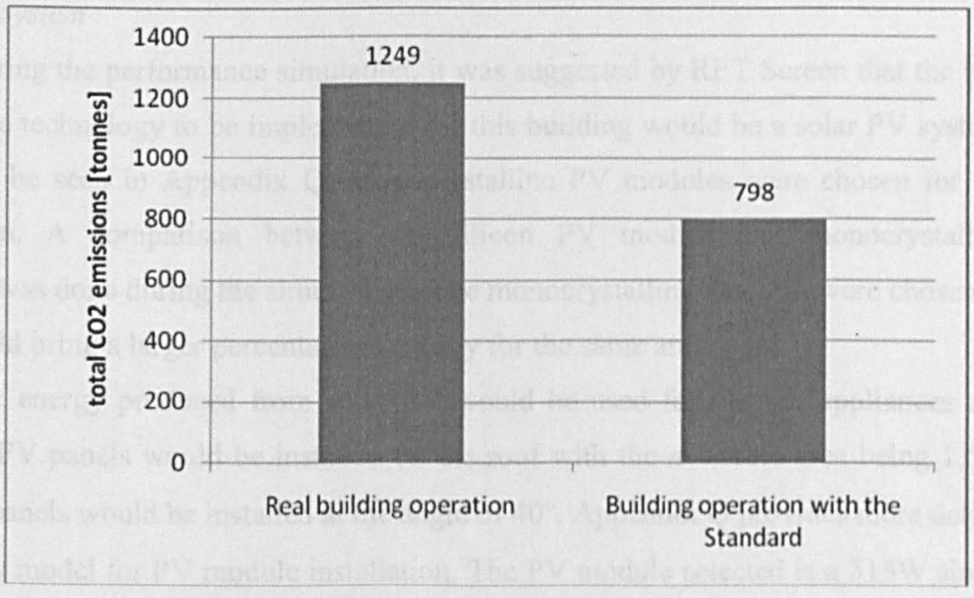

Figure 7-20 Comparison of the level of CO_2 emissions

The results of this case study show that the aim of the 50% reduction of the energy consumption would not be achieved if the Standard requirements were implemented. However, the aim of 50% is not mandatory. The aim to reduce the air source heat pump energy consumption by 13-25% has not been achieved; instead it has actually increased by 13% due to more cooling requirements during summer because of the increased building insulation. The aim to reduce lighting has been achieved as well: the lighting electric energy consumption has been reduced by 67%.

The reduction in CO_2 emissions is also not dramatic because the main source of the CO_2 emissions of the building is the heating sourced by coal. If the emissions from coal were not taken into account then the emissions level would be reduced by 14%. Overall, the total CO_2 emissions would be reduced by 36% compared to original levels.

7.5 Renewable technologies implementation

As in was discussed in the previous chapter, in order to achieve further energy consumption reduction, the simulation of renewable energy technologies was done using RETScreen International Software. Again, it must be mentioned that the results are not precise and can only be used for assuming the possible reductions in energy consumption.

The average annual sunshine hours in Beijing are 2,780 hours with an average daily solar radiation intensity of 4 $kW/m^2/d$. The average annual temperature is 11.5°C.

7.5.1 PV system

During the performance simulation, it was suggested by RET Screen that the best renewable technology to be implemented for this building would be a solar PV system. This can be seen in Appendix Q. Monocrystalline PV modules were chosen for the simulation. A comparison between polysilicon PV module and monocrystalline modules was done during the simulations. The monocrystalline modules were chosen as they would bring a larger percentage of energy for the same area.

The energy produced from solar PV would be used for electric appliances and lighting. PV panels would be installed on the roof with the available area being 1,571 m^2. The panels would be installed at the angle of 40°. Appendix Q provides more details on energy model for PV module installation. The PV module selected is a 315W single crystal grid-connected module with white backsheet and alkaline resistant glass with silicon nitride monocrystalline silicon cells SPR-315E-WHT, they manufactured by Chinese company Sunpower. An image is shown in figure 7-21.

Figure 7-21 SPR-315E-WHT PV module [Solarshop, 2009]

This PV module has aerodynamic design resistant to high winds that is important in this particular region as there are high winds during summer months. Its characteristics are given in table 7-3 [Solarshop, 2009].

Table 7-3 SPR-315E-WHT specifications [Solarshop, 2009]

Model	SPR-315E-WHT
Electrical data	
Peak power (+/-5%)	305-315W
Rated voltage	54.7V
Rated current	5.58-5.76A
Open circuit voltage	64.2-64.6V
Short circuit current	5.96-6.14A
Maximum system voltage	600V
Power temperature coefficient	-0.38%/K
Voltage temperature coefficient	-176.6 mV/K
Current temperature coefficient	3.5 mA/K
NOCT	45°C +/-2°C
Series fuse rating	15A
CEC PTC rating	282.1-291.6W
Mechanical data	
Solar cells	96 Sunpower all-back contact monocrystalline
Front glass	High transmissions tempered glass with anti-reflective (AR) coating
Junction box	IP-65 rated with 3 bypass diodes, 32×155×128 (mm)
Output cables	1000 mm length cables
Frame	Polymer material with fiber reinforcement, PPE+PS
Weight	21.3 kg, 11.7 kg/m^2
Roof coverage	85% N-S

The area of the PV module calculated by the RET Screen is proposed to be 1,467 m^2 with 900 units installed. This will provide 10% of the electrical energy required (see Appendix Q).

7.5.1.1 CO_2 emission comparison with the installation of the PV module

The installation of the PV panels allows the reduction of energy consumption from the grid by 10%, as figure 7-22 and Appendix Q show. With the implementation of both the Standard and the PV module, the energy consumption of the building is reduced by 23%. The CO_2 emissions amount is reduced by 12%, as can be seen in figure 7-23. With the implementation of both the Standard and the installation of the PV module, the energy CO_2 emissions level is to be reduced by 41%.

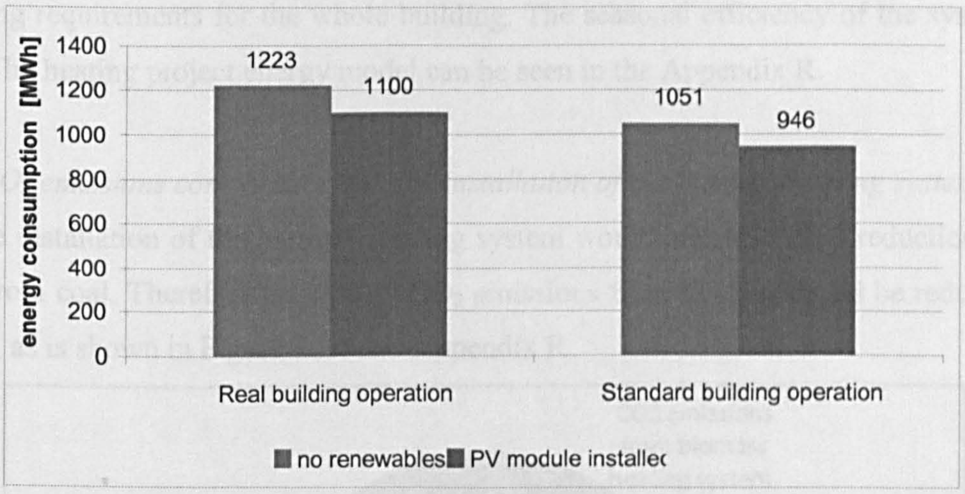

Figure 7-22 Real and Standard building grid energy consumption comparison with PV module installation

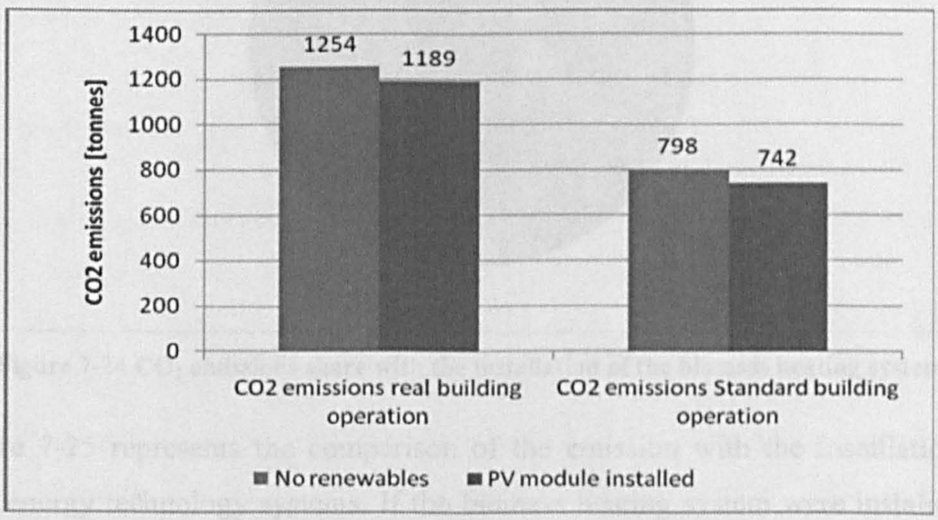

Figure 7-23 Real and Standard CO_2 emissions comparison with PV module installation

7.5.2 Biomass heating system

For this particular case study, biomass heating system has been chosen, because, as previously mentioned, the CO_2 emissions from space heating during the winter period accounts for the large amount of CO_2 emissions. RET Screen's Heating Project was used to simulate the performance of a biomass heating system for this case study. The biomass heating system is described in section 4.2.3.

With the heated floor area of the building being 49,992 m^2 and a heat load of 41W/m^2, RET Screen's heating tool suggested that a biomass system with a capacity of 2,049 kW is needed is order to provide 100% of the heating during the peak periods.

The biomass system chosen was the Chiptec Wood CX-7. Its capacity is 2, 050 kW and the heating delivered is 3,788 MWh/year, therefore one unit is enough to cover the heating requirements for the whole building. The seasonal efficiency of the system is 85%. The heating project energy model can be seen in the Appendix R.

7.5.2.1 CO_2 emissions comparison with the installation of the biomass heating system

The installation of the biomass heating system would allow a 100% reduction of heating from coal. Therefore the overall CO_2 emissions from heating would be reduced by 100%, as is shown in Figure 7-24 and Appendix R.

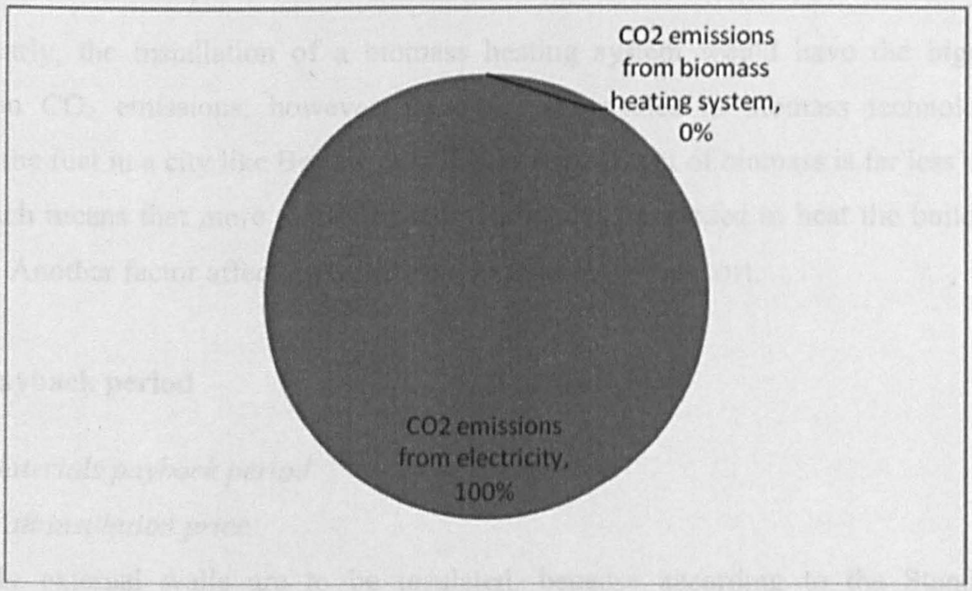

Figure 7-24 CO_2 emissions share with the installation of the biomass heating system

Figure 7-25 represents the comparison of the emission with the installation of renewable energy technology systems. If the biomass heating system were installed in the building, the overall CO_2 emissions would reduce by 48%. With the installation of both the biomass heating system and the PV system proposed, the CO_2 emissions can be reduced by 52%. With the implementation of the Standard and the installation of the biomass heating system, the CO_2 emission can be reduced by 55%. With the implementation of the Standard and the installation of both biomass heating system and PV system proposed, CO_2 emissions can be reduced by 59% compared to the real building operation CO_2 emissions.

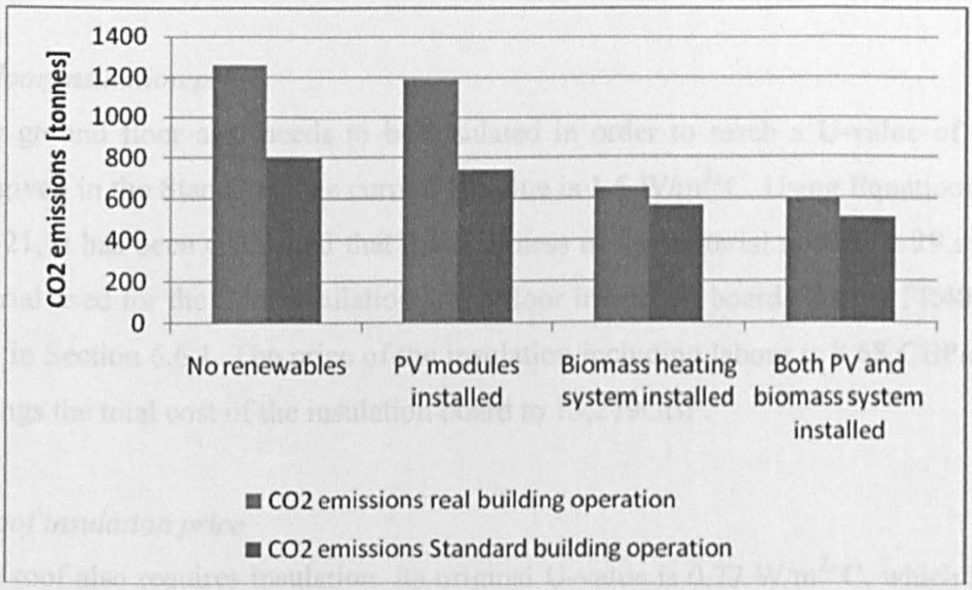

Figure 7-25 CO_2 emissions comparison in real and standard building operations with the implementation of PV and biomass heating systems

Clearly, the installation of a biomass heating system would have the biggest impact on CO_2 emissions, however, there are downsides to biomass technology, sourcing the fuel in a city like Beijing, and the energy context of biomass is far less than coal, which means that more tonnes of biomass would be needed to heat the building annually. Another factor affecting biomass is its relatively high cost.

7.6 Payback period

7.6.1 Materials payback period

7.6.1.1 Wall insulation price

Only external walls are to be insulated, because according to the Standard requirements, the U-value of existing internal walls is similar to the U-value of the internal walls proposed by the Standard. The U-value of the existing external walls is 1.7 W/m^2°C, whereas the Standard requires the U-value of external walls to be 0.6 W/m^2°C. The thickness of the insulation material, according to Equations 6-20 and 6-21, is 42 mm. The material chosen for insulation is mineral fibre quilt "Isowool". The basic constituent of the "Isowool" is glass mineral wool, produced from silica sand (Greenspec 2010). Both ODP and GWP are zero. The thermal conductivity of the material is $k=0.039$. The material comes in different thickness from 25 mm to 200 mm. The price provided by "Spon's Guide 2007" including labour is 5.2 GBP per m^2, which brings the total price to 26,031GBP.

7.6.1.2 Floor insulation price

The ground floor also needs to be insulated in order to reach a U-value of 0.6 W/m^2°C given in the Standard. The current U-value is 1.5 W/m^2°C. Using Equations 1-20 and 1-21, it has been calculated that the thickness of the material needed is 29 mm. The material used for the floor insulation is the floor insulation board Celotex FR4000, described in Section 6.6.1. The price of the insulation including labour is 8.68 GBP/m^2, which brings the total cost of the insulation board to 13,279GBP.

7.6.1.3 Roof insulation price

The roof also requires insulation. Its original U-value is 0.77 W/m^2°C, which has to be reduced to a U-value of 0.55 W/m^2°C, given in the Standard. Equations 6-20 and 1-21 show that the thickness of the insulation material needed is 17 mm. The material used for the roof insulation is 50 mm Isowool. The price including the labour of this insulation material is 5.47 GBP/m^2. The total cost of the insulation is 8,368 GBP.

7.6.1.4 Glazing replacement cost

The windows used in the building case study are double glazed wooden framed windows. Though according to the Standard the U-value of the windows has to be reduced, the calculations have shown that if the windows are not replaced, it does not affect the reduction of the energy consumption dramatically. Without the replacement of the windows energy consumption will fall by 14% (which is only 1% more than if the windows were to be replaced). Also it has been decided not to replace the windows because of its high cost. The replacement of the windows requires the investment of 464,898 GBP, which is not economically feasible.

7.6.1.5 Total payback period for materials and glazing

The electricity price per kWh in Beijing is 0.05GBP, therefore with an annual total energy consumption of 1,223 MWh, the total price paid is 61,137 GBP. If the Standard is implemented (without replacement of the windows), the electrical energy consumption will be reduced to 1,055 MWh with the total price of 52,765 GBP per annum, which brings annual savings to 8,372 GBP. The investment needed to implement the Standard is 47,677 GBP. Using Equation 6-17, it has been calculated that the simple payback period is 5.7 years. Using the Equation 6-19, the discounted payback period has been calculated to be 7.5 years, as can be seen in Figure 7-26.

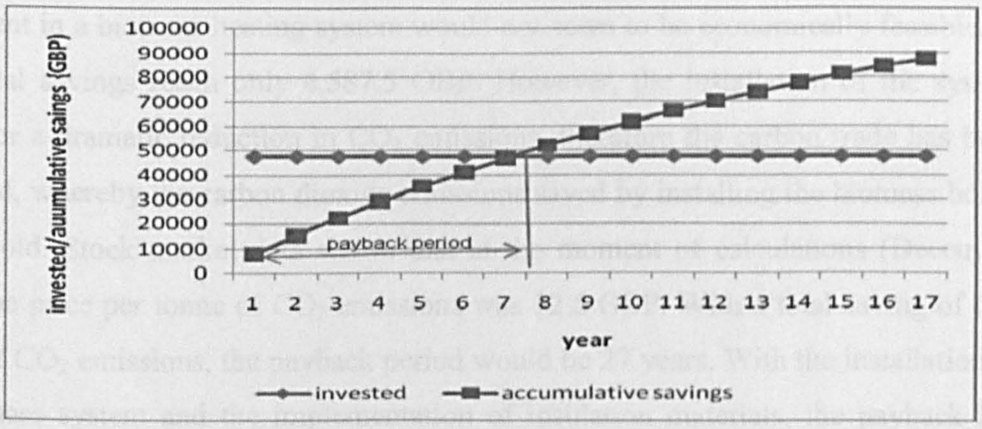

Figure 7-26 Discounted payback period

7.6.2 Renewable energy technology payback period

7.6.2.1 PV payback period calculation

According to RETScreen International calculations, the amount of energy produced by the PV system would cover 10% of the total electrical energy consumption of the building, or 105 MWh. In order to provide this amount of energy, 1,467 m^2 of PV modules would need to be installed on the roof of the building, which brings its total cost to 620,761 GBP, with the expected annual savings of 4,754 GBP, calculated using the Equation 6-22. The simple payback period, calculated using Equation 6-17, would be 86 years, which, similarly to the Case Study One PV payback period, is not economically feasible. With a FIT of 0.1 GBP the annual savings would be 15,263 GBP with a payback period of 27.5 years.

If both the insulation materials are to be used in the building and the PV module to be installed, the total investment needed is 468,854 GBP which would provide annual savings of 13,631 GBP. The total payback period is 34 years.

7.6.2.2 Biomass heating system payback period

As it has been mentioned before, heating season lasts from November 15 to March 15 every year. The price of district heating is highly subsidised by the government and it depends on the area of the buildings rather than on the heating energy consumption. Currently the price of heating per m^2 is 4.5 GBP for the heating season. This brings the total price paid per year to 247,455 GBP/year.

In order to reduce CO_2 emissions from heating, the installation of a biomass heating system has been simulated. The installed unit with a capacity of 2,050 kW would cost 123,000 GBP and the maintenance cost per year would be 4,000 GBP. Investment in a biomass heating system would not seem to be economically feasible, as the annual savings reach only 4,587.5 GBP. However, the installation of the system allows for a dramatic reduction in CO_2 emissions, therefore the carbon trade has been suggested, whereby the carbon dioxide emissions saved by installing the biomass boiler can be sold. Stock market data shows that at the moment of calculations (December 2009), the price per tonne of CO_2 emissions was 12.5 GBP. With a total saving of 687 tonnes of CO_2 emissions, the payback period would be 27 years. With the installation of the biomass system and the implementation of insulation materials, the payback has been calculated to be 13 years.

7.7 Summary

The aim of the Standard to reduce the energy consumption by 50% has not been met for this particular building. The CO_2 emissions have not been reduced dramatically either. The main reason is the heating during winter months that is supplied by coal from the local power station. Coal heating is responsible for 48% of CO_2 emissions of the building. In terms of the electrical energy consumption, office equipment is the second biggest energy consumer in the building after the cooling system, therefore the replacement of office equipment and other appliances by more energy efficient ones can provide further reductions of the electrical energy consumption.

As for the payback period, calculations have shown that the replacement of the windows would not bring a dramatic effect in energy consumption reduction, therefore the implementation of the insulation material for walls, roof and floor is enough. The insulation material payback would be 7.5 years which is economically feasible. The payback period of the installation of the PV modules is not economically feasible unless financial incentives from the government are given. The same occurs to the installation of a biomass boiler. Investment is economically feasible only in case of carbon trade, as the price of the biomass fuel in more expensive than the coal. The payback period for the implementation of all three measures (insulation, PV and biomass system) is calculated to be 8 years, taking into account that PV is supported by the FIT.

7.8 References

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Chapter 8 - Case Study Analysis: University of Nottingham Administration Building, Ningbo

8.1 Introduction

8.1.1 Case study location

The third case study building is an office building in Ningbo, Jiangsu province, near Shanghai. Its location is in a “Hot summer and cold winter” climate zone.

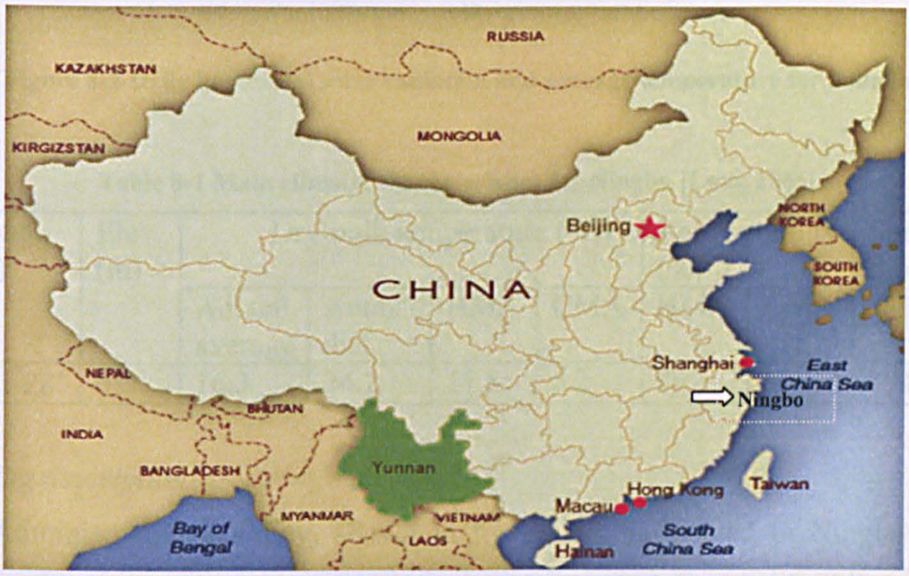

Figure 8-1 Ningbo location

This climate zone is characterised as mild and humid with distinct season divisions, abundant rainfalls and alteration of the winter and summer monsoons. The winter and summer season are about 4 months long, and spring and autumn are short. The average temperature for spring and autumn is 10-20°C, the summer average temperature is around 25°C, and the winter average temperature is less than 5°C. The hottest month is July (when temperatures can reach more than 35°C), and the coldest is January (when temperature can fall below 0°C) [Zhang, 1992]. This can be seen in figure 8-2. Table 8-1 represents the main climatic characteristics for Ningbo.

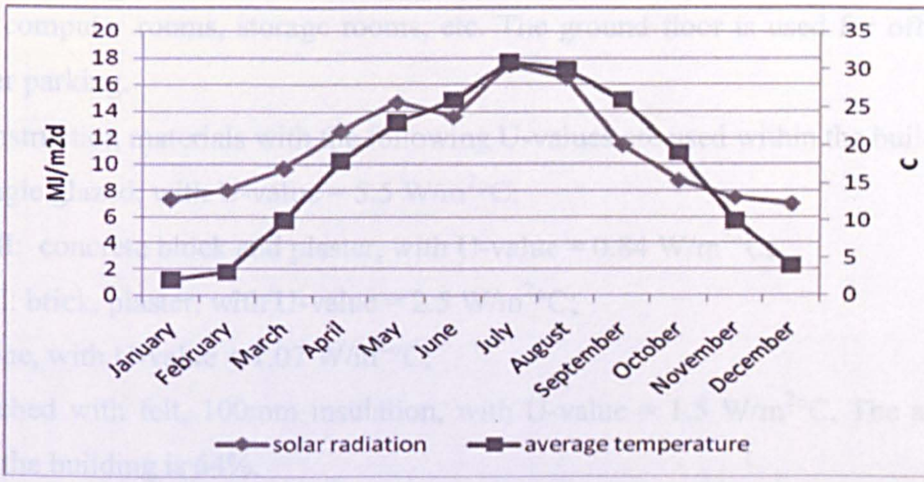

Figure 8-2 Daily horizontal solar radiation and average temperature for Ningbo

Table 8-1 Main climatic characteristics for Ningbo [Lam, 2005]

Lat. (N)	Long. (E)	Elev. (m)	Dry-bulb temperature (°C)				Rel. humidity (%)		Sunshine (hours)
			Annual average	Annual diff.	HMA	CMA	HMA	CMA	
29°55'	121°28'	6	16.3	24.2	17.8	5.2	89	60	1944

8.1.2 Building description

The Administration Building, shown in figure 8-3, is located in Ningbo City, Higher Education Park, 199 Taikang East Road. It is an administration building of the Chinese campus of the University of Nottingham.

Figure 8-3 Administrating Building, UNNC [UNNC, 2009]

The Administration Building is used as an office building for staff of the University. It is a four storey building with 274 rooms used as offices, meeting rooms, libraries, computer rooms, storage rooms, etc. The ground floor is used for offices as well as car parking.

Construction materials with the following U-values are used within the building:
Glass: single glazed, with U-value = 5.5 W/m^2°C;
Outer wall: concrete block and plaster, with U-value = 0.84 W/m^2°C;
Inner wall: brick, plaster, with U-value = 2.5 W/m^2°C;
Floor: stone, with U-value = 1.07 W/m^2°C;
Roof: pitched with felt, 100mm insulation, with U-value = 1.5 W/m^2°C. The average WWR of the building is 64%.

8.1.2.1 Occupancy

The number of employees is approximately 380 people. The building is also accessed by students visiting libraries and computer rooms. It is estimated that the occupancy of the rooms is 9 hours per day 25 days a month. The working hours for the library and computer rooms are 12 hours per day 30 days a month.

8.1.2.2 Current air source heat pump

The air source heat pump used in the building is a packaged rooftop unit LSBLG(R)R700-Z designed for outdoor installation. It is used for both heating and cooling purposes. Heating and cooling in the library, however, is not provided by the system, therefore free standing air conditioning units are used.

8.1.2.3 Hot water

There is no hot water used in the building which is a typical phenomenon for Chinese office buildings.

8.2 Scenario One: Real building operation

8.2.1 Temperature

The designated temperature variation from room to room depends upon the specific type of the room. Table 8-2 gives the temperatures for each space in every month of the year. The infiltration air rate in the rooms is assumed to be 0.6 m^3/s throughout the year.

Table 8-2 Internal and external temperatures

Space	Temperature(°C)												Lighting (lux)
	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	
Corridor	6	6	7	12	17	20	25	25	23	16	7	6	-
Office	16	16	18	19	24	27	29	29	27	21	19	16	300
Library	15	15	17	18	23	26	28	28	26	20	18	15	500
Computer room	15	15	17	18	23	26	28	28	26	20	18	15	200
Equipment room	12	12	14	15	20	22	24	24	22	19	14	12	50
Storage	12	12	14	15	20	22	24	24	22	19	14	12	50
Lounge	16	16	18	19	24	27	29	29	27	21	19	16	300
Meeting room	16	16	18	19	24	27	29	29	27	21	19	16	300
Unoccupied	12	12	14	15	20	22	25	24	23	19	14	12	-

8.2.2 Heat losses and heat gains

The main source of heat loss is through the windows. The main source of the heat gain is from equipment such as photocopiers, printers, and PCs. This has been found during the heat losses and heat gains calculations. In some cases, the occupancy of the room is the reason for high heat gains. In addition, in unoccupied rooms, the solar heat gain is the reason as there is no shading on the windows.

Figure 8-4 shows an example of the heating and cooling requirements for some of the rooms during the coldest month. Cooling is required in room 201, 202, 243, and 244 as these are computer rooms. Therefore even though the temperature outside is cold, the heat exhaust from the PC makes the heat gains much higher than the heat losses. Moreover, the students constantly occupy the computer room; therefore, the heat gain from the people is also high.

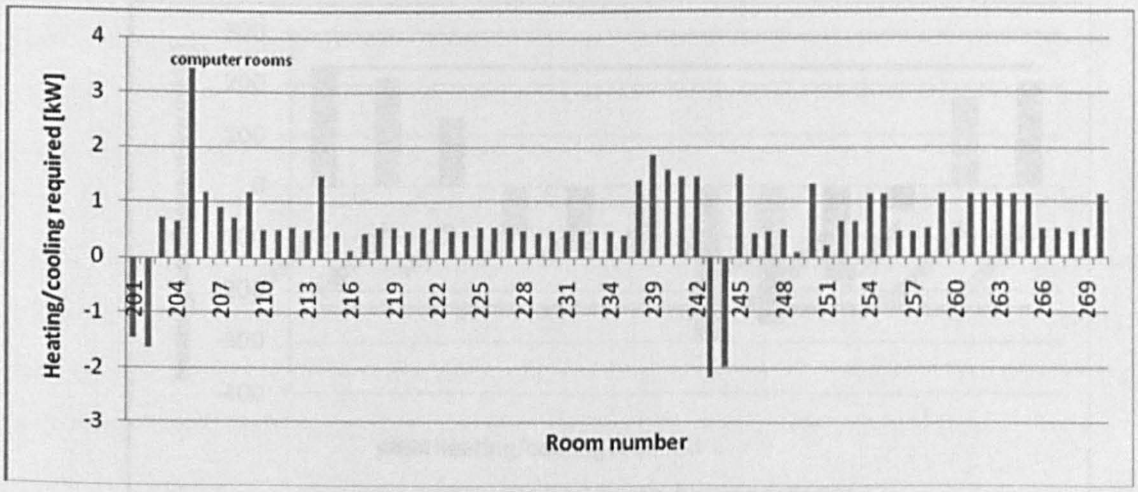

Figure 8-4 Heating/cooling requirements in January for Level 2

Figure 8-5 represents the heat gains and heat losses throughout one year for the whole building. It also shows whether heating or cooling is required during each particular month. As can be seen from the graph, heating is required from November to March. However, no artificial heating is used during March and November, as the internal temperatures are comfortable. Cooling is required from April to October. Again, artificial cooling is not needed in April and October, as the internal temperature is comfortable.

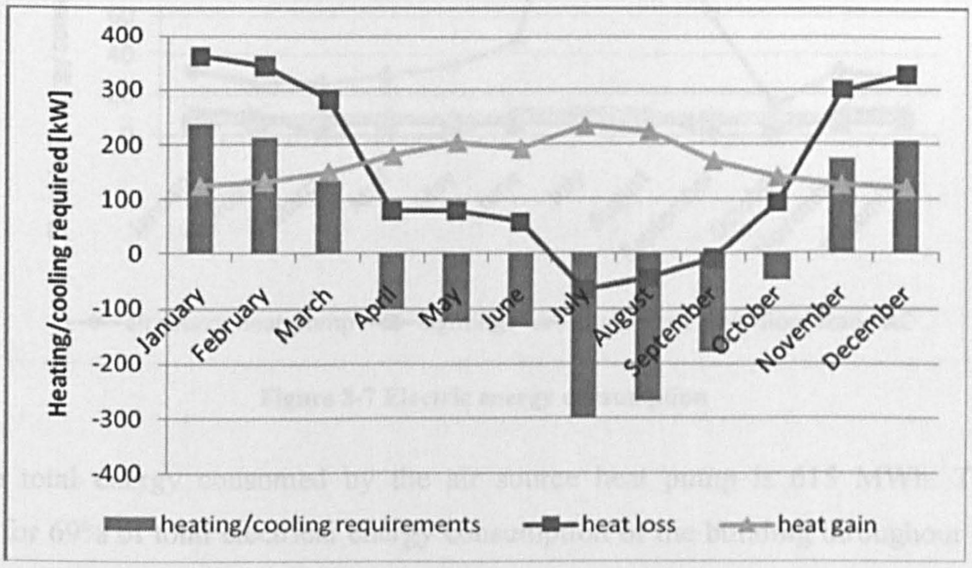

Figure 8-5 Yearly heating/cooling requirements

Figure 8-6 shows that the air source heat pump capacity to provide heating is not enough for January, and it is significantly under capacity to provide cooling in July and August. Free-standing air conditioning units are used in these months.

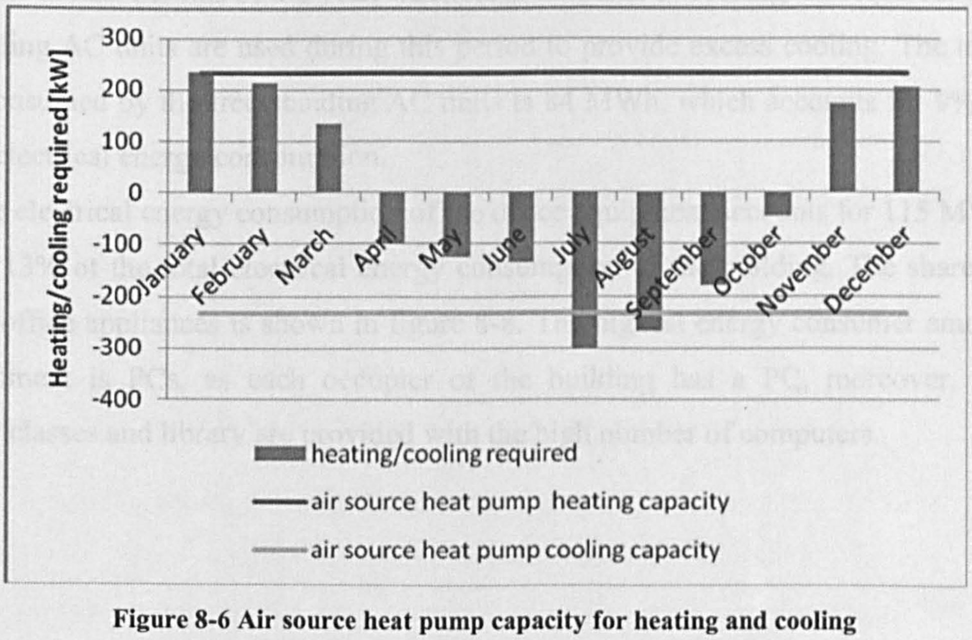

Figure 8-6 Air source heat pump capacity for heating and cooling

8.2.3 Electrical energy consumption

Figure 8-7 shows the electrical energy consumption of the air source heat pump, lighting, office equipment, and free-standing AC unit.

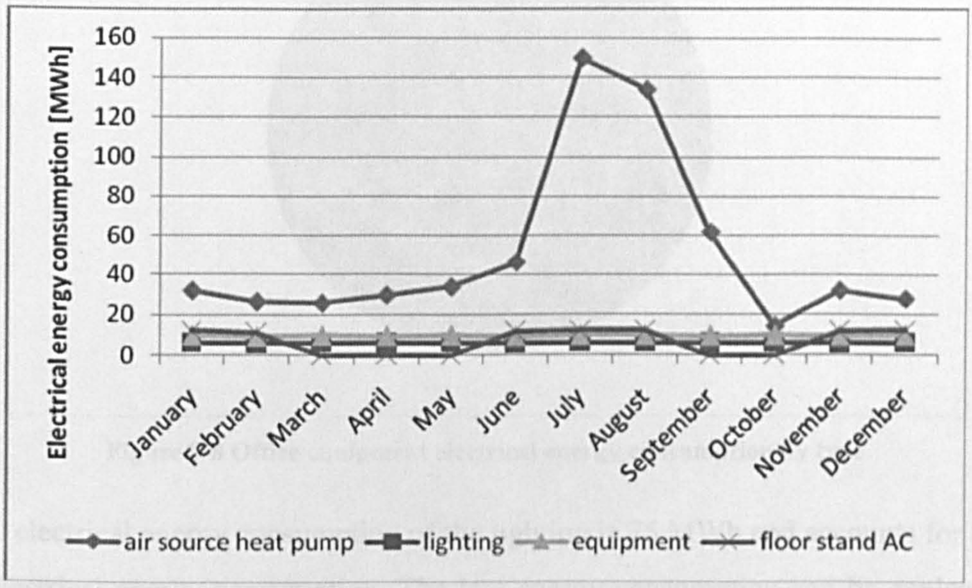

Figure 8-7 Electric energy consumption

The total energy consumed by the air source heat pump is 615 MWh. This accounts for 69% of total electrical energy consumption of the building throughout the year. The air source heat pump COP is 1.7 and it is by far the biggest energy consumer. The lowest level of energy consumed by the air source heat pump is in March and November, when due to the comfortable internal temperatures almost no heating or cooling is required. However, the energy consumption reaches its peak in July and in August, the hottest months of the year, when large amounts of cooling are required. The free-standing AC units are used during this period to provide excess cooling. The total energy consumed by the free-standing AC units is 84 MWh, which accounts for 9% of the total electrical energy consumption.

The electrical energy consumption of the office equipment accounts for 115 MWh, which is 13% of the total electrical energy consumption of the building. The share of different office appliances is shown in figure 8-8. The highest energy consumer among the equipment is PCs, as each occupier of the building has a PC, moreover, the computer classes and library are provided with the high number of computers.

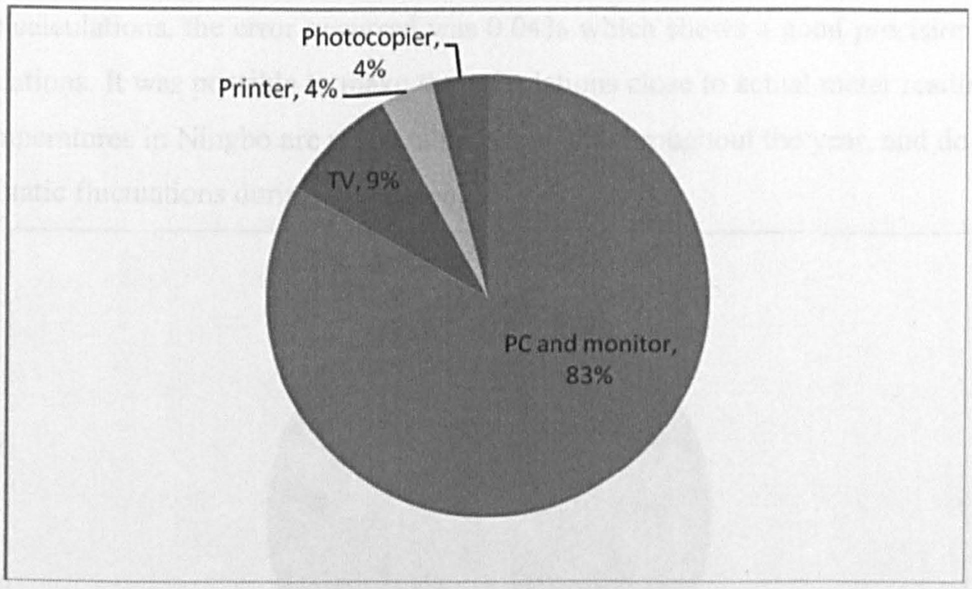

Figure 8-8 Office equipment electrical energy consumption by type

The electrical energy consumption of the lighting is 75 MWh and accounts for 8% of total electrical energy consumption. The low energy consumption can be explained by the fact that the lighting is not used constantly, but only when needed during the morning and evening hours, mostly in winter. Two types of lighting are used in the building: the offices are lighted by halogen tubes, and the corridors are lighted by the incandescent light bulbs. Their share in energy consumption is shown in figure 8-9.

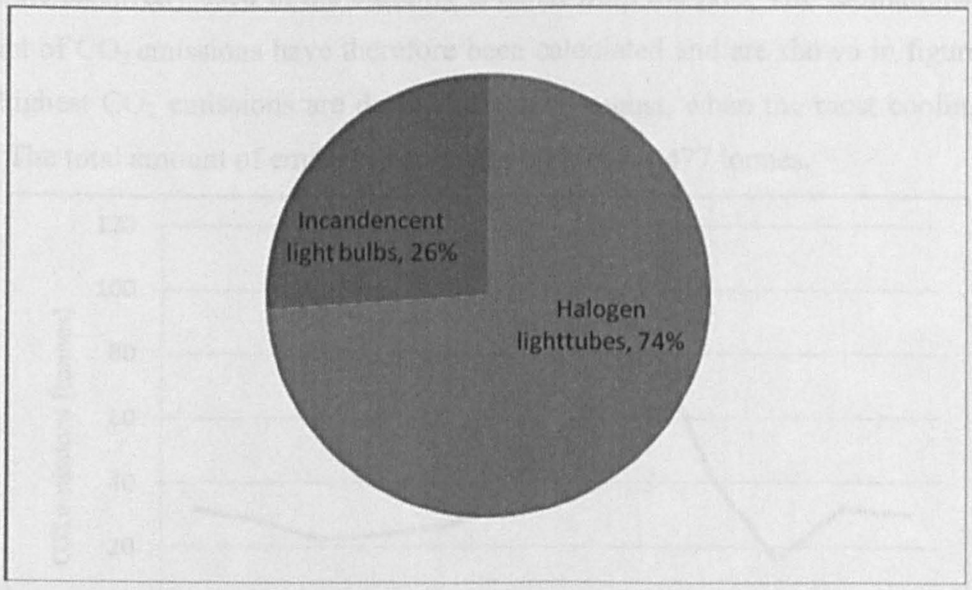

Figure 8-9 Lighting electrical energy consumption [kWh]

The following figure 8-10 shows total energy consumption of the building. The total electrical energy consumption of the building per year is 888 MWh. The total electrical energy consumption has been taken from the meter readings (887 MWh).

After the calculations, the error occurred was 0.04% which shows a good precision for the calculations. It was possible to make the calculations close to actual meter readings, as the temperatures in Ningbo are predictable and stable throughout the year, and do not have dramatic fluctuations during the season.

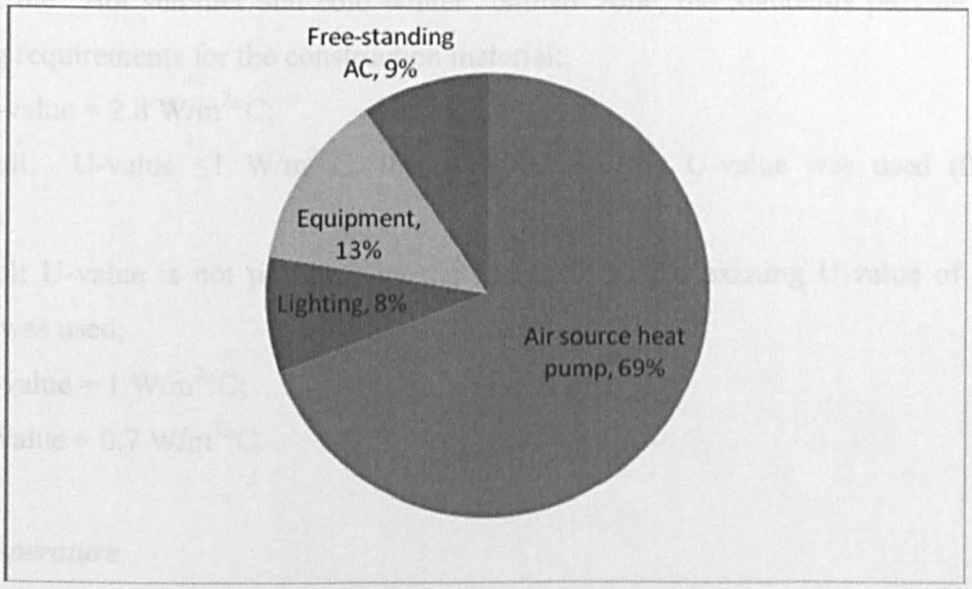

Figure 8-10 Total electric energy consumption [kWh]

8.2.4 CO_2 emissions

All the electricity used in the building is taken from the grid. The estimations for the amount of CO_2 emissions have therefore been calculated and are shown in figure 8-11. The highest CO_2 emissions are during July and August, when the most cooling is required. The total amount of emissions from the building is 477 tonnes.

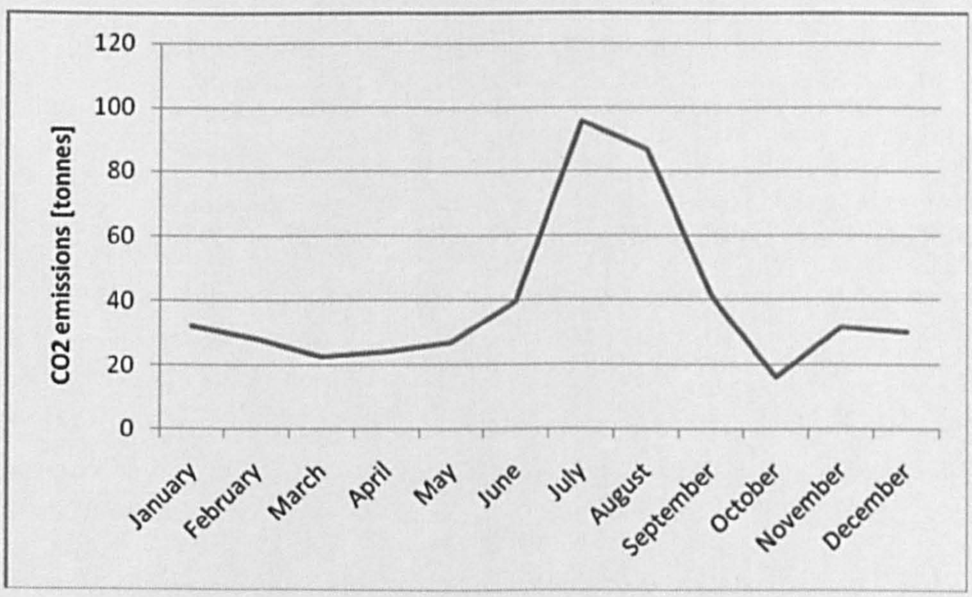

Figure 8-11 CO_2 emissions

8.3 Scenario Two: Building operation according to the requirements of the Standard

8.3.1 Construction materials

For the "Hot summer and cold winter" climate zone, the Standards provide the following requirements for the construction material:

Glass: U-value = 2.8 W/m^2°C;

Outer wall: U-value $\leq$1 W/m^2°C; therefore the existing U-value was used (0.84 W/m^2°C);

Inner wall: U-value is not provided by the Standard, so the existing U-value of 2.5 W/m^2°C was used;

Floor: U-value = 1 W/m^2°C;

Roof: U-value = 0.7 W/m^2°C.

8.3.2 Temperature

The temperatures were changed with the regards to the temperature limits given in the Standard; comfort temperatures were also taken into account, using the bioclimatic chart represented in figure 8-12. As can be seen from the chart, the comfort temperatures range is from 20 to 26°C. Therefore, the internal temperatures chosen were no colder than 20°C in the winter and no higher than 26°C in the summer.

The air rate suggested by the Standard is 0.2 m^3/s during the winter period (October – April) and 0.3 m^3/s during the summer period (May – September).

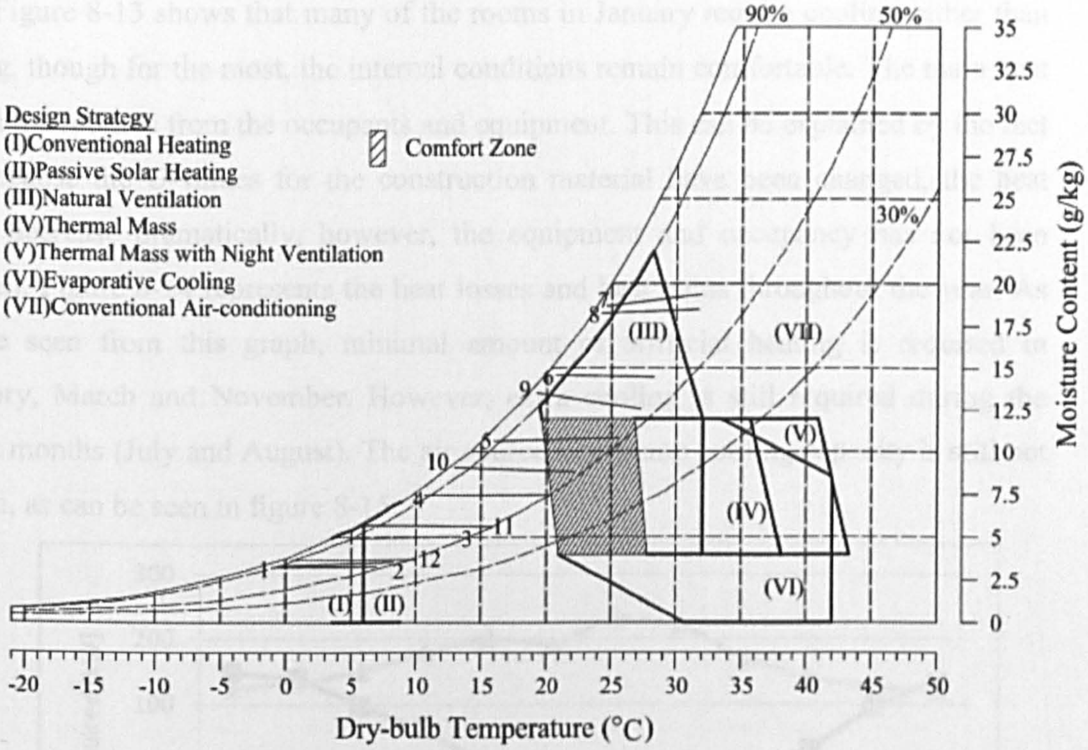

Figure 8-12 Bioclimatic chart for Ningbo [Lam, 2005]

8.3.3 Heat losses and heat gains

As the U-values of the construction materials have been changed, the level of heat losses has decreased. The decrease of the heat gains was not as dramatic due to the fact that only solar heat gain was decreased because of the improvement of the U-value of the glazing, but the heat gain from the equipment and people remained the same. The example of heat gains and heat losses is shown in figure 8-12, and can be compared with figure 8-13 to see that the heat gains have actually increased.

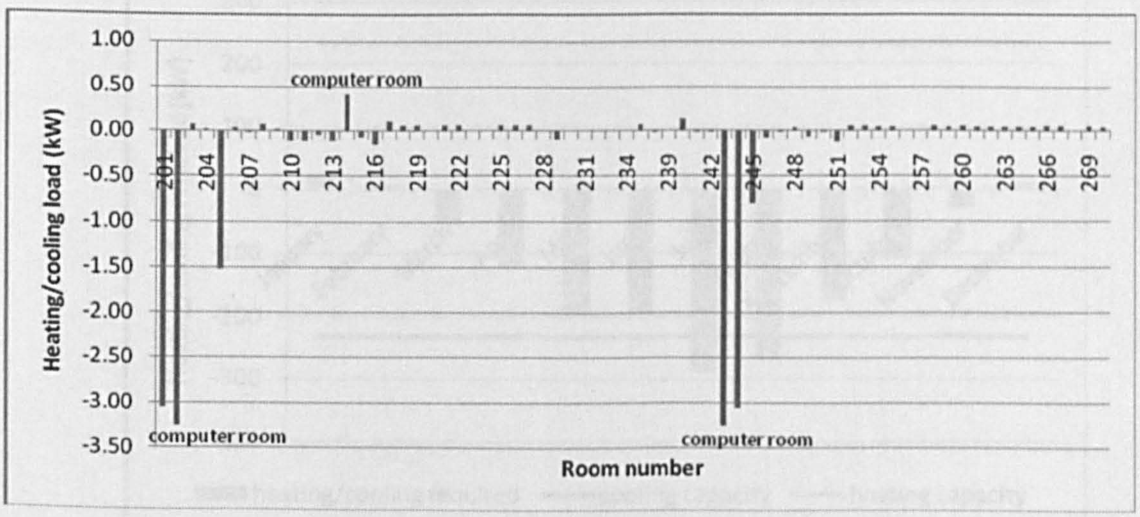

Figure 8-13 Heating/cooling requirements for Level 2 in January

Figure 8-13 shows that many of the rooms in January require cooling rather than heating, though for the most, the internal conditions remain comfortable. The main heat gain in the room is from the occupants and equipment. This can be explained by the fact that because the U-values for the construction material have been changed, the heat losses decrease dramatically, however, the equipment and occupancy has not been changed. Figure 8-14 represents the heat losses and heat gains throughout the year. As can be seen from this graph, minimal amount of artificial heating is required in February, March and November. However, extra cooling is still required during the hottest months (July and August). The air source heat pump cooling capacity is still not enough, as can be seen in figure 8-15.

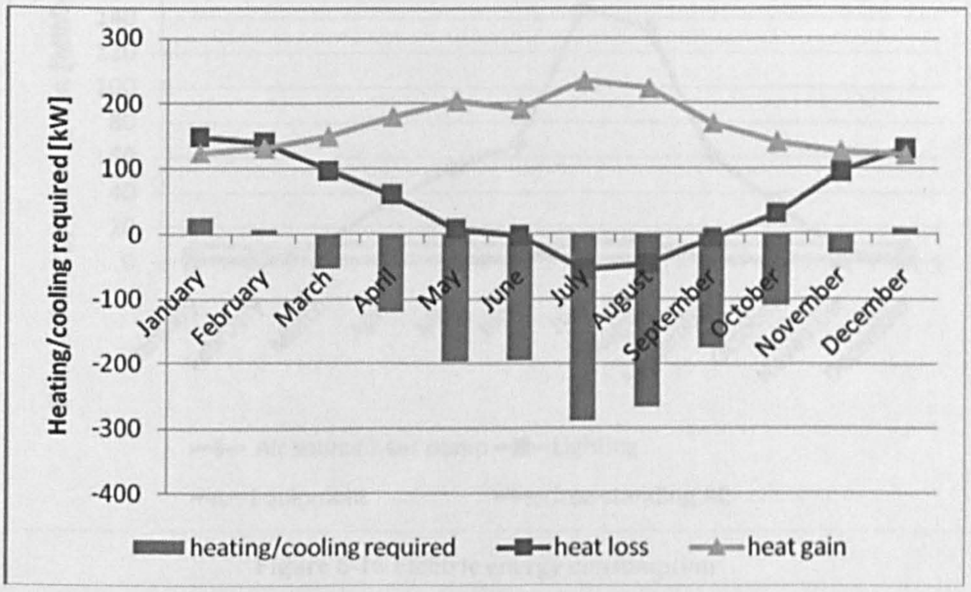

Figure 8-14 Monthly heating/cooling requirements and heat losses and gains

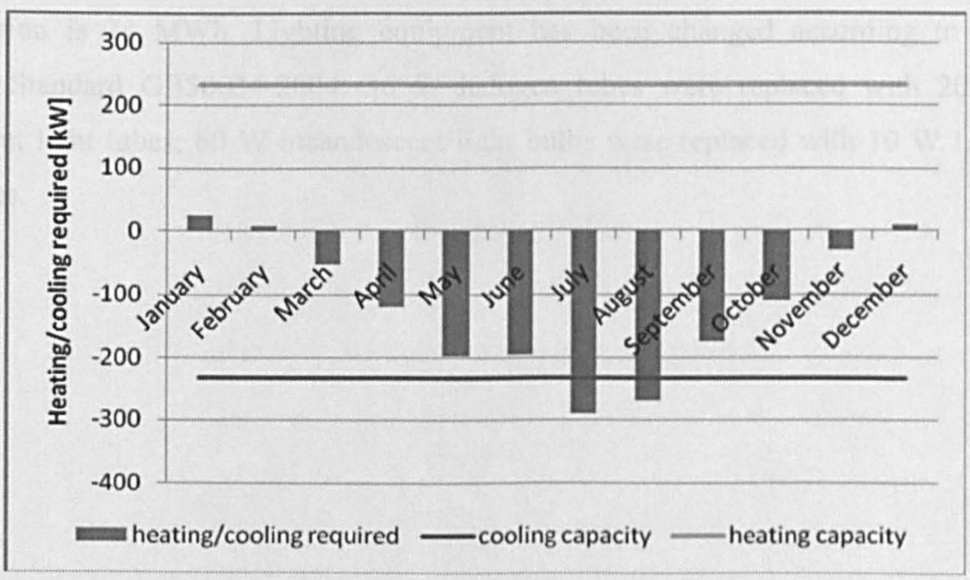

Figure 8-15 Air source heat pump capacity for heating and cooling

8.3.4 Electrical energy consumption

Figure 8-16 represents the overall picture of the electrical energy consumed by the air source heat pump, lighting and office equipment, and free-standing AC. The largest amount of energy is consumed by the air source heat pump and accounts for 550 MWh. The largest amount of cooling is needed in July and August, and it cannot be provided by the air source heat pump alone. Free-standing AC units are used to provide the amount of extra cooling needed. The Standard does not account for the use of free-standing AC units; however, they have been used for a fewer number of days. Free-standing AC unit energy consumption equals 24 MWh.

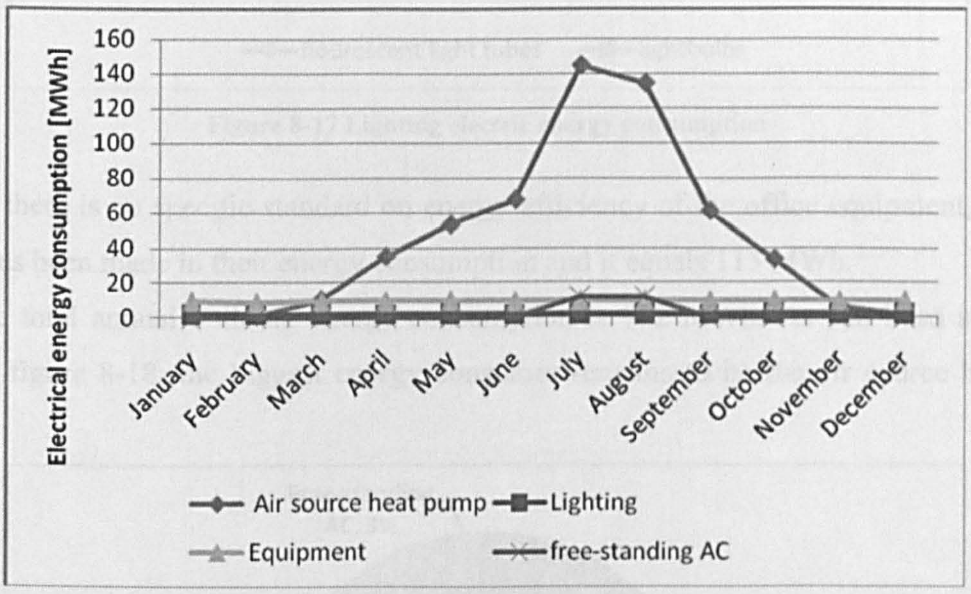

Figure 8-16 Electric energy consumption

Annual lighting energy consumption is shown on the figure 8-17. Lighting energy consumption is 24 MWh. Lighting equipment has been changed according to the Lighting Standard GB50034-2004: 36 W halogen tubes were replaced with 20 W fluorescent light tubes; 60 W incandescent light bulbs were replaced with 10 W LED light bulbs.

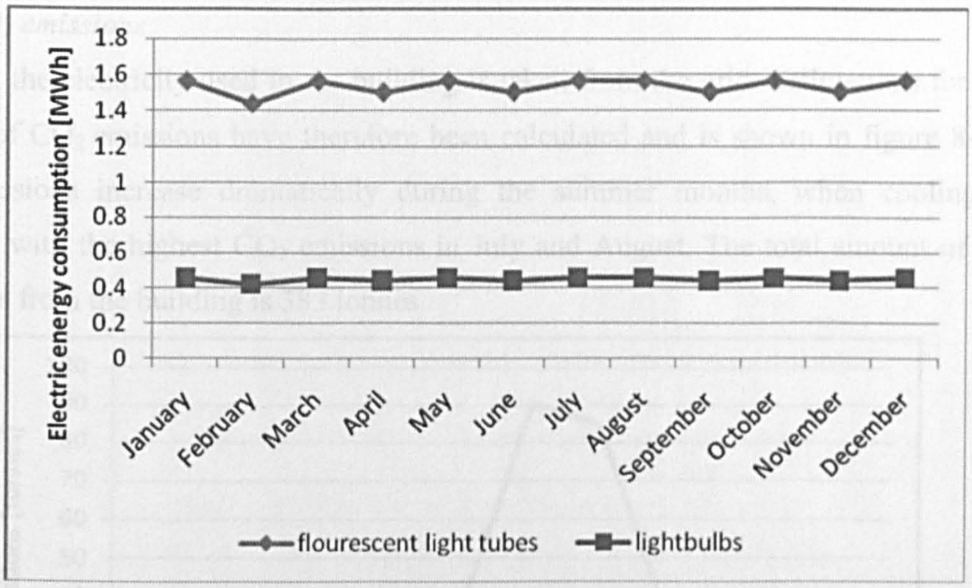

Figure 8-17 Lighting electric energy consumption

As there is no specific standard on energy efficiency of the office equipment, no change has been made in their energy consumption and it equals 115 MWh.

The total annual building energy consumption is 712 MWh. As can been seen from the figure 8-18, the biggest energy consumer remains to be the air source heat pump.

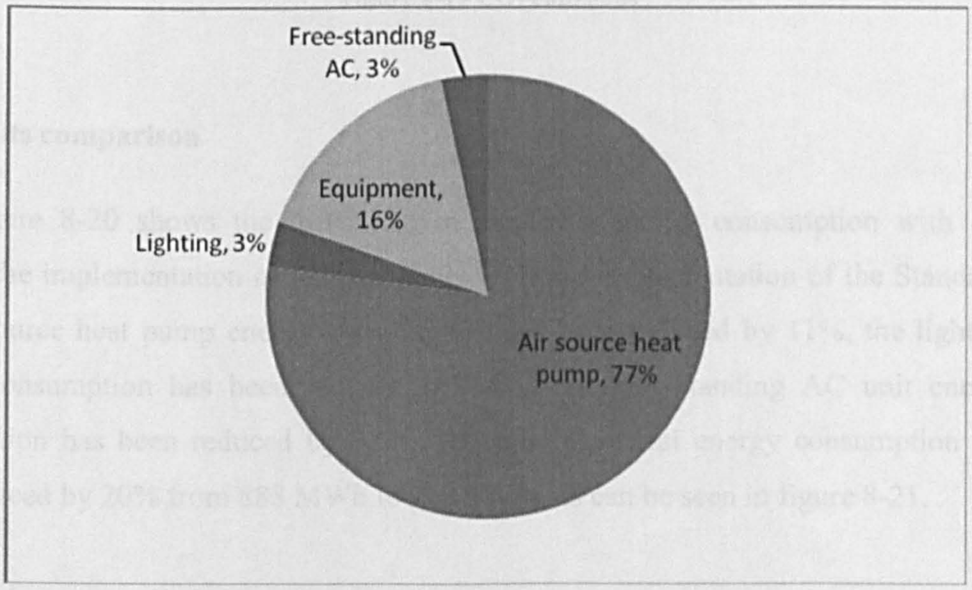

Figure 8-18 Total electric energy consumption

8.3.5 CO_2 emissions

All the electricity used in the building is taken from the grid. Estimations for the amount of CO_2 emissions have therefore been calculated and is shown in figure 8-19. The emissions increase dramatically during the summer months, when cooling is required, with the highest CO_2 emissions in July and August. The total amount of the emissions from the building is 383 tonnes.

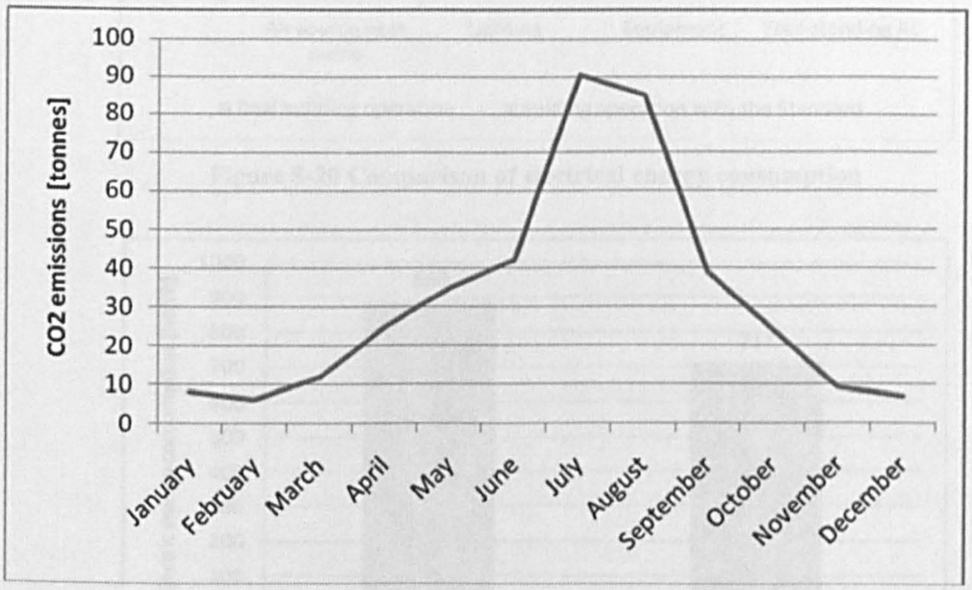

Figure 8-19 CO_2 emissions

8.4 Results comparison

Figure 8-20 shows the difference in electrical energy consumption with and without the implementation of the Standard. With the implementation of the Standard, the air source heat pump energy consumption has been reduced by 11%, the lighting energy consumption has been reduced by 68%, and free-standing AC unit energy consumption has been reduced by 71%. The total electrical energy consumption has been reduced by 20% from 888 MWh to 712 MWh, as can be seen in figure 8-21.

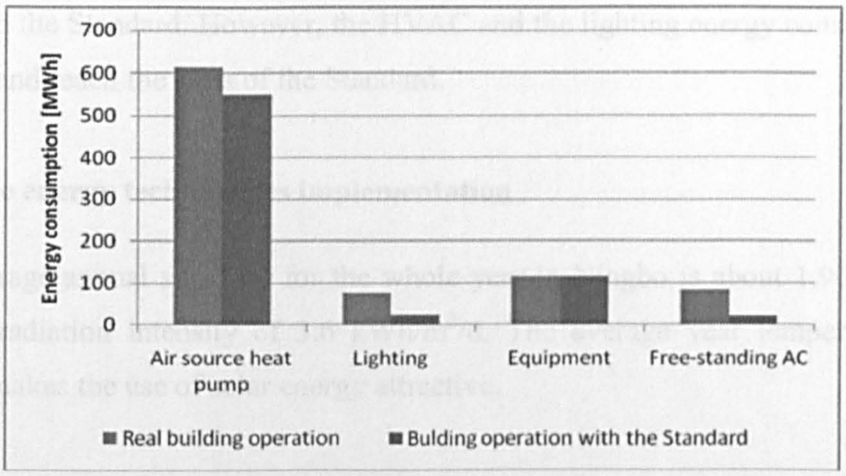

Figure 8-20 Comparison of electrical energy consumption

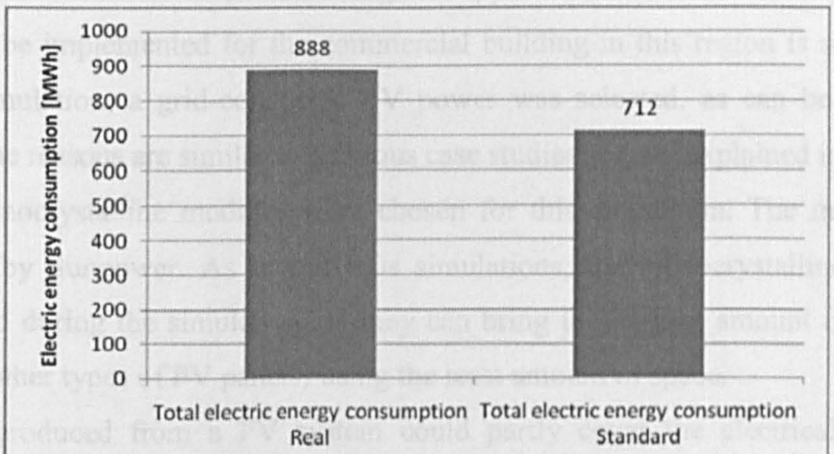

Figure 8-21 Total grid energy consumption comparison

The CO_2 emissions were also reduced by 20% from 477 tonnes to 383 tonnes, as figure 8-22 illustrates.

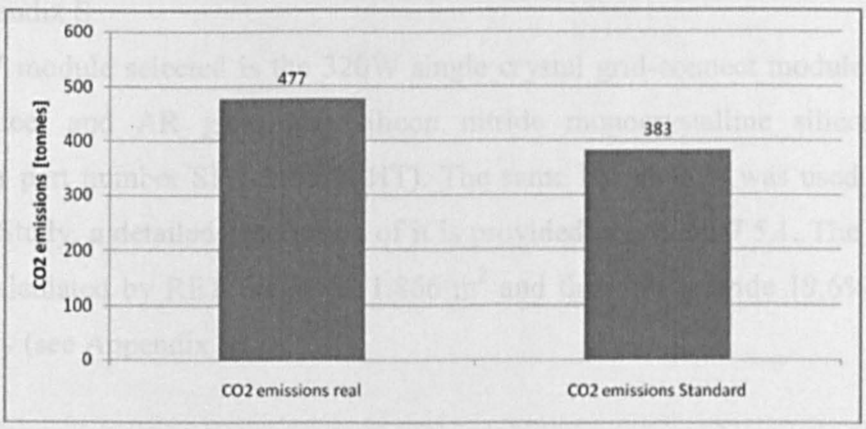

Figure 8-22 CO_2 emissions comparison

The results of this case study show that the aim of 50% reduction of the energy consumption of the building has not been achieved. This is mainly due to the fact the heat gains were not reduced, because the energy efficiency standards for equipment are not included in the Standard. However, the HVAC and the lighting energy consumption have reduced and reach the aims of the Standard.

8.5 Renewable energy technologies implementation

The average annual sunshine for the whole year in Ningbo is about 1,900 hours with a solar radiation intensity of 3.6 $kWh/m^2/d$. The average year temperature is 16.4°C. This makes the use of solar energy attractive.

8.5.1 PV system

During the simulation performance, it appeared that the best renewable technology to be implemented for the commercial building in this region is solar PV. During the simulation, a grid-connected PV power was selected, as can be seen in Appendix S; the reasons are similar to previous case studies and are explained in section 6.5.2. The monocrystalline modules were chosen for this simulation. The module is manufactured by Sunpower. As in previous simulations, the monocrystalline panels were suggested during the simulation, as they can bring the highest amount of power (compared to other types of PV panels) using the least amount of space.

Energy produced from a PV system could partly cover the electrical energy consumption of the building. The PV panels would be installed on the roof to avoid shading from nearby buildings. Panels would be put at an angle of 30°. The roof area available for the installation is 3,000 m^2. The details of the RETScreen simulations are given in Appendix S.

The PV module selected is the 320W single crystal grid-connect module with a white backsheet and AR glass and silicon nitride monocrystalline silicon cells (manufacturer part number SPR-315E-WHT). The same PV module was used for the second Case Study, a detailed description of it is provided in section 7.5.1. The area of PV system calculated by RET Screen is 1,866 m^2 and this will provide 19.6% of the electric energy (see Appendix S).

8.5.1.1 CO_2 emissions reduction after the installation of the PV module

The installation of the PV panels allows reducing electric energy consumption by 19.6%, as figure 8-23 shows. With the implementation of both the Standard and the PV modules, the energy consumption can be reduced by 46%. This means the reduction of the CO_2 emissions by 20%, as shown in figure 8-24 and Appendix S.

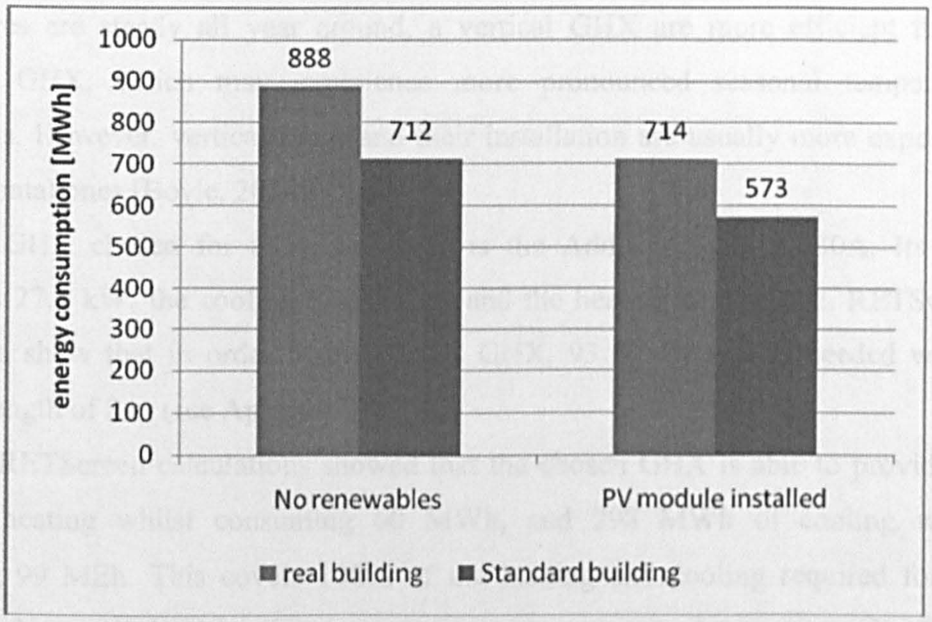

Figure 8-23 Real and Standard building grid energy consumption comparison with and without PV module installation

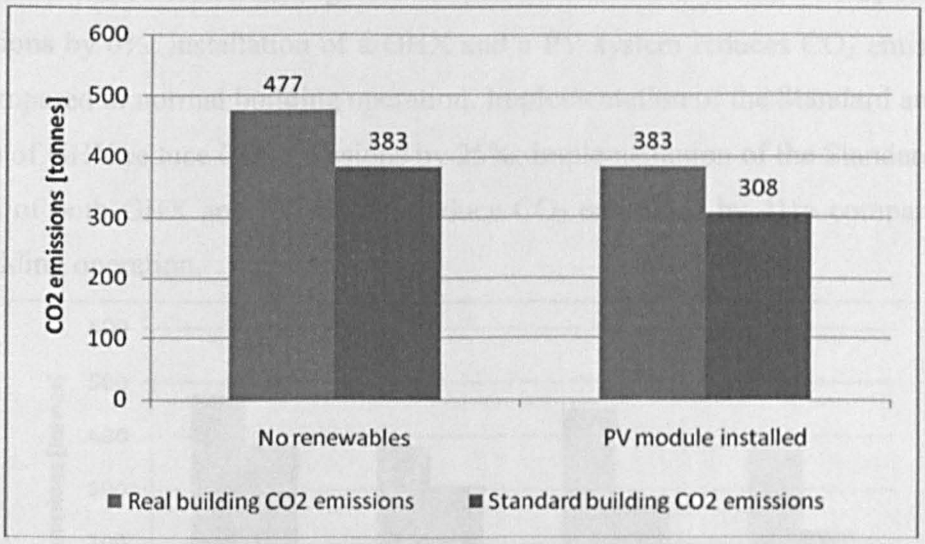

Figure 8-24 Real and Standard building CO_2 emissions comparison with and without PV module installation

8.5.2 Ground-source heat pump implementation

In order to reduce electrical energy consumption even more, a ground-source heat pump installation was simulated. As has been previously mentioned in section 8.2.3, the largest energy consumer in this case study is the air-source heat pump, which is in charge of heating and cooling.

A vertical ground-coupled heat pump (GHX) was chosen for this case study as the vertical GHX is better suited for larger buildings with limited land area. As the ground temperatures are steady all year around, a vertical GHX are more efficient than a horizontal GHX, which may experience more pronounced seasonal temperature fluctuations. However, vertical loops and their installation are usually more expensive than horizontal ones [Boyle, 2004].

The GHX chosen for this case study is the Addison VGY120-30A. Its heat capacity is 27.3 kW, the cooling COP is 3.9 and the heating COP is 3.2. RETScreen simulations show that in order to install this GHX, 93 m^2 of area is needed with a borehole length of 2 m (see Appendix T).

The RETScreen calculations showed that the chosen GHX is able to provide 78 MWh of heating whilst consuming 60 MWh, and 298 MWh of cooling whilst consuming 99 MEh. This covers 100% of the heating and cooling required for the building and no peak load heating or cooling system is required (see Appendix T). In terms of CO_2 emissions, the installation of the GHX allows 27 tonnes of emissions reductions, as it can be seen from Figure 8-25. The installation of the GHX only reduces CO_2 emissions by 6%; installation of a GHX and a PV system reduces CO_2 emissions by 21% compared to normal building operation. Implementation of the Standard and the installation of GHX reduce CO_2 emissions by 25%; implementation of the Standard and installation of both GHX and PV module reduce CO_2 emissions by 41% compared to normal building operation.

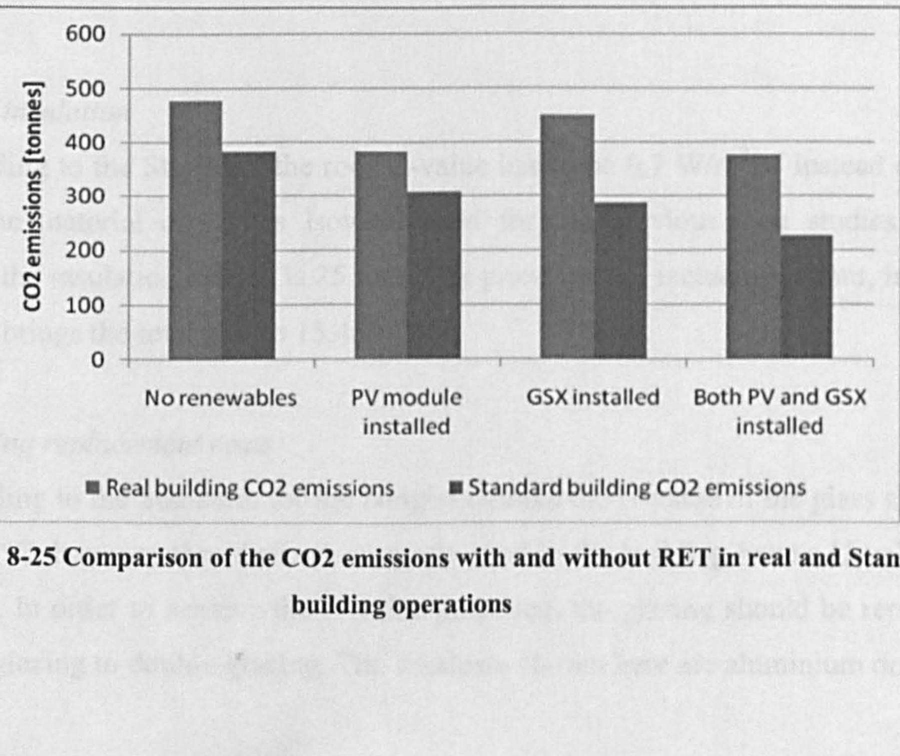

Figure 8-25 Comparison of the CO2 emissions with and without RET in real and Standard building operations

8.6 Payback period

8.6.1 Material payback period

8.6.1.1 Wall insulation

For this case study, only internal walls were insulated as the external walls U-value is similar to the requirements of the Standard. The U-value proposed by the Standard is 1 W/m^2°C, whereas the original U-value is 2.5 W/m^2°C. Equations 6-20 and 6-21 show that 14 mm thick insulation material is needed.

The material chosen for insulation is Kingspan Thermawall insulation, which is a high performance, rigid urethane insulation with thermal conductivity of 0.023 W/m K. It is a CFC/HCFC-free insulation material with zero ODP (more detailed information can be found at www.insulation.kingspan.com).

According to the Spon's Guide, the price of the insulation including labour is 14.65 GBP/m^2. The total area of the walls that needed to be insulated is 18,130 m^2, which brings the total cost of the wall insulation to 265,597.5 GBP.

8.6.1.2 Floor insulation

As the ground level floor U-value has to be improved from 1.07 W/m^2°C to 1 W/m^2°C, it was calculated that the insulation material of 2 mm thick is required. Celotex floor insulation board, which has been described above, has been chosen. The price is 8.68 GBP/ m^2 including labour, therefore the total price of the floor insulation is 19,756 GBP.

8.6.1.3 Roof insulation

According to the Standard, the roof U-value has to be 0.7 W/m^2°C instead of 1.5 W/m^2°C. The material chosen is Isowool used for the previous case studies. The thickness of the insulation needed is 25 mm. The price per m^2, including labour, is 5.47 GBP, which brings the total cost to 15,450 GBP.

8.6.1.3 Glazing replacement costs

According to the Standard, for the Ningbo climate the U-value of the glass should be 2.8 W/m^2°C, however the windows currently used in the building have a U-value of 5.5 W/m^2°C. In order to achieve the U-value proposed, the glazing should be replaced from single glazing to double-glazing. The windows chosen here are aluminium double-glazed windows in a wooden sub-frame. The price per m^2 is 410 GBP, including labour. The total price of the windows replacement would be 846,388 GBP.

8.6.1.4 Total payback period calculations for material and glazing

To calculate the payback period of the insulation material and glazing, Equation 1-17 was used. With an electricity price of 0.05 GBP/kWh, it has been calculated that with the implementation of the Standard, the expenses on the electrical energy consumption will reduce from 44,382 GBP/year to 35,615 GBP/year with the total savings of 8,767 GBP/year.

If the Standard is implemented, the total cost of the insulation material and glazing replacement is 1,144,190 GBP, with glazing being the most expensive part by far. Using the Equation 6-17, payback period has appeared to be more than 100 years, which is not economically feasible. Further simulation has been done to find out if it is possible to reduce the payback period if only glazing or insulation is changed. Results showed that the replacement of the windows not only reduces the payback period, but it also reduces the total electrical energy consumption. This can be explained by the fact that, though without walls, roof and floor insulation more heat is lost in winter, there is less cooling is needed in summer (BING, 2007), therefore more energy would be saved during summer months. The total electrical energy consumption with the replacement of the windows only is 682 MWh, which is 5% less than the electric energy consumption of the building in case walls, roof and floor are insulated as well, and 27% less than the actual electrical energy consumption of the building. If only the windows are replaced, an annual savings are 10,284 GBP with a payback period of 82 years. This is not economically feasible, as windows lifespan is limited.

Calculations also show that in case of the only improving insulation, the electrical energy consumption increases by 4% compared to the electrical energy consumption with the implementation of both insulation and glazing replacement. However, the total price spent on the insulation is just 297,803 GBP with an annual saving of 7,459 GBP, which brings the payback period to 39 years.

Though in the case of improving the building insulation without the glazing replacement the payback is the shortest, the electrical energy consumption reduction is not dramatic compared to the real electrical energy consumption. As has been mentioned previously, the investment should not be the key factor in decision making, as the most important reason influencing the decision is the reduction of the CO_2 emissions, which depends directly on the energy consumption of the building. Therefore, for this case study, the replacement of the windows seems the best option in terms of mitigating climate change.

8.6.2 Renewable energy technology payback period

8.6.2.1 PV module payback period

The Sunpower monocrystalline PV modules used in the previous case study were chosen for this case study building. The proposed PV system covers 1,866 m^2 providing 20% of the electrical energy required for the building functioning or 143 MWh annually.

Using Equation 6-22, the expected annual saving was calculated to be 6,637 GBP. This brings the total payback period to 99 years, which is obviously not feasible from the economic standpoint. If a FIT is used, then the annual saving increases up to 20,911 GBP with the total payback period decreasing to 31.5 years.

If both the glazing is replaced and the PV system is installed, the total investment required is 1,506,854 GBP. Annual savings will reach 17,421 GBP and the total payback period will be 86 years.

8.6.2.2 GHX payback period calculations

The chosen GHX system would provide 100% of heating and cooling requirements whilst reducing the amount of energy used. The current building operation heating and cooling system use 615 MWh annually. This costs 122,950 GBP per year. With the installation of the GHX the energy consumption for heating and cooling reduces to 159 MWh, which would cost 31,800 GBP. The installation of the vertical GHX costs 1,500 GBP per kW and the total price of installation would be 226,500 GBP. The price of the actual plant is 115,200 GBP [Langdon, 2009]. This brings the total price of the GHX to 341,700 GBP. With a total fuel saving of 91,150 GBP per year, it is possible to calculate the simple payback period using equation 6-18, which turns out to be a period of 3 years. The discounted rate for the GHX in China is not known; therefore, it is impossible to calculate the discounted rate payback period. Assuming from the simple payback period that the discounted payback period is less than 20 years, it would be economically feasible to install GHX. The installation of GHX system and insulation total payback period is calculated to be 6.5 years.

8.7 Summary

The analysis of the case study building has shown that the target set out in the Standard would not be reached, even with the implementation of the Standard and the renewable energy technologies although reduction came close. This is mainly due to the problem of extensive heat gains that are exhausted by the equipment, therefore highlighting the fact that equipment efficiency should be incorporated in the Standard.

With the implementation of the Standard, the energy consumption was reduced by 20%. With the implementation of the PV modules, but without the implementation of the Standard the energy consumption was also reduced by 20%. With the implementation of both the Standard and the PV modules, a reduction of 46% of electrical energy consumption has been achieved.

Payback period calculations have shown that there is no need for insulation implementation and only glazing should be replaced. Even though the payback period is too long, the future environmental benefits have to be taken into account.

As for the installation of the PV system, it is necessary for the government to provide financial incentives to make it economically feasible.

According to calculations performance here, the installation of would GHW prove economically feasible and can dramatically reduce the fuel costs and CO_2 emissions.

The installation of both PV and GHX and insulation material payback period is 10 years, if a FIT were introduced for solar PV.

8.8 References

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Chapter 9 - Case Study Analysis: Office Building, Heihe

9.1 Introduction

9.1.1 Case study location

Case Study Four is an office building in Heihe. Heihe is situated in the Heilongjiang province in the North of China. According to the climatic zone division, the province belongs to the "Severe cold climatic zone".

Figure 9-1 Heihe location

Heihe's a climate can be described as continental monsoon climate with long cold winters, and short, but warm summers. The annual average temperature in -1.3°C with January as the coldest month when the temperatures fall below -28°C and July as the hottest month when temperatures can reach up to 28°C. The average monthly solar radiation and temperature for this location in represented in figure 9-2. The table 9-1 represents the main climatic characteristics for Heihe.

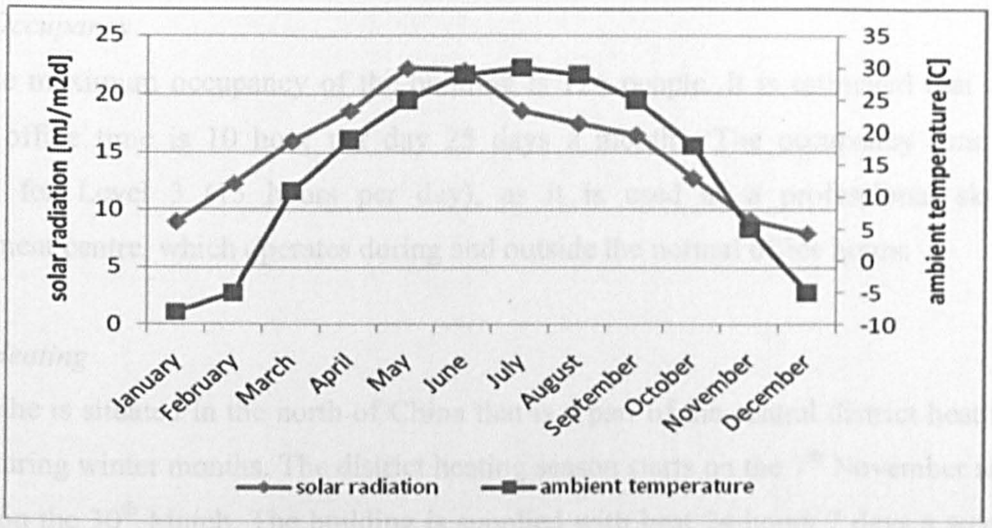

Figure 9-2 Horizontal solar radiation and average temperature for Heihe

Table 9-1 Main climatic characteristics for Heihe [Lam, 2005]

Lat. (N)	Long. (E)	Elev. (m)	Dry-bulb temperature (°C)				Rel. humidity (%)		Sunshine (hours)
			Annual average	Annual diff.	HMA	CMA	HMA	CMA	
50°16’	127°28’	171.1	-1.3	42.2	22.8	-19.4	77	74	2641

9.1.2 Building description

The office building is situated in Heihe at 48 Wangsu Street, near the city centre. It was built in 1950 and was refurbished in the 1990s.

It is a five storey building that consists of offices for different companies. The total floor area is 1,826.5 m^2. There are four levels above ground and one level below the ground. All of levels are used as office space; the underground floor is also used as storage.

9.1.2.1 Construction materials

Construction materials with the following U-values are used in this building:

Glass: double glazed; with U-value =3.26 W/m^2°C;

Outer wall: concrete block; with U-value = 1.28 W/m^2°C;

Inner wall: brick, plaster: with U-value = 2 W/m^2°C;

Floor: concrete covered with linoleum; with U-value = 1.28 W/m^2°C;

Roof: pitched; with U-value = 0.77 W/m^2°C. The average WWR of the building is 47%.

9.1.2.2 Occupancy

The maximum occupancy of the building is 126 people. It is estimated that the average office time is 10 hour per day 25 days a months. The occupancy time is different for Level 3 (13 hours per day), as it is used as a professional skills development centre, which operates during and outside the normal office hours.

9.1.2.3 Heating

Heihe is situated in the north of China that is a part of the central district heating system during winter months. The district heating season starts on the 7th November and finishes on the 30th March. The building is supplied with heat 24 hours 7 days a week. The occupants cannot regulate the temperature, as no thermostats are installed. Currently, the heating system efficiency is 65% (this is the average value for Chinese district heating systems and has been provided by the building estate manager).

9.1.2.4 Cooling

There is no cooling system required in the building as the external temperatures do not rise very high. However, individual AC units are available in all the office rooms when the temperature is too hot or too cold.

9.1.2.5 Hot water

There is no hot water in the building.

9.2 Scenario One: real building operation

The total energy consumption meter readings have been provided by the owner of the building. Calculations had to be done in order to see the separate energy consumption for cooling, lighting, and equipment

9.2.1 Temperature

As the majority of the rooms in the building are used for the same purpose (offices), the temperature variations are very low. Table 9-2 provides information about room temperatures throughout the year. The air infiltration rate is 0.3 m^3/s throughout the year.

Table 9-2 Internal temperatures and lighting level

Space	Temperature(°C)												Lightng (lux)
	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	
Corridor	17	18	18	18	19	20	22	23	21	19	18	17	-
Office	25	25	25	21	23	27	28	26	25	20	24	25	300
Computer room	25	25	25	21	23	27	28	26	25	20	24	25	300
Storage	20	20	20	18	20	22	23	23	21	19	20	20	50

9.2.2 Heat losses and heat gains

The main source of heat loss in the building is windows that remain open sometimes even during winter months, as it gets too hot in the room because the internal temperature cannot be regulated. The biggest heat gains are from office equipment, as the majority of the offices are provided with PCs, printers and photocopiers. As an example of the calculated results, figure 9-3 shows the heating and cooling requirements for Level 3 during January. Room 307 requires cooling during the coldest months of the year. This can be explained by the high internal temperatures and the exhausts from the PCs, as this room is the computer room.

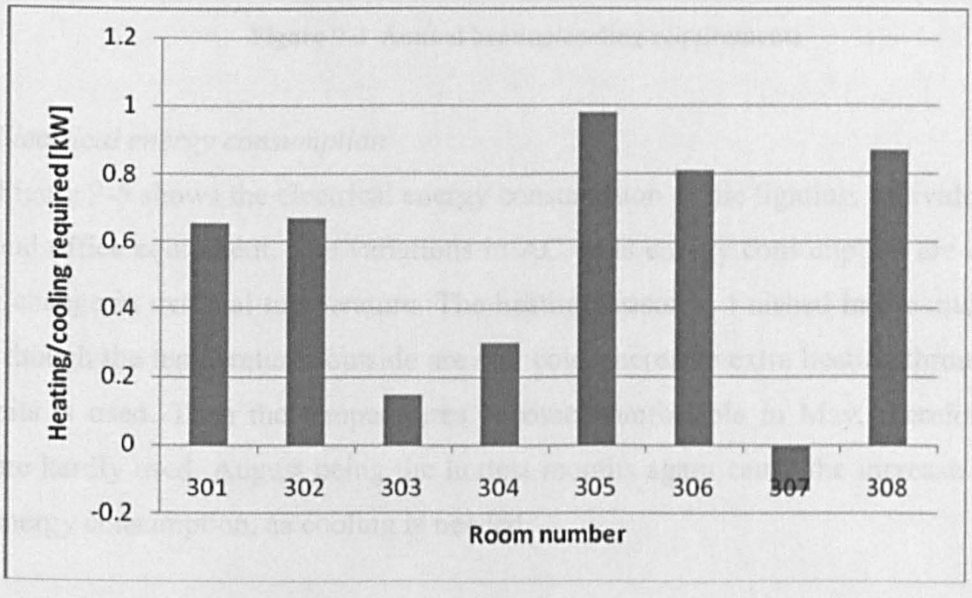

Figure 9-3 Heating and cooling requirements on the Level 3 in January

Figure 9-4 represents the heat gains and heat losses throughout the year for the whole building. The graph shows whether heating or cooling is required for each particular month. As can be seen, heating is required from October to May. District heating is provided from November to March. As the temperatures can still remain cold in April and May, individual AC units are sometimes used to warm the office. Cooling is required from June to September and is provided by individual AC units. The AC units used in the building are free-standing AC units with average power consumption of 8.14 kW. The cooling load has been calculated using equation 6-12, therefore the cooling requirement was known for summer months. Knowing the cooling load and the amount of hours individual AC units are used per month, it was possible to calculate their overall energy consumption.

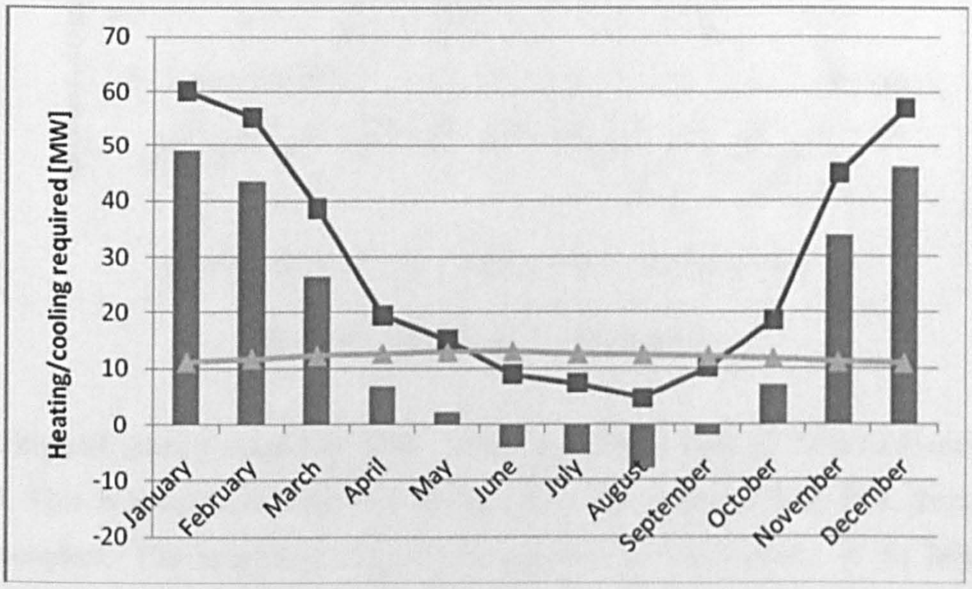

Figure 9-4 Annual heating/cooling requirements

9.2.3 Electrical energy consumption

Figure 9-5 shows the electrical energy consumption of the lighting, individual AC units and office equipment. The variations in AC units energy consumption are caused by the change in external temperature. The heating season is finished in the middle of April, though the temperatures outside are still cold, therefore extra heating through the AC units is used. Then the temperatures become comfortable in May, therefore AC units are hardly used. August being the hottest months again cause the increase in AC units energy consumption, as cooling is needed.

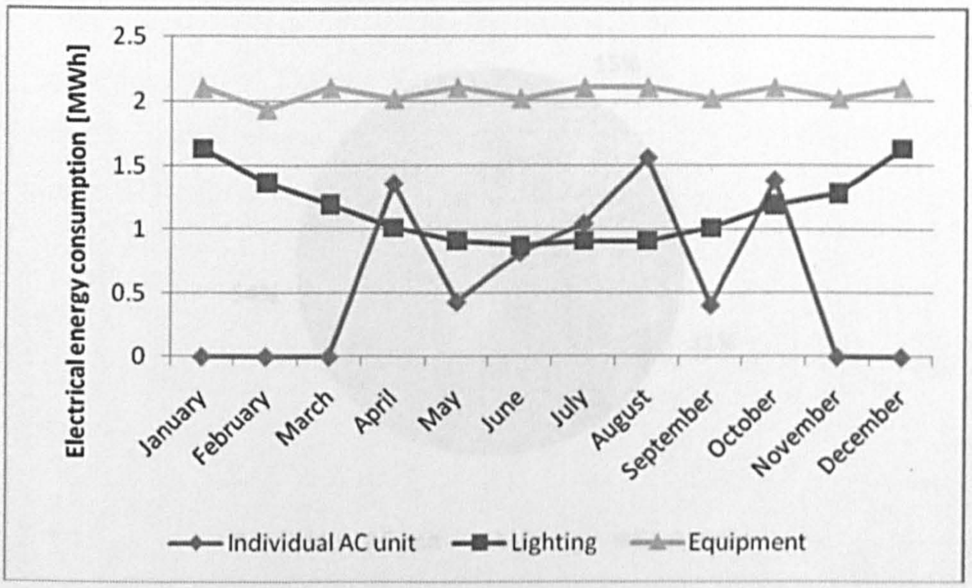

Figure 9-5 Electric energy consumption

The biggest energy consumer is the office equipment with 25 MWh of energy consumed. This is because the majority of the offices are provided with PCs, printers and photocopiers. The electrical energy consumption of the lighting is 14 MWh. Halogen tubes provide lighting in the offices; incandescent light bulbs light the corridors. Individual AC units consume 7 MWh of electrical energy. They are not used from November to March, as heating is provided by the central district heating system, and natural cooling is used when the internal temperatures are too high.

Figure 9-6 shows the electrical energy consumption by sector. The total electrical energy consumed in the building throughout the year is 45.7 MWh. The results of the calculations were compared to actual meter reading and it was found that the error was 2% which shows a good level of accuracy for the calculations.

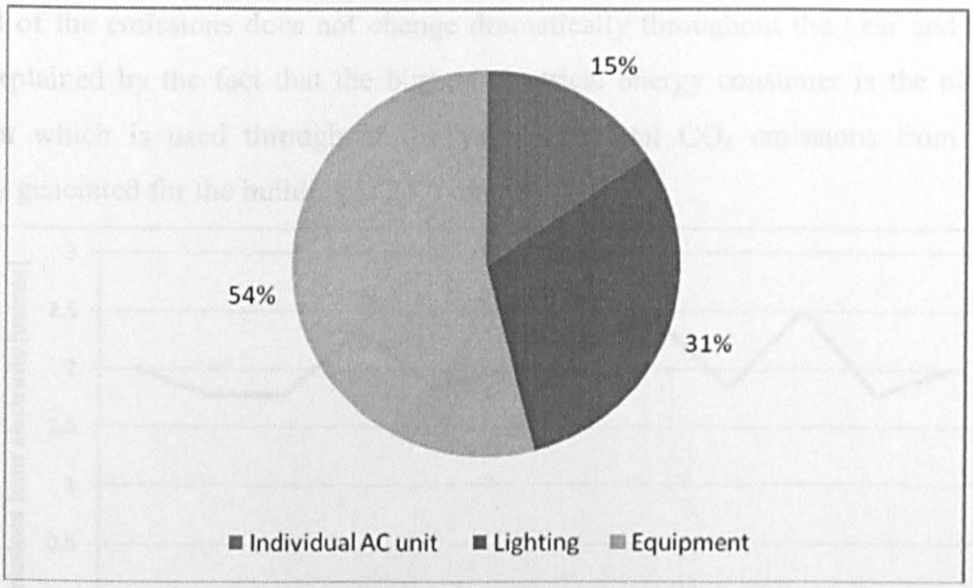

Figure 9-6 Shares in the electric energy consumption

9.2.4 Coal consumption

As has been mentioned before, heating during winter months is provided by the central district heating which is supplied by the local coal-fired power station. Figure 9-7 represents the coal energy consumption annually for heating. It has been calculated using the heating requirements of the building. The amount of energy consumed for the heating is 145 MWh.

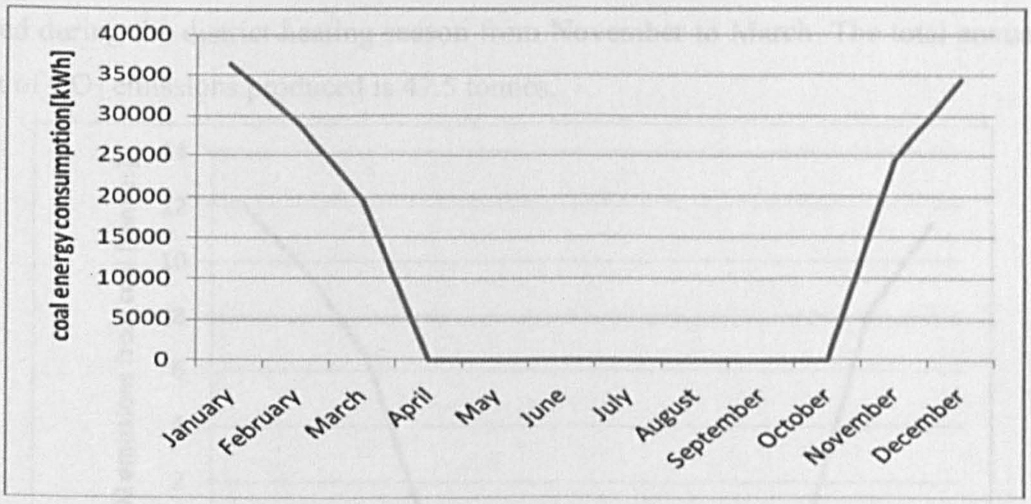

Figure 9-7 Coal energy consumption

9.2.5 CO2 emissions

9.2.5.1 CO_2 emissions from electricity

All the electricity used in the building is from the main electricity grid. Figure 9-8 represents the amount of CO_2 emissions from the electricity produced in the building.

The level of the emissions does not change dramatically throughout the year and this can be explained by the fact that the biggest electrical energy consumer is the office equipment which is used throughout the year. The total CO_2 emissions from the electricity generated for the building is 24.6 tonnes.

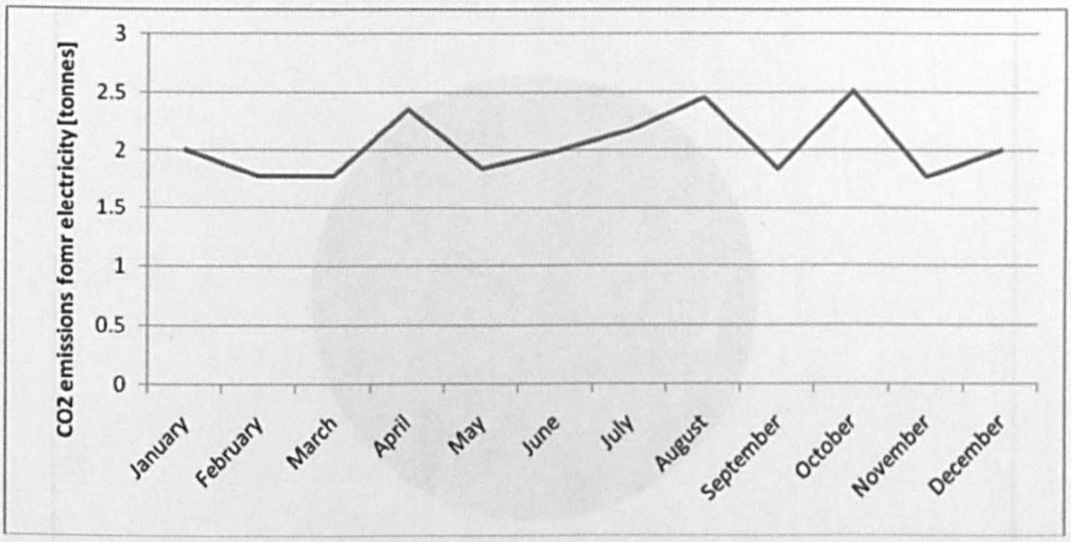

Figure 9-8 CO_2 emissions from the electricity

9.2.5.2 Emissions from coal

As mentioned earlier, heating is provided by coal. Figure 9-9 shows the emissions produced by the coal used for heating purposes. The CO_2 emissions for heating are produced during the district heating season from November to March. The total annual amount of CO_2 emissions produced is 47.5 tonnes.

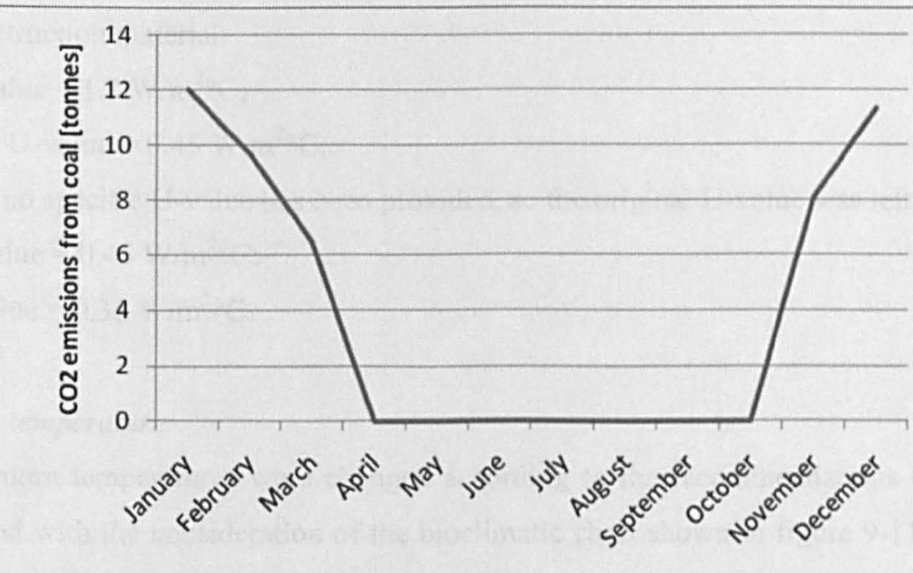

Figure 9-9 CO_2 emissions from coal

9.2.5.3 Total CO_2 emissions

There are two sources of CO_2 emissions in this building: electricity usage from equipment and heating. As can be seen in figure 9-10, coal is the biggest emitter. The total level of CO_2 emissions per year is 72 tonnes.

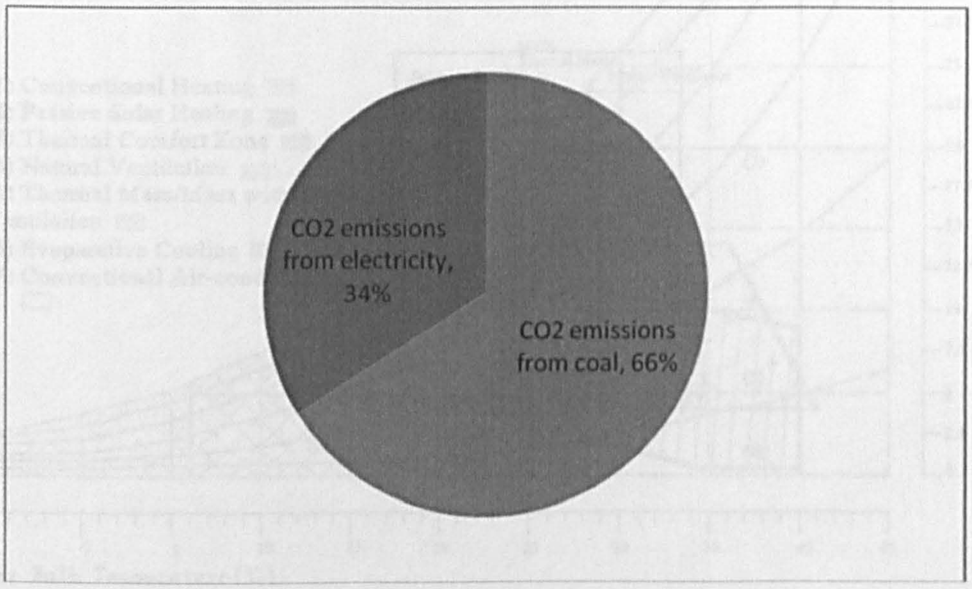

Figure 9-10 Total CO_2 emissions

9.3 Scenario Two: building operation according to the requirements of the Standard

9.3.1 Construction material

For the "Severe cold climatic zone", the Standard suggests the following U-values for the construction material:

Glass: U-value = 1.7 W/m^2°C;

Outer wall: U-value = 0.45 W/m^2°C;

Inner wall: no specific U-value has been provided, so the original U-value was left;

Floor: U-value = 0.45 W/m^2°C;

Roof: U-value = 0.35 W/m^2°C.

9.3.2 Room temperature

The room temperatures were changed according to the recommendations of the Standard and with the consideration of the bioclimatic chart shown in figure 9-11. The chart shows that the comfortable temperatures for Heihe are from 21°C to 25°C. However, the Standard states that the internal temperatures in winter cannot be higher than 20 °C; therefore the internal temperature of 20°C was used for the calculations.

The air infiltration rate suggested by the Standard is 0.2 m^3/s in the winter and 0.15 m^3/s in the summer (from May to September).

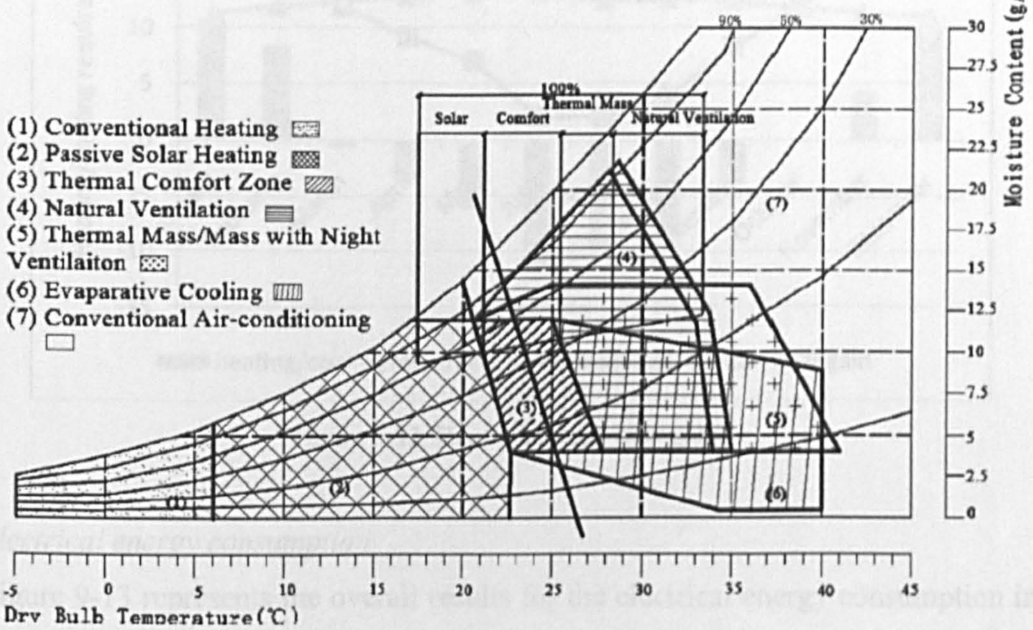

Figure 9-11 Bioclimatic chart for Heihe

9.3.3 Heat losses and heat gains

As the U-values have been changed according to the Standard, the heat losses were reduced. However, there was no change made in the heat gains that caused overheating of the office spaces. Therefore, more cooling is required with the implementation of the new U-values. To avoid the increase in heat gains the amount of equipment could be reduced or solar shading could be installed. Figure 9-12 shows the heat losses and heat gains and the requirements for cooling and heating, according to the requirements of the Standard. The figure shows that the heating is now needed from November to February. Moreover, the heat losses have been reduced, therefore less heating is needed. The amount of cooling required has increased, as it was mentioned before.

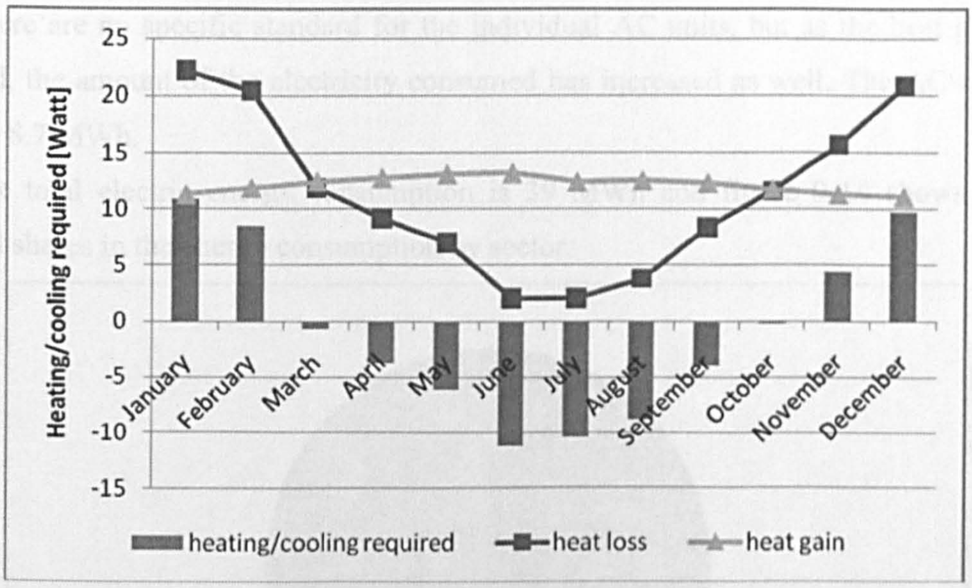

Figure 9-12 Heat losses and heat gains

9.3.4 Electrical energy consumption

Figure 9-13 represents the overall results for the electrical energy consumption in the building. The office equipment would remain the largest energy consumer. This can be explained by the fact that, as previously mentioned in earlier case studies, no changes have been made it its energy consumption as the Standard does not provide any specific energy saving measures for office equipment.

The lighting energy consumption is 5.5 MWh. The 60 W halogen tubes have been changed to 32W tubes, and the 36 W incandescent light bulbs have been changed to 10W ones which allows a significant reduction in energy consumed.

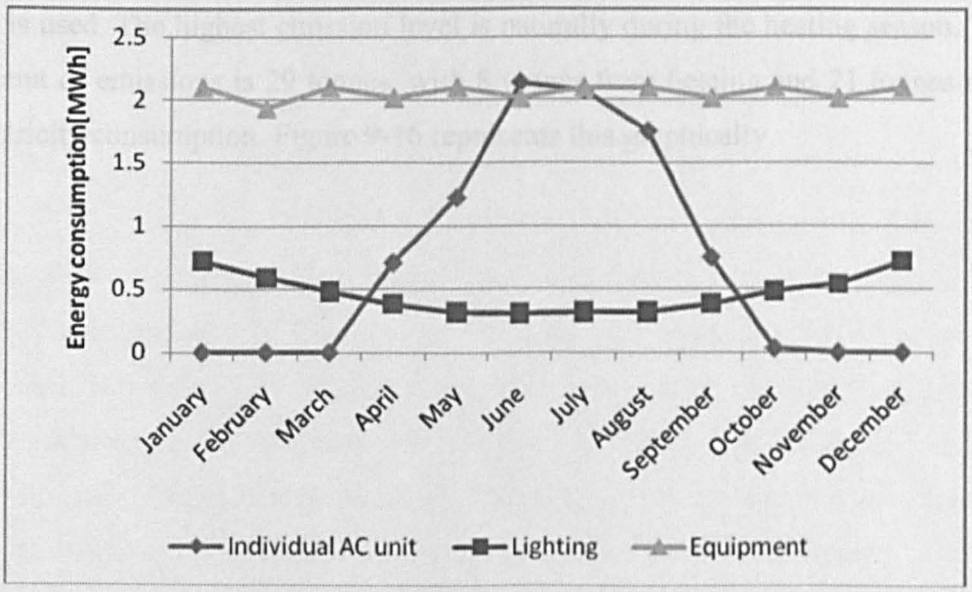

Figure 9-13 Electric energy consumption

There are no specific standard for the individual AC units, but as the heat gains increased, the amount of the electricity consumed has increased as well. The AC units consume 8.7 MWh.

The total electric energy consumption is 39 MWh and figure 9-14 shows the predicted shares in the energy consumption by sector.

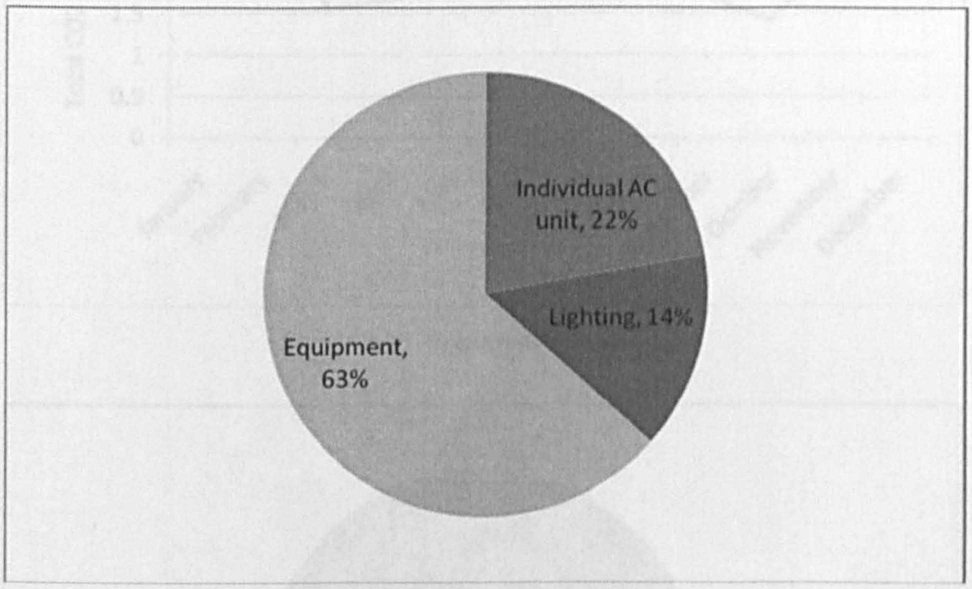

Figure 9-14 Total electric energy consumption

9.3.5 CO_2 emissions

With the reduction of the electrical energy consumption and a decrease in the amount of the heating required, the CO_2 emissions have reduced as well. Figure 9-15 represents the predicted cumulative monthly CO_2 emissions from the building if the Standard is used. The highest emission level is naturally during the heating season. The total amount of emissions is 29 tonnes, with 8 tonnes from heating and 21 tonnes now from electricity consumption. Figure 9-16 represents this graphically.

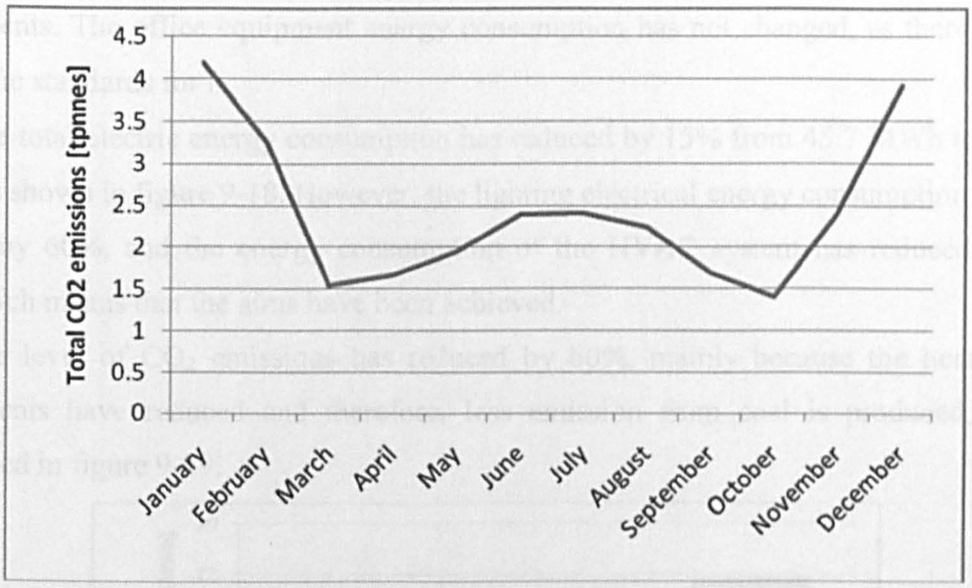

Figure 9-15 Monthly CO_2 emissions

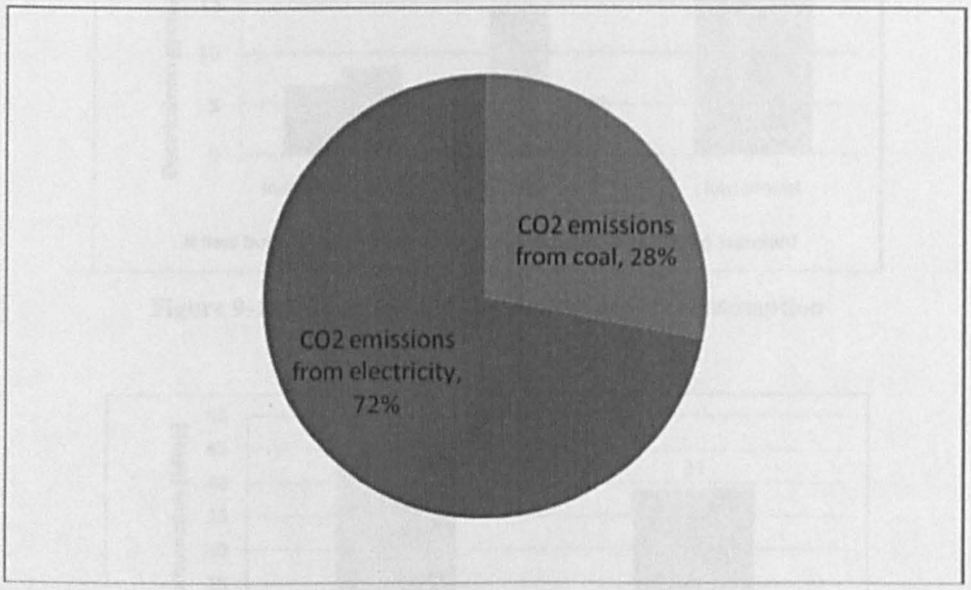

Figure 9-16 Share of the CO_2 emissions

9.4 Comparison

Figure 9-17 below shows the difference in electrical energy consumption with and without the implementation of the Standard. With the implementation of the Standard, the individual AC units have actually increased their energy consumption. This is because the heat gains did not have dramatic decrease as the heat losses and overall more cooling than heating is now required. The energy consumption of the individual AC units increased by 19%. However, the energy consumption of the lighting reduced by 60% because the lighting equipment has been changed according to the Standard requirements. The office equipment energy consumption has not changed, as there are no specific standards for it.

The total electric energy consumption has reduced by 15% from 45.7 MWh to 39 MWh, as shown in figure 9-18. However, the lighting electrical energy consumption has reduced by 60%, and the energy consumption of the HVAC system has reduced by 19%, which means that the aims have been achieved.

The level of CO_2 emissions has reduced by 60%, mainly because the heating requirements have reduced and therefore, less emission from coal is produced, as represented in figure 9-19.

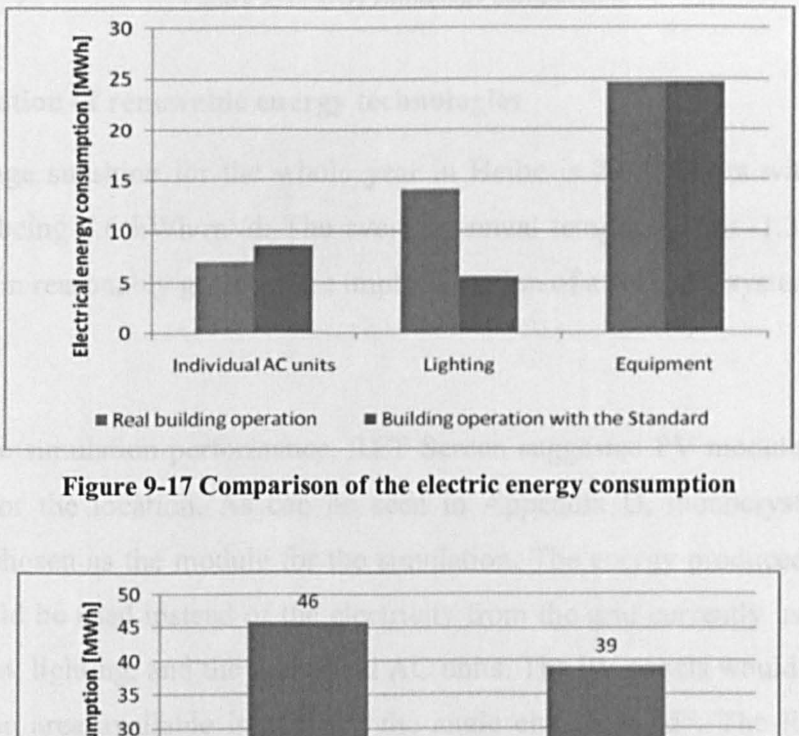

Figure 9-17 Comparison of the electric energy consumption

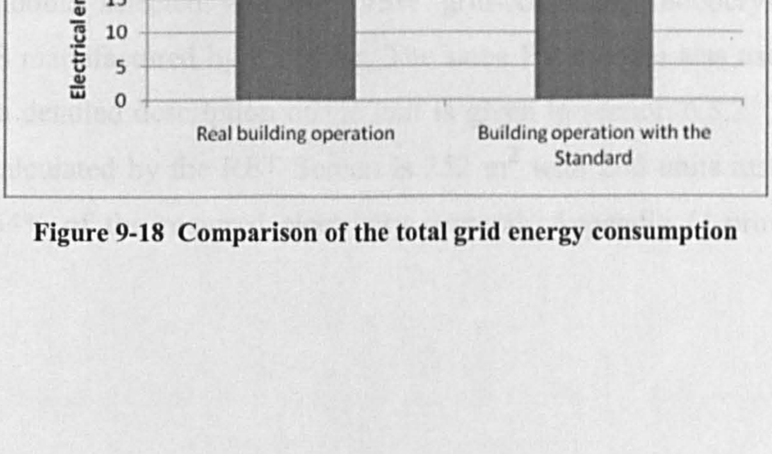

Figure 9-18 Comparison of the total grid energy consumption

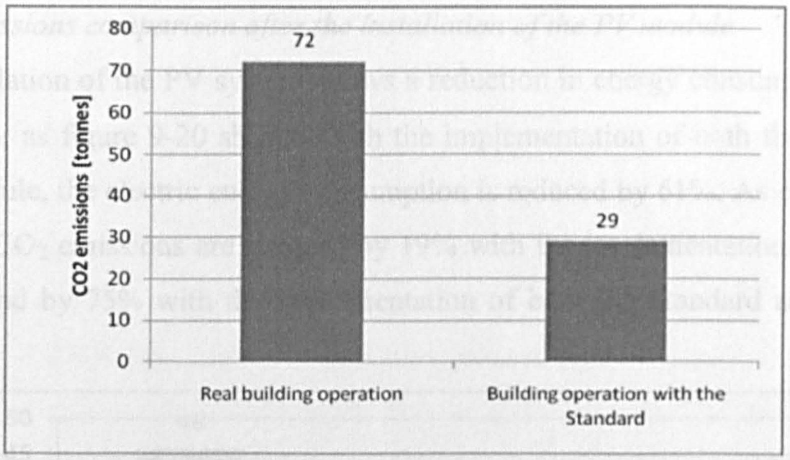

Figure 9-19 CO_2 Emissions comparison

9.5 Implementation of renewable energy technologies

The average sunshine for the whole year in Heihe is 2,641 hours with average solar radiation being 3.6 kWh/m^2/d. The average annual temperature is -1.3°C. These make the location reasonably good for the implementation of a solar PV system.

9.5.1 PV system

During the simulation performance, RET Screen suggested PV module to be the most suitable for the location. As can be seen in Appendix U, monocrystalline PV modules were chosen as the module for the simulation. The energy produced from the PV system would be used instead of the electricity from the grid currently used for the office equipment, lighting, and the individual AC units. The PV panels would be placed on the roof. The area available is 365 m^2; the angle chosen is 45°. The RETScreen analysis of the PV system is presented in Appendix U.

The PV module selected was the 175W grid-connected monocrystalline PV module BP4175S manufactured by BP Solar. The same PV module was used for Case Study One, and a detailed description of the unit is given in section 6.5.2. The area of the PV system calculated by the RET Screen is 252 m^2 with 200 units installed. This would provide 54% of the required electricity demand. Appendix U provides more details.

9.5.1.1 CO_2 emissions comparison after the installation of the PV module

The installation of the PV system allows a reduction in energy consumption from the grid of 54%, as figure 9-20 shows. With the implementation of both the Standard and the PV module, the electric energy consumption is reduced by 61%. As can be seen in figure 9-21, CO_2 emissions are reduced by 19% with the implementation of the PV system alone, and by 75% with the implementation of both the Standard and the PV system.

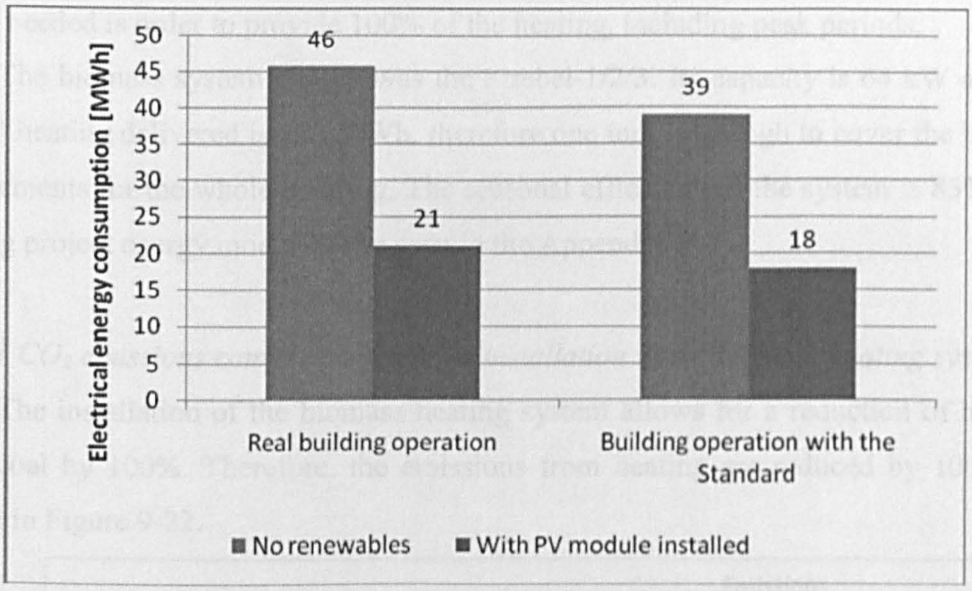

Figure 9-20 Real and Standard building grid energy consumption with and without the PV module installation

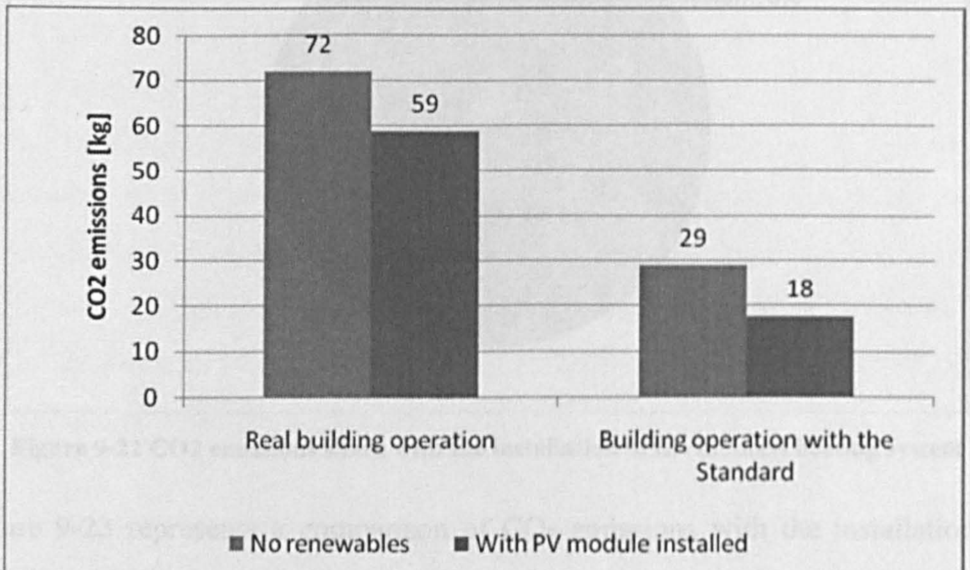

Figure 9-21 Real and Standard building operation CO_2 emissions with and without the installation of the PV module

9.5.2 Biomass heating system

As previously stated, the CO_2 emissions from space heating during winter period account to the highest of CO_2 emissions for the building. The RETScreen Heating Project was used to simulate a biomass heating system performance for this case study. The biomass heating system is described in section 4.2.8.

With the heated floor area of the building being 1,826.5 m^2 and a heat load of 33W/m^2, the RETScreen tool suggested that a biomass system with a capacity of 60.3 kW is needed is order to provide 100% of the heating, including peak periods.

The biomass system chosen was the Strebel-1/2/3. Its capacity is 64 kW and the annual heating delivered is 123 MWh, therefore one unit is enough to cover the heating requirements for the whole building. The seasonal efficiency of the system is 85%. The heating project energy model can be seen in the Appendix V.

9.5.2.1 CO_2 emissions comparison with the installation of the biomass heating system

The installation of the biomass heating system allows for a reduction of heating from coal by 100%. Therefore, the emissions from heating are reduced by 100%, as shown in Figure 9-22.

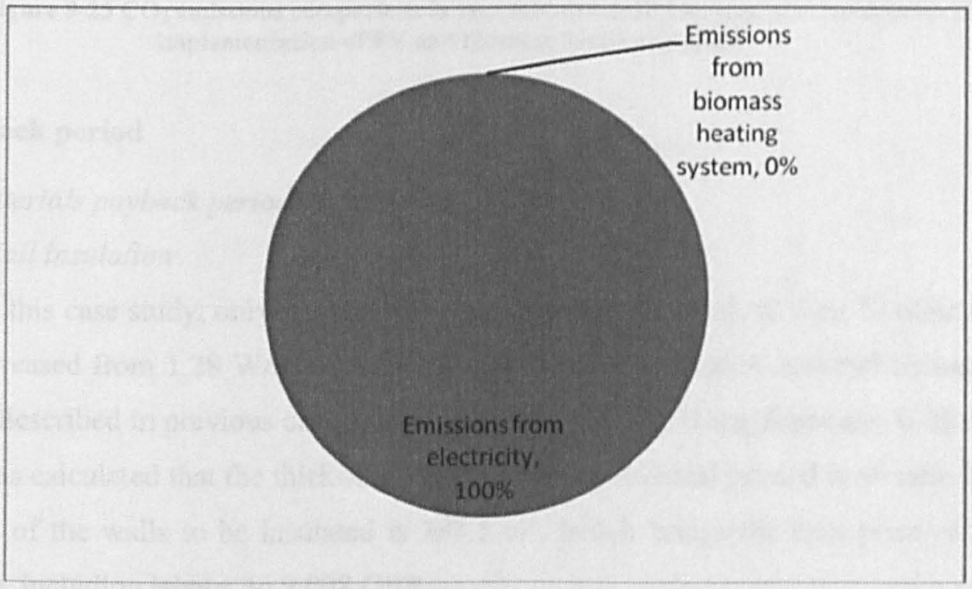

Figure 9-22 CO2 emissions share with the installation of the biomass heating system

Figure 9-23 represents a comparison of CO_2 emissions with the installation of different renewable energy technology systems. As can be seen in figure 9-23, with the installation of the biomass heating system in the current building operation scenario, the CO_2 emissions can be reduced by 66%. With the installation of both the biomass heating system and the PV system proposed, the CO_2 emissions can be reduced by 84%. With the implementation of the Standard and the installation of the biomass heating system, CO_2 emissions can be reduced by 71%. With the implementation of the Standard and the installation of both the biomass heating system and the PV system proposed, CO_2 emissions can be reduced by 87% compared to the CO_2 emissions during real building operation.

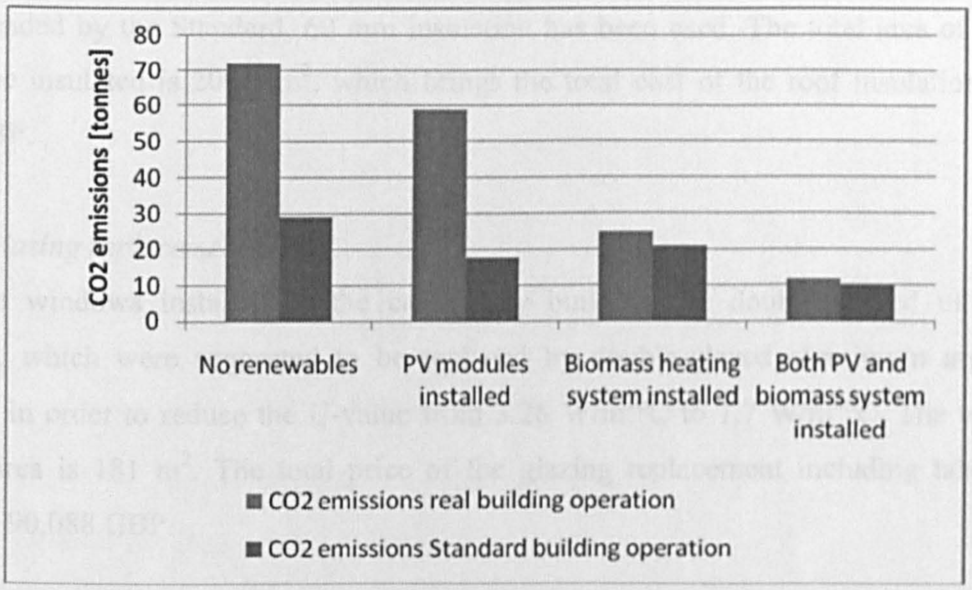

Figure 9-23 CO_2 emissions comparison in real and standard building operations with the implementation of PV and biomass heating systems

9.6 Payback period

9.6.1. Materials payback period

9.6.1.1 Wall insulation

For this case study, only the external walls need be insulated, as their U-value has to be decreased from 1.28 $W/m^2{}^\circ C$ to 0.45 $W/m^2{}^\circ C$. The insulation material chosen is Isowool, described in previous case studies in section 7.6.1.1. Using Equations 6-20 and 6-21 it was calculated that the thickness of the insulation material needed is 48 mm. The total area of the walls to be insulated is 383.5 m^2, which brings the total price of the insulation, including labour, to 2,098 GBP.

9.6.1.2 Floor insulation price

The Standard requires the U-value of the floor to be 0.45 $W/m^2{}^\circ C$ instead of 1.28 $W/m^2{}^\circ C$, which is the real U-value of the floor in this case study building. 50 mm insulation board Celotex could be used for the floor insulation. The total area of the floor is 209.5 m^2; therefore, the total price of the floor insulation would be 1,818.5 GBP.

9.6.1.3 Roof insulation

For the roof insulation, fibre glass insulation material has been chosen in order to reduce the existing U-value of 0.77 $W/m^2{}^\circ C$ to the U-value of 0.35 $W/m^2{}^\circ C$, recommended by the Standard. 60 mm insulation has been used. The total area of the roof to be insulated is 209.5 m^2, which brings the total cost of the roof insulation to 1,146 GBP.

9.6.1.4 Glazing replacement place

The windows installed in the case study building are double glazed uPVC windows, which were suggested to be replaced by double-glazed aluminium argon windows in order to reduce the U-value from 3.26 $W/m^2{}^\circ C$ to 1.7 $W/m^2{}^\circ C$. The total glazing area is 181 m^2. The total price of the glazing replacement including labour would be 90,088 GBP.

9.6.1.5 Total payback period calculations for material and glazing

The total electrical energy consumption of the building is 45.7 MWh per year with an annual fuel cost of 2,287 GBP. If the Standard were implemented with the walls, roof and floor to be insulated and the glazing replaced, the electrical energy consumption falls to 39 MWh per year with an annual spending of 1,950 GBP annually. The annual savings that the insulation and new glazing brings would be 337 GBP. The total investment needed for the insulation and glazing replacement is 95,151 GBP. This makes the payback period more than 100 years, which makes it not economically feasible.

Therefore, further calculations have been done, and the results have shown that the replacement of the glazing is not crucial, as the insulation of walls, roof and floor only reduce the energy consumption by 16%, which is one percent more than with the implementation of both insulation and new glazing. The total electrical energy consumption for the insulation of the building only is 38.6 MWh per year, which would cost 1,930 GBP. The total investment for the insulation is 5,062.5 GBP, which brings annual savings to 357 GBP and, according to equation 6-17, makes the payback period just 14 years.

The discounted payback period has been calculated, using Equations 6-18 and 6-19 and is shown graphically in figure 9-24. Taking into account the 6% interest rate, the discounted payback period is between 32 and 33 years.

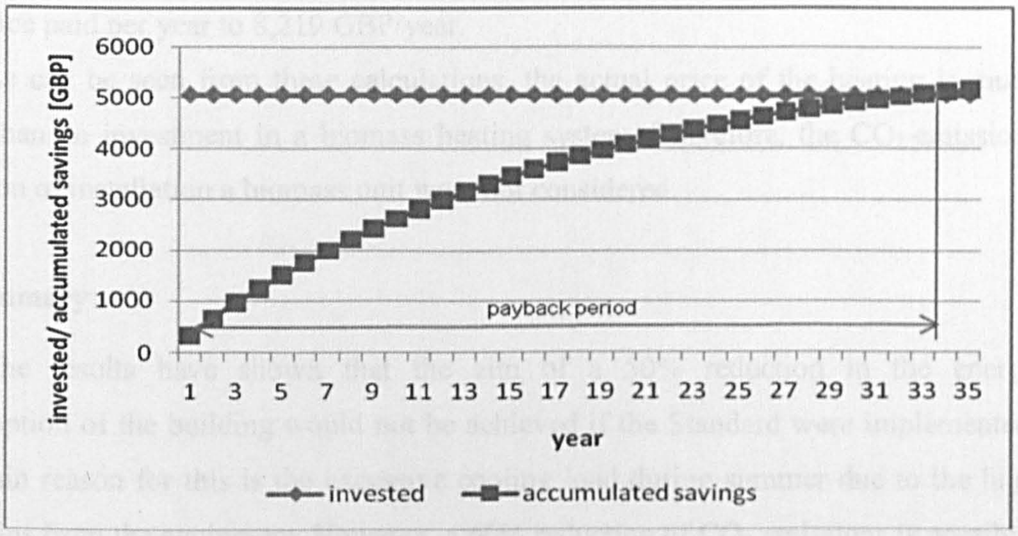

Figure 9-24 Discounted payback period for Heihe case study building

9.6.2 Renewable energy technologies payback period

9.6.2.1 PV module payback period

There are 200 PV module units installed with a total area of 252 m^2. The installed PV module provides 54% of the electrical energy needed in the building for the lighting, equipment and air-conditioning. The total investment needed to install the required amount of modules is 85,580 GBP. 200 units would generate 21 MWh per year and bring an annual saving of 553 GBP. When the payback period is calculated using Equation 6-17, it is more than 100 years, which makes it economically not feasible. As with previous case studies, the possibility of FIT was explored in this case study. If the FIT is 0.1 GBP/kWh, it will bring the annual savings to 2,659 GBP; the payback period will be 32 years. If the building were both insulated and provided with a PV system, the total investment needed would be 90,624.5 GBP and the total payback period would be 63 years.

9.6.2.2 Biomass heating system payback period

In order to reduce CO_2 emissions from heating, the possibility of installing a biomass heating system was explored. According to the RETScreen calculations, the amount of energy produced by the biomass heating system covers 100% of the heating required or 123 MWh. An installed biomass unit with a capacity of 64 kW would cost

20,000 GBP and the maintenance cost per year would be 2,000 GBP. As mentioned previously, the heating season lasts from November 15 to March 15 every year. Currently the price of heating per m^2 is 4.5 GBP for the heating season. This brings the total price paid per year to 8,219 GBP/year.

As can be seen from these calculations, the actual price of the heating is much lower than an investment in a biomass heating system. Therefore, the CO_2 emissions reduction of installation a biomass unit were not considered.

9.7 Summary

The results have shown that the aim of a 50% reduction in the energy consumption of the building would not be achieved if the Standard were implemented. The main reason for this is the excessive cooling load during summer due to the high heat gains from the equipment. However, a 60% reduction of CO_2 emissions is possible, as the heat losses have decreased considerably, and therefore less coal is required for the heating.

The calculations have also shown that the replacement of the windows is not crucial for a significant reduction in energy consumption. The payback period of the installation of insulation for the walls, roof and floor is 32 years, which would make it economically feasible only in case of a long and useful life for the building.

The payback for installing a PV system is not economically feasible without financial incentives and a biomass heating system is also not recommended because of its high price and low energy savings.

9.8 References

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Chapter 10 – Theory-based policy implementation evaluation

This chapter is the final chapter of this thesis and it brings together the policy context analysed in previous chapters and outlines the theoretical basis for the policy tool evaluations and evaluates the effectiveness of the chosen policy tool.

10.1 Theoretical approach to the theory-based policy evaluation

10.1.1 Introduction

When systematic ex-post energy efficiency policies evaluation is carried out, it can reveal factors that explain the success or failure in the implementation process of a policy. The problem is that only a few policy instruments out of many introduced all over the world have been evaluated. It is also difficult to compare evaluations that have been accomplished actually, because different methods and indicators are used. For example, the methods used in Europe are mostly focused on final effects, such as energy savings and cost effectiveness. Research on bringing policy evaluation methods to an equal footing and uniform systematic assessment process is limited [Harmelink et al., 2008]. The main evaluations that have been done to date include the following:

- The SAVE project "A European ex-post Evaluation Guidebook for DMS and Energy Efficiency Services programmes" completed in 2001. These guidelines generally describe ex-post evaluation of Demand Site Management (DMS) and energy efficiency services and were used for a number of service programmes in the EU [SRC, 2001];

- The evaluation guidebook "Evaluating EE policy measures and DSM projects", published in 2005 by International Energy Agency (IEA). This guidebook provides guidance for the systematic evaluation of the implementation process of energy efficiency policy instruments and has been used in many IEA countries (Italy, Norway, Sweden, etc) [Harmelink et al., 2008];

- The "California EE evaluation protocols: technical, methodological, and reporting requirements for evaluation professionals" is used for the evaluation of California's EE programmes. The Protocols are the guidance tools for policy makers and evaluators and assess the impact, success and failure of their policies [Hall et al., 2006];

- The New York Energy $mart Programme is aimed at validating programme interventions in order to justify the expenditure of public funds and assist policy makers in the decision making progress [Harmelink et al., 2008];

- The US Department of Energy handbook "Impact evaluation framework for technology deployment programmes" provides an approach for quantifying retrospective energy savings, clean energy advances and market effects [Harmelink et al., 2008];

- The EU-funded project "Active Implementation of the European Directive on EE" (AID-EE) develops a generic framework for ex-post evaluation. The method is based on a theory-based policy evaluation and designed to systematically assess all of the steps of the policy implementation process. This programme will be described below as it is used as a basis for the evaluation of the Standard being investigated in this body of work.

10.1.2 Ex-post policy evaluation methods

There are two types of policy theory: explicit theory and implicit theory. Explicit theory is one that is available in an ideal case, when the policy makers have clearly described how they expect the policy instrument to work, prior to its implementation. Implicit theory lacks this foresight and the evaluator must reconstruct the policy theory which might lead to misunderstanding and misinterpretations.

There are a variety of methods for ex-post evaluation of policy instruments [Harmelink et al., 2008]:

1. *The assessment of aggregated 'top-down' indicators for energy consumption per sector or end user*: a hypothetical baseline, which is based on statistics, is created. It is assumed that energy efficiency does not change from the base year or it is adjusted for autonomous efficiency improvements. The actual energy use is subtracted from this amount, and the difference is defined to be the energy saved amount. This method does not generally show the impact of individual policy instruments because of its aggregated level of analysis.
2. *Econometric modelling of the impact of policy instruments*: a list of factors (including policy instruments) that could affect the energy use sector is drawn up. Through statistical methods, the impact of a given policy instrument can be estimated. Usually this method is used for the evaluation of general policy

instruments (e.g. taxes, incentives, etc). The disadvantage of this method is that it does not provide the answer to 'why' an instrument performed or did not perform in the way it was expected to and what could be done to improve it.

3. *Detailed bottom-up policy evaluation*: this focuses on the final effects of a single policy instrument as well as the complete package of instruments. This means that the results obtained through the implementation of a specific instrument are determined in real terms such as kWh or GJ. The main issue with this method is that it is often difficult to determine the effect of a single-policy instrument, and that the impact of rebound effect, free riders, etc are not always known.

4. *Theory-based policy evaluation*: a theory is drawn up on how a policy instrument should achieve its targeted impact in terms of energy efficiency improvement. This method is complimentary to any of those mentioned above, and its main advantage is that insight can be gained on the full implementation process, including explanatory factors behind the impact. A theory-based policy evaluation focuses on the whole policy process and considers both quantitative and qualitative aspects that make it possible to provide the insight in the success or failure of policy instruments and can be used for the improvement of the policy process and the optimisation of its final effects.

10.1.3 Applied methodology: theory-based policy evaluation

The theory-based policy evaluation method has been known for a long time and is used for various types of policies. It is described in details in Rossi et al. (2004). As can be seen in Figure 10-1, the theory-based method requires an iterative process of programme design, evaluation, and redesign based on the lessons learned from previous programmes.

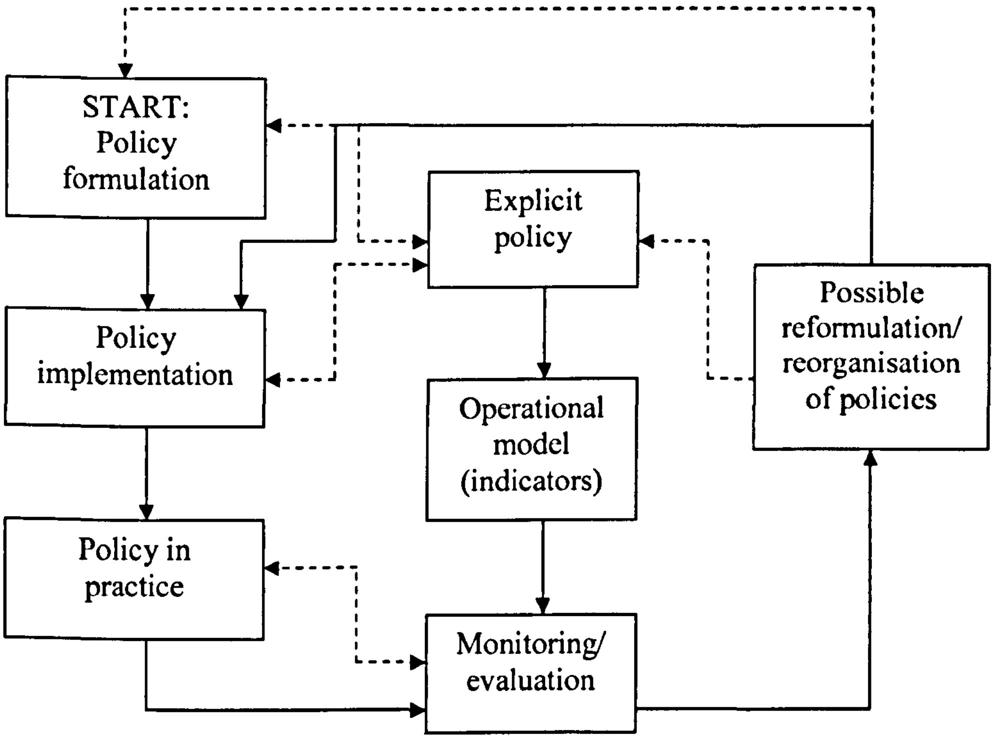

Figure 10-1 Outline of the policy cycle and the role of the programme theory in the policy cycle [Joosen and Harmelink, 2006]

In practice, it means that a theory-based policy evaluation creates a plausible theory on how a particular policy is expected to lead to energy efficiency improvements, and who is responsible for that. The basic principle is to unravel the whole policy implementation process, and through this gain the information about where, when and what went wrong. The ideal policy cycle occurs when a policy is first formulated, then implemented and ultimately put into practice leading energy savings [Joosen and Harmelink, 2006]. After its implementation, a policy should be monitored and evaluated, which might then cause policy reformulations or, in a worst-case scenario, its abolishment. Ex-post policy evaluation is an essential element in the possible reformulation/reorganisation of policies [Harmelink et al., 2008].

Advantages of a theory-based policy evaluation are that it covers different areas covered by energy efficiency policies and makes an in-depth analysis of the policy instruments which allows the drawing of specific conclusions, which could be valuable for the improvement of the evaluated policies. The disadvantages of this evaluation scheme are that it is difficult to draw generic conclusions on the effectiveness and the efficiency of actual policy as a diverse sample of policy that has been analysed and is not possible to provide a full policy analysis of a specific sector or a specific type of instrument.

A theory-based policy evaluation is an evaluation method with the following characteristics:

- The evaluation sets up a theory of the expected policy impacts and the elements and implementation steps of the policy that are the causes for these impacts that makes the perception and conception of policy makers on how a policy instrument functions explicitly;
- It evaluates the final outcome of the policy: the target achievement (the extent to which a policy achieved its stated target, and its effectiveness), the net impact (the amount of energy savings realised compared to the situation without the policy), and cost-effectiveness (the relationship between the net impact and the amount of money needed to achieve the impact);
- It does not only focus on the final outcomes but evaluates the whole policy implementation process including the identification and quantitative analysis of indicators for each step in the implementation process;
- It analyses the main success and failure factors of the policy, and provides reasons for why the policy has succeeded or failed and how it can be adjusted in order to improve its effectiveness and cost-efficiency;
- It analyses whether the theory's causes and impacts are adequate or not.

The main elements of the theory-based policy are:

- Cause-impact relationships: the first cause-impact relationship is usually related to the launching of the policy instrument or programme, and the last one to the carrying out of energy saving measures by the target group;
- Indicators: these are identified in order to measure whether the cause-impact relation actually existed and if the change that took place is actually due to the implementation of the policy; indicators are mostly quantifiable, but qualitative ones can also be useful;
- Success and failure factors: the main factors explaining success or failure of the policy; they mostly have a qualitative nature;

- Relations with other policy instruments: these can reinforce or mitigate the policy implementation; this can function as a base for further evaluation of the interlinkages of different policies and evaluate the possible packages of policy instruments (this evaluation is recommended if it is impossible to determine an isolated single policy impact).

10.1.3.1 Characteristics of the policy instruments

As has been mentioned in previous sections, there is a great variety of policy instruments implemented in order to stimulate energy efficiency: they vary from direct regulations to financial incentives to voluntary agreements. In order for the instruments to be applicable for a theory-based policy evaluation, the following criteria are suggested by the AID-EE [Harmelink et al., 2008]:

- The instruments should be aimed at achieving substantial energy savings and/or be aimed at market implementation of energy efficient technologies on a national level;
- The instruments should be aimed at the implementation of energy end-use efficiency improvement measures;
- A total package of selected instruments should be a good representation of the existing variety of implemented instruments;
- Some monitoring data should be available.

10.1.3.2 Practical framework to evaluate policy instruments

Any ex-post evaluation generally aims at answering two main questions: 'What is the contribution of policy instruments in the realisation of policy targets?' and 'What is the cost effectiveness of policy instruments (and could the targets be reached with lower costs?' [Jossen and Harmelink, 2006].

Within the framework used for the AID-EE case studies, a six-step approach was created [Harmelink et al., 2008]. The first step of the policy theory is the coverage of the initiation of the policy instrument by a government agency; its last step is when the target groups carry out measures to reach final energy savings. Between these two steps, there can be any number of different steps, which depends on the complexity of the policy.

The policy theory is used to find out why the net impact of the policy is smaller or bigger than expected or why cost-efficiencies differ from what was expected; it helps to find out the strength and weaknesses of the policy instrument.

The theory-based policy evaluation for this body of work was conducted by following these steps:

1. Make an initial characterisation of the policy instrument: a description of the policy instrument with as much basic information as possible: objectives and targets of the policy, end user areas and technologies targeted, barriers to overcome, the period that the policy instrument was active, the policy context, the target group, the policy implementing agents, and the available budget;
2. Draw up a policy theory: make a draft of the policy theory with the help of available documents and initial interviews with relevant actors: documenting all implicit and explicit assumptions in the policy implementation process, and mapping the cause-impact relationships including the relationships with other policy instruments;
3. Translate the policy theory to concrete indicators and identify success and failure factors: for each assumed cause-impact relation draw an indicator to 'measure' whether a cause-impact relation actually took place and whether the change was definitely due to the policy implementation; this also includes the development of necessary formulas to calculate the net impact, effectiveness and cost-efficiency, and the identification of the expected success and failure factors as well as coupling these to the indicators;
4. Draw up a flow chart of the policy theory: reflect the cause-impact relations, the indicators and the success and failure in a flowchart;
5. Collect information to verify and adjust the policy theory: this can be done through interviews with policy makers and implementing agents and other actors involved in the implementation and monitoring of the policy, as they are the ones who make the necessary adjustments to the policy theory;
6. Collect additional information and analyse all aspects of the policy theory: the final step includes:

- Collection and analysis of all available information to decide on the relevant indicators;
- Drawing of conclusions on the net impact, the target achievement and the cost-efficiency of the policy instrument using formulas and indicators;
- Analysis of the main success and failure factors; recommendations on how to improve the policy instrument, in particular its effectiveness and cost-efficiency.

10.1.3.3 Possibilities and limits of energy savings analysis and its potentials

The main issue when analysing energy savings is that energy savings cannot be directly observed or measured. Usually, to deal with this problem, baseline energy consumption has to be defined, and then the difference between the so-defined baseline consumption and the estimated/metered real consumption after the implementation of energy efficiency measures can be estimated. In principle, this procedure is possible for any energy saving measure or type of policy. However, the degree of complexity and uncertainly and validity of such a method can be different from case to case [Irrek and Jarczynski, 2007].

Energy efficiency is also a generic term relaed to energy savings, and it can be defined in several ways. For example, Michelsen (2005) suggests that energy efficiency has potentials and defines five types of potentials, shown in figure 10-2 and explained in the following paragraph.

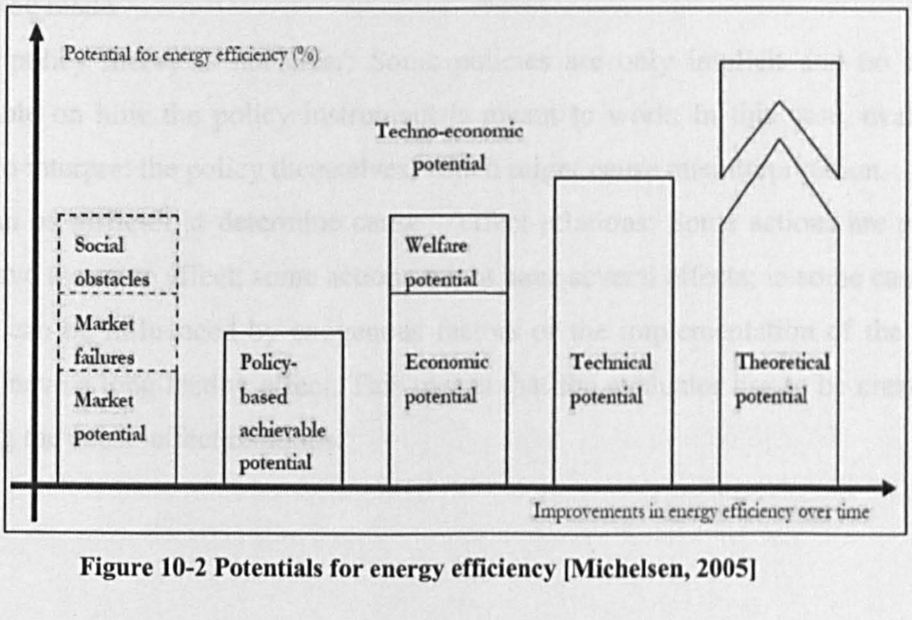

Figure 10-2 Potentials for energy efficiency [Michelsen, 2005]

Theoretical potentials are the savings that could be achieved by reaching the absolute minimum of energy required to operate. The technical potentials are energy efficiency measures that can be achieved by applying the best available technologies, which do not necessarily pay back their capital expenditure. Techno-economical potentials are the potentials that could be reached by cost-effective technologies. Market potentials are the expected potential savings in practice. Market failures and social obstacles cause the gap between the techno-economic potentials and market potentials. The role of the energy efficiency policy instruments is to close this gap. Therefore, the policy-based achievable potentials depend on the implemented policy instruments [Michelsen, 2005].

10.1.4 Main problems with theory-based policy evaluation

All policy evaluations have many practical problems, which makes it difficult to follow the exact steps of the evaluation methodology. The AID-EE report (2007) outlines the most common problems:

- A lack of monitoring data: this is the most common problem of evaluation. A lack of monitoring data is often caused by a lack of resources or because the data does not exist anymore. Thus, a lack of data is a reality for most policy evaluations.
- A lack of time and resources: this often means that compromises have to be made when it comes to data collection. Therefore, a decision on the focus of the evaluation has to be made.
- The policy theory is not clear: Some policies are only implicit and no data is available on how the policy instrument is meant to work. In this case, evaluators have to interpret the policy themselves, which might cause misinterpretation.
- It can be difficult to determine cause – effect relations: Some actions are parallel and have the same effect; some actions might have several effects; in some cases, the effect can be influenced by exogenous factors or the implementation of the action might have a long-lasting effect. This means that the evaluator has to be creative in finding the cause-effect relations.

- It can be difficult to identify the most significant success and failure factors: This difficulty is caused by the actual personal view of the evaluator and can be avoided by using several evaluators.

10.2 "Design Standard for Energy Efficiency in Commercial Buildings" theory-based policy evaluation

As was mentioned in the previous section, a theory-based policy evaluation has been done in Europe. For the evaluation performance here, similar format to the European theory-based policy evaluation has been used. The report format is given in Appendix V and is discussed in the following sections.

10.2.1 Characteristics of the selected instrument

The policy instrument chosen to be evaluated was the "Design Standard for Energy Efficiency in Commercial Buildings" described in detail in section 5.4.2. This Standard acts as a tool for the general energy efficiency policy strategy that the Chinese government has chosen. In order to evaluate the results and quantify the impacts of the Standard, the case studies described in chapters 6, 7, 8, and 9 have been undertaken. Also, chapters 2, 3, 4, and 5 provide the national and international contexts in which the Standard works.

This evaluation focuses on the commercial (public) building sector involving the operation stage of the commercial buildings life cycle. The target group of the evaluation are the stakeholders involved in the building occupation.

The type of instrument that this evaluation has been aimed at is the energy performance of the building standard. The Standard comes in the package of other policies and standards aimed at energy efficiency and emissions reduction. The package of the instruments has mainly been enforced during the 11^{th} 5-Year Plan which is described in section 3.4.3. However, though the Standard is a part of the package, it was evaluated individually.

The Standard was introduced in 2005, however it is unknown if it will be replaced by a new standard at the beginning of the 12^{th} 5-Year Plan (2011-2015). The previous standard, which had been replaced by the Standard, which covers wide range of buildings, was in use for 11 years (1994-2005).

10.2.1.1 Data availability

The main observation is that the Standard does not have a comprehensive monitoring system. The ex-ante or ex-post evaluations have not been carried out; therefore there are no expectations in terms of effectiveness and cost effectiveness of the whole instrument. In the case studies, the payback period of the implementation of the instrument has been calculated (see sections 6.6, 7.6, 8.6, and 9.6); however, it does not represent the total cost of the instrument as it does not include the spending on the implementation of the Standard (governmental spending). Data on governmental spending is not available. Data on the available budget for the enforcement of the instrument is also unknown. The side effects such as free riders, rebound, and spill over effects are also not taken into account in this evaluation.

10.2.1.2 Targets and target achievement

Harmelink et al. (2008) define a target as "*a specific, either quantitative or qualitative objective that has been set at the time the policy instrument was introduced. Target achievement is defined as the extent to which a policy instrument achieved its stated target(s)*" [Harmelink et al., p.139, 2008].

When evaluating an energy efficiency policy instrument, energy savings and CO_2 emissions reduction are usually not separated [Harmelink et al, 2008].

The Standard sets a target of 50% energy consumption reduction in commercial buildings compared to levels in the 1980s. As was mentioned before in section 5.4, this is the common target of all energy saving policies and standards in China. It also provides specific targets on savings from lighting, envelope insulation, and HVAC systems, which have been described in detail in section 5.4.2. Also, the target for renewable energy technologies (25% of energy consumed should come from renewable source) has been incorporated into this work, as the implementation of renewable energy technologies was suggested as one of the energy saving methods. The Standard does not give a target for CO_2 emissions reduction, but it has been calculated in these case studies, as the environmental impact of the Standard is the main interest in this project.

Another important point to mention is that though the targets are set, neither the Standard nor any other instrument in the policy package explains the ways of achieving the target. The Standard (or any other policy instruments) does not show the ways of introducing the public to the energy efficiency measures and their implementation, and it is left for the local governments to decide on the ways of promoting the energy efficiency policy package.

The Standard is aimed at the energy consumption of both new and existing buildings; however, it does not specify if the refurbishing of existing buildings according to the Standard is compulsory or whether it will become compulsory in the future. Therefore, it is difficult to evaluate the real energy savings in the existing buildings.

As has been seen in the case studies (chapters 6, 7, 8, and 9), the Standard as an individual instrument has achieved the specific targets set for the energy consumption reduction in the commercial buildings, but the common target of 50% can hardly be achieved with the implementation of this instrument alone.

10.2.1.3 Main problems

When it comes to practice, it is not always possible to follow the steps of the theory-based policy evaluation method. The majority of the problems experienced were because evaluation and monitoring were not considered when the policy was designed. The main problems were:

- A lack of monitoring data and information. Due to the non-transparent nature of the government, governmental data, savings, rates, and other data were sometimes impossible to reconstruct.

- A lack of time and resources: ideally, an evaluation should be started before the policy is actually implemented and be followed by a number of years of evaluation to allow for bedding in of the policy. However, due to the period of the project and the budget allowing for only one short field trip to China, this was not possible. Further time in China would have allowed more interviews to be conducted.

- Unclear policy theory: it was difficult to reconstruct the original formulation of the policy. A number of attempts were made to contact construction officials in order to conduct interviews; however, no response was received. The interviews conducted were with academics involved in the original policy making and companies engaged in the construction sector (see Appendix A for a full list of the interviewed people).

- Difficulty in determining cause-effect relations because the evaluation is not integrated into the policy design and identifying success and failure factors and their importance, as during the interviews different respondents had different views on this.

10.2.2 Policy theory

The general idea of the Standard is very simple: to reduce the energy consumption in commercial buildings. However, in order for this to work, the energy users should be aware of the Standard and its requirements. There are several steps in the policy theory, which have to be achieved before the final target is reached. In Figure 10-3, the main steps of the policy theory are presented together with the indicators that allow the measurement of possible success and failure factors, assuming that the cause-impact relations exist. The figure shows that the policy theory on the way to the Standard should lead to energy savings and emissions reductions, and this should be done with connection to a variety of policy instruments. The basic idea of this chart was developed by AID-EE (2006), however it was adjust to China's context and different indicators were chosen as the indicators presented by AID-EE are not relevant to China's policy tool. Therefore this framework presents the unique indicators relevant only to the evaluated Standard.

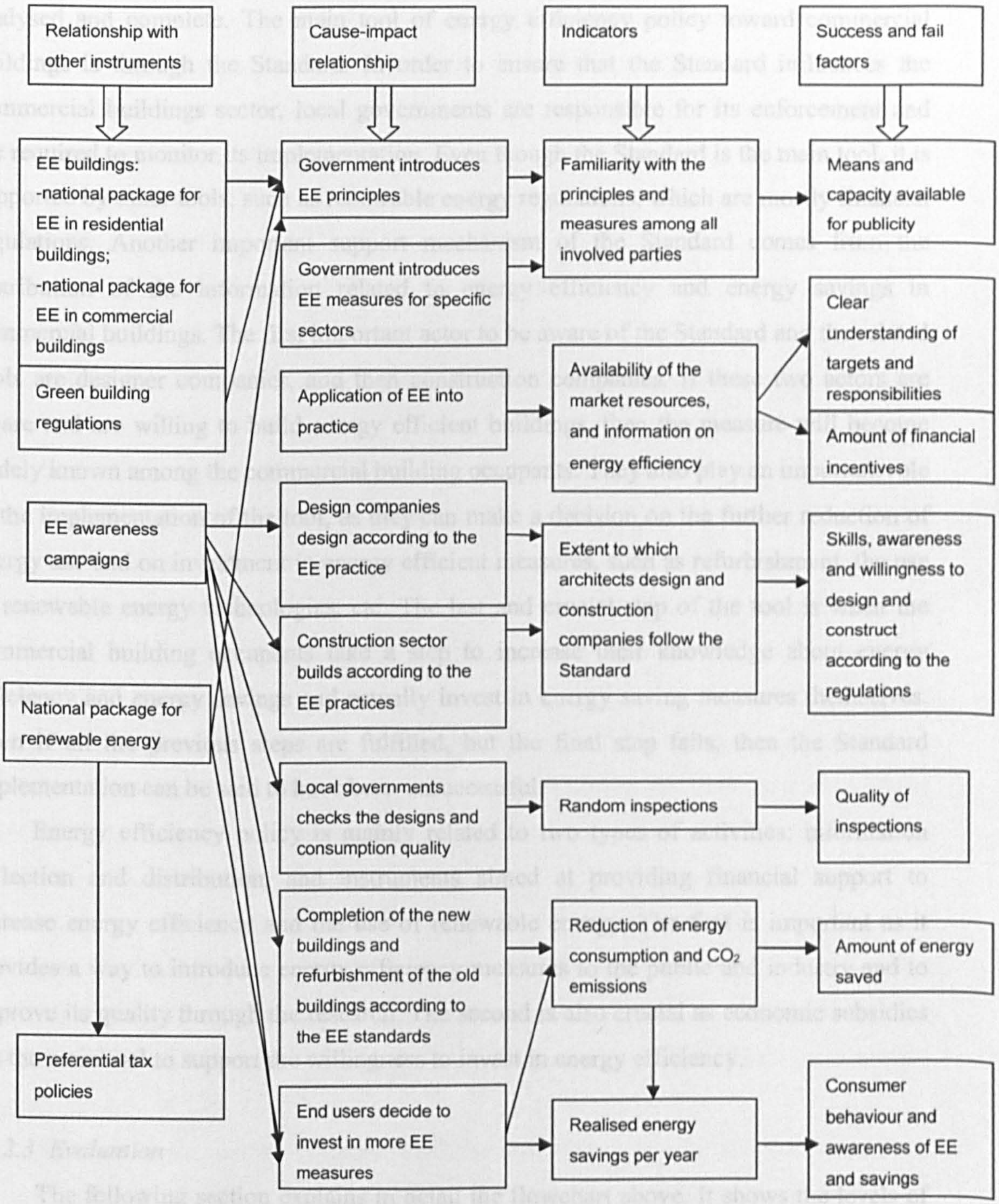

Figure 10-3 Policy theory flow chart

This framework is necessary when the policy cycle presented in figure 10-1 is implemented, as it gives the data for evaluation without which policy cycle cannot be analysed and complete. The main tool of energy efficiency policy toward commercial buildings is through the Standard. In order to ensure that the Standard influences the commercial buildings sector, local governments are responsible for its enforcement and are required to monitor its implementation. Even though the Standard is the main tool, it is supported by other tools, such as renewable energy regulations, which are mostly financial regulations. Another important support mechanism of the Standard comes from the distribution of the information related to energy efficiency and energy savings in commercial buildings. The first important actor to be aware of the Standard and the related tools are designer companies, and then construction companies. If these two actors are aware and are willing to build energy efficient buildings, then the measure will become widely known among the commercial building occupants. They also play an important role in the implementation of the tool, as they can make a decision on the further reduction of energy use and on investment in energy efficient measures, such as refurbishment, the use of renewable energy technologies, etc. The last and crucial step of the tool is when the commercial building occupants take a step to increase their knowledge about energy efficiency and energy savings and actually invest in energy saving measures themselves. Even if all the previous steps are fulfilled, but the final step fails, then the Standard implementation can be said to have been unsuccessful.

Energy efficiency policy is mainly related to two types of activities: information collection and distribution, and instruments aimed at providing financial support to increase energy efficiency and the use of renewable energy. The first is important as it provides a way to introduce energy efficiency measures to the public and industry and to improve its quality through the research. The second is also crucial as economic subsidies are the main tool to support the willingness to invest in energy efficiency.

10.2.3 Evaluation

The following section explains in detail the flowchart above. It shows the levels of awareness of the evaluated standard and also explain each and every indicator. It also gives the reasons for indicator's success or failure.

In order to evaluate the overall success of the instrument, AID-EE suggests answering the following questions [AID-EE, 2007]:

- Is the standard well-justified (e.g. through life-cycle cost studies)?
- Is the target group well prepared (e.g. through information campaigns, training programmes etc)?
- Are penalties in place for non-compliance?
- Are penalties sufficient to stimulate meeting the standard?
- Is the Standard timely adjusted to technological progress?

Within this evaluation, all these questions have to some extent been addressed.

10.2.3.1 Questionnaires and interviews analysis: end users awareness of the policy tools

As the framework in figure 10-3 has shown, the policy tool would fail if one of its parts does not work. One of the main parts of this flow chart is the awareness of end users as it dictates the consumer behaviour and their willingness to reduce energy consumption. In order to find out the end user awareness about the evaluated Standard and their general opinion on energy efficiency situation in China, information was collected using both questionnaires and interviews.

The questionnaires aimed at energy users (i.e. building users, both tenants and owners) and interviews aimed at those who were involved in the implementation of the Standard (i.e. academics consulting the MOC) and those who are directly implementing the standard (i.e. construction sector).

No policy tool can be successful if the end users are not aware of the policy. In order to find out the level of awareness, the questionnaire described in section 1.3.1 (Appendix B) was distributed among commercial building occupants in different climate zones of China. The following section will describe and discuss the results of the questionnaire responses.

As has been mentioned in section 1.3.1, the aim of the questionnaire was to evaluate the awareness of the owners and tenants of office spaces about energy efficiency and renewable energy technologies and to find out their opinion about the subject. The sample questionnaire is presented in Appendix B.

Questionnaires were distributed to 30 companies, of which 20 responses were received, including four responses that were not complete. Responses are presented in Appendix W. Therefore, 16 full responses have been analysed and the following conclusions have been drawn. Most of the respondents do not own their office space, which was one of the reasons not to invest in energy efficiency measures and renewable energy technologies.

The first part of the questionnaire was created to assess their general understanding of thermal comfort in the workplace. 69% of the respondents say that it is too cold in winter. The analysis showed that these responses came from office buildings situated in climatic zones without district heating. Most of these offices use electric heaters or free-standing air conditioning units to heat the office space and they chose heating as one of the largest energy consumers in their offices. Responses from the companies with district heating say that the temperature is comfortable in the office in winter. In summer, 50% of the respondents say that the temperature in the office is comfortable and 38% think that it is too hot. Those who chose the 'too cold' answer were located in climatic zones with hot summers and extensive air cooling. These companies also stated that their largest energy consumer is cooling. The most common type of cooling system is freestanding AC units (56%). Companies from climatic zones with mild summers were expected not to use cooling; however, they stated that they also use AC units or fans.

The aim of the next section of questions was to check the level of awareness of the office occupants about the existence of the Standard and other regulations aimed at energy efficiency in commercial buildings (such as LEED and GOBAS described in section 5.5.1). A majority of the respondents (69%) have never heard about the Standard or other regulations aimed at energy efficiency in commercial buildings, but most of them (60%) would like to learn more about them. Those who had heard about the Standard were asked about the source of their knowledge. Most of them mentioned workshops, however, they did not know the details of the Standard and the requirements it provides; the respondents stated that the only thing they knew about the Standard was that it had been adopted.

The next section was aimed at the awareness of energy efficiency measures. All the respondents agreed that there is not enough promotion of energy efficiency measures and that media should be used more to increase people's awareness about it. In addition, for the energy efficiency measures to become more popular, the respondents suggested that the Government should provide more technical training and incentives and more stringent implementation tools.

The aim of the next section was to see if the respondents had already invested in energy efficiency measures and the results showed that out of 38% who adopted energy efficiency measures, 50% use low energy light bulbs, 33% double glazing, and 33% modern low-energy office equipment (A-rated efficiency). All chose to use energy efficiency measures to reduce energy consumption and therefore save money. The main reason for the rest of the respondents not to invest in energy efficiency measures is because they felt that it is too expensive (40%). However, this is a common but wrong perception about the investment in energy efficiency measures. As the case studies have shown (see sections 6.6.1, 7.6.1, 8.6.1, and 9.6.1), the investment in energy efficiency measures (such as insulation and use of low-energy light bulbs) is economically feasible. Other reasons for not investing in energy efficiency measures is a lack of knowledge about it (20%) and disbelief that they would make a difference (20%).

The next section was aimed at the level of awareness and implementation of renewable energy technologies within the commercial buildings sector. As in the previous section, all respondents agreed that there is not enough promotion of renewable energy technologies suitable for commercial buildings' use. 31% of the respondents use renewable energy technologies such as SWH systems and GSHP systems in order to provide more heating and hot water. 75% of the respondents would consider the use of renewable energy technologies and the extension of the technologies they already use. 67% of the respondents would like to use a PV system and 58% would choose SWH system, as, according to the respondents, these are the most well-known of technologies and other companies use them successfully. The reason for SWH systems being so popular is because of their affordable price and market maturity. 69% of the respondents do not currently use any renewable energy technologies because they are believed to be too expensive and they do not have enough information about them. Other reasons stated were unpredictable payback period, a lack of quality and low level of maturity. The factors that would influence their decision to use renewable energy technologies are incentives from the Government and a reduction in their costs. None of the respondents have chosen micro-scale wind turbines or biomass boilers as the technologies they would like to install explaining it by the fact that there is no information available about these technologies.

The last section of the questionnaire targeted the energy consumption of the respondents' buildings. 94% of the respondents state that they would reduce their energy consumption only because of high electricity prices. However, there were no responses stating that they would choose to reduce their energy consumption in order to reduce their carbon footprint and mitigate climate change. This leads to the conclusion that the awareness of climate change mitigation is quite low and that the respondents do not connect climate change mitigation with a reduction of energy use.

After the questionnaire, a space has been offered in order for the respondents to provide their comments about energy efficiency measures and the reduction of energy use. Most of the respondents suggested that they would like to receive more information about energy efficiency and that the Government should enforce wider incentives for small-scale renewable energy technologies and reduce the price of energy efficiency measures and renewable energy technologies.

Interviews have confirmed the information received through the questionnaires. According to the interviewees, the main problem with the implementation of the Standard is lack of awareness and promotion, as well as lack of financial incentives. According to Yan Leng, the use of external insulation was so far only possible on the show case houses, as house and bulding owners do not wish to invest into energy efficeincy measures. This can be explained by the belief that it is cheaper to heat or cool the space using air conditioning than to use insulation, as electicity prices are heavily subsidised. This opinion was confirmed by scholars form the Qinghua University, who also added that corruption is another barrier on the way of romoting energy efficiency measures.

10.2.3.2 Indicators

Indicator 1: Familiarity with the principles and measures among all involved parties

This indicator has been described in detail in previous section. Familiarity with the policy tool is usually one of the weakest points in policy implementation. Important factors behind the familiarity include not only political commitment, but also willingness from the other parties involved. It is also important for the government to modify the programme and to listen to the feedback from the involved parties. The previous section has proved that involved parties would like to be involved in the policy-making process.

Success and failure factors:

As was seen in section 10.2.3.1, there is a general lack of familiarity with energy efficiency measures and renewable energy technologies by occupiers. This often leads to a mistaken belief that investment in energy efficiency measures is not economically feasible. However, the analysis has shown that the users of commercial buildings are eager to learn about energy efficiency and with financial support from the Government, they would like to reduce their energy consumption.

In order to achieve a greater understanding of the benefits of energy efficiency and renewable energy technology use, the Government needs to stimulate the promotion via mass media and advertise their incentive programmes within the construction sector. Additionally, it is important to promote not only energy efficiency but its connection to climate change mitigation.

<u>Indicator 2:</u> Availability of the market resources and information

Governments play a key role in distributing and popularising energy efficiency among the target audience. They are also a key distributor of the financial support to the involved parties, such as companies that want to invest in energy efficiency measures.

No information is available on how much money the Chinese Government provides to support energy efficiency initiative. Currently, there are no subsidies or incentives for the implementation of the Standard to the existing buildings. However, the Government provides tax deductions for the implementation of renewable energy technologies on a macro scale. This has been discussed in section 4.3.2. In China, it is the role of the Central government to enforce the policy, and the responsibility of the local governments to make sure it will succeed.

Success and failure factors:

The responsibility of the local governments rather than central government for the implementation of the policy tools can be a great asset of policy implementation, as the local government has more knowledge about local conditions and local actors. Work on a local level creates a better link with the different parties involved in the policy tool implementation. However, this can be affected by a lack of control from the central government and high level of corruption. There are no guidelines from the central government on how to implement the policy tool and how to actively support and promote it.

Currently, the main objection for the wider implementation of the energy efficiency measures is that the materials and technologies that need to be used to meet the requirements are very expensive. The results of the four case studies have shown that in order to implement energy efficiency measures, and especially to install renewable energy technologies, such as PV, governmental financial support is crucial. If incentives were to be distributed, the use of renewable energy technologies would be wider.

This is very important, as China's market is certainly ready for deployment of energy efficiency measures. China is one of the world's top producers of the PV cells; however, most of them are used for export. Moreover, China manufactures all other widely known renewable energy technologies, as well as materials that help to reduce energy consumption in buildings. Case studies have shown a good example of this, as all the materials and technologies used for the payback period calculations are actually produced in China. It not only reduces the cost, but also reduced the embodied energy, as the emissions from transportation are significantly less.

Indicator 3: Extent to which design and construction companies follow the Standard

No quantitative information is available about the rate of new built and existing commercial buildings that follow the requirements of the Standard, so it is difficult to evaluate this indicator. Awareness, willingness, and skills are important factors influencing the final performance of the policy tool. However, it is also important for the designers and construction contractors to evaluate the extent to which they need to follow the Standard. The Standard provides requirements for glazing, buildings envelope, lighting and HVAC, however this does not mean that all of the requirements have to be implemented. The results of the case studies have shown that in some cases the implementation of one or another measure is enough to reduce the energy consumption of the building, which would reduce the investment and therefore be more cost-effective.

Indicator 4: Random inspections

It has been described in section 5.4 that regular random inspections are taking place on the local level and that penalties are stated for those who do not comply with the

Standard requirements. There is no information available as to whether the energy performance calculations on the design stage are comprehensively checked by officials. Interviews have shown that in most cases the building permit is granted if a standard package of energy savings measures is included. Though random inspections allow for checking of the quality of the construction, they are not sufficient, as they cover only the smallest part of the new construction and do not cover refurbishment processes.

Success and failure factors:

Inspections are successful only in cases where they are carried out by an independent body. This is not really the case in China as inspections are the responsibility of the MOC. Moreover, most of the inspectors are construction engineers rather than technical engineers, and lack an understanding of electrical and mechanical installations, which are crucial, as a careful implementation of energy savings measures is essential to achieve energy savings (information is obtained through the interviews).

<u>Indicator 5:</u> Reduction of energy consumption and emissions and <u>Indicator 6:</u> Realised energy savings: These indicators are linked, as the Indicator 6 is a result of Indicator 5, therefore they will be discussed together here.

Hamerlink *et al* define the impact of a policy instrument as "the extent to which a policy instrument made a difference compared to the situation without a policy instrument (BAU)" [Hamerlink et al., p.139, 2008]. In order to see the energy-saving impact, it is presented as the annual energy efficiency improvements during the evaluated period. It is important to mention that data on the impact of energy-savings measures is highly uncertain due to the limited availability of the data. Some of this data has to be assumed to be based on the 'real-life' performance of energy saving measures. However, for the four case studies analysed here, the above mentioned equation was not used, as the Standard does not state how long it will be enforced for. Therefore, only annual savings have been calculated and the results were presented in case studies.

The results of the case studies showed that with the implementation of the Standard energy savings varied depending on the climatic zone of the case study building. As the Standard provides two aims of energy savings (a general 50% energy reduction, and specific aims for envelope, lighting and HVAC), both targets have to be taken into account when evaluating. As can be seen in figure 10-4, in terms of the general target of 50%, only one case study (Kunming Hotel building case study, see chapter 6) would reached the target. This is due to the fact that the temperature fluctuations throughout the year in Kunming are very minor, therefore when introducing energy efficiency measures such as insulation, they work well during all seasons. This was not so in other case studies, where the temperature difference between hot and cold months is large. As the energy efficiency measures suggested by the Standard are mainly aimed at heat loss reduction, it has caused the increase in heat gains and therefore increases in energy consumption for cooling purposes.

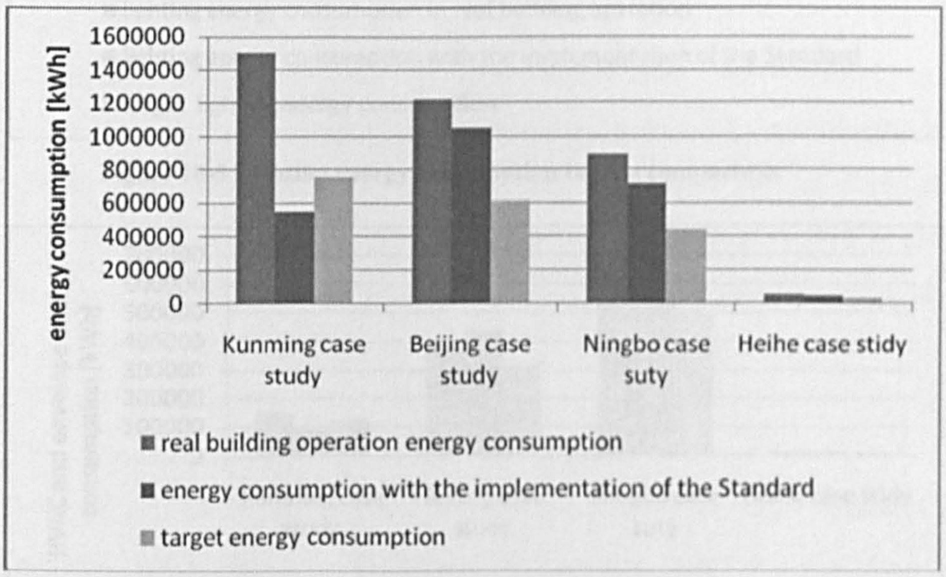

Figure 10-4 Energy consumption targets comparison

As for the specific targets mentioned in section 5.4.2, they have varied from case study to case study as well, as can be seen in Figures 10-5 and 10-6.

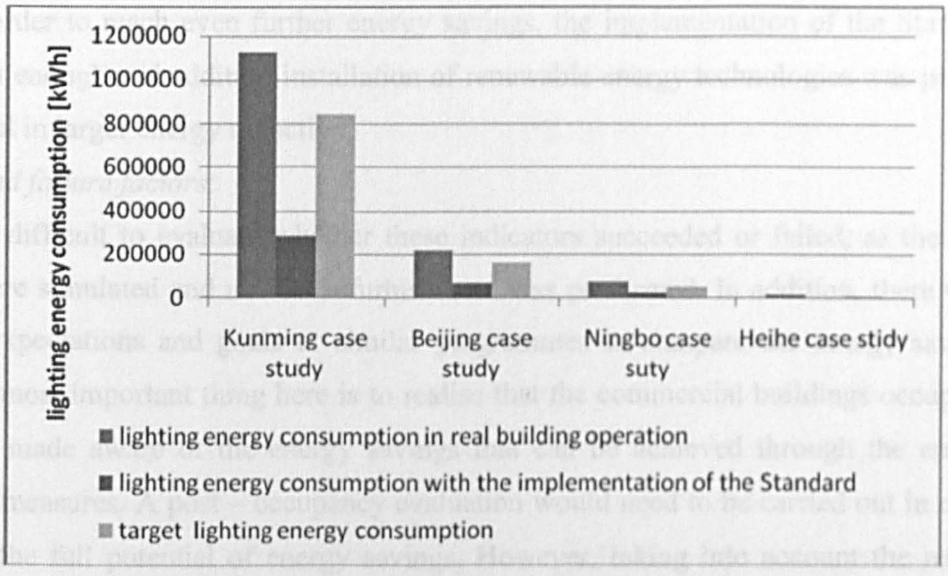

Figure 10-5 Lighting energy consumption targets comparison

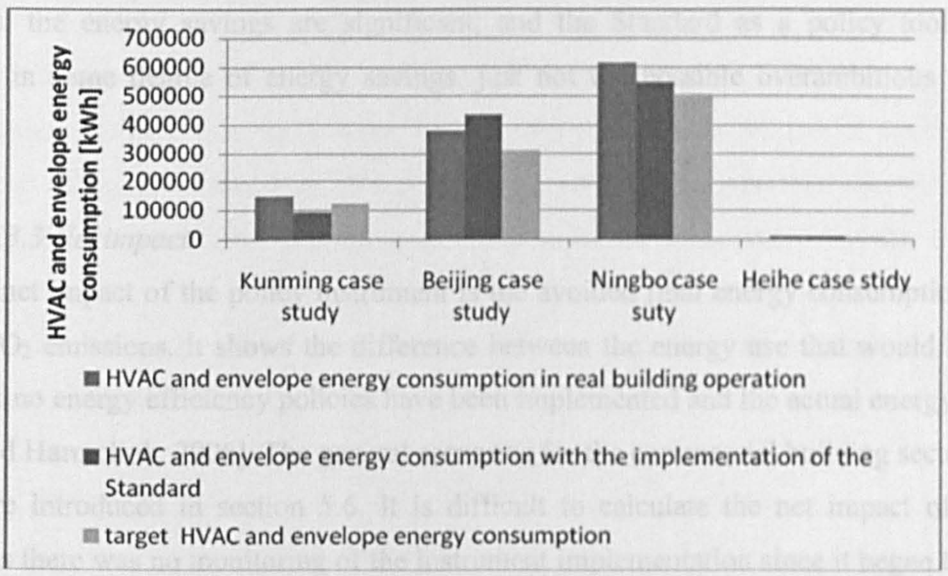

Figure 10-6 HVAC and envelope energy consumption targets comparison

All the targets for the reduction of lighting energy consumption would be achieved if the Standard were implemented, however, HVAC and envelope reduction targets failed in two out of four case studies. Again, as was explained above, the failure was due to the increase in cooling requirements during the cooling season. As for the emissions reduction, the Standard does not mention any emissions reduction target, however, it has been calculated from the energy reduction.

In order to reach even further energy savings, the implementation of the Standard only is not enough and addition installation of renewable energy technologies was proved to be useful in larger energy reduction.

Success and failure factors:

It is difficult to evaluate whether these indicators succeeded or failed, as the case studies were simulated and no real refurbishment was performed. In addition, there were no prior expectations and goals or similar programmes to compare the energy savings with. The most important thing here is to realise that the commercial buildings occupants should be made aware of the energy savings that can be achieved through the energy efficiency measures. A post – occupancy evaluation would need to be carried out in order to realise the full potential of energy savings. However, taking into account the results reached in these case studies, it can be stated that the targets of the Standard are achievable, the energy savings are significant, and the Standard as a policy tool has succeeded in some degree of energy savings, just not the possible overambitious 50% target.

10.2.3.3 Net impact

The net impact of the policy instrument is the avoided final energy consumption or avoided CO_2 emissions. It shows the difference between the energy use that would have occurred if no energy efficiency policies have been implemented and the actual energy use [Joosen and Harmelink, 2006]. The general scenarios for the commercial building sector in China were introduced in section 5.6. It is difficult to calculate the net impact of the Standard as there was no monitoring of the instrument implementation since it began to be enforced.

10.2.3.4 Effectiveness

The effectiveness of the instrument is a complex issue. In quantitative terms, it has been discussed above that the Standard has reached the target in most cases, and therefore can be considered as effective. In qualitative terms, the Standard reached the audience that is involved in design and construction. It means that most of the society is not reached, and within the target audience those who are interested in energy efficiency and renewable energy technologies are more easily influenced by the tool. It is also very difficult to decide if there will be more participants interested in energy efficiency measures if the Government provides more financial support although results of the interviews suggest this would be the case.

In terms of Chinese policy implementation, there is no doubt that the implementing body (the MOC) has a clear mandate, responsibility, and adequate resources, which are underlined by AID-EE as primary prerequisites for success [Harmelink et al., 2008]. The same refers to the continuity of a program as it is backed by strong political will. The problem that the policy instrument might be experiencing is flexibility, meaning the ability to adapt to changing conditions and to remove fail factors in the implementation process. Specific barriers, such as a lack of information and a skills base are easily removed, but this is not always possible when the government is the only body in charge of policy implementation. It was also noted by AID-EE that the involvement of stakeholders might positively influence the success of the instruments. The involvement of stakeholders is not currently practiced in China. In Europe, the involvement of stakeholders is used as a means of increasing acceptance and considering the stakeholders interests. Stakeholders should include end users and any other actors that might be affected by the policy instrument [Hamerlink et al., 2008].

Instrument cannot be effective of its own and has to be considered with regards to all the instruments related to the same issue.

10.2.3.5 Cost effectiveness

According to Harmelink et al, cost effectiveness is "the ratio between the energy-saving impact and the amount of money needed to achieve this impact and can be expressed in Euro per GJ or kWh saved" [Harmelink et al., p. 141, 2008]. In order to achieve a complete cost effectiveness evaluation, costs should be assessed from three different perspectives [Harmelink et al., 2008]:

- *End user*: these are the costs experienced by the end user responsible for the implementation of the energy efficiency measures (building owners in this case). These costs are the additional costs that have to be made by the end user compared to the BAU.

- *Society*: these are the costs experienced by the whole society for the implementation of energy efficient measures. The difference between end user costs and society costs is the time preference.

- *Government*: these costs include all expenditures related to the implementation of the policy instrument, such as subsidies, grants, etc.

It is difficult to make a complete cost effectiveness evaluation of the standard due to non-transparent documentation in China. In addition, the society cost cannot be calculated at this moment of time as the Standard has only been implemented recently and has not run to complete yet. Therefore, the costs that were calculated were end user costs.

In this project, the cost effectiveness has been presented as a length of the payback period. In his book, Bobenhausen (1994) states, that an investment is cost effective when it is paid back in no longer than 20 years. The case studies results have shown that the installation of the SWH and GSHP are cost effective in China with a payback of 3 to 9.5 years. It is not necessarily the case for the biomass heating system. Both Beijing and Heihe case study building are in climate zones where central heating is provided by district heating throughout the coldest months of the year (November to March) and the heating prices are heavily subsidised by the government. Therefore, investment in biomass heating systems is much higher than the actual price paid and should also be supported by the government. It is important however to remember that even though the installation of a biomass heating system is not cost effective, it reduces fossil fuel derived CO_2 emissions dramatically, as all district central heating is coming from the coal- fired power stations. The use of solar PV systems proved to be the most energy efficient way of reducing electrical energy consumption using renewable energy technologies and could play an important role in energy savings, but none of the case study results have shown that the installation of solar PV is cost effective. Currently, China does not provide any financial support to micro-scale renewable energy technologies. In order to provide 25% of the electricity from the renewables (as it is required by China's Renewable Energy Law) in the case studies examined here the payback period for PV would last around 90 years. The implementation of a FIT was suggested and used for further calculations, in which case the payback period was reduced to an average around 28 years. The refurbishing of the building according to the requirements has proven to be cost effective in two cases

(Kunming and Beijing case studies), but non-cost effective in the other two case studies (Ningbo and Heihe) which had payback periods of more than 20 years. This can be explained by the fact that Kunming and Beijing case study buildings had originally been better constructed and did not require dramatic changes (for example, in the case of Beijing, glazing, which is the most expensive part of refurbishing, did not have to be changed).

Another important component of energy efficiency policies and their cost-effectiveness is adequate pricing. There are two sides of this problem. First, financial support has to be offered by the government in order to promote energy efficiency: incentives for behaviour changes and correct signals to consumers should be given. Second, the prices have to be adequate and not require major subsidies from the government, as often happens in energy intensive countries. Low energy prices stimulate high energy use; therefore, a cut in subsidies can not only offer a dramatic reduction of energy use, but also bring benefits to a country's budget. Pricing has to reflect the cost of energy supply. However, many policy-makers, in fear of public resistance, do not agree with this objective, and this makes the actual price adjustment slow or impossible in many developing countries [www.worldenergy.org].

These results show that without the governmental financial support it is not cost-effective to follow the Standard requirements.

10.3 Summary

Importantly, this Standard is the only standard in China currently aimed at the energy efficiency of commercial buildings. Most of the instruments announced as energy efficiency instruments are targeted at industry or households. Using the cause-impact assessment step of the policy evaluation it is possible to identify the Standard's success and failure factors. When evaluating success and failure, it is important to take into account such general factors as the existence of clear goals and a mandate for the implementing organisation, the ability to balance and combine flexibility and continuity, the involvement of stakeholders, and the ability to adapt and integrate adjacent policies and develop the consistent policy packages [Harmelink et al., 2008].

The most important factors that determine the success of the policy tool, are:

1. The government understands the importance of the energy efficiency measures and encourages different sectors to reduce their energy consumption.
2. The market in China is prepared for the introduction and sharpening of energy efficiency standards. The energy efficient technologies and materials are available. The government also tries to make the Standard requirements compulsory in the construction sector.
3. The Standard is well tightened with other regulations and policies aimed at the energy efficiency.

However, there are still several negative factors influencing the Standard:

1. The knowledge of the targeted audience is not always sufficient.
2. The random inspections are not sufficient to understand whether the requirements are met and if the construction sector and building owners comply with them.
3. The absence of a monitoring process does not allow an evaluation of the effectiveness of the Standard.

The enforcement of energy efficiency measures is a crucial step for theory policy, but it should be noted that even if all the steps of the policy tool function perfectly well, it is very difficult to measure the impact of the policy tool like this Standard in terms of energy. This is firstly due to the fact that the Standard is a purely technical tool meaning that it would be difficult to determine how many buildings have actually been implemented without a decade of serious monitoring, which would requires a large amount of finance. Secondly, even in the case of monitoring, the information would come from different local governments, and therefore a central database would be required in order to complete any statistical analysis. Thirdly, there are tight links with other policy instruments, especially economic ones, and without their evaluation, it is difficult to determine the role that the Standard plays when compared with other policy instruments.

No one policy can achieve a total emission reduction from energy efficiency in the commercial buildings sector. A set of policies and measures would have to be implemented. The most successful type of policies for commercial buildings sector is command and control policies; however, these must be supported by information awareness campaigns and encouraging financial signals. Moreover, policies for the commercial building sector should not just focus on actual buildings but also on the implementation of renewable energy technologies, co-generation and energy generation on site, if possible. Policy instruments must be developed with the consideration of the geographical location of the commercial buildings. Some areas are more likely to implement renewable energy technologies or to be connected to the grid where the electricity comes from renewable energy source. In addition, different regions have different levels of motivation in reducing energy consumption.

Policy monitoring and evaluation have to be implemented in China in order to predict the outcome. The evaluation data has to include current market characteristics. The data for the evaluation has to be more transparent and accessible. It is also important for the policy to be certain; otherwise, no investor would risk investing in energy efficiency, especially taking into account the fact that renewable energy technologies and other energy efficiency measures can have long payback periods and are not always economically feasible.

By no means, there is no perfect instrument that can improve energy efficiency on its own. However, the effect of the policy instrument mostly depends on the way it is designed and implemented. Moreover, in order to make the policy instrument more effective, policy makers have to monitor and evaluate the instrument and continuously revise and improve it.

Considering the results of the case studies, the building performance improvement leads to the energy savings and therefore, brings advantages for the energy users. However, the value of the energy saving is not well known and understood. This, however, is not due to the technical issues. All the materials and technologies used in the case studies are known and are readily available in China. The main barriers to overcome are non-technological barriers, with the most of them being economical: poor education in the field of energy efficiency, strong dislike of change, a lack of information on energy efficiency, a lack of financial tools, and a lack of control.

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Chapter 11 – Conclusions and future work

This work has investigated the current situation of energy efficiency policies for commercial buildings in China and evaluated their effectiveness. It has also discussed energy efficiency improvement measures suitable for commercial buildings in the Chinese national context. Four detailed case studies were undertaken in order to provide technical support for the theory-based policy evaluation of the Design Standard for commercial buildings in order to be able to discuss its effectiveness and to make suggestions for future improvements.

11.1 Conclusions on energy efficiency policies implementation

Energy efficiency policies are introduced for various reasons. In some cases, it is due to economic constraints, such as high oil prices. In other cases, global issues such as climate change mitigation and adaptation as well as energy security is the reason. Policy making is often based not on science but on political rationality, and policy makers trust their experience and intuition in which direction they need to go rather than by making objective evaluations.

China's economic development speed is dramatic, and the willingness for their development is the main reason for a large increase in energy demand. China is making a great effort to increase energy efficiency and reduce energy intensity, but it is clearly hard to achieve as coal is still dominating China's energy mix and it predicted to do so for the upcoming decades. Energy efficiency is seen as one of the priority areas for the Chinese government and this can be seen form the variety of policies implemented an the role of energy efficiency in Five Year Plans. China plays an active role in international efforts on climate change mitigation. China is also undertaking many measures to improve of energy efficiency by formulating different types of legislation and introducing different renewable energy technologies.

One of the important parts of the energy efficiency legislation is the policies towards energy efficiency in commercial buildings. Their main tools are design standards, testing standards, building energy consumption standards, etc. Improvement of buildings energy efficiency is the quickest and the most effective way of creating energy savings in buildings. However, even though policies are in place, they are not fully used, as this work has found that they are not strict enough. Also the Chinese government should stimulate more interest amongst design and construction companies and building owners by creating more market incentives, promoting high-performance appliances, institutionalising the energy performance assessment system, and tightening fines for non-compliance. In other words, carrot and stick policies should be adopted. These policies should mainly be based on financial punishments and awards, as this is the only way in boost the interest into energy efficiency. This conclusion was confirmed by the result received through the questionnaires: they showed that building owner and tenants worry about reduction of bills rather than CO_2 emissions, and they do not associate one with another. This also shows that lack of awareness is present and is one of the barriers on the energy efficiency application.

Moreover, better enforcement and implementation of the energy efficiency policies can be assured by the creation of a separate governmental body in charge of energy related issues. Up to date, the energy-related problems are normally a second to the priority issues for the governmental bodies in charge, and this slows down the process of promotion and supporting of energy efficiency.

11.2 Conclusions on renewable energy technologies development

Undoubtedly, the development of renewable energy technologies is the best choice for climate change mitigation and ensuring long-term energy security. The Chinese government has issued a series of policies supporting the development of renewable energy technologies. However, for renewable energy technologies to be installed and widely popularised, more measures based mainly on economic support instruments should be taken. These measures include subsidies, tax reliefs, low interest loans, etc, and have been discussed in chapter 4. Moreover, other measures such as public awareness and maturing technologies should also motivate consumers to invest in renewables. Subsidies can be offered in order to reduce the initial costs and therefore shorten the payback period. Moreover, subsidies can show that the government is interested in the promotion of renewable energy technologies and thus stimulate public interest and build consumers confidence in reliability of the renewable energy technologies. However, the disadvantage of the subsidies is that they can have high cost on the public budget. Moreover subsidies can cause a price increase for renewable energy technologies in anticipation of the rebates that purchaser will be granted. The aim of tax reduction is similar to the effects that subsidies have. Tax reduction has been introduced in China and is widely used, mostly for large-scale wind and PV technologies. Tax reductions represent a loss in tax revenue for the government and they do not lower the barrier for the initial payment for capital and therefore are not affordable for those with low-income.

Economic incentives are often crucial when promoting renewable energy technologies. All these should be tightened together with regulations in order to achieve the wider use of renewable energy technologies. Currently, renewable energy technologies are not justifiable from a financial point of view, mainly because potential investors lack sufficient information and therefore trust in technologies; prefer immediate savings to long-term payback periods, etc. It should be pointed out that not all energy efficiency policies result in cost-effectiveness. The non-cost benefits (climate change mitigation, energy security) must be valued as they can exceed the cost values in a long term.

11.3 Case studies conclusions

The analysis of the four case study buildings in different climate zones in China allowed for the investigation into the main problems of buildings as energy consumers and discussion about the technical and economical effectiveness of the implementation of the Standard.

As the analysis has shown, for all case study buildings, the main problems with their current operations were big heat losses during winter periods and big heat gains during summer periods, which can be explained by poor thermal qualities of the construction materials and the low energy efficiency of lighting and equipment.

The simulated implementation of the Standard has shown that it is possible to achieve individual targets for lighting, HVAC and building envelope energy reduction when using the materials recommended by the Standard. The analysis has also shown that not all requirements have to be compulsory, as in some cases, the installation of just insulation or glazing was enough to achieve the target. It has also been calculated that the implementation of the Standard requirement in cost-effective. The Standard does not incorporate the office equipment energy efficiency requirements. However, as in some of the case studies the equipment is the largest energy consumer, it is clear that the incorporation of energy efficiency requirements for the office equipment would reduce to further energy consumption reduction.

It order to further reduce energy consumption and therefore emissions, a simulation of the potential installation of renewable energy technologies was performed. The results were taken as an assumption that the installation of the renewable energy technologies helps further reduction of the energy consumption. However, as was shown in the case studies, though all of the renewable energy technologies suggested for the installation are in their maturity stage in China, their installation is still very limited by economic constraints, such as high initial investment and long (and often economically non feasible) payback period, therefore the government incentives, such as Feed-In Tariff, as necessary in order to stimulate renewable energy technologies development and maturity.

11.4 Theory-based policy evaluation conclusions

The evaluation of the Standard has shown that it is an important tool in energy efficiency encouragement in commercial buildings in China, however, its effectiveness is negatively affected by the lack of a monitoring system and a lack of awareness among the involved parties, such as design and construction companies and building owners.

Energy efficiency policies on their own are not enough to improve energy efficiency. It is well known that the rebound effect might appear when the energy is saved; therefore, when introducing the policy, it is important to introduce the awareness campaign as a part of the policy as well. Energy efficiency policies on their own are not able to halt the growth in energy consumption or emissions. Taking into account concerns about energy security and the threat of climate change, policy makers should emphasise the lifestyle and behaviour of occupiers when talking about energy efficiency. Policy makers should also make sure that policies do not encourage larger spaces, more appliances, etc. As Lebot et al. when talking about sustainability in general (2005) said, "Energy efficiency is but part of the solution" [Lebot et al, 2005].

The questionnaires showed a good example of the lack of awareness in terms of energy efficiency measures, energy efficiency related policies and renewable energy. The main way of promoting this information (i.e. media) is not used properly, and the end users are not encouraged to be involved into energy conservation. Instead, the government sends mixed signals on energy consumption: a good example of it is electricity subsidies, which makes paying for heating cheaper than the installation of insulation and better glazing.

The awareness of renewable energy technologies is also low and the prices are high, which again does not help to spread renewables among the population. China' being the biggest producer of PV and having one of the largest amount of wind farms, should promote the use of renewable energy technologies not only in rural non-electrified areas, but in urban areas as well, as it would not only reduce China's coal consumption, but would increase energy security as well.

Lack of monitoring is affecting the level of policy implementation as well. In order to make the process of monitoring stronger, there is a need in a separate government body which would be in charge of energy efficiency implementation and control. Corruption is by no means is a barrier, and it is up to Chinese government to find the solution for this matter. Unfortunately, without a well-established monitoring system it is impossible to fully analyse the amount of work done by Chinese government into energy efficiency.

By no means, like any other public policy or programme, energy efficiency policies can be poorly designed or enforced. However, this does not mean that they should not be implemented. The point is to learn from the failures and find better solutions.

This evaluation has shown that the implementation and the enforcement of the policy is not the most important part of the policy cycle. Without the monitoring and awareness, the policy can fail without achieving the set targets.

11.5 Future work

Throughout the research period a number of areas were identified in which future work would be a great asset to improving energy efficiency measures for commercial buildings in China.

Research on post occupancy could play an important role in further evaluating the effectiveness of the discussed Design Standard for Energy Efficiency in Public Buildings. This is important as it is the occupants who use energy in the building, and their behaviour can change the energy consumption pattern dramatically. This research could be conducted together with the better understanding of occupants energy awareness and their willingness to have a 'greener' and more sustainable life. Moreover, the promotion of energy efficient behaviour is a very interesting area. As this evaluation has shows, this area has the biggest gaps, and it is important to find the solutions to fill these gaps.

In addition, an in-depth life-cycle analysis of the materials used to follow the requirements of the Standard could be done, in order to be able to analyse the embodied energy of the buildings and the implementation of the Standard. This is also necessary in order to find better options in building energy reduction. This should incorporate in-depth financial analysis, as well as the evaluation of a short-life span on Chinese buildings and its influence on the environment. Another interesting area to investigate would be the rebound effect that the Standard might cause among commercial buildings users and owners.

The future work should be conducted together with the specialists from different areas, as energy efficiency cannot only be analysed from technical point of view. It is necessary to involve educators, social scientists, economists, politicians, as well as engineers and architects.

Undoubtedly, today's world is facing energy challenges, which include not only the concern about climate change, but also peak of oil production and energy security. Energy efficiency is only one of the many tools that can be used to address these challenges, but it is certainly one of the most important tools.

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Appendix A - List of people interviewed during the field trip to China in October – December 2008

1. Prof. Jo Darkwa, Director, Centre for Sustainable Energy Technology, University of Nottingham, Ningbo, China
2. Prof. Wei Qingpeng, Tsinghua University, Head of Research Team, Building Energy Research Centre, Tsinghua University, Beijing
3. Mr. Wu Orlando, Head of the Estate Office, University of Nottingham, Ningbo, China
4. Mr. Yan Leng, General Manager, Construction Industry, BASF Chemical Company, Shanghai
5. Dr. Zeng Shaojun, Clean Development Mechanism Research & Development Center of Public Policy and Management School, Tsinghua University
6. Prof. Zhang Yinping, Director, School of Architecture, Tsinghua University, Beijing

Appendix B – Questionnaires

English version

PURPOSE OF THE QUESTIONNAIRE

This questionnaire is the part of a PhD project in the School of the Built Environment, University of Nottingham, UK.

The aim of the questionnaire is to evaluate the awareness of the owners and tenants of office spaces about energy efficiency and renewable energy technologies and to find out their opinion about the subject.

The questionnaire consists of just five sections covering general information about your office building and information about energy efficiency, renewable energy technology and energy consumption.

The questionnaire is anonymous. No information about the company except for its general climatic location need be provided. The questionnaire can be answered by the estate officer or by the head of the company. Some questions suggest the answers. You can choose one or more answers. Other questions ask for more information.

GENERAL INFORMATION

1. **Please indicate the location of your office building**

   Province:

   City/town:

2. **Do you own or rent the office space?**
   a) Own
   b) Rent
3. **In winter, is the temperature in your office comfortable?**
   a) Comfortable
   b) Too cold
   c) Too hot
4. **In summer, is the temperature in your office comfortable?**
   a) Comfortable
   b) Too cold
   c) Too hot

INFORMATION ABOUT THE STANDARD

In 2005 the Ministry of Construction implemented the Design Standard for Energy Efficiency of Public Buildings" GB50189-2008 (the Standard). It is a mandatory national model energy standard, which is applicable to local governments and construction commissions. The aim of the Standard is to reduce the energy use of public buildings by 50% in comparison to the buildings constructed in 1980s. The average savings from the building envelope and Heating, Ventilation and Air Conditioning (HVAC) should be 13-25%, and from lighting about 7-18%.

The Standard covers new construction, expansion, and retrofit of commercial buildings. It also covers the building envelope and HVAC system. The Standard specifies minimum insulation requirements and construction materials for different climate zones. It recommends energy efficiency for HVAC systems, and provides design guidelines for energy efficiency requirements. Moreover, it covers monitoring and control of buildings.

5. **Have you heard about this Standard before?**
   a) Yes (*move to Question 5.1*)
   b) No (*move to Question 5.4*)

5.1 How did you learn about this Standard?

5.2 What have you heard about it?

5.3 What factors would influence your decision to refurbish your office according to the Standard?

a) Climate change (Reduction of green house gas emissions)
b) In order to save energy
c) In order to reduce energy bills
d) Government offers financial support or tax reductions
e) Other (*please specify*)

5.4 More information about the Standard can be found at the Ministry of Construction website. Would you like to learn about the Standard?

a) Yes
b) No

6. **Do you know about LEED or GOBAS certification?**
   a) Yes
   b) No

ENERGY EFFICIENCY IN COMMERCIAL BUILDINGS

7. **Do you think tenants and owners of the commercial buildings receive enough information about the energy efficiency and energy savings?**
   a) Enough
   b) Not enough
   c) Too much
   d) Do not receive any information at all
8. **How do you perceive the Government to promote energy efficiency in commercial buildings?**
   a) Mass media
   b) Trainings
   c) Letters with the information on energy efficiency
   d) Invitations to visit energy efficient buildings
   e) There is no promotion
   f) Other (*please specify*)
9. **Do you think the Government promotion of energy efficiency in the buildings is enough?**
   a) Yes
   b) No

9.1 Why?

10. **Do you invest in energy efficiency measures (for example, improving insulation of the building envelope, changing single glazed windows to double glazed windows, using low-energy light bulbs)?**
   a) Yes (*please answer question 10.1*)
   b) No (*please answer question 10.3*)

10.1 How have you improved energy efficiency in the building?

a) Improved insulation

b) Changed window glazing

c) Used low energy light bulbs

d) Used modern, more energy efficient equipment and appliances

e) Used renewable energy technologies

f) Use of smart energy meters or sub-meters

g) Other (*please specify*)

10.2 What is the reason you invested in energy efficiency measures?

a) Climate change

b) To save money

c) To reduce energy consumption

d) Other (*please specify*)

10.3 What is the main reason you have not invested in energy efficiency measures so far?

a) Too expensive

b) Do not know anything about it

c) Do not see the point

d) Other (*please specify*)

RENEWABLE ENERGY TECHNOLOGIES

11. Do you think tenants and owners of the commercial buildings receive enough information about renewable energy technologies?

a) Enough

b) Not enough

c) Too much

d) Do not receive any information at all

12. How do you learn about renewable energy technologies?

a) Mass media

b) Information letters

c) Exhibitions

d) Other companies

e) I do not know anything about renewable energy technologies

f) Other (*please specify*)

13. Do you use renewable energy technologies?

a) Yes (*please answer question 13.1,13.2 and 13.3)*

b) No (*please move to question 13.4 and 13.5*)

13.1 If yes, what renewable energy technologies do you use?

a) PV

b) Wind turbine

c) Solar water heating

d) Biomass boiler

e) Ground-source heat pump

f) Other (*please specify*)

13.2 What is the reason for you have chosen to use renewable energy technologies?

13.3 How much electricity is produced from the renewable energy technologies in your office?

a) 5-10%

b) 10-30%

c) 30-50%

d) More than 50%

e) Not sure

13.4 What is the reason you do not use renewable energy technologies?

13.5 Would you consider using renewable energy technologies?

a) Yes (*please answer question 13.6, 13.7 and 13.8*)

b) No (*please answer question 13.9*)

13.6 Under what conditions would you use renewable energy technologies?

a) Cheaper price

b) Government provides financial support

c) Saving in energy and reduced energy bills

d) Other (*please specify*)

13.7 What renewable energy technologies would you use?

a) PV
b) Wind turbines
c) Solar water heating
d) Biomass boiler
e) Ground-source heat pump
f) Other (*please specify*)

13.8 Please explain your choice?

13.9 Please, explain why you would not want to use renewable energy technologies?

a) Too expensive
b) Do not know anything about them
c) Do not see the point of using them
d) Other (*please specify*)

ENERGY CONSUMPTION

14. In winter, what type of heating in the office do you use?

a) Electric heaters
b) Heating from the air conditioners
c) Heating from the central air conditioning system
d) District heating (*please answer question 14.1*)
e) Do not use heating
f) Other (*please specify*)

14.1 If you use district heating, do you think the price for the heating season is:

a) Average
b) Too cheap
c) Reasonably cheap
d) Too expensive
e) Reasonably expensive

15. In summer, what type of cooling in the office do you use?

a) Free-standing air conditioners

b) Fans

c) Cooling from the central air conditioning system

d) Do not use cooling

e) Other (*please specify*)

16. Do you think the electricity price is:

a) Too cheap

b) Reasonably cheap

c) Average

d) Reasonably expensive

e) Too expensive

17. Do you think your office annual energy consumption (in kWh) is:

a) Low

b) Average

c) High

17.1 If known, what is the annual electric energy consumption (based on the last year figure):__________kWh

18. Do you know what the biggest electricity consumer in your office is?

a) Lighting

b) Cooling

c) Heating

d) Equipment

e) I don't know

f) Other (*please specify*)

19. What would influence your decision to reduce the energy consumption in the office?

a) High electricity prices

b) Saving money on electricity bills

c) Climate change (reduce CO_2 emissions)

d) Other (*please specify*)

20. Do you know if there are any companies that offer any advice on how to reduce the energy consumption in the office?

a) Yes (*please answer question 20.1*)

b) No (*please go to question 21*)

20.1 Have you ever been offered any advice on energy consumption reduction?

a) Yes

b) No

21. Do you know about any financial incentives the Government provides for commercial buildings to reduce their energy consumption / improve their energy efficiency?

a) Yes

b) No

22. Would you like to be involved in energy efficiency policy-making?

a) Yes

b) No

23. Please leave any comments or thoughts below about improving energy efficiency in commercial buildings.

Chinese version

问卷目的:

以

下问卷是英国诺丁汉大学工程系博士研究生的课题之一.主要目的是调查公共物业主或承租人对于能量效率和可再生能源技术意识的观 点. 问卷包括五个部分: 概要、"公共建筑节能设 计标准" 的信息、公共建筑能效、可再生能源技术以 及能耗.

接受问卷调查者无需提供生名或公司其他的资料, 只要提供建筑物地点.

接受问卷调查者可以来 自贵公司的工程部员工或贵公司之领导. 选择题答案可以任挑一个或多个对建议性问 题需提个人观 点.

概要:

1. 贵公司办公楼位 于:
   省:
   城市 :

2. 您是贵公司办公楼之业主或承租人?
   a) 办公室之业主
   b) 承租人

3. 冬天的时候办公楼里的温度舒服吗?
   a) 舒服
   b) 太热
   c) 太冷

4. 夏天的时候办公室里的温度舒服吗?
   a) 舒服
   b) 太热
   c) 太冷

"公共建筑节能设 计标准"的信息:

2005 年，为贯彻"节约能源法"和推动建筑节能50%设计标准的实施，建设部颁布了"公共建筑节能设计标准"（标准）。标准对所有新建，改建和扩建的

公共建筑（办公楼、餐饮、旅馆、百货楼等）的能耗设计予以规范和要求。标准能耗主要包括围护结构以及采暖，通风，空调能源消耗。标准包括围护结构传热系数限值，风机的单位风量功率限值等。标准是在基准能耗的基础上确定了采暖，

空调能耗降低13 - 25%的节能目标。照明节能降低7 - 18%的节能目标。

5. **您听说过这个标准吗？**

   a) 听说过（*请回答5。1 - 5。3问题*）
   b) 没听说（*请回答5。4问题*）

5.1 您是从何听说这个标准？ *(请写一下)*

5.2 关于这个标准您知道多少？ *(请写一下)*

5.3 什么因素会影响您的决定根据标准装修您的办公楼？

a) 气候变化（减少二氧化碳排放）
b) 节约能源
c) 减少能源开支
d) 中国政府（建设部）提供资金资助或者减税
e) 其他（*请指定*）

5.4 更多有关此标准的咨询可以在建设部之网站上找到。 您想知道更多吗？

a) 想
b) 不想

6. **您知道关于LEED 标准（绿色建筑评估体系能源和环境设计导）、CASBEE 标准（建筑物综合环境效率评价体系）或者别绿色的建筑评价标准吗？**

a) 知道
b) 不知道

<u>**公共建筑能效**</u>

7. **您认为业主或承租者有没有收到足够的关于能效和节能信息？**

a) 太多
b) 足够
c) 不足够

d) 没有

8. 您是从何处知道中国政府（建设部）提倡公共建筑能效？

a) 大众媒体
b) 培训和专题研讨会
c) 能效有关小册子
d) 被邀请参观绿色建筑
e) 其他（*请指定*）
f) 政府没有提倡公共建筑能效

9. 您觉得中国政府（建设部）提倡公共建筑能效做得足够吗？

a) 足够
b) 不够

9.1 为什么？*(请写一下)*

10.贵公司投资建筑能效措施吗？（比如说：
改善建筑围护结构材料、用双层玻璃代替单层玻璃、用低能照明等）

a) 投资（*请回答10.1 - 10.2问题*）
b) 没有投资(*请回答10.3 问题*)

10.1 贵公司怎么改善建筑能效？

a) 改善建筑围护结构隔离材料
b) 安装更好的玻璃窗
c) 使用低能照明
d) 使用高能效的设备和电气用品
e) 使用可再生能源技术
f) 使用分支电表
g) 其他（*请指定*）

10.2 贵公司投资能效的原因:

a) 气候变化（减少二氧化碳排放）
b) 节约能源
c) 减少能源开支
d) 中国政府（建设部）提供经费资助或者减税
e) 其他（*请指定*）

10.3 贵公司不投资能效的原因:

a) 太贵
b) 不了解能效措施
c) 不愿意
d) 其他（*请指定*）

<u>可再生能源技术</u>

11.您认为业主或承租者关于可再生能源技术有收到足够的咨询吗？

a) 太多
b) 足够
c) 不足够
d) 没收到什么信息

12.您从何知道可再生能源技术？

a) 大众媒体
b) 阅览会
c) 可再生能源技术有关小册子
d) 别的公司
e) 其他（*请指定*）
f) 我不知道可再生能源技术

13.贵公司使用可再生能源技术吗？

a) 使用(*请回答13。1 - 13。3问题*)
b) 不使用(*请回答13。4 - 13。5 问题*)

13.1 贵公司使用什么可再生能源技术？

a) 光生伏打 (PV)
b) 风力涡轮机
c) 太阳能热水器
d) 生物量锅炉
e) 地源热泵
f) 其他 (*请指定*)

13.2请写一下贵公司使用可再生能源技术的原因？

13.3 安装在贵公司的可再生能源技术可提供多少电源？

f) 5-10%
g) 10-30%
h) 30-50%
i) < 50%
j) 不知道

13.4请写一下贵公司不使用可再生能源技术的原因？

13.5 贵公司会考虑使用可再生能源技术吗？

a) 会考虑 (*请回答13。6 - 13。8 问题*)
b) 不会考虑 (*请回答13。9问题*)

13.6 什么原因会影响您公司使用可再生能源技术？

a) 便宜价格
b) 节约能源和减少能源开支
c) 中国政府 (建设部) 提供经费资助或者减税
d) 其他 (*请指定*)

13.7 贵公司会使用什么可再生能源技术？

a) 光生伏打 (PV)
b) 风力涡轮机
c) 太阳能热水器
d) 生物量锅炉
e) 地源热泵
f) 其他 (*请指定*)

13.8 请阐明您的选择.

13.9 请阐明贵公司不愿意使用可再生能源技术的原因.

能耗

14.冬天的时候，贵公司的建筑里面使用什么样的采暖系统？

a) 电热器
b) 热泵
c) 集中供热 (*请回答14。1 问题*)
d) 其他 (*请指定*)
e) 不采暖建筑

14.1 您认为现有的采暖价格如何？

a) 太便宜
b) 便宜
c) 平均
d) 贵
e) 太贵

15.夏天的时候会用:

a) 中央空调
b) 风扇
c) 分体式空调器
d) 不使用空调
e) 其他 (*请指定*)

16.您人为现有的电费如何?

a) 平均
b) 太便宜
c) 便宜
d) 贵
e) 太贵

17.贵公司的一年的能耗是 :

a) 高
b) 平均
c) 低

17.1 如果您知道, 去年的**能耗是多少?**

18.贵公司最大耗电有于 :

a) 照明
b) 空调
c) 采暖
d) 电气用品和设备
e) 其他 (*请指定*)
f) 不知道

19. 什么会影响您公司减少能耗的决定？

a) 电费太高
b) 想减少能源账单
c) 气候变化
d) 其他（*请指定*）

20. 您知道有任何公司可提供减少建筑能耗咨询吗？

a) 知道 (*请回答20。1 问题*)
b) 不知道

20.1 你有接受过任何减少能耗的信息?

a) 接受过
b) 没有

21. 您是否知道中国政府（建设部）提供任何财务奖励来提倡减少能耗？

a) 知道
b) 不知道

22. 您公司愿意参与公共建筑能效标准的决策过程吗？

a) 愿意
b) 不愿意

23. 请您写一下您对于改进能效实施有何看法。

Appendix C - Validation methods

- Validation of GHG emissions reduction: [www.retscreen.net/ang/12.php], Introduction to Clean Energy Project Analysis e-textbook chapter, pp. 53-57;
- Validation of photovoltaic project analysis: [www.retscreen.net/ang/12.php], Photovoltaic Project Analysis e-textbook chapter, pp. 34 – 44;
- Validation of solar water heating project analysis: [www.retscreen.net/ang/12.php], Solar water heating project analysis e-textbook chapter, pp. 58-56;
- Validation of biomass heating project analysis: [www.retscreen.net/ang/12.php], Biomass heating project analysis e-textbook chapter, pp. 38-44;
- Validation of ground-source heat pump project analysis: [www.retscreen.net/ang/12/php], Ground-source heat pump projects analysis e-textbook chapter, pp. 60-67.

Appendix D - Energy consumption per capita 2002

	Coal (kg)	Oil (kg)	Gas (m^3)	Electricity (KWh)	Total (kgCE)
Developed provinces					
Beijing	1,779	526	148	3,064	3,164
Tianjin	2,909	671	644	2,790	3,001
Shanghai	2,883	877	27	3,974	3,766
Jiangsu	1,309	191	-	1,686	1,302
Zhejiang	1,295	267	-	2,186	1,598
Shandong	1,425	179	-	1,354	1,216
Fujian	782	96	-	1,436	1,007
Guangdong	846	250	-	2,148	1,445
Developing provinces					
Anhui	1,054	49	-	615	839
Guangxi	442	15	-	740	618
Guizhou	1,355	-	14	1,281	1,165
Yunnan	774	-	12	908	909
Shaanxi	939	192	38	1,018	1,011

Source: Crompton and Wu 2004

Appendix E - China's energy efficiency and CO_2[1] indicators

Energy efficiency and CO_2 indicators	Units	1980	1990	2000	2007
Key indicators					
Primary energy intensity (at ppp)	koe/$05p	0.735	0.435	0.200	0.186
Primary energy intensity excluding traditional fuels (ppp)	koe/$05p	0.524	0.338	0.161	0.165
Primary energy intensity adjusted to EU structure (ppp)	koe/$05p	0.793	0.396	0.159	n.a.
Final energy intensity (at ppp)	koe/$05p	0.604	0.319	0.136	0.115
Final energy intensity at 2005 GDP structure[2] (ppp)	koe/$05p	0.671	0.318	0.122	0.124
Final energy intensity adjusted to EU economic structure (ppp)	koe/$05p	0.593	0.281	0.114	n.a.
CO_2 intensity (at ppp)	kCO_2/$05p	n.a.	1.078	0.514	0.529
CO_2 emissions per capita	tCO_2/cap	n.a.	1.97	2.27	4.41
Industry					
Energy intensity of industry (to value added) (at ppp)	koe/$05p	0.640	0.314	0.105	0.11
Energy intensity of manufacturing (at ppp)	koe/$05p	0.781	0.382	0.138	0.131
Unit consumption of steel	toe/t	1.64	0.92	0.74	0.45
CO_2 intensity of industry (to value added) (at ppp)	kCO_2/$05p	n.a.	1.024	0.283	0.226
CO_2 emissions of industry per capita	tCO_2/cap	n.a.	0.78	0.69	1.13
Transport					
Energy intensity of transport to GDP (at ppp)	koe/$05p	0.030	0.019	0.014	0.012
Average consumption of road transport per equivalent car	toe/car equiv.	n.a	n.a	n.a.	n.a.
Unit consumption of goods per ton km	toe/tkm	n.a.	n.a.	n.a.	n.a.
CO_2 intensity of transport to GDP (at ppp)	kCO_2/$05p	n.a.	0.059	0.040	0.035
CO_2 emissions of transport per capita	tCO_2/cap	n.a.	0.11	0.18	0.29
Residential, service and agriculture sectors					
Energy intensity of household (to private consumption) (at ppp)	koe/$05p	0.660	0.286	0.102	0.106
Average electricity consumption of household per capita	kWh/cap	11	42	132	283
Average electricity consumption per household	kWh/hh	55	186	478	1018
Average electricity consumption of electrified household	kWh/hh	n.a.	n.a.	485	1023

[1] CO_2 from fuel combustion
[2] By main sector

Households consumption for electrical appliances and lighting	kWh/hh	n.a.	n.a.	n.a.	n.a.
Energy intensity of service sector (to value added) (at ppp)	koe/$05p	0.065	0.022	0.020	0.032
Electricity intensity of service sector (to value added) (at ppp)	kWh/0.5p	85	63	78	157
Unit consumption of services per employee	toe/emp	0.12	0.22	0.36	n.a.
Unit electricity consumption of services per employee	kWh/emp	151	632	1419	n.a.
Energy intensity of agriculture (to value added) (at ppp)	koe/$05p	0.057	0.048	0.039	0.043
CO_2 intensity of household (to private consumption) (at ppp)	$kCO_2/\$05p$	n.a.	0.339	0.076	0.083
CO_2 emissions of residential sector per household	tCO_2/hh	n.a.	1.38	0.63	0.76
CO_2 intensity of service sector (to value added) (at ppp)	$kCO_2/\$05p$	n.a.	0.059	0.040	0.049
CO_2 emissions of service sector per employee	tCO_2/emp	n.a.	0.59	0.72	n.a.
CO_2 intensity of agriculture (to value added) (at ppp)	$kCO_2/\$05p$	n.a.	0.142	0.106	0.117
CO_2 emissions of agriculture sector per capita	tCO_2/cap	n.a.	0.07	0.07	0.10
Transformation sector					
Overall efficiency of energy transformations	%	77.3	72.1	66.9	63.2
Efficiency of total electricity generation	%	27.5	31.8	34.5	34.4
Rate of electricity transmissions-distribution losses	%	8.1	6.9	6.9	6.3
Efficiency of thermal power plants	%	23.4	27.0	30.5	30.8
Diffusion of energy/CO_2 efficient technologies and practices					
Per capita installed capacity of solar water heaters	m^2/ 1000inhab	3.1	4.5	19.8	82.8
Share of biofuels in road transport energy consumption	%	n.a.	n.a.	n.a.	n.a.
Share of biomass in industry energy consumption	%	n.a.	n.a.	n.a.	n.a.
Share of renewables in electricity generating capacity	%	29.1	24.2	23.7	21.2
Share of renewables in gross electricity consumption	%	19.4	20.3	16.7	15.1

Source: www.enerdata.fr

Appendix F - Three scenarios outlines

Year 2020	Scenario A	Scenario B	Scenario C
Population	1.485 bln	1.47 bln	1.445 bln
Urbanisation rate	52.86%	55.78%	58.29%
GDP	Before 2010 grows at 7.3%, then at 6.7%	Same as scenario A	Same as Scenario A
Integration into global economy	Difficult	Low impact on China's economy	Positive impact on Chinas economy
Industrial sector	Low economic efficiency and international competitiveness	Improved energy efficiency and international competitiveness	High economic efficiency and international competitiveness
Transportation	Poor public transport development. Quick growth of private vehicle. Slow rise of fuel efficiency.	Strong development of public transport. Rise of motorcycle use. International vehicle standards are adopted.	Extensive development of public transport, slow growth of private vehicle. International vehicle standards are adopted. Advanced clean-fuel technologies are used for public transport and vehicles.
Power generation	Increased use of sulphur control technology on power plants. Coal-fired power plants generate most electricity. Graduate development of hydropower, nuclear, IGCCC and wind power	Very high-growth rate in sulphur control technology on coal - fired power plants. Clean coal power generation technologies are introduced in 2010. Development of hydropower, nuclear power, IGCC and wind power is faster than in Scenario A	Very high-growth rate in sulphur control technology on coal - fired power plants. Clean coal power generation technologies are introduced sooner than in other scenarios. Development of hydropower, nuclear power, IGCC and wind power is faster than in other scenarios.
Energy sector reform	Reform progress lacks behind other sectors. Monopoly continues to exist in some areas.	Energy enterprises will be restructures and monopoly is broken.	Reform proceeds rapidly and international competitiveness of China's energy enterprises is

			improved.
Energy conservation policies	Implementing measures to Energy conservation Law are adopted but many are not achieved.	Implemented measures to Energy Conservation Law are adopted and improved upon.	Complete implementation of financial incentives and an energy pricing system to promote energy conservation. Implementing measures to the Energy Conservation Law are successfully adopted and improved upon.
Energy efficiency level	Technological development is hindered and the operating efficiency of equipment does not reach international level.	Energy efficiency of technology in all sectors and industries on track to reach current advanced international levels.	Same as Scenario B
Energy resources	Access to international oil resources over next 30 years in unrestricted. Difference between domestic oil supply and demand is met through oil imports. Natural gas prices are too high. Imports of LNG and pipeline gas are restricted. Domestic output of gas reaches 80 bcm and imported gas 40 bcm.	Access to international oil resources over next 30 years in unrestricted. Difference between domestic oil supply and demand is met through oil imports. Domestic development and infrastructure construction of natural gas is successful and creates a strong market for natural gas. Domestic output of natural gas is 120 bcm and imported gas 50 bcm.	Access to international oil resources over next 30 years in unrestricted. Difference between domestic oil supply and demand is met through oil imports. Natural gas pricing system is improved and demand for gas grows quickly. Gas imports rise. Domestic output of natural gas reaches 120 bcm and imported gas 80 bcm.
Energy security	Relies on domestic energy resources.	Establishment of diversified energy import system to utilise	Same as Scenario B

		high quality foreign energy resources.	
Environmental protection policies	Existing environmental standards persist.	Existing environmental standards persist. Air quality in big cities is improved by increasing supply of gas fuels.	Emissions standards in large cities are tightened. More stringent legal system is put in place to enforce environmental regulations.
Public awareness	Moderate	Moderate	Good

Appendix G - Key energy policies supporting China's 20% energy intensity reduction goal

Energy policy	Date effective	Responsible agency
Fuel consumption limits for passenger cars	2004	AQSIQ
Medium and long-term plan for energy conservation	2005	NDRC
Renewable energy law	2005	
Government procurement programme	2005, 2007	NCRD, MOF
National energy efficiency design standard for public buildings	2005	MOC
Eleventh Five-year plan	2006	NDRC
The State Council decision on strengthening energy conservation	2006	State Council
Revised consumption tax for larger, energy-inefficient vehicles	2006	MOF and the State Administration of Taxation
Reduced export tax rebates for many low-value-added but high energy-consuming products	2006	MOF
Top-1000 Energy-consuming enterprise programme	2006	MEP, MOF
Revision of energy conservation law	2007	NRC, NDRC
Allocation of funding on energy efficiency and pollution abatement	2007	MOF, NDRC
China energy technology policy outline	2007	NDRC, MST
National Phase 3 vehicle emission standards	2007	
Interim administrative method for incentive funds for heating and metering and energy efficiency retrofit for existing residential buildings in China's Northern heating area	2007	MOF
Law on corporate income tax	2008	NDRC
Allocation of funding of energy efficiency and pollution abatement	2008	MOF, NDRC
Appliance standards and labelling	Various years	General Administration of Quality Supervision, inspection and Quarantine

Source: [IEECAS 2009]

Appendix H - Selected 11th Five-year Plan energy efficiency targets

	Unit	2000	2005	2010
Electricity generation				
Coal-fired	gce/kWh	392	370	355
Small and medium generators	% (rated)	87		90-92
Wind turbines	% (rated)	70-80		80-85
Industry				
Raw steel	tce/t	0.906	0.760	0.730
Avg 10 non-ferrous metals	tce/t	4.809	4.665	4.595
Aluminium	tce/t	9.923	9.595	9.471
Copper	tce/t	4.707	4.388	4.256
Synthetic ammonia	tce/t	1.372	1.210	1.140
Soda	tce/t	1.553	1.503	1.400
Cement	tce/t	0.181	0.159	0.148
Construction ceramics	kgce/m^2	10.04	9.9	9.2
Oil refining	kgce/t factor	14	13	12
Ethylene	kg standard oi/t	848	700	650
Coal-fired boilers	% (operational)	65		70-80
Pump	% (rated)	75-80		83-87
Air compressor	% (rated)	75		80-84
Appliances				
Room air conditioner	Energy efficiency rate	2.4		3.2-4
Refrigerator	% (energy efficiency indicator)	80		62-50
Household cook stove	% (heat efficiency)	55		60-65
Household gas water heater	% (heat efficiency)	80		90-95
Transportation				
Railways	Tonnes/mt km	10.41	9.65	9.4
Average automobile fuel economy	Litre/100 km	9.5		8.2-6.7

Source: NDRC 2006

Appendix I - Technology efficiency

End Use	Technology	Efficiency
Space heating	District Heating	65%
	Boiler	55%
	Gas Boiler	70%
	Small Cogen	60%
	Electric heater	90%
	Stove	10%
	Heat pump	COP=1.8
Space cooling	Centralised AC	COP=1.8
	Room AC	COP=2.5
	Geothermal heat pump	COP=3
	Centralised AC by NG	COP=1.2

Source: Zhou et al 2007

Appendix J - EES promulgated in China

	Standard number	Standard name
Household appliances	GB12021.1-1989	The limited value and the testing method of energy consumption for household and other similar electric appliances
	GB12021.2-2003	The maximum allowable values of the energy consumption and EE grades for household refrigerators
	GB12021.3-2004	The minimum allowable value of EE and EE grades for room air conditioners
	GB12021.4-2004	The minimum allowable value of EE and EE grades for household electric washing machines
	GB12021.5-1989	The limited value of energy consumption and method of testing for electrical irons
	GB12021.6-1989	The limited value and testing method of efficiency and warming energy consumption for automatic rice cookers
	GB12021.7-2005	The limited value and testing method of EE fro broadcasting receiver of colour TV
	GB12021.8-1989	The limited valued of efficiency and methods of measurements on radio receivers
Lighting products	GB17896-1999	Limited values of EE and evaluating values of energy conservation of ballasts for tubular fluorescent lamps
	GB19043-2003	Limited values of EE and grading criteria of double-capped fluorescent lamps for general lighting service
	GB19044-2003	Limited values of EE and grading criteria of self-ballasted fluorescent lamps for general lighting service
	GB19415-2003	Limited value of EE and evaluating values of energy conservation for single-capped fluorescent lamps

	GB19573-2004	Limited values of EE and grading criteria for high-pressure sodium vapour lamps
	GB19574-2204	Limited values of EE and evaluating values of energy conservation of ballasts for high pressure sodium lamps
	GB20053-2006	Limited values of EE and evaluating values of energy conservation of ballasts for metal halide lamps
	GB20054-2006	Limited values of EE and grading criteria of metal halide lamps
Industrial equipment	GB12021.9-1989	The limited value of energy consumption of electric fans and its measuring method
	GB19153-2003	Limited value of EE and evaluating values of energy conservation for displacement air compressors
	GB19762-2005	Limited values of EE and evaluating values of energy conservation of centrifugal pumps for fresh water
	GB19761-2005	Limited values of EE and evaluating values of energy conservation for fans
	GB20052-2006	Limited values of EE and evaluating values of energy conservation for distribution transformers
Commer cial	GB19576-2004	Limited values of energy efficiency and grading criteria of unitary air conditioners
	GB19577-2004	Limited values of energy efficiency and energy efficiency grades for water chilling packages
vehicles	GB18613-2002	Limited values of EE and evaluating values of energy conservation of small and medium three-phase asynchronous motors
	GB19578-2004	Limits of fuel consumption for passenger cars

Appendix K - Internal temperatures suggested of the cooling and heating periods (°C)

Building type		Office				Hotel	
		Working day		Holiday		All year around	
		Cooling	Heating	Cooling	Heating	Cooling	Heating
Time	1	37	12	37	12	25	22
	2	37	12	37	12	25	22
	3	37	12	37	12	25	22
	4	37	12	37	12	25	22
	5	37	12	37	12	25	22
	6	37	12	37	12	25	22
	7	28	18	37	12	25	22
	8	26	20	37	12	25	22
	9	26	20	37	12	25	22
	10	26	20	37	12	25	22
	11	26	20	37	12	25	22
	12	26	20	37	12	25	22
	13	26	20	37	12	25	22
	14	26	20	37	12	25	22
	15	26	20	37	12	25	22
	16	26	20	37	12	25	22
	17	26	20	37	12	25	22
	18	26	20	37	12	25	22
	19	37	12	37	12	25	22
	20	37	12	37	12	25	22
	21	37	12	37	12	25	22
	22	37	12	37	12	25	22
	23	37	12	37	12	25	22
	24	37	12	37	12	25	22

Appendix L – Standard use rates for occupancy, lighting, and equipment

Use of lighting rate throughout the day (%)

Building type		Office		Hotel
		Working day	Holiday	All year around
Time	1	0	0	10
	2	0	0	10
	3	0	0	10
	4	0	0	10
	5	0	0	10
	6	0	0	10
	7	10	0	30
	8	50	0	30
	9	95	0	30
	10	95	0	30
	11	95	0	30
	12	80	0	30
	13	80	0	30
	14	95	0	30
	15	95	0	50
	16	95	0	50
	17	95	0	60
	18	30	0	90
	19	30	0	90
	20	0	0	90
	21	0	0	90
	22	0	0	80
	23	0	0	10
	24	0	0	10

Occupancy rate throughout the day (%)

Building type		Office		Hotel
		Working day	Holiday	All year around
Time	1	0	0	70
	2	0	0	70
	3	0	0	70
	4	0	0	70
	5	0	0	70
	6	0	0	70
	7	10	0	70
	8	50	0	70
	9	95	0	50
	10	95	0	50
	11	95	0	50
	12	80	0	50
	13	80	0	50
	14	95	0	50
	15	95	0	50
	16	95	0	50
	17	95	0	50
	18	30	0	50
	19	30	0	70
	20	0	0	70
	21	0	0	70
	22	0	0	70
	23	0	0	70
	24	0	0	70

Use of equipment rate throughout the day

Building type		Office		Hotel
		Working day	Holiday	All year around
Time	1	0	0	0
	2	0	0	0
	3	0	0	0
	4	0	0	0
	5	0	0	0
	6	0	0	0
	7	10	0	0
	8	50	0	0
	9	95	0	0
	10	95	0	0
	11	95	0	0
	12	50	0	0
	13	50	0	0
	14	95	0	0
	15	95	0	0
	16	95	0	0
	17	95	0	0
	18	30	0	80
	19	30	0	80
	20	0	0	80
	21	0	0	80
	22	0	0	80
	23	0	0	0
	24	0	0	0

Appendix M -Major barriers to energy efficiency in the building sector

Barrier categories	Definitions	Examples	Countries	Possible remedies
Economic/ financial barriers	Ratio of investment cost to value of energy savings	-Higher up-front costs for more efficient equipment -Lack of accessing to financing -Energy subsidies -Lack of internalization of environment, health, and other external costs	Most countries Especially developing countries, but also developed countries	Fiscal and economic instruments (tax rebates, Kyoto flexible mechanisms, subsidized loans), regulatory instruments; increase of energy prices or remove of energy subsidies
Hidden costs/ benefits	Cost or risks that are not captures directly in financial flows	-Costs and risks due to potential incompatibilities, performance risks, transaction costs, etc -Poor power quality, particularly in some developing countries	All countries	Appliance standards, building codes, EPC/ ESCPs, public leadership programmes
Market failures	Market structures and constrains that prevent a consistent trade-off between specific EE investment and energy saving benefits	-Limitations of the typical building design process -Fragmented market structure -Landlord/ tenant split and misplaced incentives -Administrative and regulatory barriers -Imperfect information -Unavailability of energy efficiency equipment locally	All countries	Fiscal instrument and incentives Product standards Regulatory-normative Regulatory-informative Economic instruments Technology transfer, mechanisms
Behavioural and organisational barriers	Behavioural characteristics of individuals and companies	-Tendency to ignore small energy saving opportunities	Development countries	Support, information and voluntary action

	than hinder EE technologies and practises	-Organisational failures -Non-payment and electricity theft -Tradition, behaviour and lifestyle -Corruption -Transition in energy expertise (loss of traditional knowledge and non-sustainability of Western technologies)	Developing countries	Information and training programmes
Information barriers	Lack of information provided on energy saving potentials	Lacking awareness of consumers, building managers, construction companies, politicians	Especially developing countries, but also developed countries	Awareness training campaigns, training of building professionals, regulatory-informative
Political and structural barriers	Structural characteristics of the political, economic, energy system which make EE investment difficult	-Process of drafting local legislation is slow -Gaps between regions at different economic level -Insufficient enforcement of standards -Lack of detailed guidelines, tools and experts -Lack of incentives for EE investment -Lack of governance leadership/ interest -Lack of equipment testing/ certification -Inadequate energy service levels	Most developing and some developed countries	Enhance implementation of standards Incentive policy encouraging EE building design, enhance international cooperation and technology transfer, public leadership programme

Source: IPCC 2007

Appendix N – Example of case study calculations

						ll 3 height	wall 3 length	wall 3 area	wall 4 height	wall 4 length	wall 4 area	U-value outer wall	U-value inner wall	Qf wall 1	Qf wall 2	Qf wall 3	Qf wall 4
2.7	3.7	9.99	2.7	3.7	7.74	2.7	6.9	18.63	2.7	6.9	18.63	1.89	2.2	175.824	212.1147	510.5552	327.888
2.7	4.1	11.07	2.7	4.1	8.82	2.7	6.9	18.63	2.7	6.9	18.63	1.89	2.2	194.832	241.7121	327.888	327.888
2.7	3.9	10.53	2.7	3.9	8.28	2.7	6.9	18.63	2.7	6.9	18.63	1.89	2.2	185.328	226.9134	327.888	327.888
2.7	3.9	10.53	2.7	3.9	8.28	2.7	6.9	18.63	2.7	6.9	18.63	1.89	2.2	185.328	226.9134	327.888	327.888
2.7	3.9	10.53	2.7	3.9	8.28	2.7	6.9	18.63	2.7	6.9	18.63	1.89	2.2	185.328	226.9134	327.888	327.888
2.7	3.9	10.53	2.7	3.9	8.28	2.7	6.9	18.63	2.7	6.9	18.63	1.89	2.2	185.328	226.9134	327.888	327.888
2.7	3.9	10.53	2.7	3.9	8.28	2.7	6.9	18.63	2.7	6.9	18.63	1.89	2.2	185.328	226.9134	327.888	327.888
2.7	3.9	10.53	2.7	3.9	6.03	2.7	6.9	18.63	2.7	6.9	18.63	1.89	2.2	185.328	165.2522	327.888	327.888
2.7	3.9	10.53	2.7	3.9	8.28	2.7	6.9	18.63	2.7	6.9	18.63	1.89	2.2	185.328	226.9134	327.888	327.888
2.7	7.5	20.25	2.7	7.5	15.75	2.7	4.8	12.96	2.7	4.8	12.96	1.89	2.2	356.4	431.6288	413.424	228.096
2.7	4	10.8	2.7	4	8.55	2.7	6.9	18.63	2.7	6.9	18.63	1.89	2.2	190.08	234.3128	327.888	327.888
2.7	3.9	10.53	2.7	3.9	8.28	2.7	6.9	18.63	2.7	6.9	18.63	1.89	2.2	185.328	226.9134	327.888	327.888
2.7	3.9	10.53	2.7	3.9	8.28	2.7	6.9	18.63	2.7	6.9	18.63	1.89	2.2	185.328	226.9134	327.888	327.888
2.7	3.9	10.53	2.7	3.9	8.28	2.7	6.9	18.63	2.7	6.9	18.63	1.89	2.2	185.328	226.9134	327.888	327.888
2.7	3.9	10.53	2.7	3.9	8.28	2.7	6.9	18.63	2.7	6.9	18.63	1.89	2.2	185.328	226.9134	327.888	327.888
2.7	3.9	10.53	2.7	3.9	8.28	2.7	6.9	18.63	2.7	6.9	18.63	1.89	2.2	185.328	226.9134	327.888	327.888
2.7	3.9	10.53	2.7	3.9	8.28	2.7	6.9	18.63	2.7	6.9	18.63	1.89	2.2	185.328	226.9134	327.888	327.888
2.7	5.2	14.04	2.7	5.2	9.54	2.7	6.9	18.63	2.7	6.9	18.63	1.89	2.2	247.104	261.4437	327.888	327.888
2.7	3.9	10.53	2.7	3.9	8.28	2.7	6.9	18.63	2.7	6.9	18.63	1.89	2.2	185.328	226.9134	327.888	327.888
2.7	3.9	10.53	2.7	3.9	8.28	2.7	6.9	18.63	2.7	6.9	18.63	1.89	2.2	185.328	226.9134	327.888	327.888
2.7	3.9	10.53	2.7	3.9	8.28	2.7	6.9	18.63	2.7	6.9	18.63	1.89	2.2	185.328	226.9134	327.888	327.888
2.7	3.9	10.53	2.7	3.9	8.28	2.7	6.9	18.63	2.7	6.9	18.63	1.89	2.2	185.328	226.9134	510.5552	327.888

Window height	window length	window area	U-value window	Qf window	floor area	U-value floor	Qf floor	roof area	U-vlaue roof	Qf roof	Qf total	room volume	N	Qv	total heat loss	heat loss occup. Kwh	heat loss per ar
1.5	1.5	2.25	5	163.125	25.53	2.08	0	25.53	0.3	0	1389.507	68.931	0.6	199.8999	1589.4	854.5	62.25643
1.5	1.5	2.25	5	163.125	28.29	2.08	0	28.29	0.3	0	1255.445	76.383	0.6	221.5107	1477.0	794.1	52.20769
1.5	1.5	2.25	5	163.125	26.91	2.08	0	26.91	0.3	0	1231.142	72.657	0.6	210.7053	1441.8	775.2	53.580367
1.5	1.5	2.25	5	163.125	26.91	2.08	0	26.91	0.3	0	1231.142	72.657	0.6	210.7053	1441.8	775.2	53.580367
1.5	1.5	2.25	5	163.125	26.91	2.08	0	26.91	0.3	0	1231.142	72.657	0.6	210.7053	1441.8	775.2	53.580367
1.5	1.5	2.25	5	163.125	26.91	2.08	0	26.91	0.3	0	1231.142	72.657	0.6	210.7053	1441.8	775.2	53.580367
1.5	1.5	2.25	5	163.125	26.91	2.08	0	26.91	0.3	0	1231.142	72.657	0.6	210.7053	1441.8	775.2	53.580367
1.5	3	4.5	5	326.25	26.91	2.08	0	26.91	0.3	0	1332.606	72.657	0.6	210.7053	1543.3	829.7	57.350852
1.5	1.5	2.25	5	163.125	26.91	2.08	0	26.91	0.3	0	1231.142	72.657	0.6	210.7053	1441.8	775.2	53.580367
1.5	3	4.5	5	326.25	36	2.08	0	36	0.3	0	1755.799	97.2	0.6	281.88	2037.7	1095.5	56.60218
1.5	1.5	2.25	5	163.125	27.6	2.08	0	27.6	0.3	0	1243.294	74.52	0.6	216.108	1459.4	784.6	52.8768
1.5	1.5	2.25	5	163.125	26.91	2.08	0	26.91	0.3	0	1231.142	72.657	0.6	210.7053	1441.8	775.2	53.580367
1.5	1.5	2.25	5	163.125	26.91	2.08	0	26.91	0.3	0	1231.142	72.657	0.6	210.7053	1441.8	775.2	53.580367
1.5	1.5	2.25	5	163.125	26.91	2.08	0	26.91	0.3	0	1231.142	72.657	0.6	210.7053	1441.8	775.2	53.580367
1.5	1.5	2.25	5	163.125	26.91	2.08	0	26.91	0.3	0	1231.142	72.657	0.6	210.7053	1441.8	775.2	53.580367
1.5	1.5	2.25	5	163.125	26.91	2.08	0	26.91	0.3	0	1231.142	72.657	0.6	210.7053	1441.8	775.2	53.580367
1.5	1.5	2.25	5	163.125	26.91	2.08	0	26.91	0.3	0	1231.142	72.657	0.6	210.7053	1441.8	775.2	53.580367
1.5	3	4.5	5	326.25	35.88	2.08	0	35.88	0.3	0	1490.574	96.876	0.6	280.9404	1771.5	952.4	49.373302
1.5	1.5	2.25	5	163.125	26.91	2.08	0	26.91	0.3	0	1231.142	72.657	0.6	210.7053	1441.8	775.2	53.580367
1.5	1.5	2.25	5	163.125	26.91	2.08	0	26.91	0.3	0	1231.142	72.657	0.6	210.7053	1441.8	775.2	53.580367
1.5	1.5	2.25	5	163.125	26.91	2.08	0	26.91	0.3	0	1231.142	72.657	0.6	210.7053	1441.8	775.2	53.580367
1.5	1.5	2.25	5	163.125	26.91	2.08	0	26.91	0.3	0	1413.81	72.657	0.6	210.7053	1624.5	873.4	60.368444
															33130.5	17812.1	

heat gain per person	heat gain ppl	heat gain PC	heat gain PC monitor	heat gain printer	heat gain photocopier	heat gain TV	heat gain equipment	lux	heat gain lighting
54	108	0	0	0	0	100	100	300	11.457864
54	108	0	0	0	0	100	100	300	12.696552
54	108	0	0	0	0	100	100	300	12.077208
54	108	0	0	0	0	100	100	300	12.077208
54	108	0	0	0	0	100	100	300	12.077208
54	108	0	0	0	0	100	100	300	12.077208
54	108	0	0	0	0	100	100	300	12.077208
54	54	0	0	0	0	100	100	300	12.077208
54	54	0	0	0	0	100	100	300	12.077208
54	54	0	0	0	0	100	100	300	16.1568
54	108	0	0	0	0	100	100	300	12.38688
54	108	0	0	0	0	100	100	300	12.077208
54	108	0	0	0	0	100	100	300	12.077208
54	108	0	0	0	0	100	100	300	12.077208
54	108	0	0	0	0	100	100	300	12.077208
54	108	0	0	0	0	100	100	300	12.077208
54	108	0	0	0	0	100	100	300	12.077208
54	54	0	0	0	0	100	100	300	16.102944
54	108	0	0	0	0	100	100	300	12.077208
54	108	0	0	0	0	100	100	300	12.077208
54	108	0	0	0	0	100	100	300	12.077208
54	108	0	0	0	0	100	100	300	12.077208
	2160						2200		274.113576

solar radiation intensity	solar gain factor	heat gain via glass	heat gain total	heat gain occup. Kwh	heating/cooling load required
135.416	0.76	231.56136	451.0	242.5	1238.789276
135.416	0.76	231.56136	452.3	243.1	1152.622088
135.416	0.76	231.56136	451.6	242.8	1116.062432
135.416	0.76	231.56136	451.6	242.8	1116.062432
135.416	0.76	231.56136	451.6	242.8	1116.062432
135.416	0.76	231.56136	451.6	242.8	1116.062432
135.416	0.76	231.56136	451.6	242.8	1116.062432
135.416	0.76	463.12272	629.2	338.3	1043.463572
135.416	0.76	231.56136	397.6	213.8	1170.062432
135.416	0.76	463.12272	633.3	340.5	1527.57098
135.416	0.76	231.56136	451.9	243.0	1134.34226
135.416	0.76	231.56136	451.6	242.8	1116.062432
135.416	0.76	231.56136	451.6	242.8	1116.062432
135.416	0.76	231.56136	451.6	242.8	1116.062432
135.416	0.76	231.56136	451.6	242.8	1116.062432
135.416	0.76	231.56136	451.6	242.8	1116.062432
135.416	0.76	231.56136	451.6	242.8	1116.062432
135.416	0.76	463.12272	633.2	340.4	1281.101336
135.416	0.76	231.56136	451.6	242.8	1116.062432
135.416	0.76	231.56136	451.6	242.8	1116.062432
135.416	0.76	231.56136	451.6	242.8	1116.062432
135.416	0.76	231.56136	451.6	242.8	1275.348932
		5789.034	10423.1	5603.8	

Appendix O – RETScreen simulation sheet for SHW system sizing and emissions analysis for Kunming

RETScreen Energy Model - Heating project

Heating project	Unit	Base case	Proposed case	Energy saved	Incremental initial costs	
Technology		Solar water heater				
Load characteristics						
Application		○ Swimming pool				
		◉ Hot water				
	Unit	**Base case**	**Proposed case**			
Load type		Hotel/Motel				
Number of units	Unit	350				
Occupancy rate	%	80%				
Daily hot water use - estimated	L/d	21,224				
Daily hot water use	L/d	15,750	12,000			
Temperature	°C	60	55			
Operating days per week	d	7	7			
☐ **Percent of month used**						
Supply temperature method		Formula				
Water temperature - minimum	°C	13.6				
Water temperature - maximum	°C	17.3				
	Unit	**Base case**	**Proposed case**	**Energy saved**	**Incremental initial costs**	
Heating	MWh	296.8	200.6	32%	£ 1,000	
Resource assessment						
Solar tracking mode		Fixed				
Slope	°	45.0				
Azimuth	°	0.0				
☐ **Show data**						
Solar water heater						
Type		Evacuated			£ 1,390	See technical note
Manufacturer		Thermomax				See product database
Model		MS 20 - TMO 500				
Gross area per solar collector	m²	2.78				
Aperture area per solar collector	m²	2.14				
Fr (tau alpha) coefficient		0.58				
Fr UL coefficient	(W/m²)/°C	1.05				
Temperature coefficient for Fr UL	(W/m²)/°C²					
Number of collectors		265	82			
Solar collector area	m²	736.44				
Capacity	kW	396.04				
Miscellaneous losses	%	4.0%				
Balance of system & miscellaneous						
Storage		Yes				
Storage capacity / solar collector area	L/m²	70				
Storage capacity	L	39,604.3				
Heat exchanger	yes/no	No				
Miscellaneous losses	%	3.0%				
Pump power / solar collector area	W/m²	0.00				
Electricity rate	£/kWh	0.100				
Summary						
Electricity - pump	MWh	0.0				
Heating delivered	MWh	200.6				
Solar fraction	%	100%				
Heating system						
☐ Project verification		**Base case**	**Proposed case**			
Fuel type		Natural gas - kWh	Natural gas - kWh			
Seasonal efficiency		70%	70%		£ -	
Fuel consumption - annual	kWh	423,955.5	0.0	kWh		
Fuel rate	£/kWh	0.020	0.020	£/kWh		
Fuel cost	£	8,479	0			

Complete Cost Analysis sheet

RETScreen Emission Reduction Analysis - Heating project

Emission Analysis

- ○ Method 1
- ◉ Method 2
- ○ Method 3

Global warming potential of GHG

21 tonnes CO_2 = 1 tonne CH_4	(IPCC 1996)
310 tonnes CO_2 = 1 tonne N_2O	(IPCC 1996)

Base case system GHG summary (Baseline)

Fuel type	Fuel mix %	CO2 emission factor kg/GJ	CH4 emission factor kg/GJ	N2O emission factor kg/GJ	Fuel consumption MWh	GHG emission factor tCO2/MWh	GHG emission tCO2
Natural gas	100.0%	49.4	0.0036	0.0009	424	0.179	76
Total	100.0%	49.4	0.0036	0.0009	424	0.179	76

Proposed case system GHG summary (Heating project)

Fuel type	Fuel mix %	CO2 emission factor kg/GJ	CH4 emission factor kg/GJ	N2O emission factor kg/GJ	Fuel consumption MWh	GHG emission factor tCO2/MWh	GHG emission tCO2
Solar	100.0%	0.0	0.0000	0.0000	201	0.000	0
Total	100.0%	0.0	0.0000	0.0000	201	0.000	0

GHG emission reduction summary

	Base case GHG emission tCO2	Proposed case GHG emission tCO2	Gross annual GHG emission reduction tCO2	GHG credits transaction fee %	Net annual GHG emission reduction tCO2
Heating project	76	0	76		76

Net annual GHG emission reduction 75.9 tCO2 is equivalent to 15.4 Cars & light trucks not used

Complete Financial Analysis sheet

Appendix P - RETScreen PV energy and emission reduction model for Kunming

RETScreen Energy Model - Power project

☐ Show alternative units

Proposed case power system

Technology		Photovoltaic	
Analysis type	○	Method 1	
	◉	Method 2	
Resource assessment			
Solar tracking mode		Azimuth	
Slope		45.0	
☐ Show data			
Photovoltaic			
Type		mono-Si	
Power capacity	kW	122.50	See product database
Manufacturer		BP Solar	
Model		mono-Si - BP 4175	700 unit(s)
Efficiency	%	13.9%	
Nominal operating cell temperature	°C	45	
Temperature coefficient	% / °C	0.40%	
Solar collector area	m²	881	
Miscellaneous losses	%	5.0%	
Inverter			
Efficiency	%	85.0%	
Capacity	kW	3469.0	
Miscellaneous losses	%	10.0%	
Summary			
Capacity factor	%	14.4%	
Electricity delivered to load	MWh	154.149	
Electricity exported to grid	MWh	0.000	
Electricity rate - base case	£/MWh	20.00	
Fuel rate - proposed case power system	£/MWh	0.00	
Electricity rate - proposed case	£/MWh	0.02	

Operating strategy	Electricity delivered to load MWh	Electricity exported to grid MWh	Remaining electricity required MWh	Power system fuel MWh	Operating profit (loss) £	Efficiency %
Full power capacity output	**154**	**0**	**1,123**	**0**	**25,530**	-
Power load following	154	0	1,123	0	25,530	-

Select operating strategy: Full power capacity output

RETScreen Emission Reduction Analysis - Power project

☑ Emission Analysis

- ◉ Method 1
- ○ Method 2
- ○ Method 3

Base case electricity system (Baseline)

Country - region	Fuel type	GHG emission factor (excl. T&D) tCO2/MWh	T&D losses %	GHG emission factor tCO2/MWh
China	Coal	0.893		0.893

☐ Baseline changes during project life

Base case system GHG summary (Baseline)

Fuel type	Fuel mix %	Fuel consumption MWh	GHG emission factor tCO2/MWh	GHG emission tCO2
Electricity	100.0%	2,557	0.893	2,283.4
Total	100.0%	2,557	0.893	2,283.4

Proposed case system GHG summary (Power project)

Fuel type	Fuel mix %	Fuel consumption MWh	GHG emission factor tCO2/MWh	GHG emission tCO2
Solar	12.1%	154	0.000	0.0
Electricity	87.9%	1,124	0.893	1,004.0
Total	100.0%	1,278	0.785	1,004.0

GHG emission reduction summary

	Base case GHG emission tCO2	Proposed case GHG emission tCO2	Gross annual GHG emission reduction tCO2	GHG credits transaction fee %	Net annual GHG emission reduction tCO2
Power project	2,283.4	1,004.0	1,279.3		1,279.3

Net annual GHG emission reduction	1,279	tCO2	is equivalent to	234	Cars & light trucks not used

Appendix Q - RET Screen PV panel energy model sizing and emissions analysis for Beijing

RETScreen Energy Model - Power project

☐ Show alternative units

Proposed case power system

Technology		Photovoltaic
Analysis type		○ Method 1 / ◉ Method 2
Resource assessment		
Solar tracking mode		Azimuth
Slope		40.0

☐ Show data

Photovoltaic			
Type		mono-Si	
Power capacity	kW	283.50	
Manufacturer		Sunpower	
Model		mono-Si - SPR-315E-WHT	900 unit(s)
Efficiency	%	19.3%	
Nominal operating cell temperature	°C	45	
Temperature coefficient	% / °C	0.40%	
Solar collector area	m²	1,467	
Miscellaneous losses	%	5.0%	
Inverter			
Efficiency	%	85.0%	
Capacity	kW	5637.0	
Miscellaneous losses	%	10.0%	
Summary			
Capacity factor	%	14.9%	
Electricity delivered to load	MWh	370.525	
Electricity exported to grid	MWh	0.000	
Electricity rate - base case	£/MWh	20.00	
Fuel rate - proposed case power system	£/MWh	0.00	
Electricity rate - proposed case	£/MWh	0.02	

See product database

Operating strategy	Electricity delivered to load MWh	Electricity exported to grid MWh	Remaining electricity required MWh	Power system fuel MWh	Operating profit (loss) £	Efficiency %
Full power capacity output	**371**	**0**	**3,795**	**0**	**83,235**	**-**
Power load following	371	0	3,795	0	83,235	-

Select operating strategy: Full power capacity output

RETScreen Emission Reduction Analysis - Power project

Emission Analysis (checked)

- (selected) Method 1
- Method 2
- Method 3

Base case electricity system (Baseline)

Country - region	Fuel type	GHG emission factor (excl. T&D) tCO2/MWh	T&D losses %	GHG emission factor tCO2/MWh
Canada	All types	0.196		0.196

Baseline changes during project life (not checked)

Base case system GHG summary (Baseline)

Fuel type	Fuel mix %	Fuel consumption MWh	GHG emission factor tCO2/MWh	GHG emission tCO2
Electricity	100.0%	4,166	0.196	817.7
Total	100.0%	4,166	0.196	817.7

Proposed case system GHG summary (Power project)

Fuel type	Fuel mix %	Fuel consumption MWh	GHG emission factor tCO2/MWh	GHG emission tCO2
Solar	8.9%	371	0.000	0.0
Electricity	91.1%	3,795	0.196	745.0
Total	100.0%	4,166	0.179	745.0

GHG emission reduction summary

	Base case GHG emission tCO2	Proposed case GHG emission tCO2	Gross annual GHG emission reduction tCO2	GHG credits transaction fee %	Net annual GHG emission reduction tCO2
Power project	817.7	745.0	72.7		72.7

Net annual GHG emission reduction 72.7 tCO2 is equivalent to 14.8 Cars & light trucks not used

Appendix R - RETScreen biomass heating system energy model and emissions analysis for Beijing

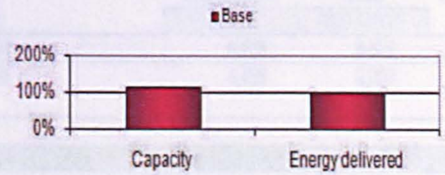
RETScreen Energy Model - Heating project

☐ Show alternative units

Proposed case heating system				
System selection		Base load system		
Base load heating system				
Technology		Biomass system		
Fuel selection method		Single fuel		
Fuel type		Biomass		
Fuel rate	£/t	20.000		
Biomass system				See product database
Capacity	kW	2,050.0	115.0%	
Heating delivered	MWh	3,788	100.0%	
Manufacturer		Chiptec Wood		
Model		CX-7	1 unit(s)	
Seasonal efficiency	%	85%		
Boiler type		Hot water		
Fuel required	GJ/h	8.7		

Proposed case system characteristics	Unit	Estimate	%
Heating			
Base load heating system			
Technology		Biomass system	
Capacity	kW	2,050.0	115.0%
Heating delivered	MWh	3,788	100.0%
Peak load heating system			
Technology		Not required	
Back-up heating system (optional)			
Technology			
Capacity	kW		

System design graph



Proposed case system summary	Fuel type	Fuel consumption - unit	Fuel consumption	Capacity (kW)	Energy delivered (MWh)
Heating					
Base load	Biomass	t	870	2,050	3,788
			Total	2,050	3,788

RETScreen Emission Reduction Analysis - Heating project

Emission Analysis

- ○ Method 1
- ◉ Method 2
- ○ Method 3

Global warming potential of GHG

21 tonnes CO2 = 1 tonne CH4	(IPCC 1996)
310 tonnes CO2 = 1 tonne N2O	(IPCC 1996)

Base case system GHG summary (Baseline)

Fuel type	Fuel mix %	CO2 emission factor kg/GJ	CH4 emission factor kg/GJ	N2O emission factor kg/GJ	Fuel consumption MWh	GHG emission factor tCO2/MWh	GHG emission tCO2
Coal	100.0%	95.8	0.0150	0.0030	6,698	0.350	2,341.0
Total	100.0%	95.8	0.0150	0.0030	6,698	0.350	2,341.0

Proposed case system GHG summary (Heating project)

Fuel type	Fuel mix %	CO2 emission factor kg/GJ	CH4 emission factor kg/GJ	N2O emission factor kg/GJ	Fuel consumption MWh	GHG emission factor tCO2/MWh	GHG emission tCO2
Biomass	100.0%	0.0	0.0320	0.0040	4,456	0.007	30.7
Total	100.0%	0.0	0.0320	0.0040	4,456	0.007	30.7

GHG emission reduction summary

	Base case GHG emission tCO2	Proposed case GHG emission tCO2	Gross annual GHG emission reduction tCO2	GHG credits transaction fee %	Net annual GHG emission reduction tCO2
Heating project	2,341.0	30.7	2,310.4		2,310.4

Net annual GHG emission reduction	2,310	tCO2	is equivalent to	939,246	Litres of gasoline not consumed

Appendix S -RET Screen PV panels energy model and emission analysis for Ningbo

RETScreen Energy Model - Power project

☐ Show alternative units

Proposed case power system

Technology		Photovoltaic
Analysis type	○	Method 1
	⊗	Method 2

Resource assessment

Solar tracking mode		Azimuth
Slope		30.0

☐ Show data

Photovoltaic

Type		mono-Si
Power capacity	kW	322.50
Manufacturer		Sunpower
Model		mono-Si - SPR-215-BLK 1500 unit(s)
Efficiency	%	17.3%
Nominal operating cell temperature	°C	45
Temperature coefficient	% / °C	0.40%
Solar collector area	m²	1,866
Miscellaneous losses	%	5.0%

See product database

Inverter

Efficiency	%	85.0%
Capacity	kW	3469.0
Miscellaneous losses	%	10.0%

Summary

Capacity factor	%	10.9%
Electricity delivered to load	MWh	307.643
Electricity exported to grid	MWh	0.000
Electricity rate - base case	£/MWh	20.00
Fuel rate - proposed case power system	£/MWh	0.00
Electricity rate - proposed case	£/MWh	0.02

Operating strategy	Electricity delivered to load MWh	Electricity exported to grid MWh	Remaining electricity required MWh	Power system fuel MWh	Operating profit (loss) £	Efficiency %
Full power capacity output	308	0	1,259	0	31,299	-
Power load following	**308**	**0**	**1,259**	**0**	**31,299**	-

Select operating strategy: Power load following

RETScreen Emission Reduction Analysis - Power project

Emission Analysis

- (•) Method 1
- ( ) Method 2
- ( ) Method 3

Base case electricity system (Baseline)

Country - region	Fuel type	GHG emission factor (excl. T&D) tCO2/MWh	T&D losses %	GHG emission factor tCO2/MWh
Canada	All types	0.196		0.196

☐ Baseline changes during project life

Base case system GHG summary (Baseline)

Fuel type	Fuel mix %	Fuel consumption MWh	GHG emission factor tCO2/MWh	GHG emission tCO2
Electricity	100.0%	1,566	0.196	307.4
Total	100.0%	1,566	0.196	307.4

Proposed case system GHG summary (Power project)

Fuel type	Fuel mix %	Fuel consumption MWh	GHG emission factor tCO2/MWh	GHG emission tCO2
Solar	19.6%	308	0.000	0.0
Electricity	80.4%	1,259	0.196	247.1
Total	100.0%	1,566	0.158	247.1

GHG emission reduction summary

	Base case GHG emission tCO2	Proposed case GHG emission tCO2	Gross annual GHG emission reduction tCO2	GHG credits transaction fee %	Net annual GHG emission reduction tCO2
Power project	307.4	247.1	60.4		60.4

Net annual GHG emission reduction 60.4 tCO2 is equivalent to 12.3 Cars & light trucks not used

Appendix T - RETScreen tools combined heating and cooling project analysis for Ningbo

RETScreen Tools - Combined heating & cooling project

Settings

☐ As fired fuel	☑ Ground heat exchanger	☐ User-defined fuel - gas
☐ Biogas	☐ Heat rate	☐ User-defined fuel - solid
☐ Building envelope properties	☐ Heating value & fuel rate	☐ Water & steam
☐ Appliances & equipment	☐ Hydro formula costing method	☐ Water pumping
☐ Electricity rate - monthly	☐ Landfill gas	☐ Window properties
☐ Electricity rate - time of use	☐ Unit conversion	☐ Custom 1
☐ GHG equivalence	☐ User-defined fuel	☐ Custom 2

Ground heat exchanger

Heat pump	Unit	Heating	Cooling	
Capacity	kW	109.0	140.6	See product database
Average load	kW	14.0	17.0	
Manufacturer		Addison		
Model		VGY120-3A		4 unit(s)
Efficiency	High			
Coefficient of performance - design		4.0	5.5	

Site conditions	Unit	Project location	Climate data location
Soil type		Heavy soil -	
Earth temperature	°C	19.1	19.1
Earth temperature amplitude	°C	11.9	11.9
Measured at	m	0.0	0.0

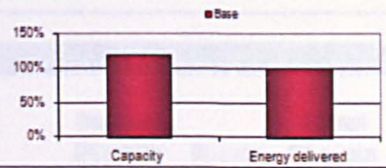
Ground heat exchanger	Unit		
Type		Vertical closed-loop	
Design criteria		Cooling	
Land area	m²	100	93
Layout		Very compact	
Borehole length	m	2,074	

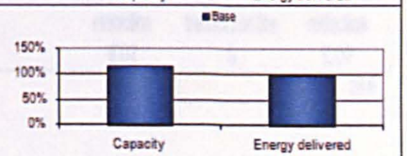
Base load cooling system				
Technology		Heat pump		Show figure
Fuel type		Electricity		
Fuel rate	$/MWh	0.020		
Capacity	kW	96.0	115.9%	See product database
Coefficient of performance - seasonal		3.00		
Manufacturer		Addison		
Model		HGY120-3A	3 unit(s)	
Cooling delivered	MWh	298	100.0%	
Peak load cooling system				
Technology		Not required		

Proposed case heating system				
System selection		Base load system		
Base load heating system				
Technology		Heat pump		
Fuel selection method		Single fuel		
Fuel type		Electricity		
Fuel rate	$/MWh	0.020		
Heat pump				
Capacity	kW	55.0	120.4%	See product database
Heating delivered	MWh	78	100.0%	
Manufacturer		Addison		
Model		VGY120-3A	2 unit(s)	
Seasonal efficiency	%	130%		
Fuel required	GJ/h	0.2		

Proposed case system characteristics	**Unit**	**Estimate**	**%**
Heating			
Base load heating system			
Technology		Heat pump	
Capacity	kW	55.0	120.4%
Heating delivered	MWh	78	100.0%
Peak load heating system			
Technology		Not required	
Back-up heating system (optional)			
Technology			
Capacity	kW		
Cooling			
Base load cooling system			
Technology		Heat pump	
Fuel type		Electricity	
Capacity	kW	96	115.9%
Cooling delivered	MWh	298	100.0%
Back-up cooling system (optional)			
Technology			
Capacity	kW		

System design graph





Proposed case system summary	**Fuel type**	**Fuel consumption - unit**	**Fuel consumption**	**Capacity (kW)**	**Energy delivered (MWh)**
Heating					
Base load	Electricity	MWh	60	55	78
			Total	**55**	**78**
Cooling					
Base load	Electricity	MWh	99	96	298
			Total	**96**	**298**

Base case system GHG summary (Baseline)

Fuel type	Fuel mix %	Fuel consumption MWh	GHG emission factor tCO2/MWh	GHG emission tCO2
Electricity	100.0%	294	0.196	57.8
Total	100.0%	294	0.196	57.8

Proposed case system GHG summary (Combined heating & cooling project)

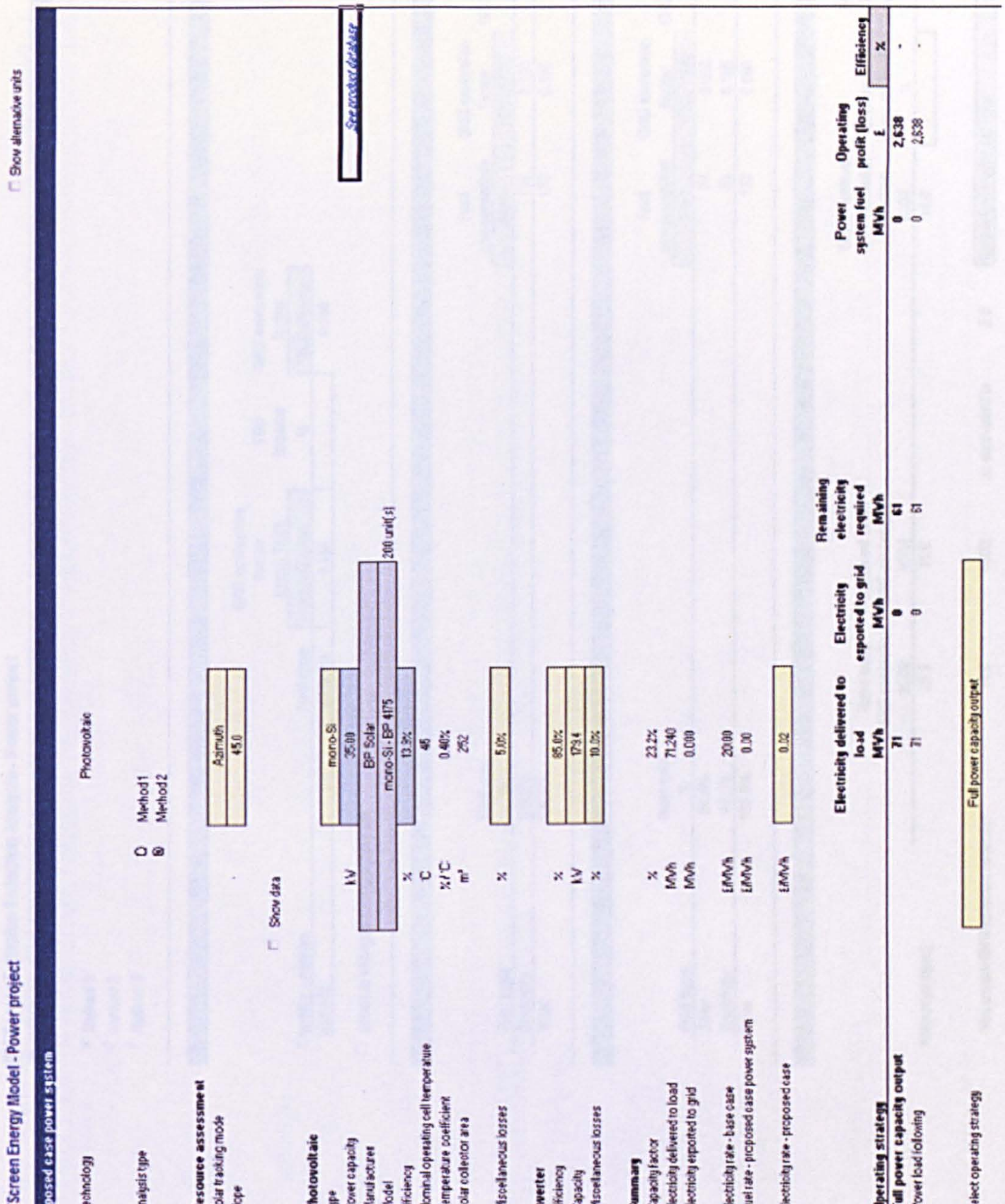
Fuel type	Fuel mix %	Fuel consumption MWh	GHG emission factor tCO2/MWh	GHG emission tCO2
Electricity	100.0%	159	0.196	31.2
Total	100.0%	159	0.196	31.2

GHG emission reduction summary

	Base case GHG emission tCO2	Proposed case GHG emission tCO2	Gross annual GHG emission reduction tCO2	GHG credits transaction fee %	Net annual GHG emission reduction tCO2
Combined heating & cooling project	57.8	31.2	26.6		26.6

Net annual GHG emission reduction 26.6 tCO2 is equivalent to 4.9 Cars & light trucks not used

Appendix U - RET Screen PV panels energy model and emissions analysis for Heihe



RETScreen Energy Model - Power project

Show alternative units

Proposed case power system

Technology		Photovoltaic
Analysis type		Method 1
		Method 2
Resource assessment		
Solar tracking mode		Azimuth
Slope		45.0
	Show data	
Photovoltaic		
Type		mono-Si
Power capacity	kW	35.00
Manufacturer		BP Solar
Model		mono-Si - BP 4175 (200 unit(s))
Efficiency	%	13.9%
Nominal operating cell temperature	°C	45
Temperature coefficient	% / °C	0.40%
Solar collector area	m²	252
Miscellaneous losses	%	5.0%
Inverter		
Efficiency	%	85.0%
Capacity	kW	179.4
Miscellaneous losses	%	10.0%
Summary		
Capacity factor	%	23.2%
Electricity delivered to load	MWh	71.240
Electricity exported to grid	MWh	0.000
Electricity rate - base case	£/MWh	20.00
Fuel rate - proposed case power system	£/MWh	0.00
Electricity rate - proposed case	£/MWh	0.02

See product database

Operating strategy	Electricity delivered to load MWh	Electricity exported to grid MWh	Remaining electricity required MWh	Power system fuel MWh	Operating profit (loss) £	Efficiency %
Full power capacity output	71	0	61	0	2,638	-
Power load following	71	0	61	0	2,638	-

Select operating strategy: Full power capacity output

RETScreen Emission Reduction Analysis - Power project

Emission Analysis

- (•) Method 1
- ( ) Method 2
- ( ) Method 3

Base case electricity system (Baseline)

Country - region	Fuel type	GHG emission factor (excl. T&D) tCO2/MWh	T&D losses %	GHG emission factor tCO2/MWh
Canada	All types	0.196		0.196

☐ Baseline changes during project life

Base case system GHG summary (Baseline)

Fuel type	Fuel mix %	Fuel consumption MWh	GHG emission factor tCO2/MWh	GHG emission tCO2
Electricity	100.0%	132	0.196	25.9
Total	100.0%	132	0.196	25.9

Proposed case system GHG summary (Power project)

Fuel type	Fuel mix %	Fuel consumption MWh	GHG emission factor tCO2/MWh	GHG emission tCO2
Solar	54.0%	71	0.000	0.0
Electricity	46.0%	61	0.196	11.9
Total	100.0%	132	0.090	11.9

GHG emission reduction summary

	Base case GHG emission tCO2	Proposed case GHG emission tCO2	Gross annual GHG emission reduction tCO2	GHG credits transaction fee %	Net annual GHG emission reduction tCO2
Power project	25.9	11.9	14.0		14.0

Net annual GHG emission reduction 14.0 tCO2 is equivalent to 2.8 Cars & light trucks not used

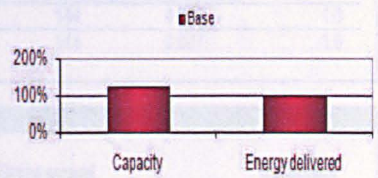
Appendix V -RETScreen Biomass heating system energy model and emissions analysis for Heihe

RETScreen Energy Model - Heating project ☐ Show alternative units

Proposed case heating system			
System selection		Base load system	
Base load heating system			
Technology		Biomass system	
Fuel selection method		Single fuel	
Fuel type		Biomass	
Fuel rate	£/t	20.000	
Biomass system			See product database
Capacity	kW	64.0	124.9%
Heating delivered	MWh	123	100.0%
Manufacturer		Strebel	
Model		NC-1/2/3	1 unit(s)
Seasonal efficiency	%	85%	
Boiler type		Hot water	
Fuel required	GJ/h	0.3	

Proposed case system characteristics	Unit	Estimate	%
Heating			
Base load heating system			
Technology		Biomass system	
Capacity	kW	64.0	124.9%
Heating delivered	MWh	123	100.0%
Peak load heating system			
Technology		Not required	
Back-up heating system (optional)			
Technology			
Capacity	kW		

System design graph



Proposed case system summary	Fuel type	Fuel consumption - unit	Fuel consumption	Capacity (kW)	Energy delivered (MWh)
Heating					
Base load	Biomass	t	28	64	123
			Total	64	123

RETScreen Emission Reduction Analysis - Heating project

Emission Analysis

- (•) Method 1
- ( ) Method 2
- ( ) Method 3

Base case system GHG summary (Baseline)

Fuel type	Fuel mix %	Fuel consumption MWh	GHG emission factor tCO2/MWh	GHG emission tCO2
Coal	100.0%	222	0.350	77.7
Total	100.0%	222	0.350	77.7

Proposed case system GHG summary (Heating project)

Fuel type	Fuel mix %	Fuel consumption MWh	GHG emission factor tCO2/MWh	GHG emission tCO2
Biomass	100.0%	144	0.007	1.0
Total	100.0%	144	0.007	1.0

GHG emission reduction summary

	Base case GHG emission tCO2	Proposed case GHG emission tCO2	Gross annual GHG emission reduction tCO2	GHG credits transaction fee %	Net annual GHG emission reduction tCO2
Heating project	77.7	1.0	76.7		76.7

Net annual GHG emission reduction 76.7 tCO2 is equivalent to 15.6 Cars & light trucks not used

Appendix W - Reporting format suggested by AIDD-EE

	Title	Description
1	Characterisation of the instrument	Characterisation of the researched policy instrument, including at least following items: 1. Targets, including relation to end-use sector and relation to national Kyoto target 2. Period the policy instrument was active 3. Actions, specific technologies and/ or energy efficiency measures 4. Target group 5. National context 6. International context (optional) 7. Market barriers to overcome 8. Organisations, which are responsible for implementation and execution 9. Available budget and source of budget 10. Side effects
2	Policy theory	
		The 6 steps of the theory based policy evaluations are guiding. Based upon already available sources a draft version of this chapter will be made. This draft version is used as basis for the interviews with policy makers. After the interviews the final version will be made.
	Cause-impact relations, indicators and success and failure factors	Description of policymakers' assumptions on how the instrument will function. Definition of indicators to monitor the effect of the various steps in the process (per cause-impact relation). Definition of success and failure factors to monitor the learning experience.
	Interaction with other policies	Which instruments are strongly related to the policy instruments, where is the process (cause – impact chain) and how do they effect the functioning of the researched instrument
3	Evaluation	
		The outcome of each indicator is presented. Indicate if the outcome is as initially expected or not. Analyse the reasons why the result correspond to (in case of success) or differ (in case of failure) from the initially expected value. In other words, go into the success and failure factors. Assess reliability and accuracy of results respectively error margins. The used sources of the data have to e carefully documented here.
3.a	Indicators 1…n	
3.n	Net impact	Is always on of the indicators
3.o	Effectiveness	Is always one of the indicators
3.p	Cost-effectiveness	Is always one of the indicators

3.p.1	Society	Outcomes and basic assumptions for calculation of cost-efficiency for the society
3.p.2	Government	Outcomes and basic assumptions for calculation of cost-efficiency for the government
3.p.3	Other organisations	Outcomes and basic assumptions for calculation of cost-efficiency for other organisations (e.g. energy companies)
3.p.4	End-user	Outcomes and basic assumptions for calculation of cost-efficiency for end- user
4	Conclusions	
4.1	Net impact, effectiveness and cost-effectiveness	Summary of the most important quantitative outcomes, net impact, effectiveness and cost-effectiveness
4.2	Success and failure factors	Summary of the most important finding of the analysis why the instrument is successful or not
4.3	Learning experience	Summary of the most important lessons learnt for this specific instrument and related policies in future

Source: Joosen and Harmelink, 2006

Appendix X – Survey responses summary

Question number	Question	Answer	Responded (%)
2	Do you own or rent the office space?	Own	43
		Rent[3]	57
3	In winter, is the temperature in your office comfortable?	Comfortable	36
		Too cold	43
		Too hot	21
4	In summer, is the temperature in your office comfortable?	*Comfortable*	43
		Too cold	14
		Too hot	43
5	Have you heard about the Standard before?	Yes (Q.5.1)	36
		No (Q 5.4)	64
5.3	What factors would influence your decision to refurbish your office according to the standards?	Climate change	7
		Save energy	7
		Reduce energy bills	57
		Financial support from the Government	29
		Other	7
5.4	Would you like to learn more about the Standard?	*Yes*	57
		No	43
6	Do you know about LEED or GOBAS certification?	Yes	36
		No	64
7	Do you think tenants/ buildings owners receive enough information about the energy efficiency and energy savings?	Enough	0
		Not enough	71
		Too much	0
		Do not receive any information at all	21
8	How do you perceive the Government to promote energy efficiency in commercial buildings?	*Mass media*	86
		Trainings	14
		Information letters	0
		Visits of energy efficiency buildings	14
		There is no promotion	14
		Other	0
9	Do you think the Government promotion of energy efficiency in	Yes	0
		No	100

[3] Most popular response is given in *Italic*

	buildings in enough?		
10	Do you invest in energy efficiency measures?	Yes (Q 10.1)	50
		No (Q10.3)	50
10.1	How have you improved energy efficiency in the building?	Improved insulation	14
		Change window glazing	29
		Use low energy light bulbs	57
		Use modern, more efficient equipment and appliances	43
		Use renewable energy technologies	29
		Use smart energy meters or sub-meters	29
		Other	0
10.2	What is the reason you invest in energy efficiency measures?	Climate change	14
		To save money	57
		To reduce energy consumption	86
		Other	14
10.3	What is the main reason you have not invested in energy efficiency measures so far?	*Too expensive*	43
		Don't know anything about it	29
		Do not see the point	14
		Other	43
11	Do you think tenants and owners of commercial buildings receive enough information about RET?	Enough	0
		Not enough	43
		Too much	21
		Do not receive any	36
12	How do you learn about RET?	*Mass media*	71
		Information letters	0
		Exhibitions	0
		Other companies	7
		I don't know anything about RET	21
		Other	7
13	Do you use RET?	Yes (Q. 13.1)	36
		No (Q. 13.4)	57
13.1	What RET do you use?	PV	0
		Wind turbine	0
		Solar water heating	40

		Biomass boiler	0
		Ground-source heat pump	60
		Other	40
13.3	How much electricity in your office is produced from the RET?	5-10%	20
		10-30%	0
		30-50%	0
		More than 50%	0
		Not sure	80
13.5	Would you consider using RET?	*Yes* (Q. 13.6)	71
		No (Q. 13.9)	29
13.6	Under what conditions would you use RET?	Cheaper price	70
		Government provides financial support	90
		Savings in energy and reduction of energy bills	30
		Other	0
13.7	What RET would you use?	*PV*	60
		Wind turbine	0
		Solar water heating	40
		Biomass boiler	0
		Ground-source heat pump	60
		Other	10
13.9	Why you would not want to use RET?	*Too expensive*	43
		Do not know anything about RET	7
		Do not see the point in using RET	7
		Other	0
14	In winter, what type of heating in the office do you use?	Electric heaters	36
		Heating from the AC	50
		Heating from the central AC system	14
		District heating (Q. 14.1)	29
		Do not use heating	7
		Other	0
14.1	Do you think the price for district heating over the heating season is:	Average	21
		Too cheap	0
		Reasonably cheap	21

		Too expensive	36
		Reasonably expensive	14
15	In summer, what type of cooling in the office do you use?	Free-standing AC	36
		Fans	7
		Cooling from central AC system	43
		Do not sue cooling	7
		Other	7
16	Do you think electricity price is:	Too cheap	7
		Reasonably cheap	0
		Average	36
		Reasonably expensive	50
		Too expensive	7
17	Do you think your office annual energy consumption (in kWh) is:	Low	0
		Average	86
		High	14
18	What is the biggest electricity consumer is your office?	Lighting	7
		Cooling	29
		Heating	14
		Equipment	36
		I don't know	29
		Other	0
19	What would influence your decision to reduce the energy consumption in the office?	High electricity prices	43
		Saving money on energy bills	93
		Climate change	0
		Other	0
20	Are there any companies offering advice on the office energy consumption reduction?	Yes (Q. 20.1)	21
		No (Q. 21)	79
20.1	Have you ever been offered any advice?	Yes	14
		No	79
21	Do you know about any governmental incentives for energy consumption reduction/ energy efficiency improvements?	Yes	21
		No	79
22	Would you like to be involved in energy efficiency policy-making?	*Yes*	57
		No	43