Energy efficient buildings
in Qingdao, China

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Abstract

At present, an important task for Chinese governments at all levels is to save energy and reduce pollutant emissions. The task of buildings energy efficiency accounts for 21% in the 12th Five Year Plan which from 2011 to 2015. With the development of social economy, the energy shortage is serious day by day. The energy-conservation of buildings is a high relevant issue in China. There are a large capacity and a wide range of existing buildings in Qingdao among which the overwhelming majority is the non-energy-efficient buildings and the operate energy consumption are enormous. At Present, according to the related statistic, the energy efficient building area only accounts for 3% to 5% of the total building area newly increased in our country every year, while in such existing buildings in Qingdao, most of them are highly energy-consuming, the energy consumption in buildings is about 100-350kWh for each floor area of the whole year, which is 2 to 3 times of the energy consumption of the same area of energy efficient buildings. So we can say that whether could we promote the effective use of resources and energy in buildings is very important, which will finally determine whether could we and take the road to sustainable development.

In respect of the application of the complicated systematic scientific conclusions, the thesis carries out the analysis of geographic and climate characteristics in Qingdao area and the research of current energy consumption.

Based on the quantitative model analysis of environmental and economic benefits of implementation of energy efficient buildings in Qingdao in scenario k, promotion and implementation of energy efficient buildings can substantially reduce the current high environmental cost associated with energy consumption for heating and cooling in buildings in Qingdao. Emission including carbon dioxides, sulfur oxide, nitrogen oxides and ash can be reduced, it means that under the scenario k energy efficient buildings has an idea performance on reducing pollutant gas. At the same time, accompanied by the great environmental benefits, there are also substantial economic benefits.

Barriers to energy efficiency in buildings in Qingdao, including political, economic, social and technological barriers are discussed in this thesis. According to the investigation and analysis about the present situation and factors affecting the implementation of energy efficient buildings in Qingdao, this thesis put forward recommendations from the aspects of environment, politics, economy, society and technology to improving energy efficient buildings in Qingdao.

**Key words:** Qingdao, energy efficient buildings, environmental impacts, economic impacts, quantitative economic model, scenario
# Table of contents

1. Introduction ................................................................. 1
   1.2 Background ................................................................. 1
   1.2 Introduction of energy efficient buildings in Qingdao ................. 4
   1.3 Aim and objective ...................................................... 4
   1.4 Methodology ............................................................... 5

2. Factors affecting the implementation of energy efficiency in buildings in Qingdao .......... 6
   2.1 Environment factors .................................................... 6
      2.1.1 Location ............................................................ 6
      2.1.2 Climate ............................................................ 7
   2.2 Political factors .......................................................... 9
      2.2.1 Laws and policies .................................................. 9
      2.2.2 Standard for energy efficiency in buildings in Qingdao ............ 10
      2.2.3 Labels for energy efficient buildings ................................ 11
   2.3 Economic Factors ....................................................... 11
      2.3.1 Economical situation ............................................. 12
      2.3.2 Energy pricing ..................................................... 12
      2.3.3 Financial support .................................................. 13
   2.4 Social factors ............................................................. 14
      2.4.1 Population .......................................................... 14
      2.4.2 Culture and lifestyle ............................................. 15
   2.5 Technological factors ................................................... 16
      2.5.1 Building envelope ............................................... 16
      2.5.2 Heating and cooling system ..................................... 17

3. Situation of energy consumption in buildings in Qingdao ..................................... 20
   3.1 Current situation of energy consumption in buildings ...................... 20
   3.2 Composition of energy consumption ..................................... 21
   3.3 Energy consumption pattern in a buildings .................................. 23

4. Evaluate Model of Direct Economic and Environmental Impacts of Energy Efficient buildings in Qingdao .............................................................. 24
4.1 Scenarios $k$ ................................................................. 24
4.2 Evaluate model of economic and environmental impacts under scenario $k$ ............... 25
  4.2.1 Analysis of economical impacts ........................................ 25
  4.2.2 Analysis of environmental impacts ..................................... 25
  4.2.3 Results of economic and environmental impacts of energy efficient buildings in Qingdao ........................................................... 25

5. Discussion ........................................................................ 29
  5.1 Analysis of benefits of energy efficient buildings in Qingdao in scenario $k$ ............... 29
    5.1.2 Energy saving ............................................................... 29
    5.1.2 Environmental benefits .................................................. 30
    5.1.3 Economic benefits ........................................................ 31
  5.2 Barriers to energy efficiency in buildings in Qingdao ............................................. 31
    5.2.1 Political barriers ............................................................ 31
    5.2.2 Economical barriers ....................................................... 33
    5.2.3 Social and culture barriers ............................................... 33
    5.2.4 Technological barriers .................................................... 35

6. Discussion and Recommendations .......................................... 36
  6.1 Optimizing the legal system .................................................. 36
    6.1.1 Enhancing monitoring system ........................................... 36
    6.1.2 Developing energy efficient standards for buildings ................. 37
  6.2 Enhance economic incentives ................................................ 37
    6.2.1 Increasing energy price in buildings .................................... 38
    6.2.2 The voluntary carbon market .......................................... 38
  6.3 Raising social awareness ..................................................... 38
  6.4 Integrated design of energy efficient buildings ................................................. 39
  6.5 Consideration of local climate ............................................... 40

7. Conclusion ........................................................................ 41

8. References .......................................................................... 43
1. Introduction

1.2 Background

In the seventies of the twentieth century, caused by the first energy crisis outbreak in the worldwide, energy issues has aroused the attention around the world, energy, population, food, environment and resources are listed as the top five problems in the world. With the development of the economic and the improvement of living standards, the severe situation of the rapid growth of the energy consumption makes people aware the seriousness and permanency of the energy issue. Building energy consumption accounted for a large proportion in the growing energy consumption. In the 8th “Western Forum” in China, Song Chunghwa, the chairman of the Architectural Society as well as the former vice minister of construction of China, said that the proportion of the building energy consumption accounted for in the total energy consumption of China has been raised from the 10% in the late 70s of the last century to 26.7% in the year 2009, reached 31.2% which was the average level of the proportion of the world's total energy consumption of building accounted for in energy consumption. (Suyi, H. & Wei, G., 2004) The energy consumption of building, including the energy consumption in the projects of materials production, building construction, building demolition and daily operations, etc. in which the largest proportion is the energy consumption in the daily operation (such as heating, air conditioning, hot water, lighting, appliances, etc.). As the developing of the national industrialization and the rising of living standards, the technology and quality of residential and public buildings also has continuous developments, the energy consumption of buildings has been increasing over time as a result. Therefore, countries in the world regard the energy efficiency of building, in particular reducing the energy consumption of building in the daily operation as the key factor of energy conservation.

The vast area of China, from north to south, in turn is divided into the very cold region, cold region, hot summer and cool winter region, the hot summer and warm winter region and temperate region. In the area of cold region, cool region and the cities and towns of hot summer and cold winter region of China, there are the needs of heating in the winter, burning the coal caused serious pollution to the atmosphere. At the same time, there is hot summer in most areas of China, with the increasing popularity of air conditioning in those areas the energy consumption has been increasing rapidly. (Fengxiang, T. et al. 1997)
Compare to the developed countries which has the similar climate conditions, the energy consumption of building per square meter per year are almost 2~3 times more than which in the developed countries. The main reason causing the above situation is that a large number of existing constructions in China without using any energy-saving measures have poor insulation and inefficient equipment system, resulting in large waste of energy in the process of cooling and heating in the daily operation. The building enclosing structure of heat insulation has generally poor performance, the thickness of the traditional solid clay brick wall is 1.5~2 brick in very cold region, 1~1.5 brick in cold region, 1 brick in hot summer cool winter region and 3/4 brick in hot summer and warm winter region. Moreover, the burning of coal, the main method of building heating in China, has a more serious impact on the environment than the developed countries in which the natural gas performs as the main heating material. (World Bank report, 2000)
Buildings without energy-saving measures continue to waste more and more limited energy and discharge large amount of carbon dioxide and other greenhouse gases to the atmosphere during the heating and cooling seasons in China. Followed by natural disasters, such as dust storms, desertification, floods and droughts, results in rapid deterioration of people's living environment. This shows that the energy-saving measures in buildings in China should be commence well in advance, otherwise, the number of energy inefficient buildings will be piled up and as a result it would be more and more difficult to sustain economic cost of energy saving for China.

There are 45 billion square meters of construction area (of which 17 billion square meters is urban construction area) in China, only 1.09 billion square meters from urban building is energy efficient construction, account for 7.3% of national existing urban construction area. And whether from the terms of building envelop, or heating and cooling systems, the remaining buildings are classified as high-energy consumption buildings. Under the most optimistic estimate, the high-energy consumption buildings account for 96% of existing buildings in the country, the buildings which do not meet the energy efficiency standards account for more than 80 percent of the new construction program. In 2009, China's building energy consumption (including construction energy, life energy, heating and air conditioning energy consumption, etc.) has accounted for about 31% of total energy consumption of China, of which the most important part is the energy consumption of heating and cooling, accounting for 20%. (Wei, X., 2010)

China currently consumes approximate 130 million tons of standard coal equivalents per year just for heating of residential and commercial buildings in urban area, according to MOC estimates. (World Bank report, 2000) Is expected by the year 2020, both the urban and rural housing building area of China will be added about 300 million square meters, existing building area will reach approximately 78 billion square meters. (Sinton, J.E., M.D. Levine, Q.Y. Wang. 1998) If the effective alteration of energy saving measures in existing buildings was not taken, then by the year 2020 the energy consumption of buildings of China will reach 1.12 billion tons of standard coal equivalents, close to 3 times compared to the current energy consumption of buildings of China. According to the cost of power generation in China per ton of standard coal is equivalent to approximate 2750 kwh of electricity. (Liangpu, W. et al. 2001) Conversely, if the programs of energy saving alteration in existing buildings of China are implemented step by step and all the projects meet the standards of energy efficiency, then by 2020, approximate 345 million tons of standard coal to be saved and 85 million kwh from the peak load of using of air conditioning to be reduced every year, equivalent to 923 billion dollar of power construction funds to be saved. (Liangpu, W. et al. 2001)
1.2 Introduction of energy efficient buildings in Qingdao

Located on the south-east coast of the Shandong Peninsula, Qingdao is a city with a temperate humid climate with moist hot summers and dry, cold winters. As a city with rich resources, strong economy and large population, in 2009, the gross domestic product of Qingdao was 485.387 billion Yuan, with an increase of 12.2% in 2009, and the rate of urbanization was above 48.3%. (Statistics yearbook of Qingdao) Companied with the growth of economy, the energy consumption in buildings has been increasing. In recent years, energy efficiency in buildings is a highly relevant issue in Qingdao and supported by government of Qingdao and China.

The project of energy efficient building has achieved initial achievements and become one of the most important measures of reducing energy consumption as well as promoting economic development. The program of energy efficient buildings was in the early start of the similar cities in China. Launched in the year 1998, the projects of renovation of wall material and construction of energy saving, through a series of measures including establishing industry policies and standards for energy efficient buildings, promotion of economic leverage, pilot demonstration, strengthening supervision and publicizing, achieved effective results and as a result deepened market bodies involved the knowledge of energy saving technology. According the actual situation of building energy saving in Qingdao area the government formulated a strategic goal: from the year 2011 to 2015, the project of energy saving alteration in existing residential buildings is basically completed, 65% of public buildings meet the energy efficiency standard and all the buildings meet the energy saving standards of state. (Urban and rural construction committee of Qingdao, 2010)

1.3 Aim and objective

This work aims to further improve and continue government planning of implementation of energy efficient buildings in Qingdao. And then, proposing reasonable suggestions to promoting and implementation energy efficiency in buildings in Qingdao.

More specifically, the objectives of this research are:

(1) Based on the analysis and research on the factors affecting the implementation of energy efficient buildings in Qingdao, to demonstrate the necessity, possibility and practical feasibility of project of energy efficient buildings in Qingdao from the political, economical, social and technological aspects.

(2) Based on quantitative model in scenario k, to analyze the economical and environmental benefits of implementation of energy efficient buildings in Qingdao, and then discuss the barriers to implementation and promotion of energy efficient buildings in Qingdao.
(3) To proposes the recommendations of implementation of energy efficient buildings in Qingdao.

1.4 Methodology

This paper established a quantitative economic model, adopted the method of scenario, aims to evaluate the direct economic and environmental impact of implementation of energy efficient building in Qingdao. Under a reasonable scenario, by using evaluate model, and analyze the results.

The scenario method is employed to analyze the benefits of implementation of energy efficient buildings in Qingdao. There are varying definitions of the scenario method but main characteristics are concluded in the various definitions including hypothetical, causally coherent, internally consistent, and/or descriptive characteristics. The definition of scenario method is below.

“Scenarios are consistent and coherent descriptions of alternative hypothetical futures that reflect different perspectives on past, present, and future developments, which can serve as a basis for action”. (Van Notten, 2006)

The method of scenario is chosen to offer a quantitative way for the model to analyze the benefits for implementation of energy efficient buildings in Qingdao for the future in this study. Under this scenario, namely $k$ scenario, there will be no significant changes in laws, policies and standards for energy efficient buildings in Qingdao. The aim of predictive scenarios is to try to predict and analyze the economical and environmental benefits for implementation of energy efficient buildings in Qingdao on the condition of scenario $k$.

Model-based analysis approach is utilized in this thesis. The time scale adopted is from 2011 to 2015, five years is considered as a reasonable scenario because the 12th five year plan (2011-2015) which set a 65% energy efficient goal for energy efficient buildings in Qingdao. (Design standard for 65% energy efficiency in buildings in Qingdao, 2006)
2. Factors affecting the implementation of energy efficiency in buildings in Qingdao

2.1 Environment factors

Natural conditions, one of the most important factors which affecting the energy consumption of buildings in Qingdao, has significant impact on the pattern of the construction, orientation, structure and material of construction, especially critical to the reduction of energy consumption of buildings. Climate factors are the pre-condition of designs and implementation of technologies of energy efficiency in building including lighting, insulation, ventilation and heating, etc.

2.1.1 Location

Figure 2 Location of Qingdao

Source: Statistical Yearbook of Qingdao, 2010

Qingdao is located on the south-east coast of the Shandong Peninsula, as shown in figure 2. Qingdao is between 35°35'N - 37°09'N latitude and 119°30'E - 121°00'E longitude, and has a temperate humid climate, with moist hot summers and dry, cold winters. It borders three prefecture-level cities, namely Yantai to the northeast, Weifang to the west, and Rizhao to the southwest. The total area of Qingdao occupies 10,656 square kilometers. The populated parts of Qingdao are relatively flat while mountains spur up within city limits and nearby. The highest elevation in the city is 1,133 meters above sea level. 15.5% of the total area is highland, while the foothill, plain and lowland areas constitute 25.2%, 38.8% and 22.7%. The city has a coastline of 730.65 kilometers. (Statistical Yearbook of Qingdao, 2010)
2.1.2 Climate

Qingdao has a warm temperate monsoon climate with most rainfall concentrated in the hot summer, located in the south temperate humid climate zone of China. It has a short spring and autumn but a long winter and summer. Data of weather conditions of Qingdao are shown in the table 1 below:

<table>
<thead>
<tr>
<th>Average temperature (°C)</th>
<th>Highest temperature (°C)</th>
<th>Lowest temperature (°C)</th>
<th>Precipitation (mm/year)</th>
<th>Sunshine (h/year)</th>
<th>Atmospheric pressure (hPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>13.2</td>
<td>35.8</td>
<td>-11.1</td>
<td>667.3</td>
<td>2300</td>
<td>1019.1</td>
</tr>
</tbody>
</table>

Source: Statistical Yearbook of Qingdao, 2010

(1) Temperature

The average temperature in Qingdao area is 13.2°C, the highest temperature which appeared in August is 29.1°C, and the average temperature is 25.1°C. (Statistical yearbook of Qingdao, 2010) The lowest temperature which appeared in January is -3°C, the average temperature is -0.2°C. There are four months in which the temperature exceeds 20°C in a year, and only one month which is January in which the temperature is lower than 0°C. (Statistical yearbook of Qingdao, 2010) Figure 3 indicates the regular changes of temperature in one year in Qingdao area.

Figure 3 Monthly temperature changes in Qingdao in 2009

Source: Statistical Yearbook of Qingdao, 2010
(2) Precipitation

The total annual precipitation is 667.3mm in Qingdao area, the average precipitation is 55.6mm, decreasing from southeast to northwest. (Statistical yearbook of Qingdao, 2010) Specifically, most rainfall is concentrated in the months of May, June, July and August. August has the maximum precipitation, reaching to 258.6mm. January has the minimum precipitation which is only 0.6mm. (Statistical yearbook of Qingdao, 2010) The precipitation trend is shown in Figure 4 below:

![Figure 4 the monthly precipitation in Qingdao area in 2009](image)

Source: Statistical Yearbook of Qingdao, 2010

(3) Sunshine

The accumulate l sunshine time in Qingdao is 2300 hours, average sunshine time is 191.7 hours, the total solar radiation is 119.2kcal/cm2. Except February, the sunshine time is distributed evenly in every month (Statistical yearbook of Qingdao, 2010), as shown in the Figure 5 below:
2.2 Political factors

The legal environment in Qingdao is the main factor affecting the implementation and promotion of energy efficiency in buildings. The determinants in this sphere derive from local and national political structure regarding energy efficiency in buildings.

The city government of Qingdao has set a standard of a 58% reduction of energy consumption in heating and cooling for new buildings, 8 percentages more than the national one which is 50%. (The twelfth five-year plan of Qingdao, 2011) In its 12th five-year plan for local social and economic development in Qingdao (2011-2015), the city government of Qingdao has set the goal for energy efficiency in building during the period of 2011-2015, presented that to the end of the year 2015, 65% of new residential buildings, 50% new public buildings and 30% existing buildings meet the requirement of energy efficiency standards through implementation of energy efficiency building and refurbishment. (The twelfth five-year plan of Qingdao, 2011)

2.2.1 Laws and policies

To achieve the aim of reducing of energy waste and energy efficiency in buildings, several laws were established and/or revised to enhance the implementation of energy efficiency in buildings in China as well as Qingdao.

(1) Energy saving law.

According to the article 37, the law says “Building designs and construction shall (...)
employ energy-saving types of construction structures, materials, facilities and products improve heat insulation properties and reduce energy consumption for space heating, heating and lighting.” (Chinagb.net, 2008) It indicates that the implementation and promotion of energy efficiency in buildings is considered as one factor when evaluating the performance of city governments in China.

(2) Renewable energy law
Renewable energy law, as the first law concerning the utilization of renewable energy such as solar power and biogas, is published in the year 2006. One important measure is the setting up of the fund of renewable energy, which entered into effect in 2007. The main task of the fund is to subsidize the building constructors and owners who using the renewable energy. (Baker & McKenzie et al. 2007)

(3) Regulations of energy efficiency in buildings
Issued the year 2006, regulations of energy efficiency in buildings contain the principles and guidelines for new buildings, existing buildings, electric appliances, energy efficient building standards and measures of economic incentives. It states that the residential buildings which saving 32.5% energy can get tax reductions. Furthermore, it states that the central air condition in the public buildings should not be set below 25 degree in the summer and above 25 in the winter. It also regulates those regulations of energy saving in the government office. (Carmen Richerzhagen et al., 2008)

2.2.2 Standard for energy efficiency in buildings in Qingdao

Presently, there are two standards for energy efficiency in buildings implementing in Qingdao, national and local standards. The difference is that national standard is used in whole China area while local standard which must go beyond the national standard can only be used in Qingdao. Both national and local standards regulate the regulate goals and technologies that the building constructors must reach and employ. Buildings with different functions, such as residential building and public building, have to reach differently specific standards.

(1) National standard
The chapter from the new standards for energy efficiency in buildings published in August of 2010, namely “Design standard for energy efficiency in buildings in cold zone (JGJ 26-2010)”, set the goal of energy efficiency of both residential and public buildings and regulate the technologies of energy efficiency in buildings. One important detail in this national standard is that the requirement of energy saving is improved from 45% in 2006 to50% in 2010. Furthermore, there are further specific standards which prescribe technical requirements:

- Standard for external insulation of outside walls (JGJ1442004)
Qingdao city has its own standard for energy efficiency in buildings. “Design standard for 65% energy efficiency in buildings in Qingdao”, established in the year 2006, and is targeted to reach 65% energy saving to the new residential buildings. Systems of the monitor of quality and identification of project were established to ensure the implementation of energy efficient standard for buildings in Qingdao. Furthermore, personnel trainings concerning technologies and management skills were carried out to provide human resources to the implementation of system of monitor and identification. (Design standard for 65% energy efficiency in buildings in Qingdao, 2006)

2.2.3 Labels for energy efficient buildings

In March 2008, at the 4th Green Building Conference in Beijing, a new “Building Energy Efficiency Label” is established and introduced to the public, as shown in figure . The label started to use in August 2008 in China. The label is mandatory for the public and residential buildings in China, it regulates that: 1) any public buildings applied the government provision and/or financial subsidize must be evaluated by the labeling system; 2) any residential buildings declaring the national or regional project must be evaluated by the labeling system; 3) in the pilot cities, all the buildings must be evaluated and certificated by the labeling system. The energy efficient label program enhances the supervision and implementation of energy efficiency in buildings. In the process of evaluation, energy consumption of buildings is reflected. (Carmen Richerzhagen et al., 2008)

2.3 Economic Factors

In addition to political factors, economic factors also play an important role in
promotion and implementation of energy efficiency in buildings in Qingdao. High prices of energy efficient technologies and limited access to capital for investments are the main economic barriers to implementation and promotion of energy efficient buildings. The following chapter is analysis of economic factors in three key fields:

- Local economic situation
- Financial support

### 2.3.1 Economical situation

Qingdao is a city with rich resources, strong economy and large population. In 2009, the gross domestic product of Qingdao was 485.387 billion Yuan, with an increase of 12.2% in 2009 and 13.2% in 2008, and the rate of urbanization was above 48.3%. (Statistical Yearbook of Qingdao, 2010)

In the year 2009, the gross domestic product of building industry is 68.647 billion RMB, accounts for 14.15% of the total gross domestic product of Qingdao. (Statistical yearbook of Qingdao, 2010) The area of new buildings is 30.79 million square meters, in which the area of residential buildings is 11.32 million square meters and the area of public buildings is 17.17 million square meters. (Statistical Yearbook of Qingdao, 2010)

### 2.3.2 Energy pricing

Energy price for buildings mainly refer to electricity price and heating price in this study. In Qingdao, heating and cooling consume the most energy in buildings, accounts for almost more than 40% of total energy consumption of public buildings, followed by the energy consumption on lighting and hot water, 20% and 15% respectively. (Tsinghua Background Report, 2000)

- Electricity prices. In Qingdao, 89 percent energy used for cooling, lighting and hot water in a building is electricity in cities and towns. Different electricity prices are set for different utilization and amount in buildings in Qingdao. **Table 2** lists the electricity prices for residential and public buildings.

<table>
<thead>
<tr>
<th>Electricity prices for residential buildings</th>
<th>Electricity prices for public buildings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Below 1kv</td>
<td>1kv and above</td>
</tr>
<tr>
<td>0.5469</td>
<td>0.4929</td>
</tr>
</tbody>
</table>

*Source: Standard for classified electricity prices in urban and rural in Qingdao, 2008*

- Heating prices. As Qingdao is located in cold winter and hot summer zone, the heating is necessary for residents in winter, therefore the cost of heating and...
energy consumption is relatively high than the cities in the south of China. Table 3 shows the average heating price in Qingdao. The model of centralized heating is adopted in Qingdao, 48% residents have to pay the heating bills by their own, and 39% residents pay a small portion of the heating bills while the remains is afforded by their employer.

**Table 3 Average price for centralized heating in Qingdao, 2006 (unit: yuan RMB)**

<table>
<thead>
<tr>
<th>Heating degree days</th>
<th>Heating price</th>
<th>Connection charge</th>
</tr>
</thead>
<tbody>
<tr>
<td>2445</td>
<td>18.8</td>
<td>99</td>
</tr>
</tbody>
</table>

*Source: China’s annual report on energy efficiency in buildings, 2007*

### 2.3.3 Financial support

(1) Fund

City government of Qingdao has its own financial support programs. For example, the city government has established the “Energy efficient building project management rules” in August 2008. According to these rules, each of 30 energy efficient buildings projects was able to receive a fund of 60,000 yuan RMB in 2008. (The twelfth five-year plan of Qingdao, 2011) These rules, with a design of incentive structure, provided a fund of 30,000 yuan RMB before construction and 30,000 yuan RMB afterwards. (The twelfth five-year plan of Qingdao, 2011)

(3) Subsidize

During the period 2011 to 2015, the government of Qingdao will subsidize 85 yuan/m² to the project of energy saving buildings in Qingdao. Through a monitoring and evaluation of the energy efficient performance by urban and rural construction committee, the new building which reach 65% energy efficient standards has the qualification of applying the subsidize offered by government. (Yuhong, S., 2010)

(4) Loan and tax

Low interest loans was offered to energy efficient buildings projects by the banks in Qingdao in the year 2008, annual interest rate on loan is 4.64% while the normal rate is 5.85%. Tax reduction was provided to projects of energy efficient buildings as well in Qingdao. (Yuhong, S., 2010)
2.4 Social factors

2.4.1 Population

Referring to the "Statistical Yearbook of Shandong Province (1990-2009)\(^\text{1}\), the total population of Qingdao in 2007 was 7.62 million while the population density was 603/km\(^2\); the population density in inland areas increased faster than that in the coastal areas. This trend has resulted in an imbalance of population distribution between the inland and the coastal areas (Statistical yearbook of Qingdao, 2010). Table 4 shows the statistics of population in Qingdao.

\[\text{Table 4 Statistics of population in Qingdao, 1990 to 2009}\]

<table>
<thead>
<tr>
<th>Year</th>
<th>Total population</th>
<th>Classified by gander</th>
<th>Average population</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Man</td>
<td>Woman</td>
</tr>
<tr>
<td>1990</td>
<td>6 666 482</td>
<td>3 392 253</td>
<td>3 274 229</td>
</tr>
<tr>
<td>1991</td>
<td>6 709 277</td>
<td>3 411 776</td>
<td>3 297 501</td>
</tr>
<tr>
<td>1992</td>
<td>6 731 072</td>
<td>3 420 886</td>
<td>3 310 186</td>
</tr>
<tr>
<td>1993</td>
<td>6 753 497</td>
<td>3 431 149</td>
<td>3 322 348</td>
</tr>
<tr>
<td>1994</td>
<td>6 785 291</td>
<td>3 446 019</td>
<td>3 339 272</td>
</tr>
<tr>
<td>1995</td>
<td>6 846 346</td>
<td>3 476 300</td>
<td>3 370 046</td>
</tr>
<tr>
<td>1996</td>
<td>6 902 677</td>
<td>3 502 600</td>
<td>3 400 077</td>
</tr>
<tr>
<td>1997</td>
<td>6 954 391</td>
<td>3 527 588</td>
<td>3 426 803</td>
</tr>
<tr>
<td>1998</td>
<td>6 995 666</td>
<td>3 545 403</td>
<td>3 450 263</td>
</tr>
<tr>
<td>1999</td>
<td>7 029 707</td>
<td>3 561 061</td>
<td>3 468 646</td>
</tr>
<tr>
<td>2000</td>
<td>7 066 481</td>
<td>3 577 367</td>
<td>3 489 114</td>
</tr>
<tr>
<td>2001</td>
<td>7 104 875</td>
<td>3 595 652</td>
<td>3 509 223</td>
</tr>
<tr>
<td>2002</td>
<td>7 156 537</td>
<td>3 619 778</td>
<td>3 536 759</td>
</tr>
<tr>
<td>2003</td>
<td>7 206 806</td>
<td>3 644 032</td>
<td>3 562 774</td>
</tr>
<tr>
<td>2004</td>
<td>7 311 228</td>
<td>3 692 991</td>
<td>3 618 237</td>
</tr>
<tr>
<td>2005</td>
<td>7 409 052</td>
<td>3 740 309</td>
<td>3 668 743</td>
</tr>
<tr>
<td>2006</td>
<td>7 493 812</td>
<td>3 779 891</td>
<td>3 713 921</td>
</tr>
<tr>
<td>2007</td>
<td>7 579 910</td>
<td>3 816 620</td>
<td>3 763 290</td>
</tr>
<tr>
<td>2008</td>
<td>7 615 647</td>
<td>3 824 665</td>
<td>3 790 982</td>
</tr>
<tr>
<td>2009</td>
<td>7 629 161</td>
<td>3 823 534</td>
<td>3 805 627</td>
</tr>
</tbody>
</table>

*Source: Statistics year book of Qingdao, 2010*

**Figure 6** indicates the population in Qingdao has been increasing stably from 1990 to 2009, according the prediction of population, to the year 2015 the population will reach 8 million in Qingdao. Therefore an increasing demand of both residential and public buildings will leads to increasing energy consumption in buildings in Qingdao. (Statistics yearbook of Qingdao, 2010)
2.4.2 Culture and lifestyle

The rapid economic growth of Qingdao in the recent decades has changed consumption patterns and lifestyles of the Chinese population. More and more people are looking forward to more comfortable living environment. More and more household appliances and larger houses are being purchased in Qingdao. Consequently it has led to an overall increase in energy consumption.

Table 5 Investigation among 2,000 people concerning priorities for residential building purchasing under the assumption of the same price 1,000,000 yuan RMB of house

<table>
<thead>
<tr>
<th></th>
<th>Size</th>
<th>location</th>
<th>Pattern</th>
<th>Energy efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Population</td>
<td>1,110</td>
<td>340</td>
<td>320</td>
<td>140</td>
</tr>
<tr>
<td>Proportion</td>
<td>55.5%</td>
<td>17%</td>
<td>16%</td>
<td>7%</td>
</tr>
</tbody>
</table>

Source: the Urban and Rural Construction Committee, 2008

According the investigation on the tendency of residential building purchasing, investigated by the urban and rural construction committee in 2008, under the same price assumption of 1,000,000 yuan RMB, 55.5% people of 2,000 interviewees range the house size as the priority of consideration for residential building purchasing, followed by 17% chose the location and 16% chose the residence pattern, only 7% interviewees consider the performance of energy efficiency in buildings as one important factor. (The Urban and Rural Construction Committee, 2008)
2.5 Technological factors

2.5.1 Building envelope

A building envelope includes all components of a building that enclose conditioned space. The building envelope separates conditioned spaces from unconditioned spaces or from outdoor. For example, doors and windows, walls, floors between unheated and heated area. Although floors of conditioned basements and conditioned crawlspace are technically part of the building envelope, the code does not specify insulation requirements for these components. In Figure 7 below shows the components of building envelope. (Resource center, 2009)

“The government-sponsored Building Energy Codes Resource Center defines the building envelope as “the area that separates conditioned space from unconditioned space or the outdoors. A building envelope includes all components of a building that enclose conditioned space. Building envelope components separate conditioned spaces from unconditioned spaces or from outside air”. (The government-sponsored Building Energy Codes Resource Center, 2002)

Figure 7 the components of building envelope

There is the closed relation between the energy efficiency and building envelope in a building, the nodes of building envelope structure, having a direct impact on the energy efficiency in a building, is often the weak part of the thermal performances in a building, improving the building envelope is critical to reduction of energy waste. The design of energy efficient building envelope includes the energy saving design of walls, windows, doors, roof and floor in a building. (Minglei, Xu., 2006) As high as 72% to 78% of consumption of heat transfer in a building lost mainly through the building envelope, in which heat loss in external wall accounts for 26%, heat loss in wall next to stairs accounts for 15%. (The government-sponsored Building Energy
Therefore, improving the energy efficient performance of heat insulation wall will significantly reduce the energy consumption in a building.

**Table 5 features of building envelope in Qingdao in 2007**

<table>
<thead>
<tr>
<th>Feature</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Insulation wall</td>
<td>42%</td>
</tr>
<tr>
<td>Enclosed balconies</td>
<td>78%</td>
</tr>
<tr>
<td>Metal window mounts</td>
<td>79%</td>
</tr>
<tr>
<td>Single pane glass window</td>
<td>60%</td>
</tr>
</tbody>
</table>

*Source: Shumei, L., 2008*

Table 5 indicates that only 42% buildings use insulation wall, as most energy is lost from the building envelope, the small proportion of insulation wall cause a large energy waste in billings in Qingdao. (Shumei, L., 2008) Meanwhile, single pane glass window accounts for 60% of all window types used in Qingdao, compared to double glasses pane window, the poor performance of energy efficiency of single pane glass window leads to an unnecessary energy waste neither in summer and winter. (Shumei, L., 2008)

In Qingdao, for the purpose of increasing the space in a building, residential and public buildings owner always enclose the balconies, from the Table 5 we see 78% balconies in Qingdao is enclosed. Enclosed balconies has a poor energy efficient performance that in summer it increase the temperature while the residents looking forwards to a cool indoor temperature and in winter it decrease the temperature while a higher indoor temperature is needed. Thus a large amount of energy is wasted through enclosed balconies in buildings in Qingdao. (Shumei, L., 2008)

### 2.5.2 Heating and cooling system

40% energy consumption comes from the heating and cooling, therefore the heating and cooling system directly linked to performance of energy efficiency in daily building operation, and affects the air quality and temperature in a building. (Minglei, Xu., 2006)

(1) Heating system

The independent heat-supply system are using generally at present in Qingdao, there are almost 3/4 of the buildings are running with independent supply. (Statistics yearbook of Qingdao, 2010) The limitation of the system is the average thermal efficiency which is only 20%-25%. In Qingdao, more than 300 plants with heat-boilers-equipment, boilers generally in the low load and low efficiency, and the heating area in average heating capacity area accounted for only 40%. (Minglei, Xu., 2006)
In the heating boiler plant, heat energy contained in the fuel into heat for the effective conversion rate is generally around 55% to 70%. Consider the outdoor heating network should transport the coal to the indoor heating equipment, the heat pipes and heat to the surrounding medium leakage will be inevitable, along the way, the heating energy will lose 10% to 15% since the last time decrease with equipment low efficiency. (Minglei, Xu., 2006)

(2) Cooling system

Energy efficiency ratio (EER) is a score applied to air conditioners in China. It is the mandatory standards for all the air conditioners offered for sale in China. All the air conditioners in the market must be labeled with the EER, otherwise it`s not allowed to sale in the market. EER ranges from grade 1 to grade 5- the lower the number of grades, the better of the performance of energy efficiency. As shown in Table 6, the grade 1 presents the highest energy efficiency and grade 5 is the lowest.

<table>
<thead>
<tr>
<th>Grade</th>
<th>Grade 1</th>
<th>Grade 2</th>
<th>Grade 3</th>
<th>Grade 4</th>
<th>Grade 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>EER</td>
<td>3.4~</td>
<td>3.2~3.4</td>
<td>3.0~3.2</td>
<td>2.8~3.0</td>
<td>2.6~2.8</td>
</tr>
</tbody>
</table>

*EER=Cooling capacity/Operating power

Source: The national standards of energy efficiency ratio, 2008

In Qingdao, almost 100% residential and public buildings use the air conditioners in summer. As shown in Figure 8, from the assessment of Qingdao energy conservation committee in 2007, in Qingdao the products with energy efficiency ranks 1 is 3 percent, and rank 2 is 5 percent share of the room air conditioner market respectively. In contrast, the air conditioners with energy efficiency rank 5 have a market share of 81 percent. Therefore, most air conditioners are sold with the lowest energy efficiency level in Qingdao.

Figure 8 Composition of air conditioners by energy efficiency in Qingdao, 2007

Source: China`s annual report on energy efficiency in buildings, 2007
As the composition of air conditioners by energy efficiency shown in Figure 8, air conditioner of which the energy efficient performance ranked Grade 5 occupies the market in Qingdao, grade 1 and grade 2 which have best energy efficient performance only accounts for 8% of total market in Qingdao. One most important reason is that the air conditioners with a better energy efficient performance such as grade 1 and grade 2 have much more expensive price than grade 5. People don’t want to pay more money to purchase the air conditioner with energy efficient performance of grade 1 and grade 2. (China’s annual report on energy efficiency in buildings, 2007)
3. Situation of energy consumption in buildings in Qingdao

3.1 Current situation of energy consumption in buildings

The current energy consumption in buildings is 6044.43 million kWh in 2010 in Qingdao, equals to 742,860 tons of standard coal consumption for power generation coal. Energy consumption in buildings accounts for 25.8% of total energy consumption in 2009 in Qingdao. (Statistical yearbook of Qingdao, 2011)

To the end of the year 2010, there are about 183.23 million square meters of completed building area in Qingdao city, in which the residential buildings with an area of 105.06 million square meters accounts for 78.7% of total buildings area. Figure 9 shows the composition of buildings by energy efficiency in Qingdao in 2010. There is an area of approximate 84.05 million square meters buildings (built in 1990~2007) without energy efficient technologies and design, only 21.02 million square meters buildings adopt energy efficient technologies and design. (Statistical yearbook of Qingdao, 2010)

Figure 9 the composition of building area by energy efficiency in Qingdao in 2010(million square meters)

Source: Statistical Yearbook of Qingdao, 2010

From the year 2005 to 2010, 46 projects of energy efficient buildings with a total area of 2,400,700 square meters, including 439 constructions of buildings and covering 19,562 households, were completed. With the indoor temperature which is hot in summer and cold in winter, those residential buildings have high energy consumption from heating and cooling. During the period 2011 to 2015, the government of Qingdao will subsidize 85 yuan/m$^2$ to the project of energy saving buildings in
Qingdao. There would be great economic value and energy saving potential in the project of energy saving building in Qingdao. (Yuhong, S., 2010)

3.2 Composition of energy consumption

In Qingdao, civil buildings are divided into two categories, namely residential buildings and public buildings. In which public buildings are divided into large-scale public buildings and common-scale public buildings. The so-called general public building refer to single commercial building with an area below 20,000 square meters and above 20,000 square meters but without central air conditioning, including industry buildings, office buildings, education buildings, medical buildings and culture buildings, etc. large-scale building refer to the single building with the area of more than 20,000 square meters, including large shopping mall, hotels, government outpatient, museum buildings and hospital buildings, etc. (Zhifeng, X., 2007)

Figure 10 The result of existing civil buildings 2009 in Qingdao cities and towns (m²)

<table>
<thead>
<tr>
<th>Area of civil buildings (183,230,000m²)</th>
<th>Area of public buildings (78,170,000m²)</th>
<th>Area of residential buildings (105,060,000m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Area of common buildings (47,639,800m²)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Area of large buildings (30,530,200m²)</td>
</tr>
</tbody>
</table>

Source: Statistical yearbook of Qingdao, 2010

Figure 10 shows the areas of existing civil buildings 2009 in Qingdao cities and towns. To the end of the year 2010, there are about 183.23 million square meters of building area in Qingdao city, existing residential buildings with the area of 105.06 million square meters accounted for 78.7% of total buildings area. There are approximate 84.05 million square meters of existing buildings (built in 1990~2007) in the need of energy saving alteration, of which about 27 million square meters of residential building (built in 1990~2005) require three measures of energy saving alteration. (Statistical yearbook of Qingdao, 2010) Information of energy consumptions in Qingdao cities and towns is significant to the planning and implementation of energy efficiency in buildings in Qingdao area.
**Figure 11** shows the results of area and energy consumption (EC) of civil buildings in Qingdao cities and towns:

*Figure 11 The result of civil buildings energy consumption 2009 in Qingdao cities and towns (ton of standard coal consumption for power generation coal)*

![Diagram of Figure 11](image)

**Source:** Statistical yearbook of Qingdao, 2009

**Figure 12** shows the largest proportion of civil building area is residential buildings which account for 64% of total area of civil buildings in Qingdao cities and towns, but in the pie chart of energy consumption, the public buildings accounts for 63% of energy consumption of civil buildings, respectively common public buildings 58% and large-scale public buildings 5%. (Statistical yearbook of Qingdao, 2009) It means that the public buildings consume more energy than residential buildings in Qingdao cities and towns.

**Figure 12 the areas and energy consumption pie chart of buildings in Qingdao in 2009**

![Diagram of Figure 12](image)

**Source:** Statistical yearbook of Qingdao, 2009

22
3.3 Energy consumption pattern in buildings

Heating in a building is a basic need for survival in Qingdao, where the winter temperature is below 0 degrees C. And the summer average temperature is 25.1 degree c, thus cooling is important to improving living comfort. (Statistical yearbook of Qingdao, 2009) In 2007, around 63 percent residents in Qingdao used air conditioner for an average of 2.8 hours a day. 28 percent of electricity in a building is used for cooling. (Zhifeng, X., 2007)

\[ \text{Figure 13 Energy consumption pattern in buildings in Qingdao} \]

As shown in the Figure 13, from the perspective of energy usage, heating and cooling consume the most energy in existing buildings in Qingdao, accounts for almost more than 40% of total energy consumption of public buildings, followed by the energy consumption on lighting and hot water. It reveals that most of energy is used for cooling and heating in buildings in Qingdao.
4. Evaluate Model of Direct Economic and Environmental Impacts of Energy Efficient buildings in Qingdao

This paper established a quantitative economic model, adopted the method of scenario, aims to evaluate the direct economic and environmental impact of implementation of energy efficient building in Qingdao. Under a reasonable scenario, by using evaluate model, and analyze the results. In this study, direct economic impacts refer to the cost reduced by implementation of energy efficient measures in buildings in Qingdao; and environmental impacts refer to the major pollutants including emission of sulfur dioxide, carbon dioxide, nitrogen oxides, soot, ash as well as water resource reduced by implementing energy efficient measures in buildings in Qingdao.

4.1 Scenarios $k$

The method of scenario is chosen to offer a quantitative way for the model to analyze the benefits for implementation of energy efficient buildings in Qingdao for the future in this study. Under this scenario, namely $k$ scenario, there will be no significant changes in laws, policies and standards for energy efficient buildings in Qingdao. The aim of predictive scenarios is to try to predict and analyze the economical and environmental benefits for implementation of energy efficient buildings in Qingdao on the condition of scenario $k$.

Model-based analysis approach is utilized in this thesis. The time scale adopted is from 2011 to 2015, five years is considered as a reasonable scenario because the 12th five year plan (2011-2015) which set a 65% energy efficient goal for energy efficient buildings in Qingdao. (Design standard for 65% energy efficiency in buildings in Qingdao, 2010)

The scenario $k$, regardless of energy-efficient buildings which have been built before the year 2010, assume that in the time scale of 2011-2015, 65% energy efficient standards for buildings are implementing in all new buildings in Qingdao, the average time in public buildings and residential buildings is 182.5 days in Qingdao. (Xiuli, L.et al., 2009) According to the average price of energy in the year 2010 in Qingdao, the price of standard coals and electricity is set at 0.92yuan per kv and 500yuan per ton of standard coal price at the factory gate respectively in scenario $k$ in this model. (Standards for classified electricity prices in urban and rural in Qingdao, 2009)
4.2 Evaluate model of economic and environmental impacts under scenario $k$

4.2.1 Analysis of economical impacts

The evaluate model of direct economic impacts is as follows.

$$\Delta Y_{ek} = \Delta Q_{ck} P_c + \Delta Q_{ek} P_e \times CC_e \quad (1)$$

In equation (1), $\Delta Y_{ek}$ is the reduced cost of energy consumption under $k$ scenario, $\Delta Q_{ck}$ is the reduced amount of standard coal, $\Delta Q_{ek}$ is the reduced electricity, $P_c$ is the price of standard coal per ton at the gate of factory, $P_e$ is the average price of electricity in Qingdao. $CC_e$ is the principal diagonal element in the cost-benefit flow coefficient matrix for the generation and supplying of water and energy including thermal electricity. (Xiuli, L. & Shouyang W. et al, 2010)

4.2.2 Analysis of environmental impacts

The evaluate model of direct environmental benefits is as follows.

$$\Delta Q_{sk} = \Delta Q_{ck} Q_{cs} + \Delta Q_{ek} Q_{es} \quad (2)$$

In equation (2), $\Delta Q_{sk}$ is the reduced emission of sulfur dioxide under $k$ scenario; $\Delta Q_{ck}$ is the reduced amount of standard coal, $\Delta Q_{ek}$ is the reduced electricity under $k$ scenario. $Q_{cs}$ is the amount of sulfur dioxide reduced by saving 1 ton standard coal; $Q_{es}$ is the amount of sulfur dioxide reduced by saving 1kWh electricity.

$$\Delta Q_{hk} = \Delta Q_{ck} Q_{eh} + \Delta Q_{ek} Q_{eh} \quad (3)$$

In equation (3), $\Delta Q_{hk}$ is the reduced emission of carbon dioxides under $k$ scenario; $\Delta Q_{ck}$ is the reduced amount of standard coal and $\Delta Q_{ek}$ is the reduced electricity under $k$ scenario. $Q_{eh}$ is the amount of carbon dioxides reduced by saving 1 ton standard coal; $Q_{eh}$ is the amount of carbon dioxides reduced by saving 1kWh electricity.

$$\Delta Q_{wk} = \Delta Q_{ek} Q_{ew} \quad (4)$$

In equation (4), $\Delta Q_{wk}$ is the reduced amount of water under $k$ scenario, $\Delta Q_{ek}$ is the saving amount of electricity under $k$ scenario, and $Q_{ew}$ is the amount of water reduced by saving 1kWh electricity.

$$\Delta Q_{dk} = \Delta Q_{ek} Q_{ed} \quad (5)$$
In equation (5), $\Delta Q_{dk}$ is the reduced amount of nitrogen oxides under $k$ scenario, $\Delta Q_{ck}$ is the saving amount of electricity under $k$ scenario, and $\Delta Q_{cd}$ is the amount of nitrogen oxides reduced by saving 1 kWh electricity.

$$\Delta Q_{gk} = \Delta Q_{ck} Q_{cg}$$ \hspace{1cm} (6)

In equation (5), $\Delta Q_{gk}$ is the reduced amount of ash under $k$ scenario; $\Delta Q_{ck}$ is the saving amount of standard coal under $k$ scenario. $\Delta Q_{cg}$ is the amount of ash reduced by saving 1 ton standard coal.

### 4.2.3 Results of economic and environmental impacts of energy efficient buildings in Qingdao

The scenario $k$, Regardless of energy-efficient buildings which have been built before the year 2010, assume that in the time scale of 2011-2015, 65% energy efficient standards for buildings are implementing in all new buildings in Qingdao, the average time in public buildings and residential buildings is 182.5 days in Qingdao. (Xiuli, L. et al., 2009) According to the average price of energy in the year 2010 in Qingdao, the price of standard coals and electricity is set at 0.92 yuan RMB per kw and 500 yuan RMB per ton of standard coal price at the factory gate respectively in scenario $k$ in this model. (Standard for Classified Electricity Prices in Urban and Rural in Qingdao, 2009)

The current energy consumption in buildings is 6044.43 million kWh in 2010 in Qingdao, equals to 742,860 tons of standard coal consumption for power generation coal. (Statistics yearbook of Qingdao, 2011) The parameters applied for the calculating in equation 1 to 6 under scenario $k$ are listed below:

<table>
<thead>
<tr>
<th>Parameters under scenario $k$:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy consumption in 2010 6044.43 million kWh</td>
</tr>
<tr>
<td>Consumption of standard coal 742,860 tons</td>
</tr>
<tr>
<td>The generation of 1 kWh electricity leads to 1 kg CO2 and 0.03 kg SO2</td>
</tr>
<tr>
<td>Every 1 kg standard coal contains 0.7 kg C</td>
</tr>
<tr>
<td>1000 kg C leads to 2130 kg CO2</td>
</tr>
</tbody>
</table>

*Source: Xiuli, L. et al., 2009; Statistics yearbook of Qingdao, 2011*
Table 7 shows the results of economic and environmental benefits for implementation of energy efficient buildings in Qingdao in the scenario $k$.

<table>
<thead>
<tr>
<th></th>
<th>2011</th>
<th>2012</th>
<th>2013</th>
<th>2014</th>
<th>2015</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reduced consumption of standard coal (tons)</td>
<td>27175.02</td>
<td>54350.09</td>
<td>81525.10</td>
<td>112414.23</td>
<td>148790.03</td>
</tr>
<tr>
<td>Cost saving (million yuan RMB)</td>
<td>25.60</td>
<td>51.19</td>
<td>76.79</td>
<td>96.14</td>
<td>121.03</td>
</tr>
<tr>
<td>Reduced emission of carbon dioxides (tons)</td>
<td>5502.40</td>
<td>11004.91</td>
<td>16506.41</td>
<td>216581.13</td>
<td>267183.10</td>
</tr>
<tr>
<td>Reduced emission of sulfur dioxide (tons)</td>
<td>1635.59</td>
<td>3271.18</td>
<td>4906.78</td>
<td>6893.23</td>
<td>9014.04</td>
</tr>
<tr>
<td>Reduced emission of nitrogen oxides (tons)</td>
<td>744.57</td>
<td>1489.15</td>
<td>2233.70</td>
<td>3017.43</td>
<td>3845.52</td>
</tr>
<tr>
<td>Reduced emission of ash (tons)</td>
<td>109.83</td>
<td>219.65</td>
<td>329.48</td>
<td>431.55</td>
<td>542.78</td>
</tr>
<tr>
<td>water saving (tons)</td>
<td>198565.03</td>
<td>397131.31</td>
<td>595697.04</td>
<td>799855.42</td>
<td>100124.53</td>
</tr>
</tbody>
</table>

According to the results of economic and environmental impacts of energy efficient buildings in Qingdao as shown in Table 7, there are great environmental benefits if the 65% energy efficient standards for buildings are implemented in Qingdao in the next five years. 27175.02 tons standard coal will be saved in 2011 and to 2015 the number will be 148790.03 tons; an amount of 5502.40 tons carbon dioxides will be reduced in 2011, and to 2015 the number will reach 267183.10 tons. Thus great contribution to reduction of emission of green house gas will be created. At the same time, there will be great reductions of emission of nitrogen oxides as well as sulfur oxide by implementing energy efficient measures in buildings in Qingdao during the period of 2011 to 2015, in the year of 2011 an amount of 744.57 tons nitrogen oxides and 1635.59 tons sulfur oxide will be reduced, and to the year 2015, an amount of 3845.52 tons nitrogen oxides and 9014.04 tons sulfur oxide will be reduced in one year. 198565 tons water used in buildings will be reduced in 2011 and in 2015 the number will reach 100124.53 tons.

As shown in Table 7, accompanied by the great environmental benefits, there are also economical benefits brought by the implementation of 65% energy efficient standards for buildings in Qingdao. 25.6 million yuan RMB will be saved in 2011 due to
implementation of energy efficiency in buildings, and 51.9 million yuan will be saved in 2012, almost two times more than the amount in 2011. In the year 2015, 121.03 million yuan will be saved in Qingdao, which is almost four times as the amount in 2011.
5. Discussion

5.1 Analysis of benefits of energy efficient buildings in Qingdao in scenario $k$

5.1.2 Energy saving

Promotion and implementation of energy efficient buildings can substantially reduce the current high environmental cost associated with energy consumption for heating and cooling in buildings in Qingdao. Around 742,860 tons standards coal were burned in 2009 for energy consumption in residential and public buildings in Qingdao, the resulting emission of greenhouse gas is about 1.87 million tons of carbon oxides per year. According the model analysis in scenario $k$ in previous chapter, Figure 14 shows the reduced standard coal from 2011 to 2015 by implemented energy efficient buildings in Qingdao.

*Figure 14 Comparison between reduced consumption and current consumption in 2009 of standard coal in Qingdao in scenario $k$ (unit: tons)*

<table>
<thead>
<tr>
<th>Year</th>
<th>Reduced Consumption of Standard Coal</th>
<th>Total Consumption of Standard Coal</th>
</tr>
</thead>
<tbody>
<tr>
<td>2011</td>
<td>27175.02</td>
<td>715684.98</td>
</tr>
<tr>
<td>2012</td>
<td>54350.09</td>
<td>688509.91</td>
</tr>
<tr>
<td>2013</td>
<td>81525.1</td>
<td>661334.9</td>
</tr>
<tr>
<td>2014</td>
<td>112413.23</td>
<td>630446.77</td>
</tr>
<tr>
<td>2015</td>
<td>148790.03</td>
<td>594069.97</td>
</tr>
</tbody>
</table>

*Figure 14* indicates that the associated reduced consumption of standard coal increased at a rate of about 80% year by year, from 27175.02 tons of standard coal which accounts for 3.66% of total to 148790 tons of standard coal which accounts for 20.02% of total consumption of standard coal in buildings in Qingdao.
5.1.2 Environmental benefits

*Figure 15 Reduced emissions by implemented energy efficient building from 2011 to 2015 in scenario $k$ (unit: tons)*

*Figure 15* reveals the environmental benefits of energy efficient buildings in Qingdao in scenario $k$. As large amount greenhouse gas and other kinds of gas and ash which harmful to the environment are generated in the process of burning coal, the reduction of standard coal lead to overall reduction in emission of greenhouse gas and harmful gas. From *Figure 15* we see all the chart of reduced emission including carbon dioxides, sulfur oxide, nitrogen oxides and ash appear increasing trend, it means that under the scenario $k$ energy efficient buildings has an idea performance on reducing pollutant gas. Especially the emission of carbon oxides is reduced from 55020.4 tons per year to 267183.1 tons per year, and the increasing rate is more than 485% in five years. The implementation of energy efficient building will have great performance on alleviating greenhouse effect and reducing atmosphere pollutions. The environmental benefits of which is significant in scenario $k$. 
5.1.3 Economic benefits

*Figure 16* Cost saving by implemented 65% energy efficient standards in building from 2011 to 2015 in scenario k (unit: million yuan RMB)

Figure 16 shows the economic benefit predicted by the quantitative model in the scenario *k*, accompanied by the great environmental benefits, there are also substantial economic benefits generated by the implementation of 65% energy efficient standards for buildings in Qingdao. The main reduced cost mainly come from reduced consumption standard coal and water saving. If 65% energy efficient standards for buildings are fulfilled in scenario *k*, 25.6 million yuans will be saved in 2011, 51.19 million yuans in 2012, 76.79 million yuans in 2013, 96.14 million yuans in 2014 and 121.03 million yuans in 2015, the increasing rate of cost saving will reach approximately 45% in the five years.

5.2 Barriers to energy efficiency in buildings in Qingdao

5.2.1 Political barriers

Politically it is obvious that the legal system and enforcement issues constitute a major barrier. The political barriers in Qingdao are:

(1) Low standards for energy efficient buildings.

From the year 1986 to 2008, Chinese Ministry of construction and Qingdao Urban and Rural Construction has issued totally 21 national standards and industry standards for energy efficiency in buildings, but most of the standards in which is relatively low and not linked to the actual situation of Qingdao, in particular, the lack of technical details can lead to poor implementation of standards and regulations.
Table 8 Comparison of building standards
(Heating performance coefficients in W/m²·°K)

<table>
<thead>
<tr>
<th></th>
<th>External wall</th>
<th>Roof</th>
<th>Window</th>
</tr>
</thead>
<tbody>
<tr>
<td>Qingdao, China</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Conventional building standards</td>
<td>1.70</td>
<td>1.26</td>
<td>6.40</td>
</tr>
<tr>
<td>1986 energy efficient standards</td>
<td>1.28</td>
<td>0.91</td>
<td>6.40</td>
</tr>
<tr>
<td>1996 energy efficient standards</td>
<td>1.16 or 0.82/a</td>
<td>0.80 or 0.60/a</td>
<td>4.00</td>
</tr>
<tr>
<td>2008 energy efficient standards</td>
<td>1.02 or 0.82/a</td>
<td>0.65 or 0.50/a</td>
<td>4.00</td>
</tr>
<tr>
<td>2008 Russia</td>
<td>0.77</td>
<td>0.57</td>
<td>2.75</td>
</tr>
<tr>
<td>2008 US</td>
<td>0.45/b or 0.32/c</td>
<td>0.59</td>
<td>2.04</td>
</tr>
<tr>
<td>2008 Canadian</td>
<td>0.38</td>
<td>0.40/d</td>
<td>2.86</td>
</tr>
</tbody>
</table>

/a: The larger value refers to buildings with shape coefficient smaller than 0.3, while the smaller value refers to buildings with shape coefficient larger than 0.3.
/b: External insulation.
/c: Internal insulation.
/d: Non-flammable roofs.

Sources: Tu Fengxiang, 1997; Wei X., 2010

Table 8 reveals that standards for energy efficient building in Qingdao is relatively low compared to Russia, US and Canada. From the data in the Table 8 we can see that there have been gradually progress in the energy efficient standards in buildings from 1986 to 2008, but the heating performance coefficients of external wall, roof and window regulated by the energy efficient standards established in 2008 are smaller than those in US, Russia and Canada. Especially in which the external wall heating performance coefficients, the most important energy efficient coefficient for a building energy efficient performance, are 1.02 or 0.82/a in China while in US which are 0.45/b or 0.32/c, more than two times as US.

(2) Legal enforcement

The legal enforcement in the case of non-implementation of standards for energy efficiency is insufficient. Officially there are legal penalties, but in practice those penalties are hardly enforced due to the weak legal system in China, of course the same in Qingdao.

(3) Weak monitoring

The lack of effective monitoring to the implementation of energy efficiency is a great barrier to implementation energy efficient buildings policies, regulations and standards. Monitoring has been becoming better but it is still too simple that almost 70% buildings are not monitored at all in Qingdao. Meanwhile, methods to measure the energy consumption of buildings are still hardly available in Qingdao. (Asia Alternative Energy Programme and Energy & Mining Unit, East Asia and Pacific
(4) Ignoring the implementation of energy efficient building in rural area

The current projects of energy efficient buildings are mainly carried out in urban area of Qingdao, in rural areas are not subject to attach importance to energy efficient buildings. In fact, very few rural buildings in Qingdao have adopted scientific insulation measures and cooling system especially in winter heating efficiency is very low. There is large energy waste in buildings in rural area of Qingdao.

5.2.2 Economical barriers

Apart from political barriers, economical barriers are important reason for non-compliance with energy efficiency in buildings in Qingdao. Planned electricity and heating pricing system and limited capacity for construction of energy efficient buildings are main economical barriers in Qingdao.

(1) Planned energy prices

In Qingdao, energy prices for buildings are set and controlled by the government, in most of time this planned pricing mechanism make a slow response to the energy market, in consequence it cannot reflect the actual scarcity of energy. As a result there are inadequate incentives for implementation of energy efficient buildings in Qingdao.

(2) Limited access to capacity

Although Qingdao government has set a fund of 60,000 RMB and offered 85 yuan/m2 subsidize to each of energy efficient buildings projects, but compared to the total cost of project, the money was far from enough. Only large construction firm have the qualification for applying national and local government funds in Qingdao, the application submitted by the remaining firms are often rejected because their relatively less capacity compared to the large firms. Meanwhile, apart from government funds, subsidizes and loan, there are limited access to capacity for energy efficient buildings in Qingdao. (Carmen Richerzhagen et al., 2008)

(3) High initial investment

The initial investment for energy efficient buildings in Qingdao is about 6% to 8% higher than conventional buildings, and the cost of construction including the material, design and technologies are even higher. (Carmen Richerzhagen et al., 2008) Thus in Qingdao market there is little advantage for energy efficient buildings as the demand is low.

5.2.3 Social and culture barriers

Social and culture factors are the pre-condition of implementation of the policies and
standards for energy efficient buildings in Qingdao. Thus social and culture barriers lead to a low acceptance of energy efficient building buildings in Qingdao. Two main factors which are lack of awareness and lifestyle are discussed here.

(1) Lack of awareness

As several studies, including this study (discussed in this paper in 2(4), p.15), indicate that public knowledge and awareness of the benefit of energy efficient buildings is poor in China as well in Qingdao (Wei, X., 2010; Urban and construction committee of Qingdao, 2010). In consequence, the lack of awareness of the possible impact of EEB on environment and its economic as well as social benefits lead to a low acceptance of energy efficient building buildings in Qingdao.

(2) Buying decision

\textit{Figure 17 Composition of priorities for residential building purchasing under the assumption of the same price 1,000,000 RMB of house}

As shown in Figure 17, according the investigation on the tendency of residential building purchasing by the urban and rural construction committee in 2008, under the same price assumption of 1,000,000 RMB, 55.5% people of 2,000 interviewees range the house size as the priority of consideration for residential building purchasing, followed by 17% chose the location and 16% chose the residence pattern, only 7% interviewees consider the performance of energy efficiency in buildings as one important factor. In consequence, there are few incentives to developers for implementation of energy efficient buildings in Qingdao. (Real Estate Market Report, 2008)

(3) Heating welfare

In Qingdao, 48% residents have to pay the heating bills by their own, and 39%
residents pay a small portion of the heating bills while the remains is afforded by their employer. (Liang et al. 2007) The heating welfare has a neglect impact on the promotion energy efficient buildings and enhancing people’s energy saving awareness in Qingdao.

5.2.4 Technological barriers

Technological barriers lead to a low awareness and higher cost of energy efficient buildings, and therefore hinder the implementation and promotion of energy efficient buildings in Qingdao. Focus on the limitations of professional human resource, technical measures and options, technological barriers are discussed here.

(1) Energy efficient technology

Energy efficient technology is relatively backward in China, especially the lack of personnel and research institution leads to a slow progress of study and promotion in the field of energy efficient buildings. In recent years, although the government and public put more attention to this field, the study and promotion of energy efficient buildings are still constrained by the limited research fund and small market share.

(2) Neglect of new energy resource

Located in a hot summer and warm winter region, Qingdao City owns abundant solar energy resources, wind force resources and ocean energy resources. Because of the dependence on the fossil energy, it is neglected to use and explore new energy resources for a long time. Due to the use of central heating and air condition in residential buildings in Qingdao, the application of the energy saving technologies on civil buildings are excluded. But it is imperative to economize energy in buildings for improving the energy efficiency in buildings.

(3) Energy efficient building materials and products

Construction of energy efficient building needs various kinds of materials and products which affect the integrated performance of energy efficiency in a building. A variety of materials and products have been developed and introduced in Qingdao, but the quality, performance and availability of these materials and products are relatively poor. This is largely because use of such materials and products in building designs is still a low priority, as design institutes and developers are not under the pressure which is high enough to force the developer built more energy-efficient buildings. (Asia Alternative Energy Programme and Energy & Mining Unit, East Asia and Pacific Region, the World Bank, 2011)
6. Discussion and Recommendations

Qingdao is suffering from severe energy scarcity. Meanwhile, with the rapid economic and social development, the growing energy demand will result in much more serious economic and environmental problems. In this context, taking effective measures to achieve improved energy efficient in buildings situation is a primary task to alleviate the emerging energy problems.

Based on the investigation and analysis about the present situation and factors affecting the implementation of energy efficient buildings in Qingdao, with the help of the advanced experience and developing path of some developed countries, this thesis put forward a thought and relative suggestions about promoting energy efficient buildings in Qingdao.

Regarding the barriers discussed in chapter 5, corresponding recommendations from the aspects of environment, politics, economy, society and technology are presented in this chapter to improving energy efficient buildings in Qingdao.

6.1 Optimizing the legal system

According the political factors affecting the implementation of energy efficient buildings in Qingdao discussed in chapter 3, increased and sustained supports from laws, policies and standards for energy efficient buildings will be essential to improve the energy efficiency in buildings in Qingdao in the coming years. In addition, effective monitoring system is highly required to ensure the laws, policies and standards to be effective implemented. Optimizing the legal system is the pre-condition of successful achievement of energy efficiency in buildings in Qingdao. After the discussions in chapter 5, the following suggestions are proposed to overcome the political barriers in Qingdao.

6.1.1 Enhancing monitoring system

According to the discussions in chapter 5, the lack of effective monitoring to the implementation of energy efficiency is a great barrier to implementation energy efficient buildings policies, regulations and standards. Monitoring has been becoming better but it is still too simple that almost 70% buildings are not monitored at all in Qingdao. (Asia Alternative Energy Program and Energy & Mining Unit, East Asia and Pacific Region, the World Bank, 2011) To achieve a high quality monitoring, three suggestions are proposed:

- Involvement of the third parties to monitor and evaluate the energy efficient
performance in buildings in Qingdao. As being absent in the construction sectors’ value chain, the third parties, such as independent companies, NGOs, private agencies and organizations, can carry out impartial and objective results of evaluation the energy efficient performance in building in Qingdao.

- Enhancing training measures for inspectors. To achieve a high quality evaluation of energy efficient performance in buildings, fixed criteria and regulated procedures need to be developed for all inspections in the monitoring system.

- Severe punishment. To behavior of misconduct of the monitoring bodies, hush punishment such as fines and revocation of licenses should be imposed to ensure successful implementation of monitoring.

### 6.1.2 Developing energy efficient standards for buildings

According to the discussions in chapter 5, the current energy efficient standards for buildings are relatively low and not linked to the actual situation of Qingdao and in particular the lack of technical details can lead to poor implementation of standards and regulations hinder the improving energy efficiency in buildings. In this study, performance-based standards for buildings design are proposed.

Standards based on energy efficiency performance for building designs could encourage implementation and innovation of energy efficiency in buildings, but would be more complicated and at the same time a higher level of professional skills from the designers are required. For better flexibility and optimal efficiency, Qingdao should move towards performance-based standards and take more consideration on local characteristics including political, economic, social and technological situations in the design of energy efficient standards for buildings.

### 6.2 Enhance economic incentives

For the promotion of energy efficient building in Qingdao, economic instruments are essential. With the establishment of socialist market economic system in China, a large number of effective economic instruments should be applied to achieve the sustained and effective promotion of energy efficient building in Qingdao. Based the analysis of economical situation and economic barriers to implementation of energy efficient buildings in Qingdao, suggestions are proposed to enhance the economic incentives.
6.2.1 Increasing energy price in buildings

Current energy price in China is relatively low compared to other countries in the world, especially the heating price in buildings are set and controlled by the government. This planned pricing mechanism makes a slow response to the energy market, in consequence it cannot reflect the actual scarcity of energy. As a result, there are inadequate incentives for implementation of energy efficient buildings in Qingdao. Only if consumers pay the real price which is higher than current energy price in buildings, they can be able to benefit from energy saving in buildings, and in this way do they have economic incentives to invest in energy efficient buildings.

6.2.2 The voluntary carbon market

Through establishing the voluntary carbon market in Qingdao, companies can have more economic incentives to developing energy efficient buildings. Being different from the single profit model that the energy efficient buildings developers can only get benefits from housing sales, in this voluntary market, developers, individuals can buy carbon offsets in order to reduce their carbon footprints. The project of energy efficient building can be benefit from selling carbon offsets to other companies. The constructors can create voluntary carbon credits if carbon offset providers provide funds for construction of energy efficient buildings. In this way, the capital for implementation of energy efficient buildings is increased in Qingdao.

6.3 Raising social awareness

According to the social and culture barriers discussed in Chapter 5, social and culture factors are the pre-condition of implementation of the policies and standards for energy efficient buildings in Qingdao. As one of the most populated cities in China, the Qingdao population in 2009 reached 7.62 millions. In addition, the rapid urbanization process will greatly increase the energy consumption in building sector. (Statistics yearbook of Qingdao, 2010) Through the education and publicity of the necessary of energy saving and protection of environment, raising social awareness of energy efficient buildings will lead to a substantial contribution to implementation of energy efficient buildings in Qingdao.

Based on the situation of culture and lifestyle in Qingdao introduced in Chapter 3 and focused on how to overcome the social and culture barriers discussed in chapter 5, two suggestions are proposed.

- Strengthening media campaigns
- Strengthening the education in school
- Information publicity of energy performance in main buildings in Qingdao
6.4 Integrated design of energy efficient buildings

Based on the investigation and analysis about the present situation and factors affecting the implementation of energy efficient buildings in Qingdao, with the help of the advanced experience and developing path of some developed countries, this thesis put forward a thought and relative suggestions about promoting energy efficient buildings in Qingdao.

*Figure 19 flow chart of system optimization analysis of energy efficiency in buildings*

Source: Own design
The performance of energy efficiency in buildings is decided by various factors, including the building thermal comfort, the housing structure, construction material, etc.

Source: Own design

Figure 19 shows the flow chart of system optimization of energy efficiency in buildings. It illustrates that the process of the design of energy efficient buildings is constituted by three steps:

1. Design of the local environment. The consideration of external environment includes the selection and reform of external environment, such as location, pavement, greening and arrangement of buildings, etc.

2. Design of the macroclimate. It mainly refers to the construction design. The factors from the building itself are considered in this section, including the overall layout of the building, size, altitude and building orientation, etc.

3. Design of the indoor thermal environment. Concerning the technologies of energy efficiency in this process it includes the construction technology and the energy utilization technology. A construction technology includes the design of energy efficiency in wall body, doors and windows, floor and roof; energy utilization technology includes the utilization of solar power, wind power, greening and design of air conditioning system.

6.5 Consideration of local climate

The building thermal design should be suitable to the local climate, for example, the design of building envelope in cold region should firstly meet the requirement of insulation. According to the climate analysis, Qingdao is located in the cold zone of China, the average temperature in Qingdao area is 13.2°C, the highest temperature which appeared in August is 29.1°C, in which month the average temperature is 25.1°C. The lowest temperature which appeared in January is -3°C, the average temperature is -0.2°C. There are four months in which the temperature exceeds 20°C in a year, and only one month which is January in which the temperature is lower than 0°C. (Statistics of yearbook of Qingdao, 2010) Therefore, the factor of heat insulation should be considered in advance in the design of building envelope to meet the requirement of heating in the winter, while the requirement of cooling in the summer should be considered as well.
7. Conclusion

In this thesis, in connection with the natural, economical, political, social and technological factors affecting the implementation of energy efficient buildings in Qingdao, in accordance with the current situation of energy consumption in buildings in recent years, the trends of energy consumption have been analyzed. As a sequence, the economic and environmental benefits as well as the barriers for implementing energy efficient buildings in Qingdao in the future has been evaluated and analyzed. Based the discussion of benefits and barriers for implementation of energy efficient buildings in Qingdao, recommends concerning how overcoming the current barriers and promoting energy efficient buildings are proposed. The main conclusions of this thesis are as follows.

Located on the south-east coast of the Shandong Peninsula, Qingdao is a city with a temperate humid climate with moist hot summers and dry, cold winters. As a city with rich resources, strong economy and large population, in 2009, the gross domestic product of Qingdao was 485.387 billion Yuan, with an increase of 12.2% in 2009 and13.2% in 2008, and the rate of urbanization was above 48.3%. Companied with the growth of economy, the energy consumption in buildings has been increasing. Around 742,860 tons standards coal were burned in 2009 for energy consumption in residential and public buildings in Qingdao, the resulting emission of greenhouse gas is about 1.87 million tons of carbon oxides per year. (Statistics yearbook of Qingdao, 2010)In recent years, energy efficiency in buildings is a highly relevant issue in Qingdao and supported by government of Qingdao and China.

Based on the quantitative model analysis of environmental and economic benefits of implementation of energy efficient buildings in Qingdao in scenario k, promotion and implementation of energy efficient buildings can substantially reduce the current high environmental cost associated with energy consumption for heating and cooling in buildings in Qingdao. Emission including carbon dioxides, sulfur oxide, nitrogen oxides and ash can be reduced, it means that under the scenario k energy efficient buildings has an idea performance on reducing pollutant gas from 2011 to 2015. Especially the emission of carbon oxides is reduced from 5502.4 tons per year to 267183.1 tons per year, and the increasing rate is more than 485% in five years. The implementation of energy efficient building will have great performance on alleviating greenhouse effect and reducing atmosphere pollutions. At the same time, companied by the great environmental benefits, there are also substantial economic benefits generated by the implementation of 65% energy efficient standards for buildings in Qingdao. The main reduced cost mainly come from reduced consumption standard coal and water saving. If 65% energy efficient standards for buildings are fulfilled in scenario k, 25.6 million yuans will be saved in 2011, 51.19 million yuans in 2012, 76.79 million yuans in 2013, 96.14 million yuans in 2014 and 121.03 million yuans in 2015, the increasing rate of cost saving will reach approximately 45% in the
five years.

Barriers to energy efficiency in buildings in Qingdao, including political, economic, social and technological barriers are discussed in Chapter 5. In which, politically it is obvious that the legal system and enforcement issues constitute a major barrier. The political barriers in Qingdao are: I) low standards for energy efficient buildings; II) legal enforcement; III) weak monitoring and VI) ignoring the implementation of energy efficient building in rural area. Apart from political barriers, economical barriers are important reason for non-compliance with energy efficiency in buildings in Qingdao. Planned electricity and heating pricing system and limited capacity for construction of energy efficient buildings are main economical barriers in Qingdao. Social and culture factors are the pre-condition of implementation of the policies and standards for energy efficient buildings in Qingdao. Thus social and culture barriers lead to a low acceptance of energy efficient building buildings in Qingdao. At last, Technological barriers lead to a low awareness and higher cost of energy efficient buildings, and therefore hinder the implementation and promotion of energy efficient buildings in Qingdao.

Clearly, there are no easy answers to the question of how the implementation of energy efficient buildings can be improved in Qingdao. Regarding the barriers discussed in chapter 5, corresponding recommendations from the aspects of environment, politics, economy, society and technology are presented in this thesis: I) enhancing monitoring system; II) enhance economic incentives; III) Increasing energy price in buildings; IV) raising social awareness and V) integrated design of energy efficient buildings.
8. References


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