POLITECNICO DI TORINO

I FACOLTÀ DI INGEGNERIA

Corso di Laurea Magistrale in Ingegneria Edile

Master Thesis

Analysis of energy efficiency policies in residential construction

Supervisor:
Prof. Ing. Marco Perino
Vice Supervisor:
Dott. Enrica Monticelli

Candidate:
Hong QU

Academic Year 2017/2018

Contents

CHAPTER 1

INTRODUCTION

1.1 Energy Efficiency

1.1.1 Energy Crisis and global environment problem

Since the energy crisis began in last century 70s, the whole world came to realize the importance of saving energy and using renewable energy. With the fact that the buildings consumption was about one-third of world's total end use of energy, the potential of saving energy in the building sector would greatly contribute to a society wide reduction of energy consumption. Buildings are considered the main energy consumer, especially for the purposes of heating and cooling.

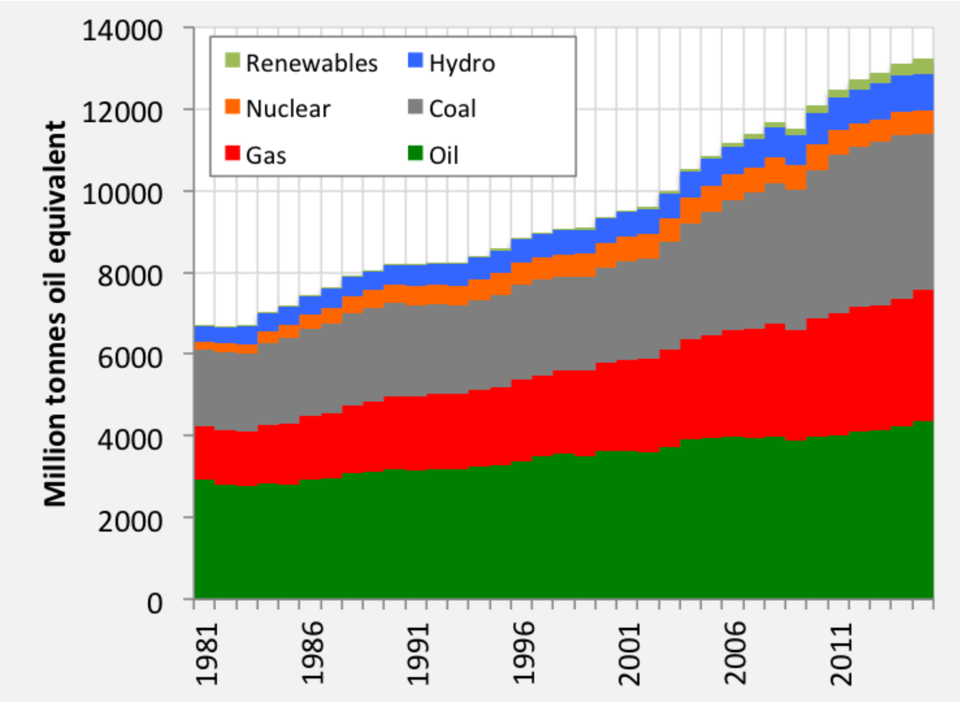

Figure 1.1 Global primary energy productions

Final energy consumption of buildings has increased at world level by around 1% per year since 2005 and around 3% per year for electricity. Most of the energy consumption was fossil fuels, which have been formed after millions of years on earth will be consumed in generations. Moreover, tens of billions of tons of trees and mineral materials are consumed each year by tens of millions of new and reconstructed buildings, causing excessive deforestation (currently only 22% of the world's forest is covered and unevenly distributed), causing damage to the land and greatly damaging the natural environment, aggravating global warming. Therefore, building energy efficiency has became the focus of energy saving and it shows a lot of potentials.

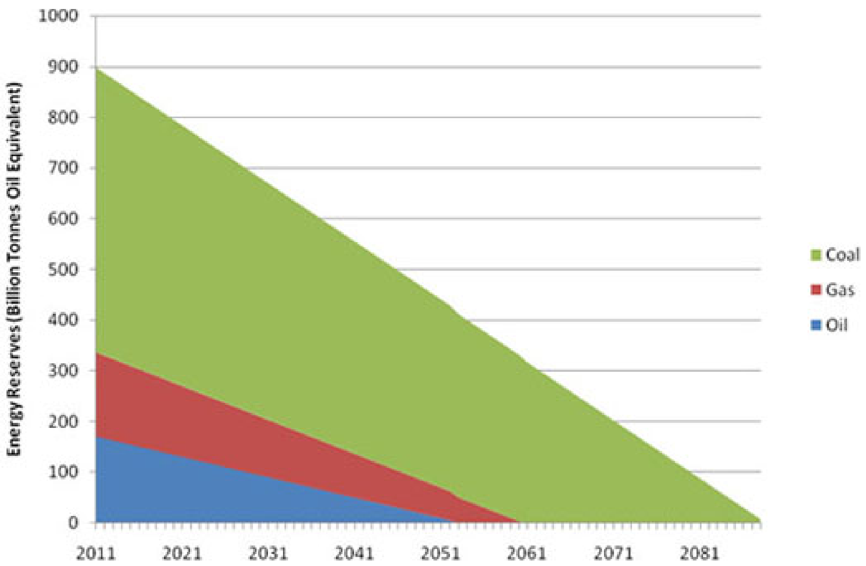

Figure 1.2 Predict of world energy reserve

Energy efficiency aims to save energy during the planning, design, construction and using of construction projects, though complying the criterion of building energy efficiency policies to improve the thermal performance of building envelope structure, using renewable energy and raising the usage efficiency of energy. Under the promise of guaranteeing the quality of the indoor thermal environment, increases the thermal resistance of indoor and outdoor energy exchange. In order to reduce the energy consumption of the space heating, space cooling, lighting, hot water supply, cooking and appliances. It helps to improve the thermal environment of buildings, which will contribute to the sustainable, rapid and healthy development of economy and protection of the ecological environment.

As we have been aware of the necessity of eco-sustainable development, building energy saving becomes the concrete manifestation of it. It also becomes a worldwide tide of architectural design. At the same time, it is also a new orientation of building science and technology. It has become a common concern in the world's architectural community.

After decades of exploration, the meaning of building energy efficiency has also deepened. This has gone through three stages: the first to be called "energy saving"; then the further definition is "energy conservation", which is to reduce the loss of energy in the building. The more motivated definition is "improving energy efficiency in buildings" (energy efficiency), that is, saving energy consumption and improving energy efficiency at the same time through initiative and proactive strategies.

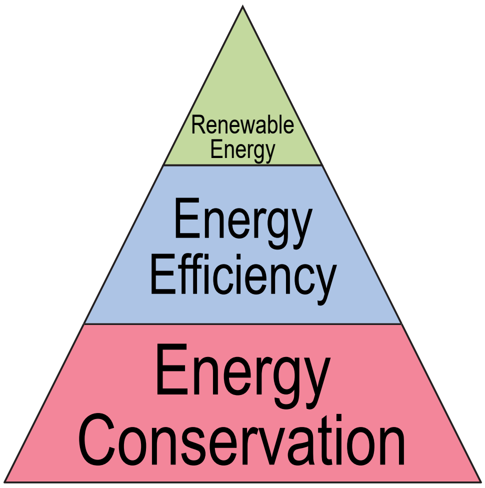

Figure 1.3 The energy pyramid

Building energy efficiency is a complex and arduous task. It involves government, enterprises and ordinary citizens. It involves many industries and enterprises, including both new construction and existed buildings. It is very difficult to implement, which means, it needs each part of society to make its own effort, such as, financial and tax policy support. For existing buildings, they are needed to transform step by step, and follow “easy one comes first” strategy, such as public and commercial buildings, the residential buildings left for the last, which have more complex energy efficiency problems will leave for the last.

1.1.2 Benefits of energy efficient buildings

There are many benefits to applying energy efficiency on building construction. First of all, it’s an effective way to support eco-sustainable development. As the world is improving dramatically, lack of energy is becoming a limiting factor. Energy development lagging behind economic development will cost lots of troubles. Adopting energy efficiency on buildings will effectively solve this problem, and it will work for a long term.

On the other hand, it also helps to protect the atmospheric environment. Moderation of energy-end use in buildings will also reduce greenhouse gas emissions and pollution produced by the combustion of fossil fuels. Air pollution has caused serious concern in many countries around the world. The carbon dioxide produced during combustion has lead to major climate changes on the planet and endanger human survival.

This environmental benefit appears on two aspects, local and global. As the buildings' demand for energy requires local energy combustion in district heating or individual heating systems, reduced energy demand improves air quality at the local level. In particular in developing countries, a reduced demand for energy requires fewer power plants, therefore less generation and grid capacity are needed for public construction.

Comparing with traditional buildings, energy efficient buildings offer a more stable indoor climate, since households use less energy for building-related uses, less local fuel is burned and improving public health.

And for the last, as the technology and economic level is heightening, people have more and more requires for the living circumstance. A comfortable, pleasant and healthy indoor thermal environment is the basic symbol of modern life. Creating a comfortable and pleasant indoor thermal environment means maintaining a comfortable temperature and relative humidity by using heating in winter and air conditioning in summer, which all require the support of energy.

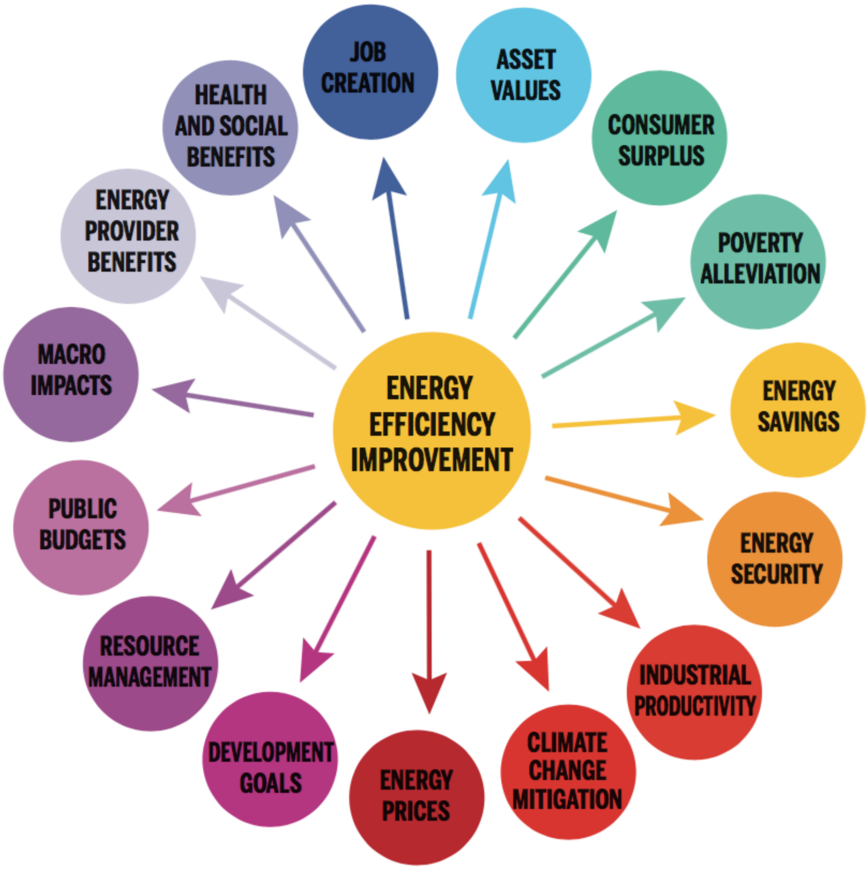

Figure 1.4 Benefits of energy efficiency

In many developing countries, the energy savings by energy efficiency in new buildings will have a large and fast impact on the economy, because of a larger share of new construction buildings. Individual homeowners and building users investing in energy efficiency will recover costs in a certain period though lower energy expenses. Further more, many counties have already implemented incentive policies to encourage high-energy efficiency building and invested large budget to reward homeowners, building users and building constructors.

Developing and adopting energy efficient building concepts is not a new practice. But since the sustainability goals are far from being reached, the world is looking forward to move from Low-Energy Building or Passive House concepts towards a nearly Zero-Energy Building (nZEB) or Zero-Energy Building (ZEB) concept.

1.2 Personal Comfort System

As energy supply is limited, improving indoor environmental quality requires technologies that enable energy efficiency. However, the climatic conditions of different regions can vary greatly, which creates differences in demand for heating and cooling. Even within the same region, there can be variations when time and degree of temperature changes. Therefore, when creating energy efficient designs, subdivisions must be made with the sub-climate areas in mind. Building envelope structures for thermal insulation in different climate zones require different solutions. Also even under the same macro-thermal zone, occupants may have diffident feelings, therefore, creating the idea of Personal Comfort System (PCS).

In building engineering, defining a range of temperature and humidity, which are considered to be comfortable and maintaining the indoor environment conditions within this range, is defined occupant comfort.

Recent decades, the capable of maintaining occupant comfort in building with subdivisions, as different thermal micro-zones, is called Personal Comfort System. Most of occupants' satisfaction caused by their own thermal comfort, which influenced by their immediate vicinity. And this environment can be changed from the rest of building by small devices near occupant, such as space heaters, fans and PCS's. The choice of device also has an impact on the macro-zone maintained by the building heating, ventilation, and air-conditioning (HVAC) system, as shown in Figure 1.5.

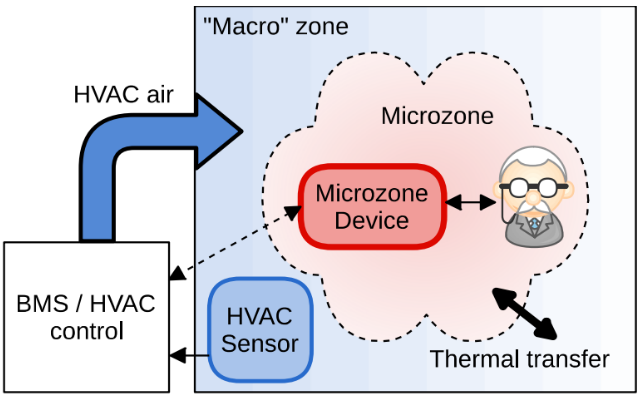

Figure 1.5 A person interaction with a micro-zone inside the building controlled macro-zone

Although traditional devices are able to provided a personalized environment, it still can conflict with the building environment and caused waste of energy. In order to solve this problem, it needs to create a more isolate circumstance.

Each person has a different ideal environment and a different definition of which they are willing to express their discomfort. As a large zone with multiple occupants may only have a single temperature sensor, the HVAC system is only optimizing for a single point in the zone, and not necessarily one that represents the midpoint of temperatures across the zone (Arens and Brown 2012). Introducing connected micro-zones can solve this knot.

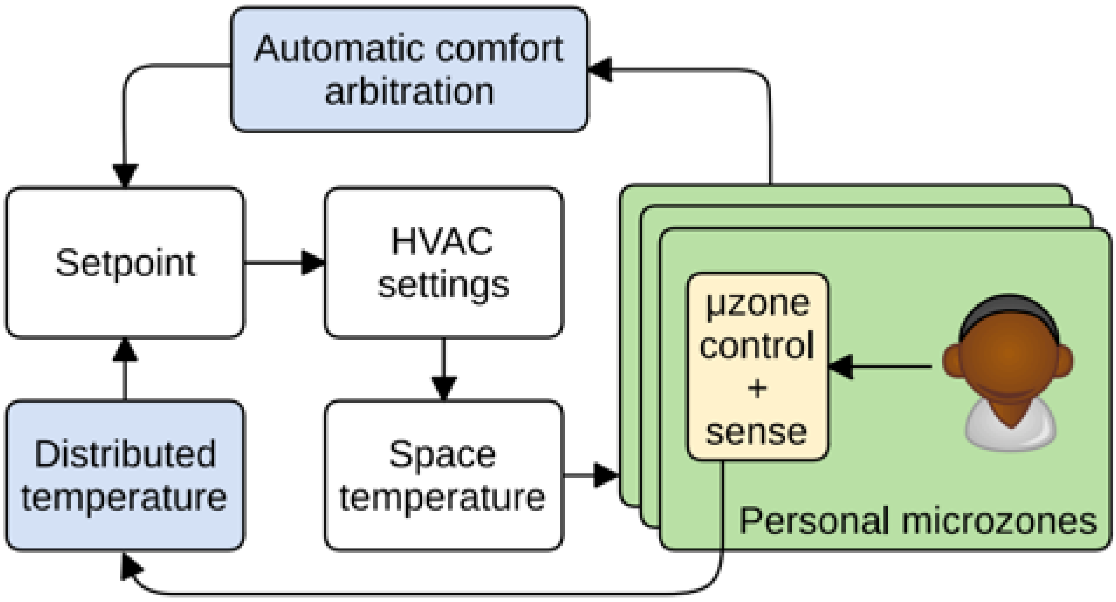

Figure 1.6 PCS comfort feedback loop

The Figure 1.6 shows that every occupant can adjust their micro-zone to their own comfort requirements and to create feedback loop to the HVAC system. The feedback loops are based on each occupant comfort temperature data, which greatly increased the accuracy over a single set-point.

As PCSs work at the individual level, they allow each individual to meet their own thermal comfort needs without greatly affecting the thermal environment of other nearby occupants. This leads to higher personalized comfort by providing heterogeneous comfort requirements to be simultaneously achieved.

Figure 1.7 Example of local cooling/heating devices

1.3 Zero Energy Building

The ideal solution is to create net zero energy building (NZEB), which is defined as a building with zero net energy consumption, where in the total amount of energy used by the building on an annual basis is roughly equal to the amount of renewable energy created on site, or by renewable energy sources elsewhere. This idea has already been realized in many countries, but it still needs to be promoted around the world.

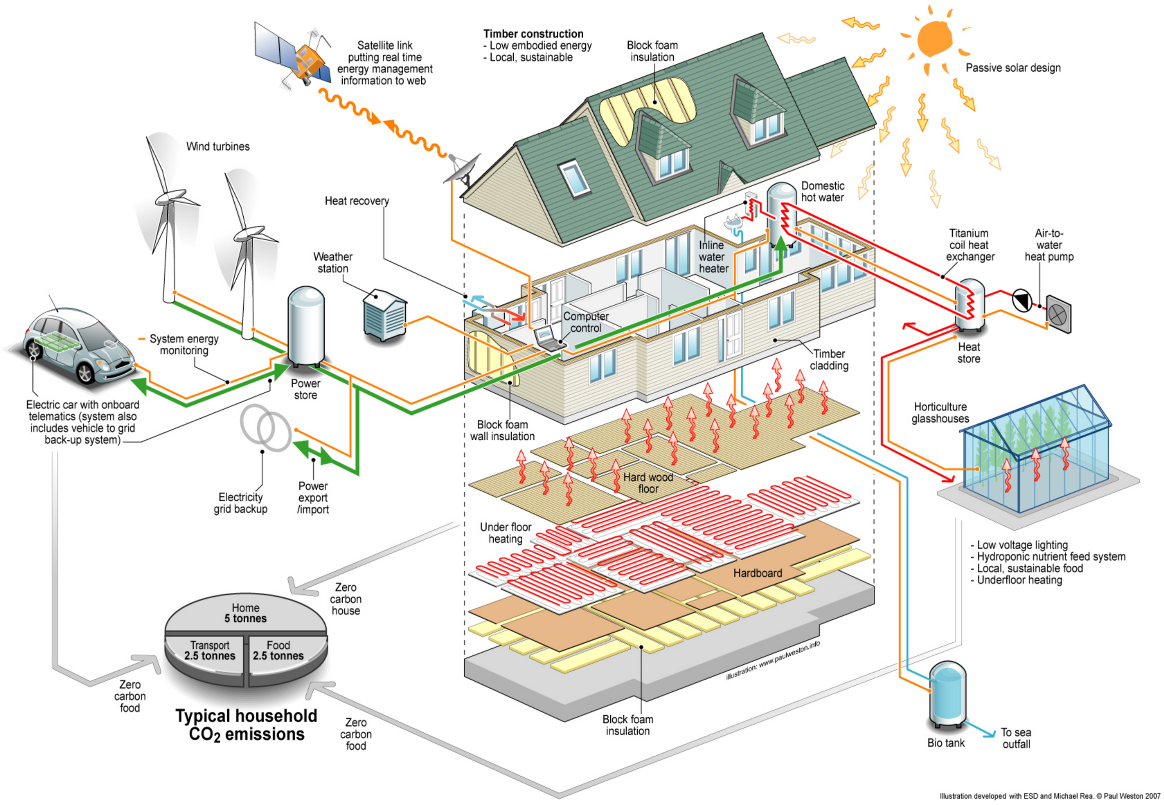

Figure 1.8 Zero carbon houses schematic

The Energy Performance of Buildings Directive (EPBD) defines nearly zero energy building (nZEB) as buildings that have a very high-energy performance. The nearly zero or very low amount of energy required should be covered to a very significant extent by renewable sources. For instance in EU countries, the EPBD (Direttiva Europe a 2010/31/UE) has set the goal of having all new buildings to be nZEB, by 31 December 2020.

The main advantage of ZEBs is significantly increased energy efficiency. And it should also include a long life of building and an indoor environment of high quality. Therefore, it needs the support of different technical solutions that realize this kind of building. However, energy efficiency is not the only problem that needs to be tackled in order to meet the ZEB requirements. Renewable energy is also another field of solutions that need to be utilized. High-energy efficiency and a significant share of renewable energy, those are the two goals that need to be achieved for zero-energy status.

It also needs to consider the location of buildings, not only for availability of renewable energy sources, but also for climate condition. Since space cooling and space heating are major part of energy consumption, and much related to the local climate conditions, each climate zone is required to specify a numerical indicator of total primary energy use expressed in kWh/m^2 per year. When designing a zero-energy building it is necessary to understand energy efficiency, which should be the primary goal of designing if needs the best energy performance and cost ratio.

Thus, PCS shows its huge advantage to increase energy efficiency. As we have discussed above, PCS increases energy efficiency and satisfy more person by personalize comfort air temperature, which expands the range of ambient air temperature set-points. And it also saves energy because the macro-zone could be maintained at lower temperature to heat or cool just the micro-zone, the temperature of which is decided by occupant. Further more, Personal Comfort System is more controlled and quickly responding system than normal systems.

Traditionally, sensing has been difficult in buildings. But with the help of Personal Comfort Systems, central system can collect data from Personal Comfort System to set a feedback system.

Micro-zones in general can keep occupants comfortable over a wider set-point temperature, but this is not enough to guarantee the decreasing of building energy consumption unless the micro-zone devices are more energy efficient than the building systems. A 2014 study detailing parametric simulation of six distinct building types in seven different ASHRAE climate zones (Hoyt et al. 2015) showed that widening the set-point temperature decreases the total energy spent on HVAC by roughly 10% per degree Celsius in either direction.

As Personal Comfort Systems can adjust temperature, these systems offer potential for improving occupant comfort while simultaneously decreasing energy consumption in buildings, and can operate independently from the building's environmental control.

Personal Comfort Systems show the capable of influencing a person's thermal comfort while using minimal energy and not influencing other occupants. And also PCS shows the capability to maintain occupants comfort over a wide rage using minimal energy and performing negligible heat transfer.

CHAPTER 2

ANALYSIS RESIDENTIAL BUILDING ENERGY CONSUMPTION IN ASIA

Because there are many types of energy used in residential area, including coal, gas, electricity and etc., and every country has its own way to calculate. And in this thesis we are going to talk about the energy consumption in coal consumption method to calculate primary energy consumption. We will use tonne of coal equivalent (tce) [1] to be the unit.

In this thesis, building energy use means the primary energy used in the operational phase of civil buildings, namely all the energy consumption supplying building services including space heating, space cooling, ventilation, lighting, cooking, domestic hot water, use of appliances and other equipment in civil building such as residential building, public and commercial buildings, etc.

For studying residential energy consumption, mostly are using kgce/hh or kWh/hh to be indictor. Nonetheless, for space cooling and heating, which mainly have related to size of space, we will use kgce/m^2 or kWh/m^2 as an auxiliary indictor.

2.1 Building energy use in urban residential buildings (excluding NUH) in China

2.1.1 Background situation

With economic development and increasing living standards, China has become the largest energy-consuming economy in the world. For example, China's primary energy consumption has increased from 1.56 billion tce 2001 to 4.30 billion tce in 2015.

[1] 1 tce = 29307.6 MJ

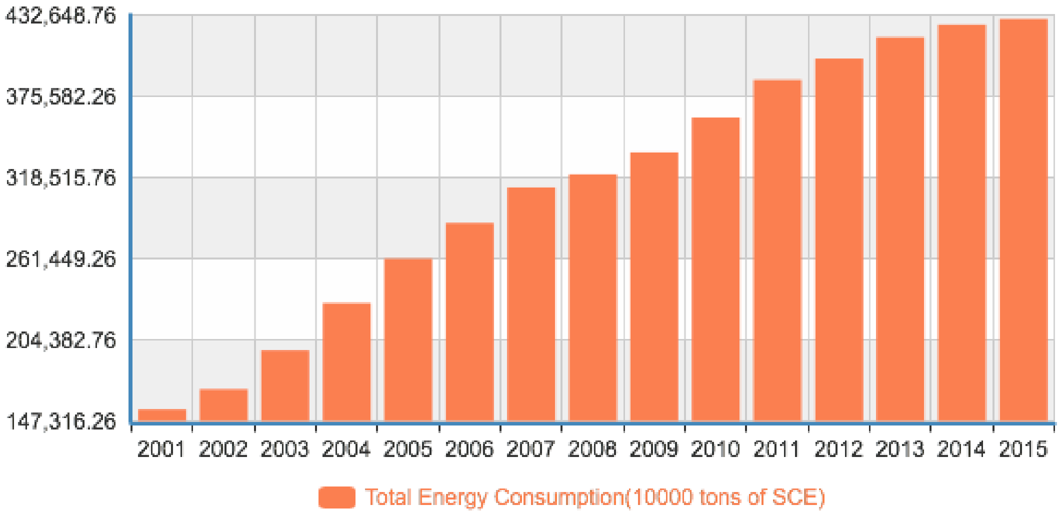

Figure 2.1 China's primary energy consumption (2001-2015)

With a fast-growing economy, the urbanization of China also increased significantly. In 2015, 56.1% of China's total population lived in urban areas, which the target in 2020 is 60% (Xinhua News Agency, 2016). However the rate in 2001 was only 37.7%. To satisfy the housing demand of new urban residents, urban residential floor area skyrocketed. In the past five years, urban residential building increased from 9.5 billion to 21.9 billion m^2, while new rural residential building decreased along with rapid urbanization. In 2015, China's total floor area was approximately 57.3 billion m^2, in which urban residential floor area was 21.9 billion m^2, rural residential floor area was 23.8 billion m^2, while the new completed buildings reached 2.8 billion m^2, about 64% are residential building.

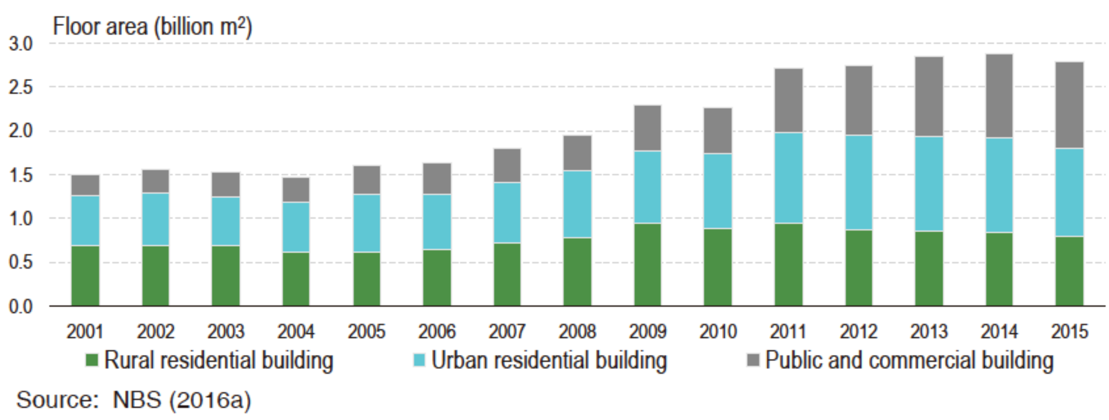

Figure 2.2 China's total primary energy consumption and its composition (2001-2015)

Since 2001, both total energy consumption and electricity consumption in China building sector increased more than 200%. In 2015, the total building energy consumption was 964 megatonnes of coal equivalent (Mtce), including 100 Mtce of biomass energy consumption, Building energy use accounted for about 20% of total primary energy consumption.

Since the energy model used in China are not perfect complete, China building energy model (CBEM) is normally used to analyze the energy consumption in building sector in China, which based on the differences of heating in different climate zones and the gap between urban and rural residential buildings. China's building energy use has been divided into four categories: northern urban heating (NUH), public and commercial buildings (excluding NUH), urban residential buildings (excluding NUH) and rural residential buildings.

The Qinling Huaihe line distinguishes the Northern and Southern China. Space heating in winter is traditionally supplied by city centralized heating networks in northern China, according to China's policy. However, the Southern China uses totally another method for heating, major building uses decentralized heating system. Thus, there is a huge different between them. Since the decentralized heating system is simile to other appliances which use in building. Therefore, in this report, we only discuss the local heating system along with the lighting, cooling, ventilation, domestic hot water (DHW), space heating, space cooling, use of appliances and other miscellaneous equipment in urban residential building.

The building floor area and energy consumption for the four subsectors shows in Figure 2.3. Floor area of residential buildings accounts for 80% of total buildings. As it shows in figure, energy use intensity (EUI) of P&C buildings (excluding NUH) is the highest one. P&C buildings (excluding NUH) used the most energy in 2015 because of growing stocks and average energy intensity. Generally, the energy use of each subsector is approximate, which means each roughly accounts for one quarter of total building commercial energy use.

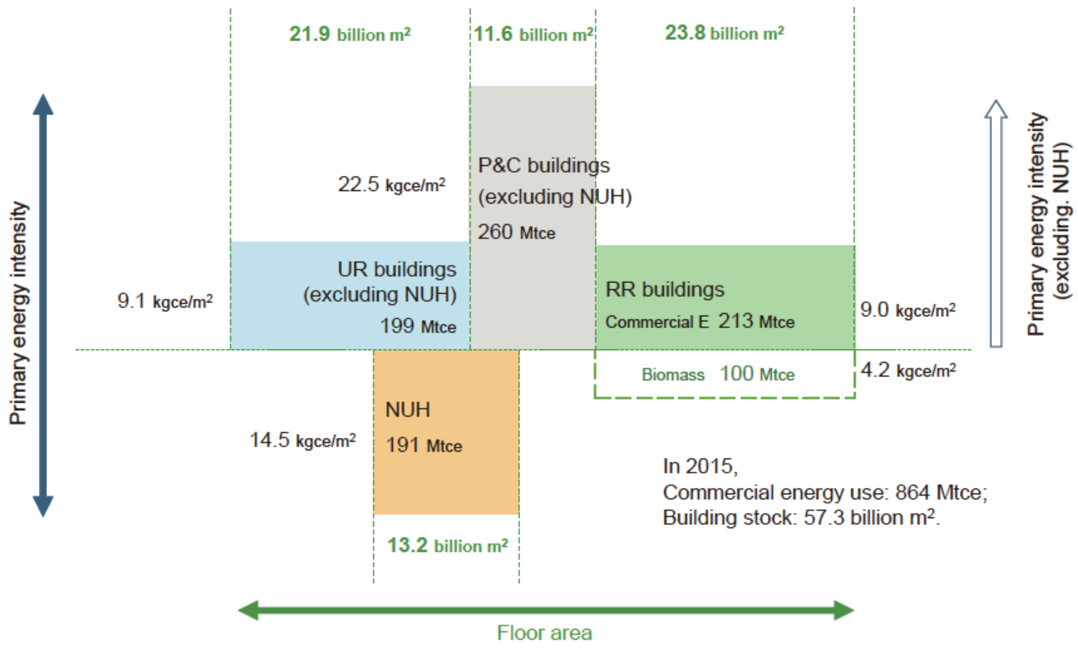

Figure 2.3 Primary energy consumption indicators of four China building subsectors (2015)

Figure 2.4 shows the energy use intensity of UR buildings and RR buildings from 2001 to 2015.

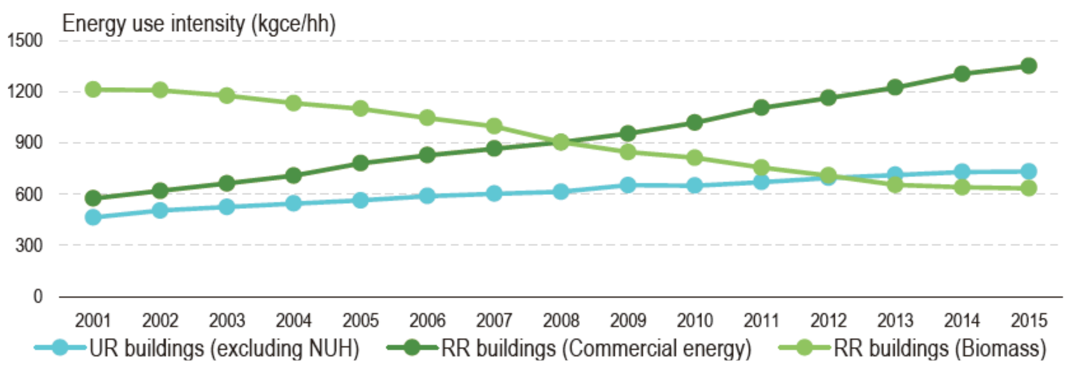

Figure 2.4 Energy intensity for UR buildings (excluding NUH) and RR buildings (2001-2015)

2.1.2 Energy consumption

With the rapid urbanization, China's urban population has grown in high-speed over the past twenty years, from 373 million in 1996 to 771 million in 2015(NBS, 2017a). As the family structure has changed from mainly extended family into mainly nuclear family, the number of people per household decreased from 3.2 in 1996 to around 2.8 in 2015.

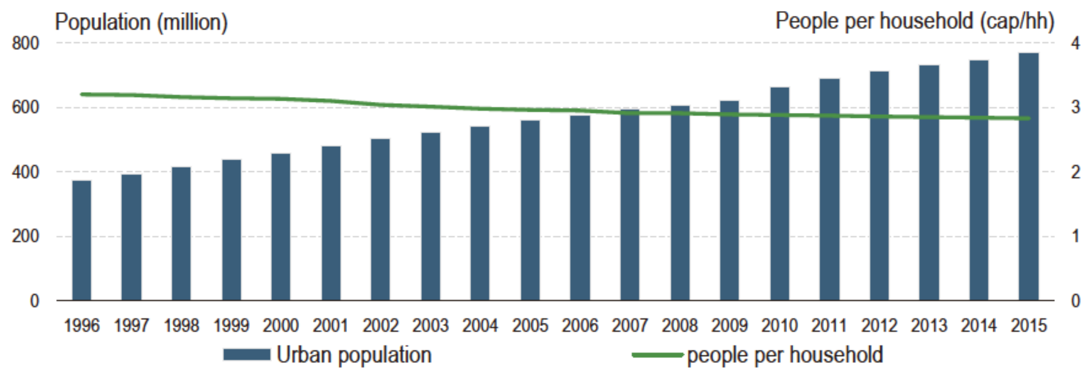

Figure 2.5 China's urban population and people per household (1996-2015)

Thus, According to the NBS residential household surveys, floor area per capita (FAPC) has increased from 24.5 to 36.6 m^2/cap. It should be noted that the data doesn't include the population in collective households (e.g. students living in dormitory), making the indicator higher. However, BERC has published another value, which has this aspect considered, and it shows FAPC increased from 19.8 to 28.4 m^2/cap.

In order to get a better understanding of energy consumption in urban residential building, BERC made a nationwide online survey in 2015 (Urban household energy consumption survey). Figure 2.6 shows the distribution of floor area per unit based the survey. Nearly 70% of the surveyed house was sized between 70 to 130 m^2.

Newly completed residential building improved living standards, but they also increased the average vacancy rate. According to the China Household Finance Survey (SHFS), the vacancy rate in 2015 was 21.9% and in most provinces the rate was above 15%.

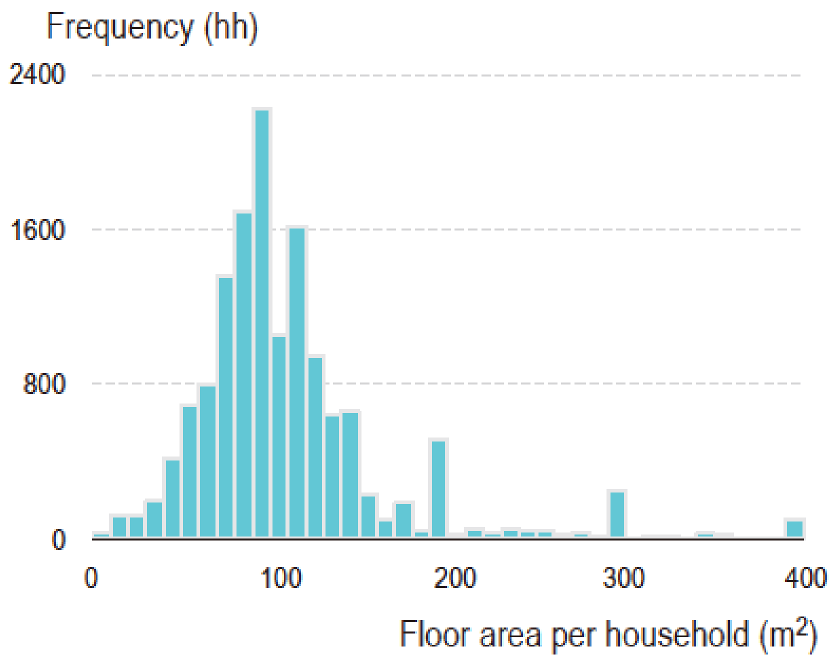

Figure 2.6 Urban household floor area situation

In 2015, the energy consumption in urban residential buildings (excluding NUH) was 199 Mtec, while electricity consumption was 430.0 TWH. Apart from electricity, other fuel types (including natural gas, coal gas, LPG and coal) are used in residences. Based on the UHECS survey, natural gas is used in 56% of urban households, coal gas in 19%, LPG in 17%, and coal in 8%, including 4% using the cleaner honeycomb briquette, and another 4% low efficiency bulk coal.

Figure 2.7 shows the energy consumption for each end-use. It shows the proportion of cooking, appliance and lighting are large but relatively stable, due to continuous energy efficiency improvements.

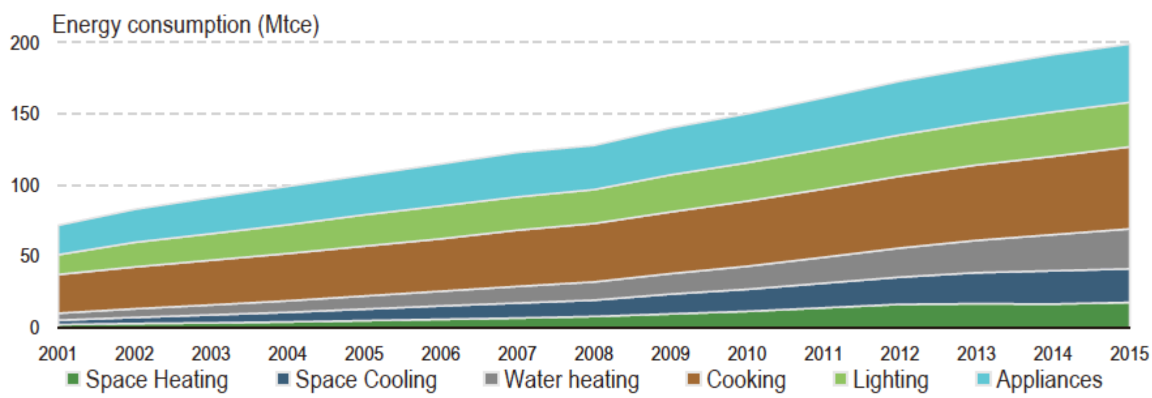

Figure 2.7 UR energy consumption (excluding NUH) by end-use (2001-2015)

Another key characteristic of UR energy consumption (excluding NUH) is that the energy consumption of each household differs by a large amount. In 2015, the average annual electricity consumption was about 1500 kWh/hh, although case study shows that some families used about 4000 kWh/hh or even higher. This is because the diverse life style and behaviors. Such as, urban residents in hot summer cold winter (HSCW) zone use various heating devices with different usage modes. Some urban families use an individual air purifier and a household ventilation system to address concerns about air quality. Using this kind of appliances will use another 500 to 1500 kWh electricity all around year. Therefore, the technical regulation should be established, in order to achieve the energy consumption cap.

- Space heating in the HSCW climate zone

The hot summer and cold winter climate zone is the transient climate region between the cold and the hot zones in China, which refers to all of Shanghai, Chongqing, Hubei, Hunan, Jiangxi, Anhui, and Zhejiang, and parts of Jiangsu, Henan, Shanxi, Gansu, Guangdong, Guangxi and Fujian. The average outside temperature during the coldest winter mouth in this zone is 0 to 10°C. Yangtze River Basin (YRB) is used when discussing the heating problem there, which refers to Hubei, Hunan Jiangxi, Anhui, Jiangsu, Zhejiang and shanghai. The YRB area is the major area in HSCW zone on a building scale, with holding 75% of total urban residential buildings. Unlike the northern part, district heating is not required by law, while in YRB area, space hating is still needed in this area. This is the reason which makes the features of heating differ substantially between regions.

According to this situation, most households use a decentralized heating. The most popular heating devices in this area are electrical heaters and air-source heat pump in each room, more than 60% households owns at least one of these heating devices. However, recently, with the living standards increase, centralized heating systems (including district heating similar to that used in the north or geothermal heat pumps), household air-source heat pump and gas boilers with radiant floor systems or radiant heating systems expanded rapidly, from less than 3% in 2009 to about 10% in 2015.

The heating season in this area varies from less than one moth to more than four months. During the heating season, most households use heating only when they feel cold in the house. About 60% of the households use heating for two or three months, from December to

February.

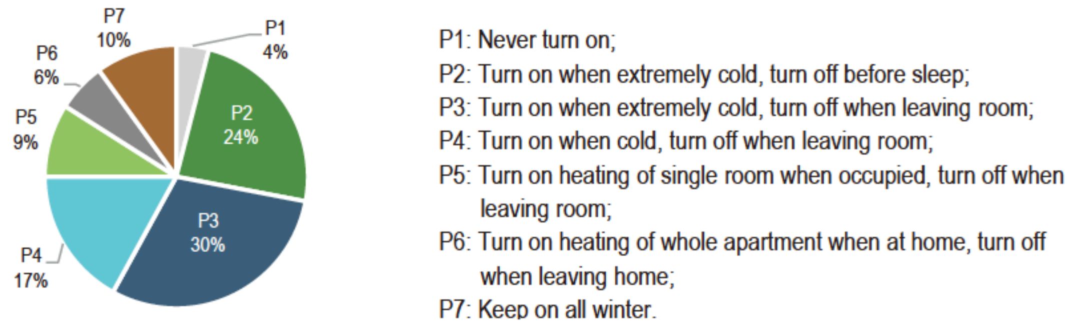

Figure 2.8 Usage patterns of space heating in HSCW climate zone (2015, n=4595)

Different heating usage patterns lead to dissimilar amounts of heating energy consumption. For who using air-source heat pumps, the average consumption is about 1.15 kgce/m^2. For households using gas boilers, the energy consumption is around 6 to 12 kgce/m^2. For district heating was 15 to 20 kgce/m^2.

- Space cooling

The energy consumption for space cooling is the amount of energy used for cooling in summer, mainly by air conditioners and fans.

The electricity consumption for cooling in urban residential in 2015 was 74.5 TWh. It is 12% of total UR energy consumption (excluding NUH) and the energy use intensity was 3.4 kWh/m^2. From 2001 to 2015, as shown in Figure 2.9, the total energy consumption grown about 8 times while energy use intensity increased around 3 times.

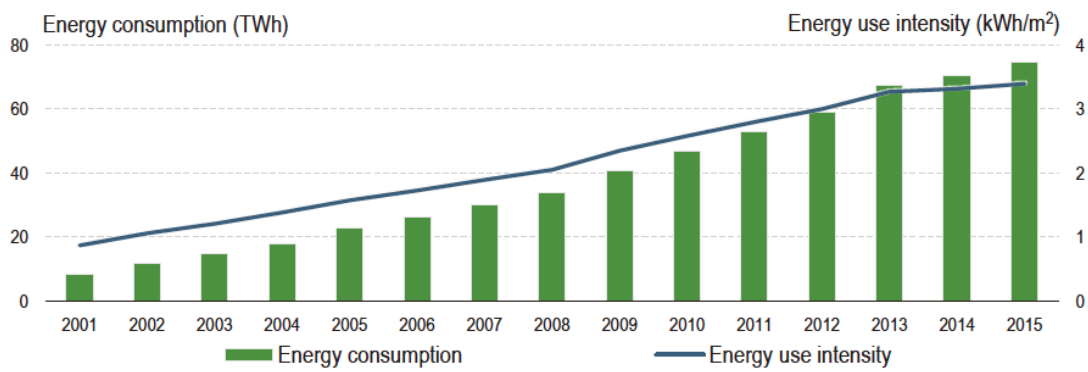

Figure 2.9 Energy consumption of space cooling (2001-2015)

In urban China, 49% of households choose room air conditioners for cooling, 31% choose electric fans. About 14% household does not own a cooling device, and 6% household use central air conditioners. Due to the climate variation and living standards cause the difference of the distribution across each province. There is only 1% of the households use district cooling system, and this number has increased rapidly in recent years.

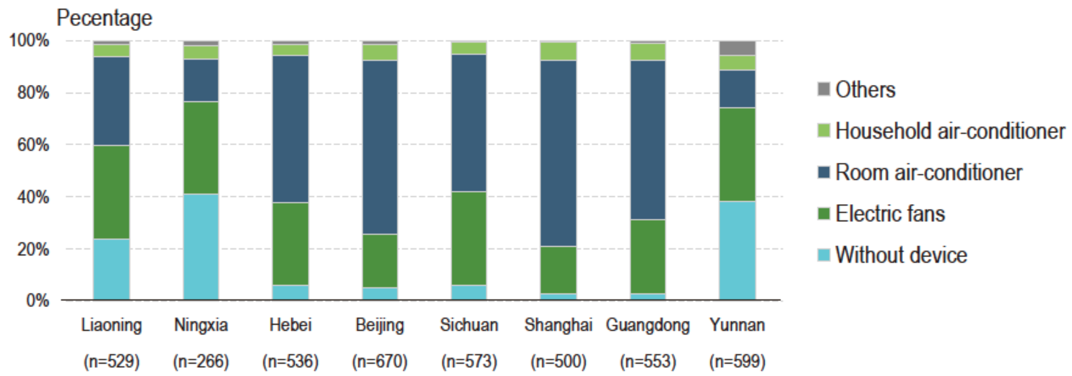

Figure 2.10 Distribution of cooling devices in select provinces (2015)

The cooling energy consumption in south China is obviously higher than north China. Most households use the air conditioners from mid-June to late August. According to investigations, the cooling energy use of Guangzhou was about 2 to 3 times higher than that of Beijing.

The main usage pattern is part time and part space, which means to turn on the device when the space is hot and turn off when leaving room. Meanwhile, centralized systems of cooling is consumed more energy than that of decentralized system. Sometimes, it might be more than 10 times difference in energy consumption, due to the amount of time and system operates.

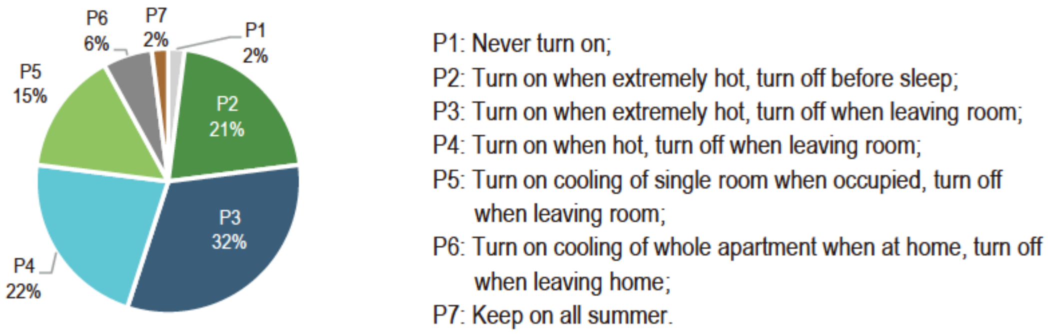

Figure 2.11 Usage patterns of air conditioning for space cooling (2015, n=7890)

- Water heating

In 2015, the energy consumption for urban residential water heating was 27.9 Mtce, holding 14% of the total energy consumption of UR buildings (excluding NUH). And the energy use intensity for UR water heating was 102 kgce/hh.

Respectively, the electrical heaters still the major water heating equipment, which taking 39% of portion. Meanwhile, the solar heaters and gas boilers are nearly equal, the share of which are 24% and 22%. Because of variations in climate energy provision and life style, the water heating equipment has the difference between provinces, as shown in figure 2.12.

The solar heaters increased quickly due to the promotion policy, in the meantime, the share of electrical heaters decreased and that of gas boilers did no much change.

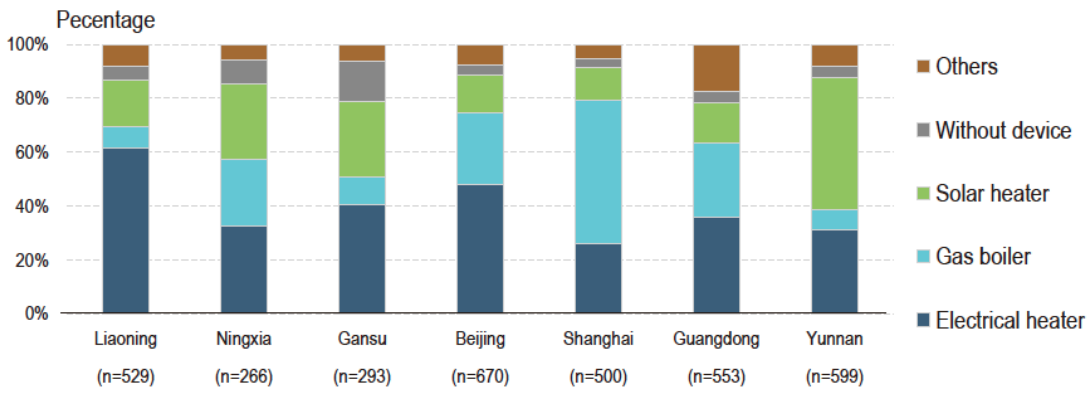

Figure 2.12 Distribution of water heating equipment in select provinces (2015)

The daily hot water consumption in China is around 50L for household, which is used for personal hygiene, dish washing and clothes washing.

- Cooking

In 2015, cooking consumed 57.6 Mtce of UR building energy consumption (excluding NUH), still being the largest share of the total subsector (taking 29%). While the energy use intensity was 211 kgce/hh.

According to the UHECS survey, in urban residential building, about 50% of the households use piped gas for cooking, 24% use electricity and 20% use bottled gas. The share of electricity for cooking increased significantly. The survey indicates the growth in ownership of special kinds of appliances, for example, electric rice cookers, kitchen ventilators, the induction hobs, soymilk maker/juicer and microwave oven. Another important trend is that the changing lifestyle in big cities, which has reduced the number of meals cooked at home, and is spreading to more cities.

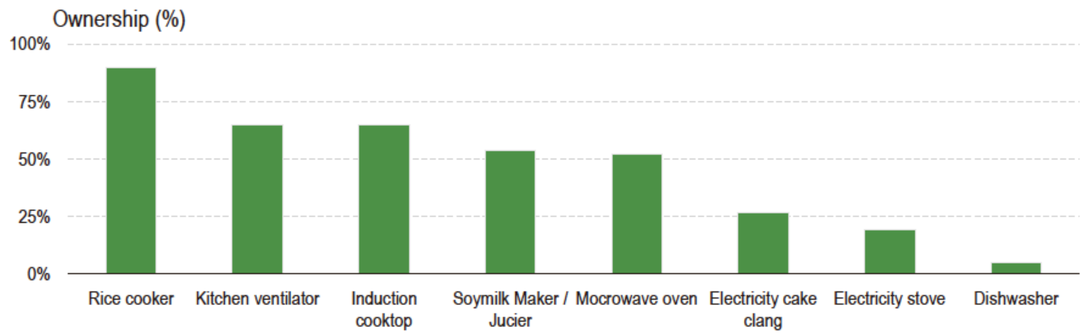

Figure 2.13 Ownership of select kitchen appliances (2015)

- Lighting

In 2015, the total electricity consumption for lighting was 98.4 TWh, taking 16% of the total UR subsector (excluding NUH). The energy use intensity by unit of floor area was 4.5 kWh/m^2.

Notional Development and Reform Commission (NDRC) has launched the Green Lights Program (GLP) in China, since 1996, which aims to promote high-efficiency lighting.

- Appliances

In this thesis, appliance in the urban residential building refers to electrical equipment for household functions except for the other five end-uses mentioned above, such as refrigerators, laundry machines, televisions and computers, etc.

In 2015, the total electricity consumption in appliances was 127.9 TWh, taking 20% of the total UR energy (excluding NUH). The energy use intensity per household was 470 kWh/hh.

With the growth in living standards, the ownership of the appliances raised, along with their frequency operating. Some energy-hungry appliances such as air purifier have begun to increase in the past years. All these, have made a quick increasing of energy consumption.

Form the view of total energy consumption, cooking, appliances and lighting are still the major part of energy consumption in urban residential buildings (excluding NUH). In the other hand, the increasing rate of heating in HSCW zone, cooling and water heating was very high. Especially, the space heating in HSCW zone, the increasing rate is over 50%.

Categories	Energy consumption	Energy use intensity	Percent of total energy consumption	Increasing rate of energy consumption since 2001
Space Heating	17.5 Mtce	1.84 $kgce/m^2$	9%	800%
Space Cooling	74.5 TWh	3.4 kWh/m^2	12%	800%
Appliance	127.9 TWh	470 kWh/hh	20%	30%
Lighting	98.4 TWh	4.5 kWh/m^2	16%	150%
DHW	27.9 Mtce	102 kgce/hh	14%	500%
Cooking	57.6 Mtce	211 kgce/hh	29%	20%
Total	199 Mtce	-	100%	-

Table 2.1 Overview of China's UR energy use

Table 2.1 has shown the current situation of China's UR energy use and the increasing trend.

2.2 Building energy use in residential buildings in Japan

2.2.1 Background situation

According to the Energy Data and Modelling Center (EDMC), Japan's total primary energy consumption has increased from 155 Mtce in 1965 to 537 Mtce in 2000. Since 200 the consumption began to decrease, in 2015 the total primary energy consumption was 450 Mtce.

The population of Japan is more than 127 million, in 2015, and there are nearly 57 million households in Japan. The energy consumption of residential building in Japan from 1965 to 2005 has increased 4.1 times, up to 79 million tce in 2005, as shown in Figure 2.14. After that, the energy consumption began to decrease. From 2010 to 2015, the energy consumption in residential building has kept 4% decreasing annual rate. In 2015, the total energy consumption of residential building in Japan was reduced to 67 million tce.

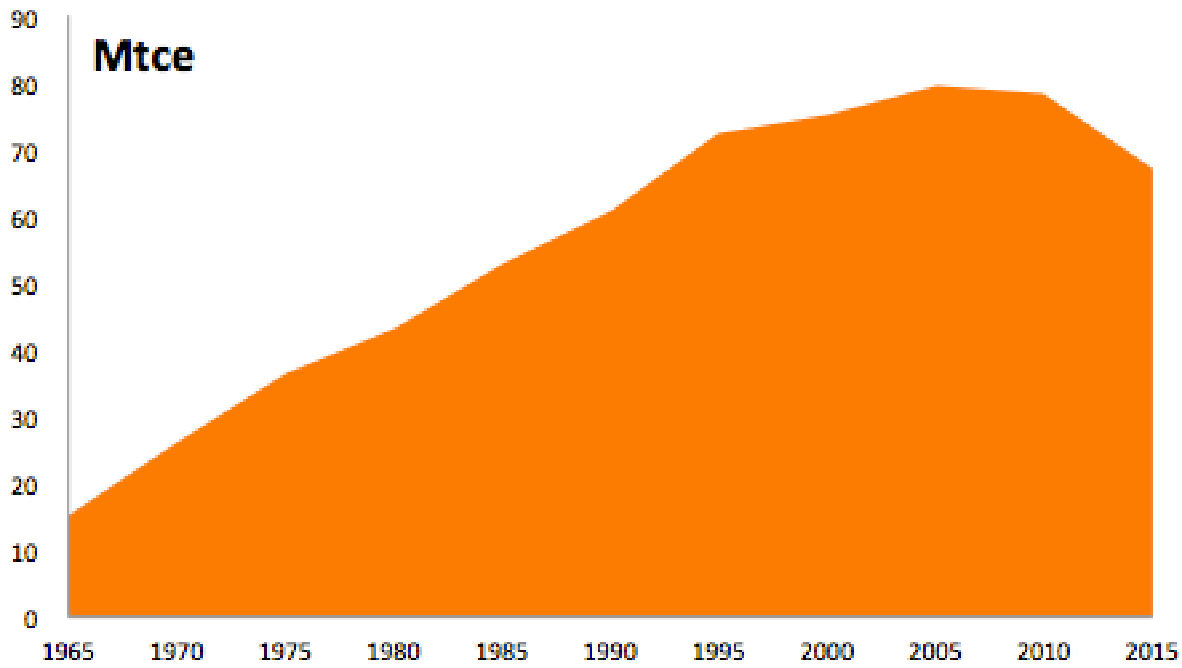

Figure 2.14 Japan's residential building primary energy consumption (1965-2015) (source:EMDC)

However, the residential sector has increased its share of energy consumption until 2010. In 2010, the share of residential energy consumption has taken 16% of total energy consumption, and has decreased to 14.9% in 2015, as shown in Figure 2.15. Thus, even the usage of energy in residential area began to decrease since 2005, the share of it was still increasing until 2010. Because the total energy consumption is deceasing since 2000, and the other areas have been deceased faster than residential area.

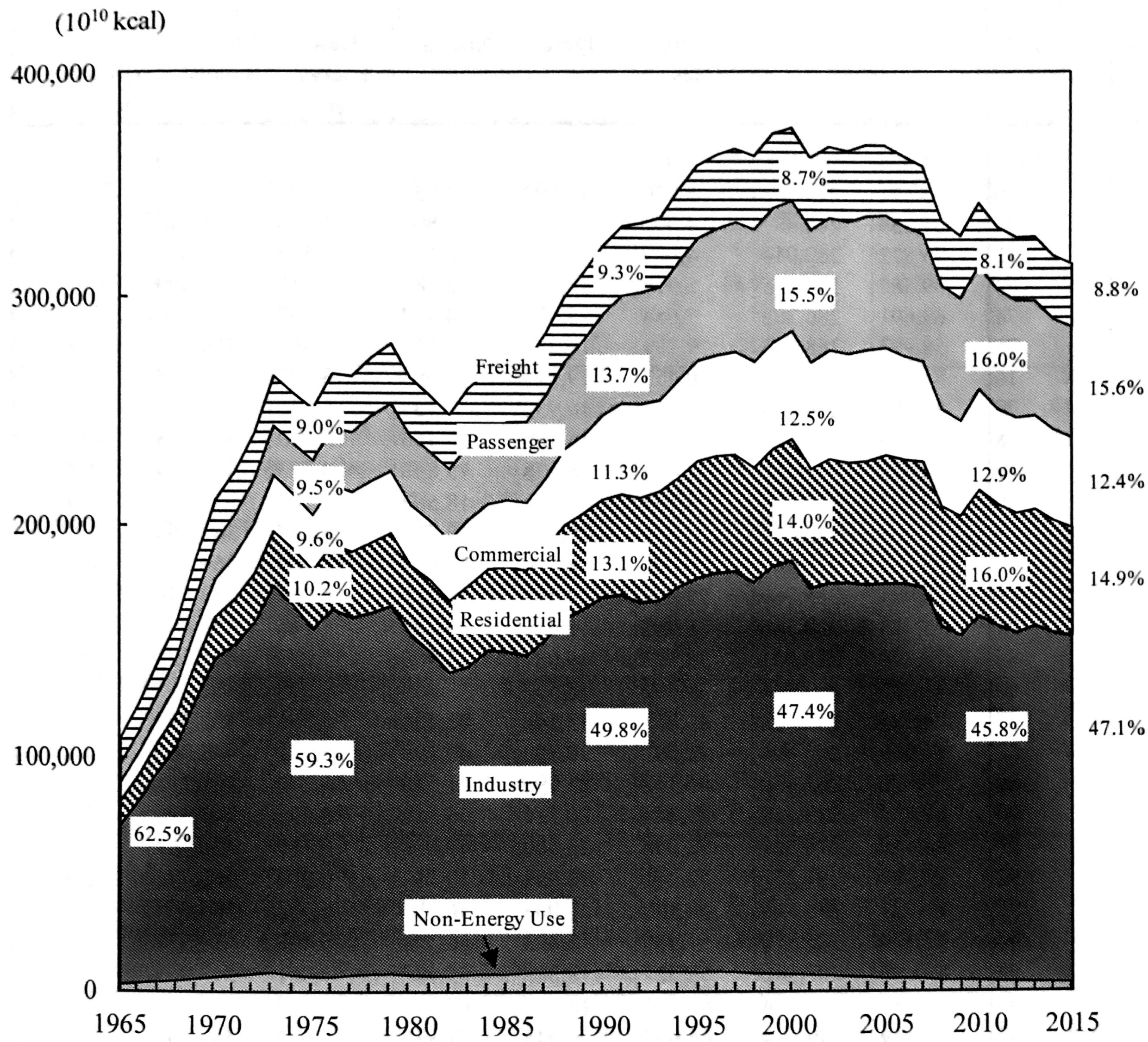

Figure 2.15 Japan's primary energy consumption (1965-2015) (source:EMDC)

Unlike China, Japan building energy model is divided residential energy consumption to 5 subsectors, which are space cooling, space heating, water heating, cooking and appliances.

Since 1990, the coal consumption in Japan building sector decrease to under 1%. And in 2015, electricity consumption represents approximately half of the sector. Kerosene and gas takes almost the same share.

2.2.2 Energy consumption

In last two decade, Japan's population has changed slowly, from nearly 126 million in 1996 to 127 million in 2015. As the number of household has kept a stable increasing rate, the number of people per household decreased from 3.34 in 1996 to 3.02 in 2015.

According to JSB, the residential building in Japan is composed by detached house, tenement-house and apartment. The average house size was 92.41 m^2 in 2008. And the detached house takes the major part of residential building.

Thus, MLIT published guidelines on the minimum and recommended (ideal) amount of living space, as shown in Figure 2.16. According to the guidelines, a two-person household living in the city should have a minimum of living and ideally was 55 m^2, and for three person should be 75 m^2.

	Overview		Calculation
Minimum recommended living area standards	Minimum living area standard needed to meet the minimum essentials for a healthy and cultural life.		**Single Person:** 25-sqm **For households with 2 or more people:** 10-sqm x Number of People + 10-sqm
Recommended (Ideal) residential living area standards	Recommended living area standard for leading a fulfilling life with various lifestyle activities.	Residing in a multi-family dwelling unit (apartment building) in a city center or suburb.	**Single Person:** 40-sqm **For households with 2 or more people:** 20-sqm x Number of People + 15-sqm
		Residing in a single-family dwelling outside a city center or suburb.	**Single Person:** 55-sqm **For households with 2 or more people:** 25-sqm x Number of People + 25-sqm

Figure 2.16 Residential living area standard (source:MLIT)

According to the survey was conducted by the Ministry of Land, Infrastructure and Transport (MLIT) in 2008, there is still 59% person that have less than the minimum per-person recommended amount of living space, shown in Figure 2.17. According to white paper of MLIT, floor area per capita has increased from 33 m^2/cap in 1998 to 39 m^2/cap in 2015.

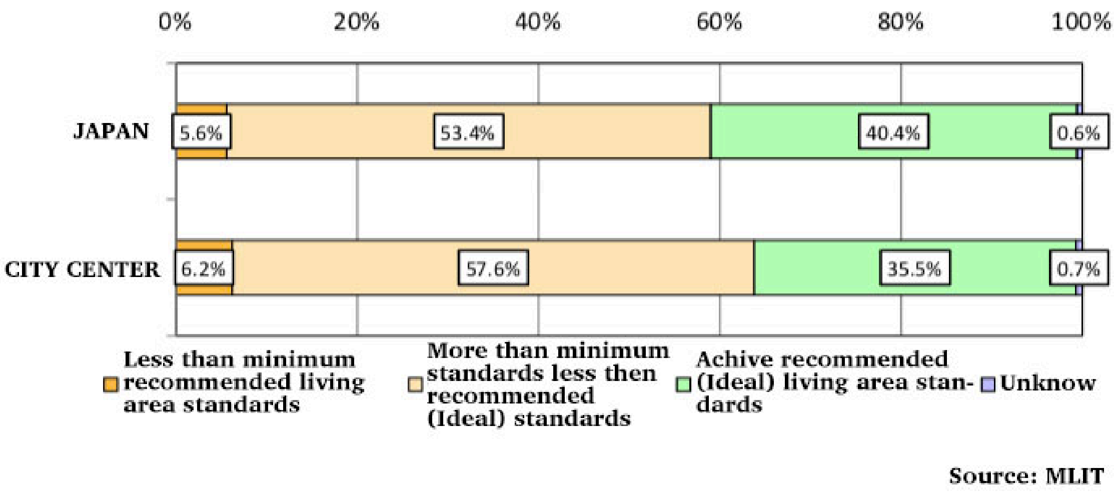

Figure 2.17 Residential living area standard (source:MLIT)

In 2015, the energy consumption in residential buildings was 67 Mtce, while electricity consumption was 33.2 Mtce. Apart from electricity, other fuel types (including city gas, LPG and kerosene) are used in residences. Based on EDMC <handbook of Japan's & World energy &economic statistics 2017>, city gas was taking 19.6%, kerosene 19.5 LPG 10.9 and other 0.6% with coal and solar heat.

Figure 2.18 shows the energy consumption for each end-use. It shows the proportion of cooking and space cooling are little and stable, while DHW and space heating are large but relatively stable, due to continuous energy efficiency improvements. On the contrary, appliance was increased a lot in the past thirty years.

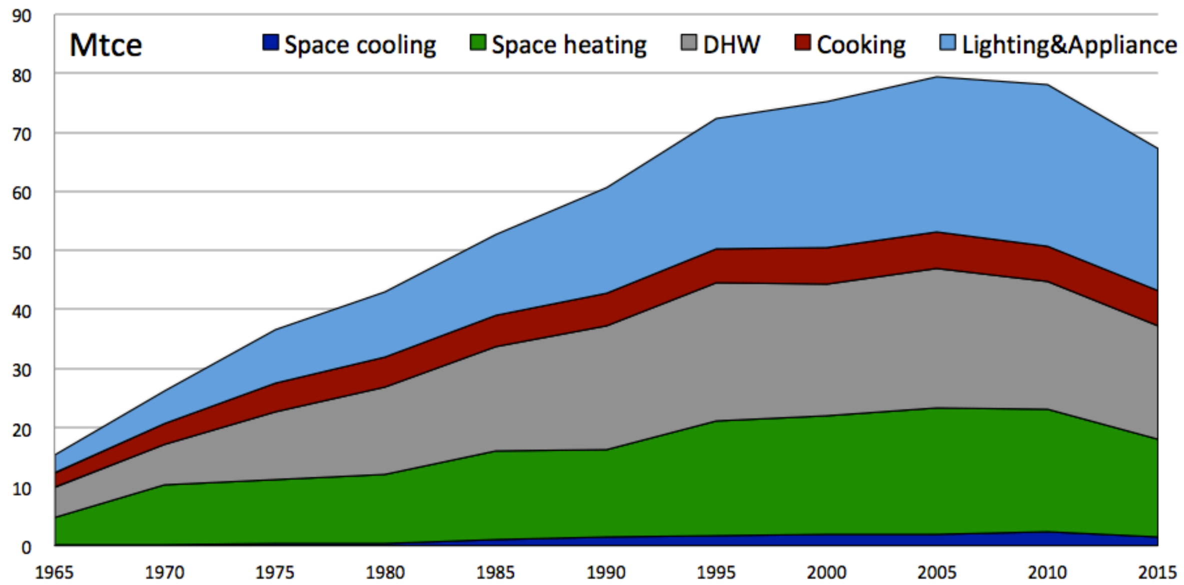

Figure 2.18 Residential energy consumption by end-use (1965-2015)

Appliances are the major part of Japan's residential building energy consumption, taking 36% of total subsector. In 2015, the average usage of Japan was 1192.57 kgce/hh. This part of usage kept increasing since 1965 until 2005 to the top, keeping stable since then.

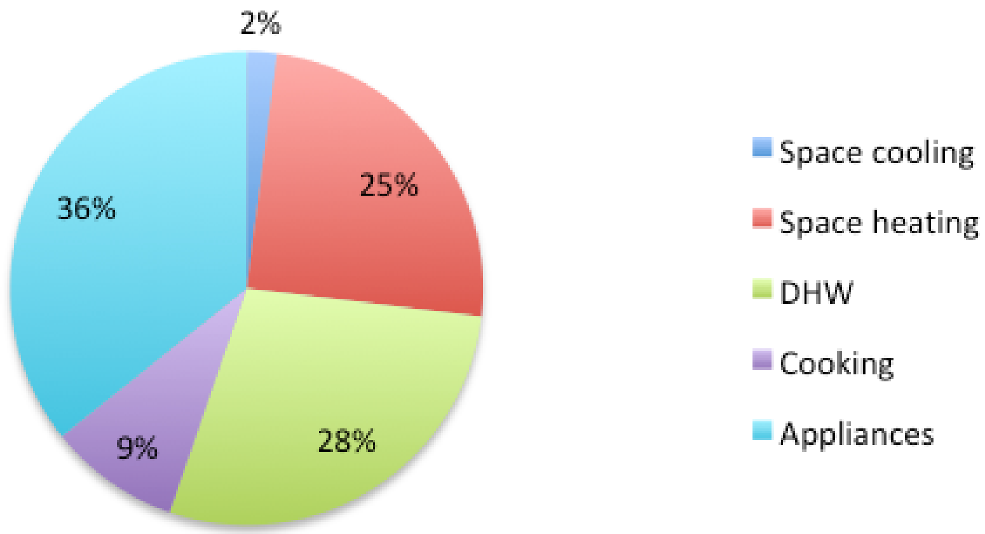

Figure 2.19 Residential energy consumption per household (kgtc/hh)

Space heating and water heating was almost equal, taking 25% and 28%. However, cooking and space cooling only takes a little part of Japan's building energy consumption, holding 9% of total residential building energy consumption. In 2015, cooking energy use intensity in residential was only 107.0 kgce/hh, and has not much changed since 1980. In the meantime, energy consumption of space cooling kept slowly increasing. As the temperature in summer is not too high, actually, only little household has air condition.

- Space heating

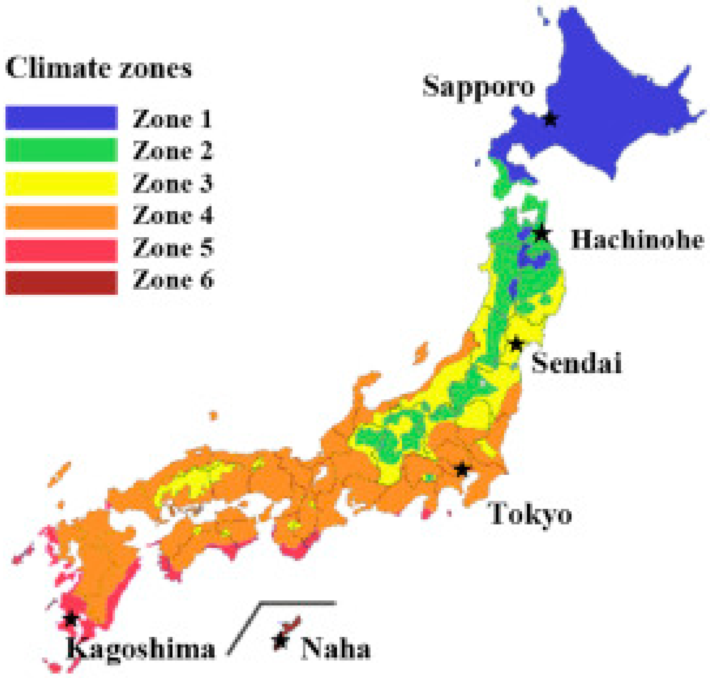

Figure 2.20 Map of Japan's climate zones

According to Japan's policy, the whole country is divided to 6 zones by climate condition, as shown in Figure 2.20. Except zone 1 uses centralized heating networks, other zones are all use decentralized heating networks. In Figure 2.21 shows some normal devices used in house. Nowadays, more and more household are changing to use air conditioners as heat devices, which increases energy consumption in this subsector.

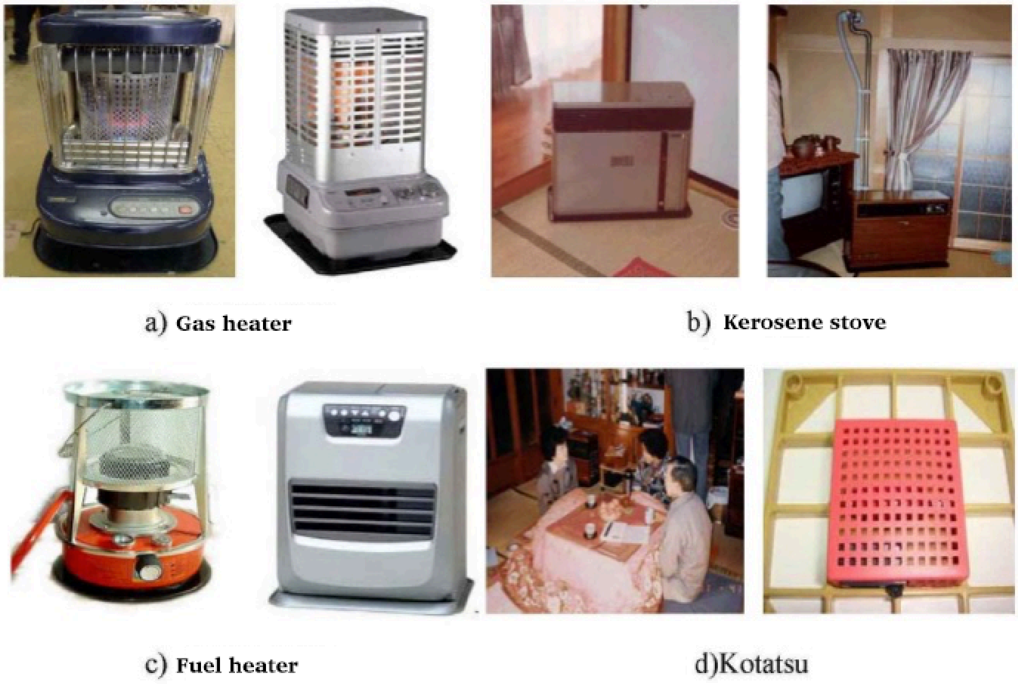

Figure 2.21 Example of heating device

In 2015, the energy consumption for space heating was 16.7 Mtce, while energy use intensity for residential heating was 296 kgce/hh, taking 25% of total residential energy consumption.

- Space cooling

In 2015, the energy consumption for space cooling was 1.4 Mtce, only taking 2% of the total subsector and the energy use intensity was 24.6 kgce/hh. Since Japan is an island, the cooling device is not popular in Japan, actually most households don't have one. Although many houses have more than one air conditioner, they are still merely use in summer. Most households used them for space heating.

- Water heating

Since 2000, water heating was always taking the second place of residential building energy consumption. In 2015, the energy consumption for water heating was 19.11 Mtce. And the energy use intensity for residential water heating was 338.7 kgce/hh.

The daily hot water consumption in Japan is around 700L for household, which is used for personal hygiene, dish washing and clothes washing. Most of the households use hot water for bathing while less than 20% for showering. The usage of hot water for bathing is about 300L-500L. Because of this kind of custom, causes the energy consumption for water heating.

- Cooking

In 2015, cooking consumed 6 Mtce of residential building energy consumption, holding only 7% of total subsector, while the energy use intensity for residential cooking in Japan was 107.1 kgce/hh.

- Appliances

According to EDMC, appliances energy consumption has included lighting consumption. Appliances have taken the first place in residential energy consumption since 2000. In 2015 the toal energy consumption in appliances was 24 Mtce. The energy use intensity per household was 3469 kWh/hh.

The most frequency used appliances was dust collector, more the 98.6% of households use it to clean the house. On the other side, Japan's households used to use water spray toilet seat, which is an energy-hungry appliances. The ownership of appliances raised, because of the growth of living standards. Some energy-hungry appliances, such as dehumidifiers have begun to increase in the past years. All of these increased the energy consumption in residential building.

Categories	**energy consumption**	**Energy use intensity**	**Percent of total energy consumption**	**decresing rate of energy consumption since 2001**
Space Heating	16.7 Mtce	22.9 kgce/m^2	25%	30%
Space Cooling	11.3 TWh	15.5 kWh/m^2	2%	41%
Lighting&Appliance	196 TWh	3469 kWh/hh	36%	19%
DHW	19 Mtce	338.7 kgce/hh	28%	29%
Cooking	6 Mtce	107.14 kgce/hh	9%	17%
Total	67 Mtce	-	100%	-

Table 2.2 Overview of Japan's residential energy use

Table 2.2 has shown the current situation of Japan's residential energy use and the increasing trend.

2.3 Perspectives for residential building energy use

2.3.1 China

With the economic development, rapid urbanization and rising living standard, the most critical issue for China's building energy conservation is energy demand. Due to different choices of lifestyle and behaviors, it will lead to different levels of energy consumption.

During the process of industrialization, satisfying human needs for indoor comfort will still be considered the primary goal. However, the increasing energy demand leads to serious environmental and ecological problems. There should be a balance between human development and environmental impact.

The national 13^{th} Five-year Plan published in the 18^{th} Central Committee pointed out that the total amount and intensity double control action should be implemented for energy, water and land resource management (Xinhua News Agency, 2015). Thus, the target of China's building energy conservation will be to control not only the total amount but also intensity.

Through the existing national plans and research, the total primary energy use will be limited to no more than 4.8 billion to 5 billion tce in 2020 (NDRC, 2014; Xinhua news Agency, 2016; NEA, 2016 and Chinese Academy of Engineering, 2017). Since total energy use has to be limited, the energy use for each sector needs to be restricted.

The energy consumption of China's building sector is expected to be limited to less than 1.1 billion tce, as an expectation for a population of around 1.47 billion and floor area of 72 billion m^2. Through analysis, the energy consumption of UR buildings (excluding NUH) is expected to be less than 384 Mtce for floor area of around 35 billion m^2. The energy use targets for each subsector are shown in Table 2.3.

Categories	**Energy use intensity**		**Commercial energy consumption**	
	Current	Future	Current	Future
NUH	14.5 kgce/m^2	6.1 kgce/m^2	191 Mtce	122 Mtce

UR buildings (excluding NUH)	732 kgce/hh	1098 kgce/hh	199 Mtce	384 Mtce
P&C buildings (excluding NUH)	22.5 $kgce/m^2$	24.6 $kgce/m^2$	260 Mtce	444 Mtce
RR buildings	1350 kgce/hh	988 kgce/hh	213 Mtce	132 Mtce
Total			864 Mtce	1.1 Gtce

Table 2.3 China buildings energy primary consumption target

The approach to the energy intensity target for UR building (excluding NUH) is different from other subsector. For UR buildings (excluding NUH), the main approach is encouraging green lifestyles and promoting energy efficient technologies. The most important part includes space heating in HSCW zone, space cooling, appliances, renewable energy, etc.

Though the top-level design and detailed planning, it is possible to control energy consumption. An initial planning for each end-use is shown in Table 2.3

Categories	**Energy use intensity**	
	Current	Target
Cooling - A*	1.7 kWh_e/m^2	4 kWh_e/m^2
Cooling - B*	6.7 kWh_e/m^2	12 kWh_e/m^2
Heating + Cooling - C*	9.4 kWh_e/m^2	20 kWh_e/m^2
Appliance	470 kWh_e/hh	700 kWh_e/hh
Lighting	5.6 kWh_e/m^2	4 kWh_e/m^2
DHW	36 kWh_e/cap	45 kWh_e/cap
Cooking	75 kWh_e/cap	70 kWh_e/cap
Total	199 Mtce	384 Mtce

Table 2.4 Energy use target of UR buildings (excluding NUH)

In the table 2.4, Cooling-A refers to space cooling energy use in cold climate zone and severe cold climate zone, Cooling-B refers to space cooling energy use in hot summer and warm winter climate zone and mild climate zone. Heating+Cooling-C refers to space heating energy use and space cooling energy use in HSCW climate zone.

2.3.2 In Japan

Japan is a nation that relies on imports for the major part of energy resources. However, since the Great East Japan Earthquake and Fukushima Daiichi Nuclear Power Plant accident of March 2011, the Japanese government has been published a variety of new energy policies.

Since the suspension of nuclear power generation after the Great East Japan Earthquake, Japan's self-sufficiency rate in primary energy has decreased to 6.1% in 2013. And then it caused electricity prices and CO_2 emissions in japan have risen sharply.

Japan has set long-term targets for self-sufficiency, electricity prices and greenhouse gas emissions for 2030. To meet these targets, Japan will complement serious of polices while ensuring safety, shown in Figure 2.22.

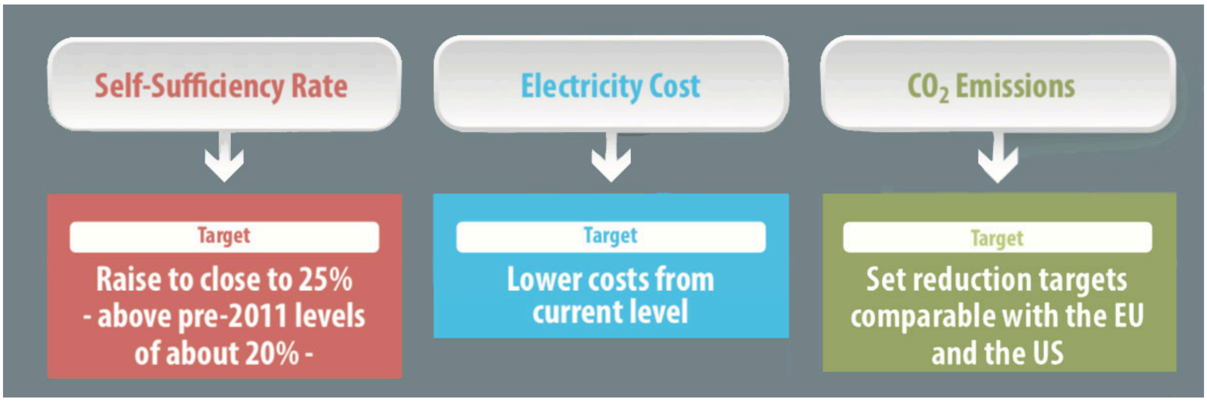

Figure 2.22 Japan's energy target for 2030

Japan has identified two methods to overcome its energy challenges and realize a stable energy mix:

1. Energy conservation promotion

   According to economic growth forecasts, Japan aims to promote energy conservation measures, while will enable Japan to reduce the total volume of electricity generation by 17% in 2030.

   To achieve this level of energy conservation, Japan will take a smart and detail-oriented approach to energy conservation leveraging energy management systems to clearly track use and consumption for optimal utilization.

One of tangible approach for residential sector is to build and renovate houses based on energy conservation standards. Japan plans to improve to introduce home energy management system (HEMS) into residential sector. Another tangible approach is to replace equipment with high-efficiency consumer electronics and water heaters.

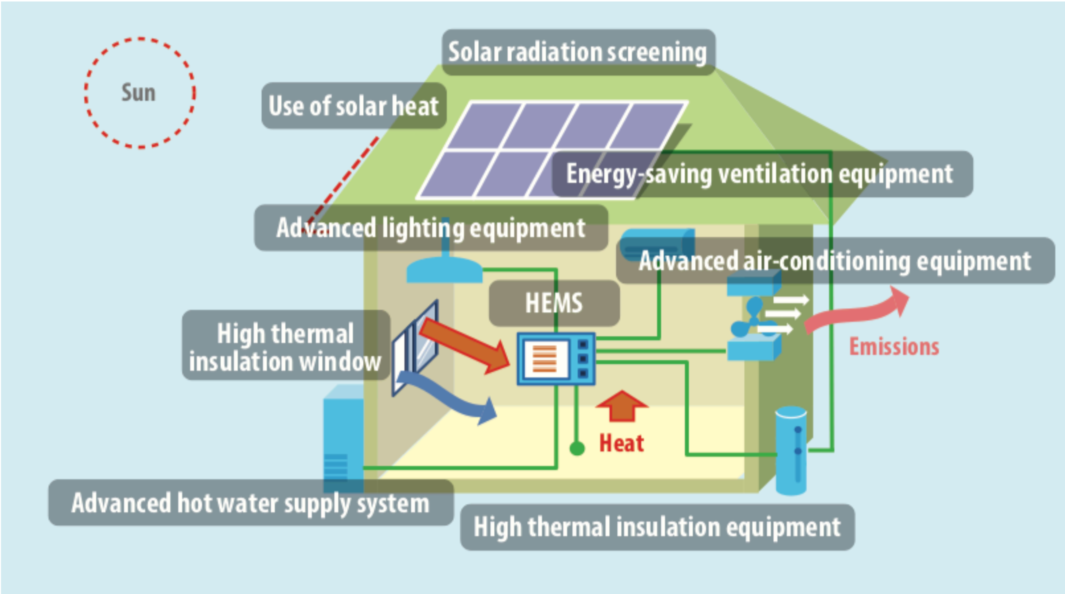

Figure 2.23 HEMS

2. Balance energy supply

Japan aims to realize its goal by expand the use of a variety of renewable energy sources and more efficient thermal power generation to secure a safe energy supply. It will implement a policy program, which is economically efficient and environmentally sustainable.

In Mid-and-Long Roadmap, Japan plans to decommission Fukushima Daiichi Nuclear Power Station within 30-40 years.

CHAPTER 3

ENERGY POLICY OF RESIDENTIAL BUILDINGS

Almost all countries are implementing a wide range of policy measure on energy efficiency in buildings. Regulations are dominant in buildings, which including the labeling of electrical appliances, minimum energy performance standard (MEPS) for new buildings and appliances. Financial measures are in second position and include subsidies and soft loans. Fiscal measures, such as tax on inefficient appliances, or tax reductions, are marginal, and very few voluntary agreements are implemented.

The building codes can ensure the concern of energy efficiency at the design phase and can help to realize the potentials for energy efficiency in new buildings. The building codes have been changing over time, from simple standards on building components to more complex requirements. Energy requirements for new buildings are set in different ways, based on national or local government. The requirements can be either integrated in general building codes or standards, or can be set as separate standards for energy efficiency.

Integrating energy efficiency into building codes is a recognized strategy to reduce energy consumption. Across the globe countries are designing and implementing energy efficiency policies independently. The policies are programmed to decrease energy waste both in the new building stock and existing stock. This chapter will discuss the building efficiency policies in Asia and Europe. And lays out the status of building energy codes, labels and incentives.

The construction market is under constant change. The energy efficiency requirements for new buildings are one of the drivers for these changes in the markets. New products come into the market and existing products become improved and more cost effective. With the changed possibilities and the changed conditions for the products and price, will change the feasibility for different solutions. Further more, with the energy price and solutions for heating and cooling change will change the limits to set as minimum requirements in building codes.

Not only the new products will lead to the possibility of increasing the requirements for energy efficiency, vice versa, the increased requirements for energy efficiency in building codes will lead to the development of intelligent solutions and improvements of products.

Zero Energy Buildings, Passive Houses and other low energy buildings are inspiring the market and help to demonstrate new technology and products. On the other hand, the policies are forcing the least efficient part of buildings to be more efficient. Strong policies can be a driver for highly energy efficient buildings. In the long term, the trends of new buildings even existing buildings is to be sustainable, which mean, many countries have already o will take initiatives and define ZEB o Passive House as a target for building policies.

3.1 The main energy policy of residential in Asia

3.1.1 Building energy codes In China

China set an energy saving standard of 50% reduction (65% for provincial leveled municipal cities) compared to energy consumption levels of 1985. Carbon trading program is implemented in several low carbon pilot provinces and cities. And carbon tax policy of building sector is still under design. The main energy building energy saving (BES) policies applying on residential buildings are listed in Table 3.1

Categories	Title	Applicable Building Type	Policy Requirement Level	Applicable Climate zone
Codes	Design Standard for residential Building 1995	New residential	Mandatory	Severe Cold and Cold Zone
	Design Standard for residential Building 2013	-	Mandatory	Hot Summer Warm Winter Zone
	The national Standard for energy consumption of building			National
Labels	Passive House (2012)	New residential	Voluntary	National

	MOHURD Green Building Rating	-	-	-
Incentive	-			

Table 3.1 China's main BES policies

In 2016, MOHURD implemented the first standard, the national Standard for energy consumption of building (GB/T51161-2016), focusing on actual energy use (MOHURD, 2016). The Standard covers energy use in commercial buildings and urban residential building. The target for building energy conservation is EUI. The indicator for urban residential building is per household, and different climate zones have different targets, shown in figure 3.1.

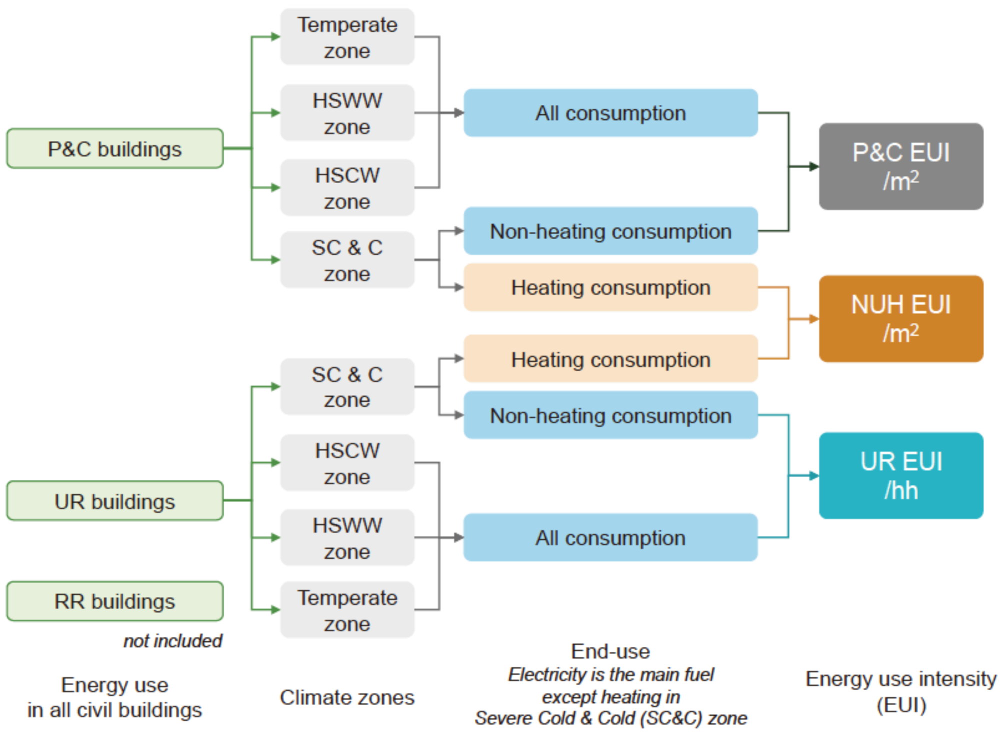

Figure 3.1 EUI in the standard for different subsector

Two indicators of EUI were adopted in this standard, called the constraint value (CV) and the leading value (LV) of the indicator. The CV is designed as a bottom line for mandating actual energy use in building, while the LV is designed to target actual energy performance indicator for energy efficient building in China.

For UR building (excluding NUH), energy use intensity per household (hh) is used for a better understanding of energy usage. In this area, energy types mainly include electricity, nature gas, etc.

On account of the energy use character, the indicator is divided into two subsector, electricity and gas use. The first includes the usage of electricity and other types of energy excluding gas, while the other includes nature gas and coal gas. The CVs and LVs given in the Standard are different for different climate zones. Heating consumption is excluded in the values in SC&C zones while included in other zones.

The CVs in the Standard are determined as the threshold of the energy consumption, shown in Table 3.2. Based on their actual utility bill, 80% of the families would not exceed. The LVs are not given in the Standard because energy saving are difficult to enforce at the residential level.

	Severe cold zone	**Cold zone**	**HSCW zone**	**HSWW zone**	**Temperate zone**
Electricity [kWh/(hh*a)]	2200	2700	3100	2800	2200
Gas [m^3/(hh*a)]	150	140	240	160	150

Table 3.2 Indicators for electricity and gas consumption in residential buildings

In residential buildings, the values in the Standard are equal to the basic level in pricing scheme, as the tiered energy pricing schemes for electricity and gas have been implemented national wide.

Family size will also effect on the energy consumption for different households. In the Standard, the value is assumed for the household size no more than three people.

The consumption Standard provides the target of energy use, aiming to regulate the building's actual energy consumption during the operational phase. The design standards provide technical guidance to achieve high efficiency from building physical aspects (e.g. building envelope, lighting and HVAC). However, high-energy efficiency does not only depend on physical aspects. High building energy consumption can cause by other reasons: extent of thermal comfort, poor management.

The real aim of energy conservation is to decrease the actual energy consumption and salve the problem of lack of energy, climate change and the indoor air quality. Therefor the control of the actual building energy consumption and energy usage intensity has trend to the main mission in China. According to the Ministry of Construction in China, more than 2 billion m^2 are constructed in China every year, which takes more than 40% of all new constructions in the world.

3.1.2 In Japan

Japan's regulation on building energy efficiency is based on the "Energy Conservation Law (ECL)" which was first adopted in 1979. The standards for energy efficiency of residential and commercial buildings were supported by different measures including the "Housing Qualification Assurance Law" released in 2000. MLIT issued the "Basic Program for Housing" in 2006, which aimed to improve housing standards.

The main Building Codes and BES policies are shown in Table 3.3.

Categories	Title	Applicable Building Type	Policy Requirement Level	Applicable Climate zone
Codes	Rational use of energy within buildings (2009)	New residential	Voluntary	Japan
	Energy Efficiency Standard and Notification System	New residential, New non-residential, Existing residential, Existing non-residential	Mandatory	Japan
	House Builders' Standard: Housing Top-Runner Program	New residential	Mandatory	National
	Building Energy Efficiency Act (2015)	New residential, New non-residential, Existing residential, Existing non-residential	Mandatory	National
Labels	Passive House (1990)	New residential	Voluntary	National
	Zero Energy Buildings (ZEB)	New residential, Existing residential	-	National

	Energy Efficiency Performance of Buildings Label	New residential, New non-residential, Existing residential, Existing non-residential	Voluntary	National
	Compliance with Energy Efficiency Standards Label	New residential, New non-residential, Existing residential, Existing non-residential	Voluntary	National
Incentive	Energy Conservation Facilities	-		National
	Green investment tax cut	-		National
	Support for Energy Oriented Houses	-		National
	Voluntary Energy Efficiency Standard with Incentive	New residential, New non-residential, Existing residential, Existing non-residential	Voluntary	National
	Promotion of Zero Energy Building (ZEB) and Zero Energy Houses (ZEH)	New residential, New non-residential, Existing residential, Existing non-residential	Voluntary	National

Table 3.3 Main building efficiency policies in Japan

Japanese government considers Zero Energy Buildings (ZEB) and Zero Energy House (ZEH) are recognized as the key energy savings technologies. Government's national strategic documents such as 2011 Energy conservation technology strategy and the latest 2014 Basic Energy Plan, importance of ZEB and ZEH are identified as the key driving technologies for energy savings in the residential and commercial sectors. In 2016, Ministry of Economy, Trade and Industry (METI) has started "Registration System of ZEH Builder" in order to promote and improve the awareness of ZEH. A homebuilder registers this system can receive a grant for the construction of ZEH.

Meanwhile, the registered homebuilders are required to comply with some obligations listed as below:

- To set the annual target of the number of ZEH through on condition that more than half of the total newly constructed houses would have to satisfy the ZEH definition by 2020.

- To publish an annual target on the ZEH builders' home page

- To implement measures to achieve the target.

- To report an annual achievement such as implementation of measures, the number of total newly built house, the number of ZEHs and the percentage of ZEH to total number of newly built house.

METI's Agency of Natural Resources of Energy has been allocating large amount of budget for the promotional projects (in the form of subsidies) toward the introduction of energy savings technologies that can meet the ZEB/ZEH criteria.

Japanese government also implements voluntary Energy Efficiency Standard with Incentive, which is regulated by the Act on the Improvement of Energy Consumption Performance of Buildings (Building Energy Efficiency Act) in 2015. It is specified in 10%-20% higher than the Energy Efficiency Standard. When buildings comply with Voluntary Energy Efficiency Standard and introducing energy efficiency technologies such as fuel cell power generation and solar hot water supply system, cogeneration and renewable energy, home builders/ construction companies/ owners can be allowed larger floor area ratio (upper limited 10%).

The energy consumption per Japanese household has gradually declined, as shown by Figure 3.1. This decrease in energy use per household reflects the impact of the BES policies implemented by the Japanese government. Although the energy consumption per household declined in the wake of the nuclear disaster in Fukushima, it is not clear whether this downturn trend will be temporary or persistent. An additional policy intervention is necessary to further constrain energy use in the residential sector because of a rising concern about the security of the electricity supply in Japan.

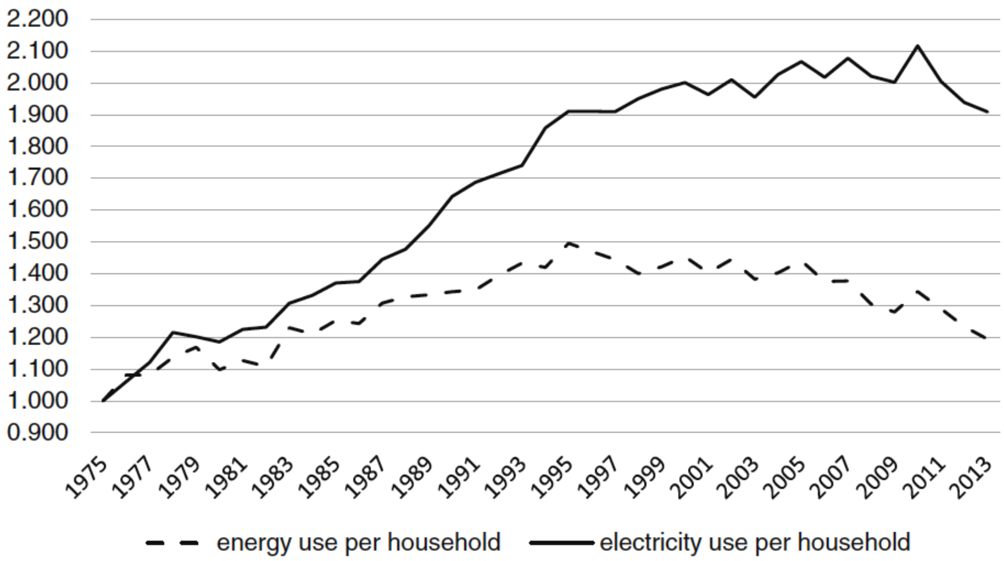

Figure 3.2 Energy use per household in Japan, 1975-2013 (1975=1). Source EDMC (2015)

3.2 Policy effects

From above review discovers that Japan released their policies much earlier than China, and has more regulations and financial and fiscal measures. In China, financial and fiscal measures are only in practice in those pilot regions. This shows the typical developed and developing situations in Asia.

Comparison object	Japan	China
Implementation effect Responsible department	80% buildings met the standards	Less than 60% of buildings met the standards
	Ministry of Land, Infrastructure and Transport	Ministry of Housing and Urban-Rural Development
	Ministry of Economy, Trade and Industry	Chinese Academy of Building Research
	Bureau of Environment in Tokyo	Ministry of Environmental Protection
	Tokyo Metropolitan Government	Local Construction Commissions

Table 3.4 Implementation effect and responsible departments on BES policies in Tokyo and Shanghai, two example cities of Japan and China

In Japan, the relevant regulations and energy saving standards have been carefully designed and well implemented (Laustsen, 2008). The effective enforcement on these regulations led to improved energy efficiency in appliances and other equipment installed in buildings (International Energy Agency, 2008)

Considering the Cap and Trade Program, because Japan offers directions on how to execute energy saving and how to meet the energy efficiency requirements, most of enterprises received profits from emission trade. This approach has ensured the effectiveness of the released and implemented of energy efficiency policies.

The energy efficiency policies in China also have positive effects in promoting energy efficiency. The recently released regulations, such as the energy consumption standard, will undoubtedly encourage the energy consumption monitoring and energy saving actions.

Although in both countries, the energy efficiency policies have contributed to the building energy saving, significantly improved energy efficiency can only be observed if buildings are actually constructed in accordance with these requirements. As only 60% of building were designed and constructed according to energy efficiency standards in China, the enforcement of energy efficiency policies is not as effective as in Japan. Therefore, there is still much more room for improving of these regulations in China. The stakeholders also indicated that the complicated administrative organization is one of the reasons for its effective enforcement.

In Japan, the enforcement responsibility of the Building Energy Codes is at national level. Building officials from the Ministry of Land, Infrastructure and Transport and from municipal governments have a focus on the inspection of the buildings in the phases of design and construction. Funding renewable energy, energy efficiency, rational use of fossil fuel and technologies related with climate change is been taken care of the Ministry of Economy, Trade and industry.

Instead, in China, the Ministry of Housing and Urban and Rural Development administer mainly construction laws, while building codes and mandatory standards are drafted and maintained by both Ministry of Housing and Urban and Rural Development and Ministry of Environmental Protection. The Chinese Academy of Building Research (affiliated to the State-owned Assets Supervision and Administration Commission of the State Council) is the main institute to provide related technical expertise and support for the building industry. Regional governments constantly develop regional codes and mandatory standards and also in charge of policy enforcement. From above, it is clear that the current administrative framework on energy efficiency policies is too complicated to be effectively operated. Consequently, Japan has more effective regulation system with clearer responsibilities.

From the policy has already implemented, shows that successful energy efficiency programs should be based on the development of appropriate strategies. Even both Japan and China have released abundant of building efficiency polices. They are still facing several policy obstacles to further promote energy saving in the building sector. In order to remove these obstacles, the international collaboration would be a very useful method so that each country can learn from another.

3.3 Policies obstacles

Even current energy efficiency building codes can improve energy efficiency in building sector, still existed obstacles. When buildings are designed and constructed, energy efficiency is not the only concerned. Some other aspects are considered more urgent. Such as structural or fire safety, room size, etc. Some of the constructors even only focus on investment and construction costs without consideration of buildings' future running costs. Normally, it happened with these parties only interest in the construction budget not the total budget. Making high-energy efficiency is kind of ultra costs for them.

Few actors involved in buildings' construction have the training required to analyze a buildings' lifecycle costs and guide construction practices to improve future efficiency. This kind of situation normal happens with residential building. After construction, buildings are sold to families, who will pay the energy bills in the future. Moreover, most building buyers only buy a few times during their lives. Unpracticed buyers may not be cared about the implications of low energy efficiency and are more concerned about immediate interests. Since investments in energy efficiency in buildings are often only profitable over a long term.

Many contractors and designers reach the mere existence of building codes because these are enforcement policies. However, the efficiency standards in building codes rarely represent the optimum for building efficiency, but the minimum to entre the market. And lack of incentives for innovation is still a big obstacle either for China or Japan.

Many barriers obstruct energy efficiency in new and existing buildings. Energy efficiency in buildings may be low on the list of requirements for the building. The development of most buildings focuses on construction costs instead of concern for running energy costs. Most contractors or designers will not have the data or capability to calculate a building's lifetime costs and estimate the consequences of early design decisions. Considering the fact that energy is invisible, the energy costs for a household are merely a main factor for buying a house.

Therefore, there is a strong request for policies for energy efficiency requirements to reduce energy consumption in buildings. And also successful energy efficiency programs should base on appropriate strategies. Thus, in order to remove these obstacles, more efforts should be initiated by considering the current situations.

3.4 The comparison with Europe

3.4.1 Building codes

European countries have set up mandatory energy-efficiency standards for new residential and service sector buildings. The EPBD (2002/91/EC) was the first major attempt requiring all member states to introduce a general framework for setting building energy code requirements based on a 'whole building' approach (so-called performance based).

With the development of economic and technology, evolution of building codes has become increasingly regular. For instance, over the past 30 years, standards have been reinforced three to five times in most EU-15 countries and independent from the oil price level. Most EU countries have reinforced their standards since 2000, with the implementation of the EPBD. In addition, this directive has, for the first time, provided for mandatory revision every five years.

In this aspect, EU and Japan were released building codes earlier than China, and has carried out evolutions of their building codes. And also EU has higher performance standards.

3.4.2 Energy-efficiency labels

In the EU, a more recent trend is to extend regulations to existing buildings, by imposing minimum standards in the case of renovation and energy-efficiency labels for existing buildings.

Such certificates are mandatory in EU countries each time there is a change of occupant or a sale. Energy-efficiency certificates were introduced in Denmark in 1999 and extended in 2006 to all EU countries with the EBPD. These certificates enable consumers to obtain information about the energy consumption of the residential buildings they are going to buy or rent and are differently implemented within the boundaries set by the EBPD.

In Japan, there are similar standards for existing residential buildings. Meanwhile, an energy-efficiency label is only for new residential buildings in China.

3.4.3 Financial measures

Financial incentives offer subsidies and loans at low interest even at zero interest, or more often, a combination of both systems. Most programs require implementation of certain technical actions to get the support, such as, in Germany, the program of the public bank, KfW, supports the energy-efficient refurbishment of existing buildings by offering household low-interest loans with a range of subsidies related to the energy performance of the refurbishment.

In Japan, has the same kind of program, such as the Flat-35 Mortgage Program. It is a state-run mortgage scheme encouraging energy efficiency in buildings with long-term loans. The basic offer is a 35-year, fixed-rate mortgage with a relatively low interest rate, available to buildings achieving an overall thermal efficient standard. It is a new approach, which offers loans on a period long enough to have a monthly reimbursement similar to the savings in the energy bill.

On the other sides, China has not published such kind of policies at a national level, only few pilot cities are practicing trial implementation.

3.4.4 Labels for appliances

Labels are more oriented to customers, and represent key elements of the diffusion of energy-efficient equipment, while MEPS are more oriented to manufacturers. Labels for air conditioners (AC) in the residential sector are mandatory in European, Japan and China. A relevant aspect of labeling programs is how to promote adjustments in the certification criteria.

The situation in these three regions is the same for MEPS for AC in the residential sector, which is mandatory. MEPS are often linked to label classification. More and more standards on AC are integrated in building codes and building certificates. MEPS and energy labeling for new buildings (and extensions to existing buildings) have a direct impact on AC loads.

Energy-savings in AC systems can be implemented before the AC system is installed and during the installation by energy-efficient architecture and proper selection of equipment and controls like MEPS or technology procurements.

It can also be achieved after the systems have been installed, during operation and maintenance. Measures such as information campaigns can target behavioral change and help achieve energy efficiency. Demand response approach can also limit the use of air conditioners at peak time. Other measures consist of indoor temperature limitation, as in Tunisia, with a regulation in public buildings, or in Japan where further electricity restrictions are limited (including AC use in public buildings).

Regulations on electrical appliances are dominant in most countries including all the counties we are discussed in this thesis. Indeed, to slow down or even reverse the trend in the electricity consumption of households, many countries have introduced labeling programs and MEPS for a selection of electrical appliances. At the meantime financial or fiscal incentives (i.e. subsidies or tax reduction) for efficient appliances are less common.

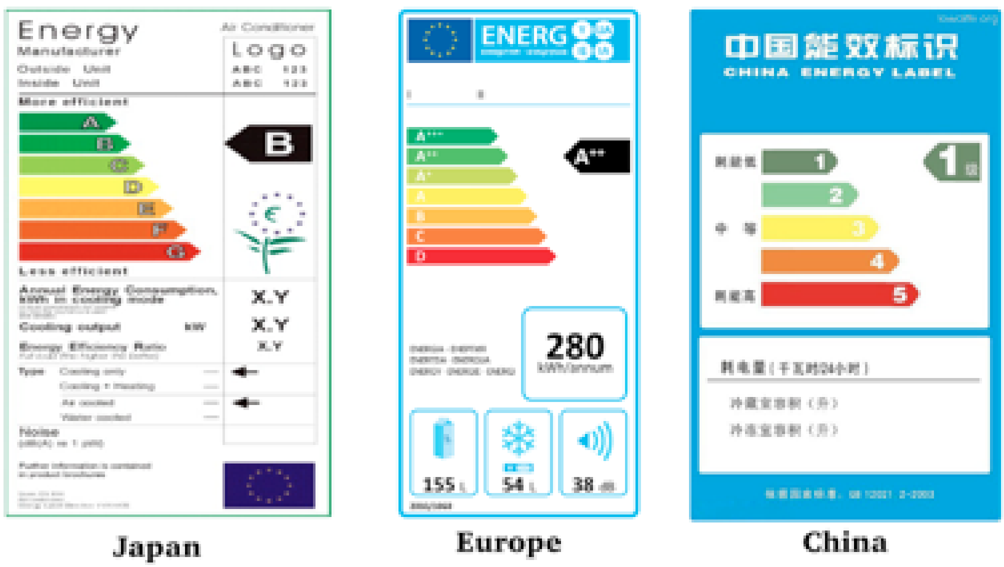

Figure 3.3 Examples of energy labels

3.4.5 Solar water heaters

The installation of solar water heaters has increased four-fold since 2000 at word level. And most countries have financial policies to promote solar water heaters, including most of EU countries, China and Japan. Though, the incentives maybe different, they influence the development of the solar water heater market significantly. And the energy saving targets has been set by counties.

Country	Type of measures	Target	Expected CO_2 emission reduction $(ktCO2)^2$
Austria	Rebates Subsidies	169 ktoe by 2020	1,000
Cyprus	Subsidies	90 ktoe by 2020	1,000
France	Tax credit Investment grants	927 ktoe by 2020 4 million homes equipped with SWH by 2020	3,100
Germany	Preferential loans Subsidies	1,245 ktoe by 2020	4,400
Greece	Tax reductions Minimum solar contribution to the hot water supply	355 ktoe by 2020 60% of hot water needs from solar	1,100
Italy	Tax credit Subsidies	1,586 ktoe by 2020	5,000
Portugal	Subsidies Tax reductions Preferential Loans Mandatory SWH system on new buildings	160 ktoe by 2020 + 100,000 m^2/year until 2020 1 m2/occupant in new buildings	510
Spain	Minimum solar contribution to the hot water supply	644 ktoe by 2020 10 million m^2 by 2020	2,300
Source	ENERDATA, from National Renewable Energy Action Plans, International Energy Agency and REN21		

Figure 3.4 Promotional policies for solar water heating in selected countries in EU

CHAPTER 4

ANALYZING THE CLIMATIC CONDITIONS

Building and climate are closely related. Climate may have a dramatic impact on architectural planning, design, and construction. Building design, construction specification and implementation of regional energy efficiency standards are all dependent upon the basis of the building climate demarcation (BCD). The BCD is to distinguish the role of climatic regionalization, specify the basic requirements for architectural construction in various regions, make rational use of climate resources and prevent the adverse effects of climate on architecture.

Climate is one of the most important factors during architectural design. The climatic conditions can affect the design operation of buildings envelope in order to achieve comfort and saving energy. Energy consumption of a building is strongly related to the local climatic conditions.

The climatic conditions include not only temperature but also other factors, which are important influencing for human thermal comfort, such as solar radiation, humidity, pressure and winds. The regionalization's method is under multiple factors.

4.1 Climatic regions in China

China is a vast country with a range of climates differing from tropical to cold temperate. And the great seasonal wind called the Asiatic monsoon influences the climate of China significantly. From October until April winds tend to blow out from China and the heart of Asia under the influence of the great high-pressure system, which develops in Siberia and central Asia. From May until September or October, as the continent of Asia heats up, this area becomes one of low pressure and winds are drawn into China, both from the Indian Ocean and the Pacific. These warm moist winds bring most of the annual rainfall to China.

Another important factor for the Chinese climate is latitude. When most of the country has warm or hot summers there are also some area having a low temperature. Those places are distributed all over the country.

Because of the large of China, analyzing China's weather condition has a lot of different aspects. And the worldwide classification is Köppen classification. As for the standards, there are two standards in China related to climatic regionalization: one is <Standard of climatic regionalization for architecture> (GB50178-93), another one is < Thermal design code for civil building> (GB50176-93).

4.1.1 Köppen climate classification

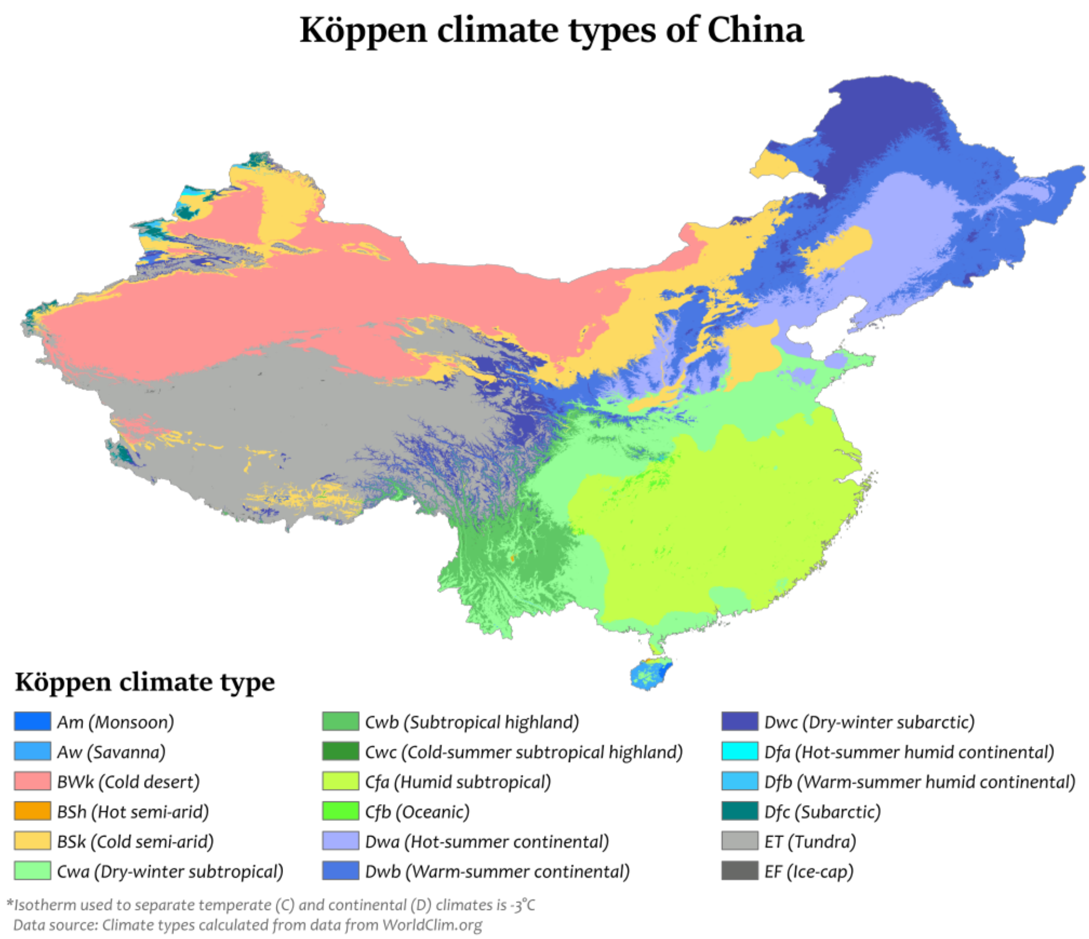

Figure 4.1 Map of China Köppen classifications

The figure 4.1 shows the 1990 base year Köppen classes over China, and encompasses 13 subtypes from all 5 basic types. It lists the Köppen classes observed or projected in China from Peel et al. (2007).

Köppen–Geiger climate classes were determined using the criteria defined in Peel et al. (2007). The classification process first identifies five major climate types: A–tropical; B–dry (arid and semiarid); C–subtropical; D–continental; and E–polar. Type B is based on moisture availability, while the other types are based on annual temperature. Each major type has two or three subtypes, and each subtype in types B–D has two to four minor subtypes, all classified according to the seasonal cycle of temperature, precipitation, or both.

In the far south of China, there is a small area of tropical climate (Am). Deserts (Bw) and steppe (Bs) are main types over northwestern China. Temperate climate (C), which mainly includes three subtypes: humid (Cfa), subtropical winter dry (Cwa), and oceanic climate (Cwb), is dominated over Southwest and southeastern China. While continental humid climate (Dwa and Dwb) is found in North and Northeast China, the northernmost region is characterized by sub-polar climate (Dwc). At last, the central and southwestern Tibetan Plateau are characterized by alpine climate (ET), while continental climate (mainly Dwb and Dwc) is dominated over the eastern and southern Tibetan Plateau and arid climate (mainly BWk and BSk) is detectable over the western and northern Tibetan Plateau. In 1990, the coverage of the major climate types A–E is about 0.5%, 29.7%, 27.9%, 32.1% and 9.8% of the total mainland area.

4.1.2 <Standard of climatic regionalization for architecture> (GB50178-93)

The BCD work in China began in the early 1980s. The first BCD Standard was published in 1993. According to the Standard of climatic regionalization for architecture (GB50178-93), the country is divided into seven divisions or zones. Different climate zones have different architectural design and construction requirements.

The Standard (GB50178–93) was mainly based on the average temperature in January and July, as well as the average relative humidity in July. So the BCD depends on local climate, especially on local temperature. The Standard (GB50178-93) in China has been used for 18 years, and the demarcation results are based on the weather data of 1951–1985.

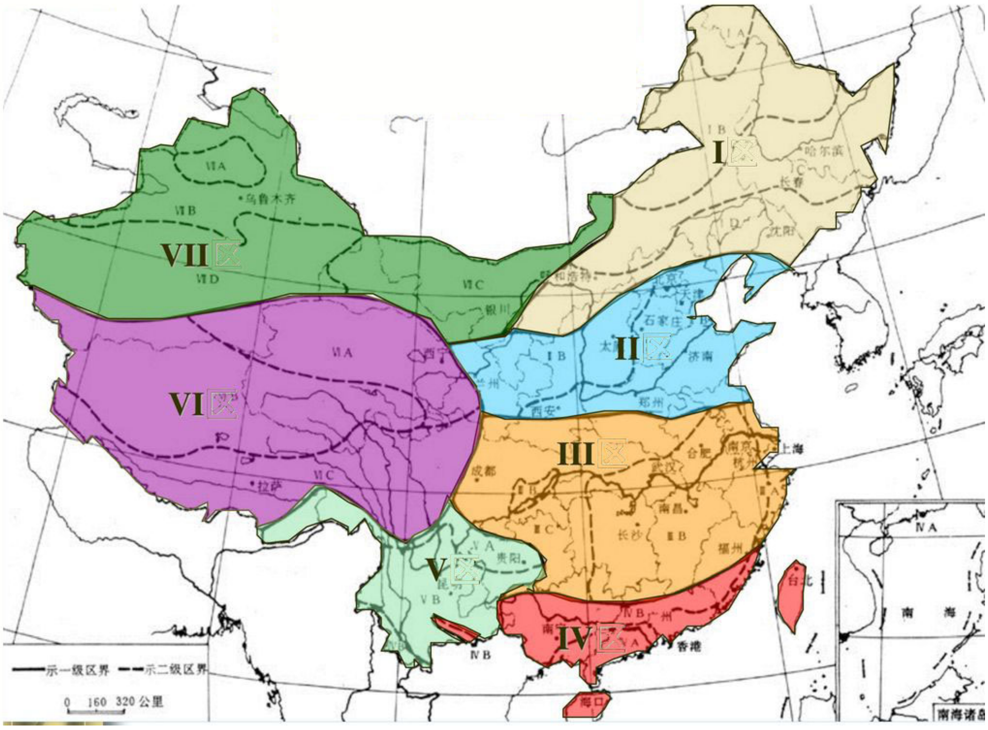

Figure 4.2 Map of Standard of climatic regionalization for architecture

The main indictors for regionalization is average temperature of January, the average temperature and humidity of July, and also considering annual precipitation, the annual days of daily average temperature below or equal to 5°C and over or equal to 25°C.

- I architecture climatic regionalization:

This area has long and cold winter, and very short and comfort summer. Annual temperature range is large. Freeze-up period is long with deep permafrost and a lot of snow cover. Solar radiation is intense, with plenty of sunshine.

Average temperature in Jan. is from -31°C to -10°C, and average temperature in July is below 25°C. Annual temperature range is from 30°C to 50°C, while annual average temperature of daily range is around 10°C to 16°C. And the number of days with daily average temperature equal or less than 5°C is over 145d.

Average annual relative humidity is from 50% to 70%. Annual precipitation is from 200mm to 800mm.

Annual total solar radiation is from 140 to 200 w/m^2, and annual sunshine hours is

2100—3100h.

- II architecture climatic regionalization:

This area has long, dry and cold winter. And the summer is different in plain and plateau area. In plain area, summer is hot and humid, however, in plateau area is cool. Precipitation is concentrated in summer. And spring and autumn is short, with large changes of temperature. Usually, there is only a little snow and rain but more windy days in spring. And in summer and autumn, there are a lot of hail and lightning.

Average temperature in Jan. is from -10°C to 0°C, while average temperature in July is 18°C-28°C. Annual range is from 26°C to 34°C while annual average temperature of daily range is around 7°C to 14°C. The number of days with daily average temperature equal or less than 5°C is 145 – 90d. The number of days with daily average temperature higher or equal to 25°C is less than 80d, while the number of days with the maximum temperature higher or equal to 35°C is from 10 to 20d.

Average annual relative humidity is from 50% to 70%. Annual precipitation is from 300mm to 1000mm. Annual rainy days are between 60 to 100d, with the daily maximum precipitation around 200 – 300mm, with some exception, over 500mm.

Annual total solar radiation is from 150 to 190 w/m^2, and annual sunshine hours is 2000—2800h.

- III architecture climatic regionalization:

Most part of this area is hot and stuffy in summer, while wet and cold in winter. The daily temperature range is small, but the precipitation is large. During the late spring and early summer is East Asian rainy season, commonly called the plum rain, which is caused by precipitation along a persistent stationary front. The east Asia rainy season usually happens in middle and lower reaches of Chang Jiang region, with cloudy and rainy days, more often with rainstorm. However in summer and autumn, coastal, middle and lower reaches of Chang Jiang areas are often attacked by tropical storm or typhoon, which brings rainstorm and windy rains.

Average temperature in Jan. is from 0°C to 10°C, and average temperature in July is

25°C-30°C. The number of days with daily average temperature equal or less than 5°C is 90d – 0d, while the number of days with daily average temperature higher or equal to 25°C is 40 -110d.

Average annual relative humidity is from 70% to 80%. Annual precipitation is from 1000mm to 1800mm. The annual rainy days are around 150d, with some exception, over 200d

Annual total solar radiation is from 110 to 160 w/m^2. The lowest value can be found in the east of Sichuan Basin, which is below 110 w/m^2. The annual sunshine hours in this area is 1000-2400h, and in the south of Sichuan and the north of Guizhou have only 1000 – 1200h annual sunshine hours.

- IV architecture climatic regionalization:

This area has long summer without winter, which has high temperature and humidity inter year. Annual and daily temperature range are both small. The precipitation is huge, with a lot of tropical storm and typhoon. The solar zenith angle is large, while the solar radiation is intense.

Average temperature in Jan. is higher than 10°C, while average temperature in July is 25°C-29°C. Annual temperature range is 7-19°C, while annual average temperature of daily range is around 5-12°C. The number of days with daily average temperature higher or equal to 25°C is 100-200d.

Average annual relative humidity is around 80%. Annual precipitation is from 1500mm to 2000mm. The annual rainy days are around 120-200d, while the annual days of rainstorm are 5–20d, mainly from April to October.

Annual total solar radiation is from 130 to 170 w/m2, while the annual sunshine hours of this area is 1500-2600h.

- V architecture climatic regionalization:

This area has cool summer and warm winter with the obviously wet and dry season. Thunderstorm and fog are normal weather throughout the year. Annual temperature range is small, while the daily temperature range is large. The solar radiation is intense with little sunshine. In some part of this area, the temperature is lower than the major part.

Average temperature in Jan. is from 0 to 10°C, and average temperature in July is 18°C-25°C. Annual temperature range is 12-20°C. the number of days with daily average temperature lower or equal to 5°C is 90-0d. Because of the influence of wet and dry season, in some area, the hottest month maybe find in May or June.

Average annual relative humidity is 60% to 80%. Annual precipitation is from 600mm to 2000mm. the annual rainy days are around 100-200d. This area has wet season (rainy season) and dry season (windy season). The wet season is from May to October, with the rain concentrated and high relative humidity, while the dry season is from November to April, with low relative humidity and high wind speed.

Annual total solar radiation is from 140 to 200 w/m^2, while the annual sunshine hours of this area is 1200-2600h.

- VI architecture climatic regionalization:

This area has long winter without summer. The weather is cold and dry. In south part, the temperature is a little higher and precipitation is a little more. Annual temperature range is small, while the daily temperature range is large. The atmosphere is low and the air is thin, which causes high transparency. The solar radiation is intense with a lot of sunshine. In winter there is a lot of west-south wind, and there is a lot of cover snow with deep permafrost. The climate changes obviously at the different altitudes.

Average temperature in Jan. is from 0 to -22°C, and the average temperature in July is 2°C-18°C. Annual temperature range is 16-30°C, while annual average temperature of daily range is around 12°C to 16°C, and in winter can be reached to 16 – 18°C. The number of days with daily average temperature lower or equal to 5°C is 90 -285d.

Average annual relative humidity is from 30% to 70%. Annual precipitation is from 25mm to 900mm. the annual rainy days are around 20-180d. This area has wet season (rainy season) and dry season (windy season). The wet season is from May to October or April to September, with the rain concentrated.

Annual total solar radiation is from 180 to 260 w/m^2, while the annual sunshine hours of this area is 1600-3600h.

- VII architecture climatic regionalization:

This area has cold and long winter, and most of the area has hot summer. The annual and daily temperature range is large. Since most of the area has little precipitation, the weather is dry with a lot of wind and sand. Some part of the area has deep permafrost, and the snow covers in mountain. However, the sunshine is rich and solar radiation is intense.

Average temperature in Jan. is from -5 to -20°C, and average temperature in July is 18°C-33°C. Annual temperature range is 30-40°C, while annual average temperature of daily range is around 10°C to 18°C. The number of days with daily average temperature lower or equal to 5°C is 110 -180d, while the number of days with daily average temperature higher or equal to 25°C is less than 120d

Average annual relative humidity is 35% to 70%. Annual precipitation is from 10mm to 600mm, while the annual rainy days are around 10-120d. This area is the least precipitation area in China.

Annual total solar radiation is from 170 to 230 w/m^2, while the annual sunshine hours of this area is 2600-3400h.

Zone	Thermal region	Weather indicators		
		Average temperature in Jan.	Average temperature in July	Auxiliary indicator
I	Serve Cold Zone	≤-10°C	≤25°C	Relate humidity ≥ 50%
II	Cold Zone	-10 – 0°C	18 -25°C	
III	Hot Summer Cold Winter Zone	0 - 10°C	25 - 30°C	
IV	Hot Summer Warm Winter Zone	> 10°C	25 - 29°C	
V	Temperate Zone	0 - 13°C	18 - 25°C	
VI	Serve Cold and Cold Zone	0 - -22°C	< 18°C	

VII	Serve Cold and Cold Zone	-5 - -20°C	≥18°C	Relate humidity < 50%

Table 4.1 Table of Standard of climatic regionalization for architecture

4.1.3 < Thermal design code for civil building> (GB50176-93)

Thermal design code for civil building mainly uses to guarantee the internal thermal environment. The code (GB50176-93) was based on the average temperature in the coldest mouth and the hottest mouth, which is primary indicator. Annual days of daily average temperature below or equal to 5°C and over or equal to 25°C are taken as auxiliary indicator.

Figure 4.3 Map of Thermal design code for civil building

Figure 4.3 shows the divisions according to <Thermal design code for civil building>. Comparing with Figure 4.2, the III, IV and V almost the same with HSCW, HSWW and temperate zones. And the I, II, VI and VII have turned to Serve Cold and Cold Zone, which are serve by centralized heating in winter.

Zone	Primary Indicators		Secondary Indicators
	Average temperature in the coldest mouth	Average temperature in the hottest mouth	
Serve Cold Zone	≤-10°C	-	The number of the days with average daily temperature ≤5°C is ≥ 145d.
Cold Zone	-10 - 0°C	-	The number of the days with average daily temperature ≤5°C is 90 - 145d.
Hot Summer Cold Winter Zone	0 - 10°C	25 - 30°C	The number of the days with average daily temperature ≤5°C is 0 - 90d, while the number of the days with average daily temperature ≥25°C is 40 - 110d.
Hot Summer Warm Winter Zone	> 10°C	25 - 29°C	The number of the days with average daily temperature ≥25°C is 100 - 200d.
Temperate Zone	0 - 13°C	18 - 25°C	The number of the days with average daily temperature ≤5°C is 0 - 90d.

Table 4.2 Table of Thermal design code for civil building

Table 4.2 shows the method to regionalization climatic zones and main features of climatic zones.

4.2 Climatic zones in Japan

Japan is a large archipelago, aligned from southwest to northeast, between 30°N and 45°N off the eastern seaboard of Asia. Consisting of more than 3,000 islands and islets, is very extended in latitude: Hokkaido, the northernmost of the main islands, touches the 45th parallel north, the same latitude as Montréal, Canada. Tokyo, the capital, is located on the 36th parallel. While the southern part of the island of Kyushu touches the 31th parallel, and the small southern islands (Ogasawara and Ryukyu) reach tropical latitudes (the Yaeyama Islands, the southernmost of the Ryukyus, are located just north of the Tropic of Cancer).

All the islands are hilly or mountainous. Japanese archipelago shows great climatic variation within its approximately 3,000 kilometers of length from northeast to southwest. It consists of more than 6,800 islands - the four largest islands are Hokkaidō, Honshū, Shikoku, and Kyūshū. And the country has around 30,000 kilometers of coastline, which is longer than the United States. 75% of the country is mountainous, and Japanese Alps and other ranges occupy most area of the main island of Honshū.

The climate of Japan is cold in the north, where snow and ice dominate in winter, temperate in central regions, and almost tropical in the small southern islands. The rains are abundant almost everywhere. Between summer and autumn, torrential rains and typhoons hit the country. The monsoon circulation influences the climate of Japan: in winter it's affected by cold currents from northwest, and in summer by wet humid currents from tropic.

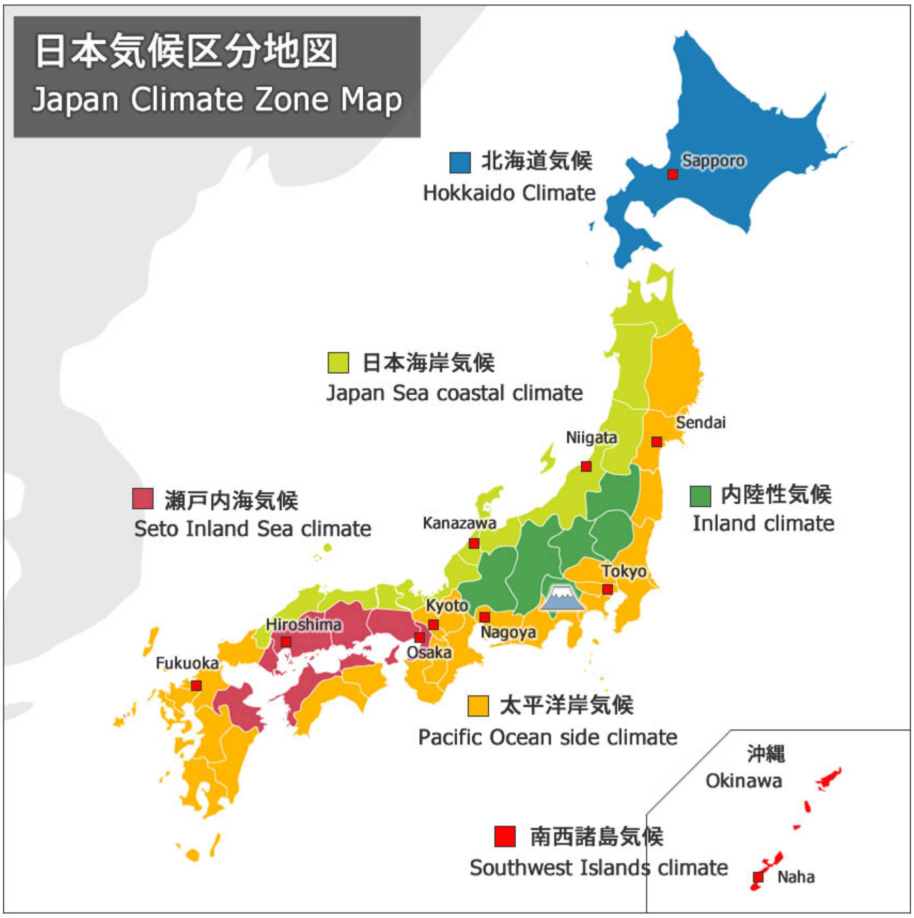

Figure 4.4 Map of Japan climate zone

In the Köppen climate classification, the Japanese archipelago belongs to the temperate humid climate or cold humid climate. Generally, the climate zones in Japan are classified into six categories: Hokkaido climate, Pacific ocean side climate, Japan Sea coastal climate, Inland climate, Seto Inland Sea climate, Southwest islands climate.

- Hokkaido Climate

In Hokkaido, there is no rainy season, where the rainfall is small and summer is cool. It is characterized by severe coldness in winter. The average temperature in winter is below 0°C.

In Sapporo, from 1981 to 2010 the annual average number of days with maximum temperature less than 0°C is 45.0 days. On the other hand, the average number of days with the minimum temperature below 0°C is 124.8 days. The average number of days with the maximum temperature higher than 30°C is 8.0 days. However, in the inland area of Hokkaido, the temperature is often higher than 30°C in summer, which has the largest range of year in the country.

There is also a lot of snow, and snow falls as much as 1348 cm a year in Horokanai Town, and 597 cm in Sapporo. In the Okhotsk Sea, drift ice is laid on the mainland for about three months in winter. And dry summer monsoon blows in both summer and winter, making the precipitation decreasing. In addition, winds and snows are heavy in winter in the side of Japan Sea, but high temperature and pleasant weather continue in the summer.

- Pacific ocean side climate

The climate of the Pacific side is characterized by heavy rain in the summer and less rain in the winter due to the southeastern seasonal wind. Winter monsoon that brought heavy snow to the Japan Sea side has been transferred to dry-air over the mountains, which brings the fine weather to the Pacific Ocean side in winter.

- Japan Sea coastal climate

The characteristic of Japan Sea coastal climate is that there are many rains and snows in the winter due to the northwesterly seasonal wind. As snow falling on Japan Sea in winter, snow becomes heavy along the mountain because it becomes a snow cloud when the seasonal wind hits the ridge. When the snow cloud arrives at the plains, it will become heavy snow, which makes the area one of the world's heaviest snowfall areas.

- Inland climate

In this area, precipitation is small throughout the year, and it changes a lot form year to year. The annual difference in Nagano is second largest in Japan, except Hokkaido inland area. Precipitation is about 1000 mm of the year in Yamanashi basin. And especially in Nagano along the Chikuma River, the precipitation is even less than 1000mm. It is the second smallest after the eastern side. This rain is little since it’s surrounded by mountains and it is hard to be affected by typhoons, low pressure, fronts, etc., and annual sunshine hours are long. Also, because the yearly difference and diurnal difference are large, it is hard to be affected by the ocean.

And for summer, it gets hot, but with low humidity, it gets cooler in the evening and rarely to have a tropical night. The lowest temperature in winter sometimes is below -15 ° C in central of Nagano basin. The average of the minimum temperatures of the coldest early February is from -14 ° C to -10 ° C at an altitudes above 1000 m in highlands, as low as in Hokkaido. In winter, there are many snowing days in the northern part of Nagano, as the influence of the seasonal wind. However, sunny days are not common in the middle of Nagano. South part sometimes has some snow, due to south coast low pressure. In Yamanash, except for mountainous areas in the western and northern areas, snow is rare because of the cold atmospheric pressure, and there are many snows since low pressure in the south coast.

- Seto Inland Sea climate

As for this area, the rainfall is very little throughout the year. But even in relatively mild zone, in winter, there exists a frost zone in the Rosai peninsula in Kagawa. The rainfall is about from 1000 mm to 1400 mm, far less than either the Pacific Sea or the Japan Sea. However, from March to June, there is a lot of fog in the Seto Inland Sea. Since the seawater temperature rises later than the atmospheric from the winter to the summer, mist is easy to occur because of the difference of temperature. In addition, at summer, the hot is unbearable in coastal areas because there are no winds. This phenomenon is called Yunagi.

- Southwest islands climate

For this area, the temperature keeps 15°C or higher even in winter. For this reason, both regions are considered having subtropical climate. Additionally, with a lot of typhoons, the average number of approaching of typhoons is 7.4 per year in the Okinawa, 5.4 per year in the Ogasawara Islands and 3.8 per year in the Amami.

Chapter 5

Features and performance of portable HVAC PRODUCTS

5.1 Introduction

5.1.1 Overview

In construction, a complete system of heating, ventilation and air conditioning is referred to as HVAC, which aim to provide thermal comfort and acceptable indoor air quality. Nowadays, HVAC system is been installed in most of residential building and very common in everyday life.

Every air conditioner has 4 main components: compressor, condenser, expansion valve and evaporator. Air conditioners that used in residential area are categorized by the placement of these four units in the air conditioner.

- Split system

Figure 5.1 Example of two main types of split air conditioners (internal unit)

Split systems are preferred and widely used in the world. In order to reduce noise, the compressor and condenser have been put in an external metal unit. It is connected remotely with an internal unit containing the evaporator and expansion valve. As they are connected with copper piping, the external unit usually is located near the internal unit on the outer wall.

Figure 5.2 External and internal unit

- Central system

In a central system, compressor and condenser are like split system, which are located outside. However, the external unit is far away from the room to be cooled or heated. The external and multiple internal units are connected though multiple ducts. As the variety types of internal units, they can be placed on ceilings, walls and floors for cooling or heating any size of the room.

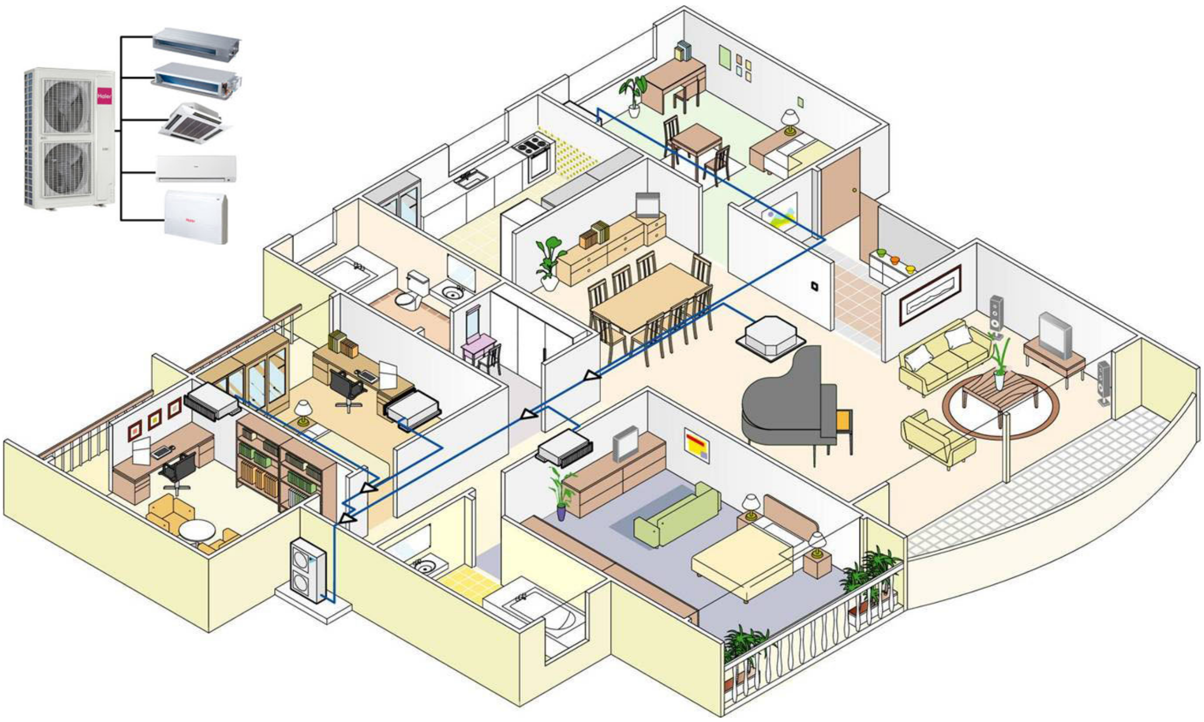

Figure 5.3 Types and ducts of central air conditioner

- Portable system

  This system is a unitary HVAC system. Portable air conditioners (PAC) are packed in one unit and don't have any external unit, which are a little noisier than other types of systems. And the other downside of PAC is that needs a flexible hose for exchange air.

Figure 5.4 Example of portable air conditioner

5.1.2 Portable HVAC system

In recent years, portable air conditioner has been widely used because of their solace, adaptability, and high-energy performance. Some household discover portable air conditioners (PAC) the ideal appliance either to cool a room up with roughly about 10 – 15 m^2 and able to move it from one room to another.

How ever though years of developing, the portable air conditioners has more classifications according to their single or multiple functions, which are air purification, ventilation, cooling, heating, dehumidifying.

With some disadvantages has been motioned above, the PAC still gets some its own advantages.

No setup required: Portable HVAC unit is easy to install and do not require a specialist.

Portable and convenient: PACs use rollers or light enough to transport.

Energy effective: Portable air conditioning system can be effective and economic compared other air conditioning system. Using PACs can focus on locations needed. And they are more efficiency to cool or hear locale place than the whole space.

Duct circulation: The design of duct circulation is different from other systems. Meanwhile the portable air conditioners reduce indoor air temperature, gets the fresh air from outdoor to ensure the exchange of air with the room.

5.2 The PAC products in Chinese market

There are only a few PAC products in Chinese market comparison with split air conditioners and central air conditioners. However, the portable air purifier and dehumidifier are showing it own potential in this area.

The development of domestic air-conditioning industry takes the imitation of Japanese air-conditioning technology as its development route. The low industry entry threshold of domestic air conditioner market and the temptation of early profiteering make the domestic air conditioner consumer market in China develop along with the growth of domestic air conditioner industry.

In the recent years, with the operation and promotion of the portable air conditioning industry in China, the cost of production dropped drastically and was able to officially start to reach every household. Though the existing main products of each brands, analyses the feature and performance of portable HVAC devises.

5.2.1 Midea

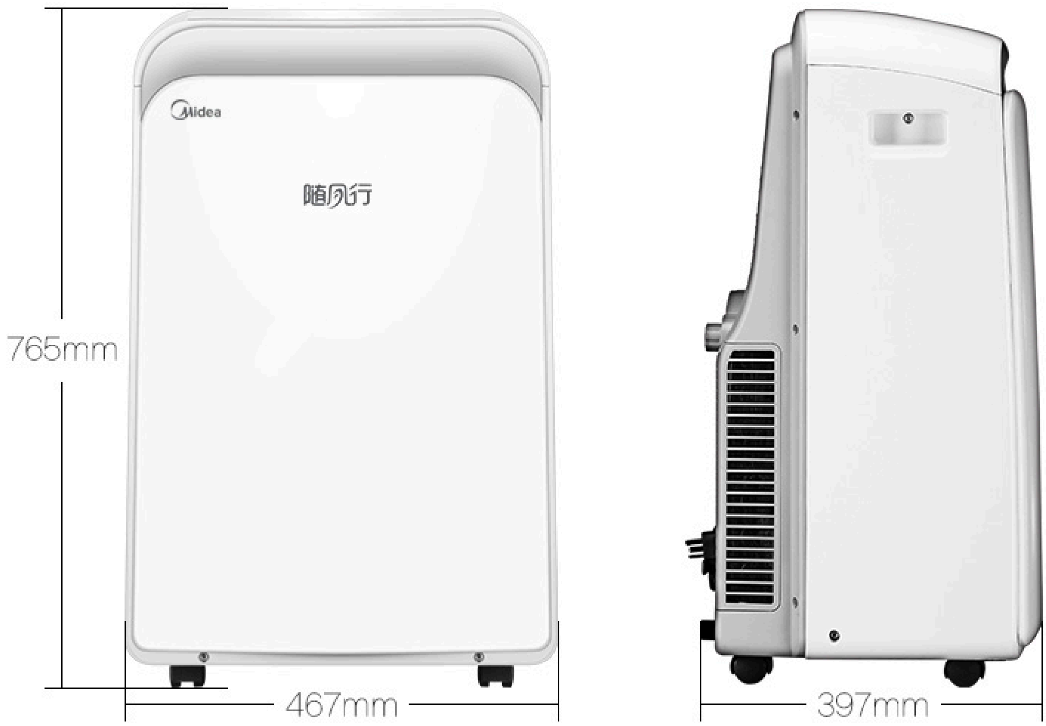

Figure 5.5 Midea KYR-35/N1Y-PD

Midea Group is a Chinese electrical appliance manufacturer. Midea produces wide ranges of lighting, water appliances, floor care, small kitchen appliances, laundry, large cooking appliances, and refrigeration appliances. Further more, it is one of the leader companies in air conditioning product.

KYR-35/N1Y-PD, is the main PAC product of Midea. The product provides not only traditional function of air conditioner, which includes rapid cooling, heating and dehumidifying, but also energy saving mode and 24h timer in this product. The energy saving mode aims to adjust temperature to 25 – 28 °C when the temperature is too low, because of the inside temperature sensor. The product is able to store 500ML of water and present of casters and handle groove, which is convenient to move around. The product made some update comparison with previous product, it added sealing plates for window to make less air infiltrated inside.

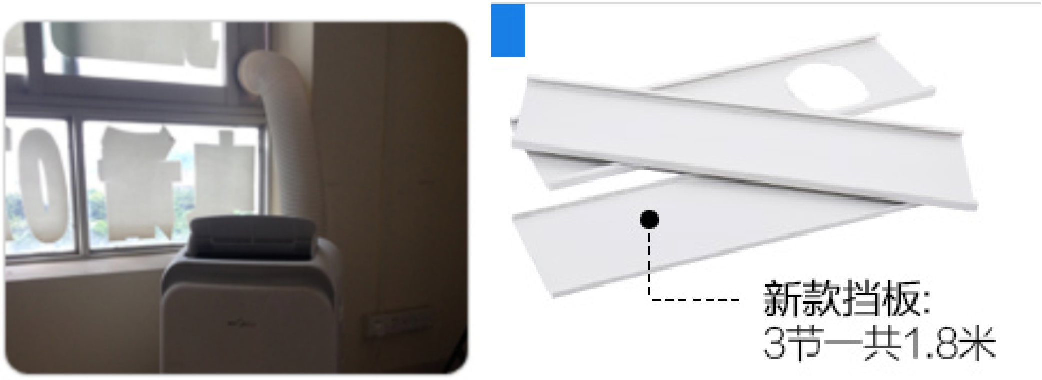

Figure 5.6 Sealing plates for window

Type	KYR-35/N1Y-PD
Dimensions (w*d*h mm)	467*397*765
Weight (kg)	30
Price (CNY)	2780
Rated Voltage (V)	220
Rated Power (W)	1390
Cooling function	Yes
Heating function	Yes
Dehumidifying function	Yes
Air filtration function	Yes
Technology	Constant frequency
Energy Efficiency Index	3
Cooling for rooms up to (m^3)	23
Heating for rooms up to (m^3)	17
Rate Power for Cooling (W)	1390
Rate Power for heating (W)	1180
Fan speed	3
Circulating Air (m^3/h)	400
Maximum sound power level (dB)	52
Rated refrigerating capacity (w)	3550
Rated heat capacity (w)	3250
EER	2.5
Refrigerant gas	R410A
Hose diameter (mm)	150
Hose length (mm)	1500
Anti dust filter	Yes
Remote control	Yes
Display	Yes
Timer	24h

Table 5.1 Features of Midea KYR-35/N1Y-PD

5.2.2 TCL

TCL Corporation (originally an abbreviation for Telephone Communication Limited) is a Chinese multinational electronics company, which was taken the first place in portable HVAC market in 2015. And the most popular PAC product is TCL KY-35/KY.

Figure 5.7 TCL KY-35/KY

Expect the functions represented above, this product is able to control the temperature during the sleeping, which called “Smart stay”. Additionally, there are two models to control the temperature. During the heating, the PAC will reduce the set-temperature by 1 or 2 °C, on the contrary, during the cooling, the PAC will raise the set-temperature by 1 or 2 °C, to make the environment more comfortable.

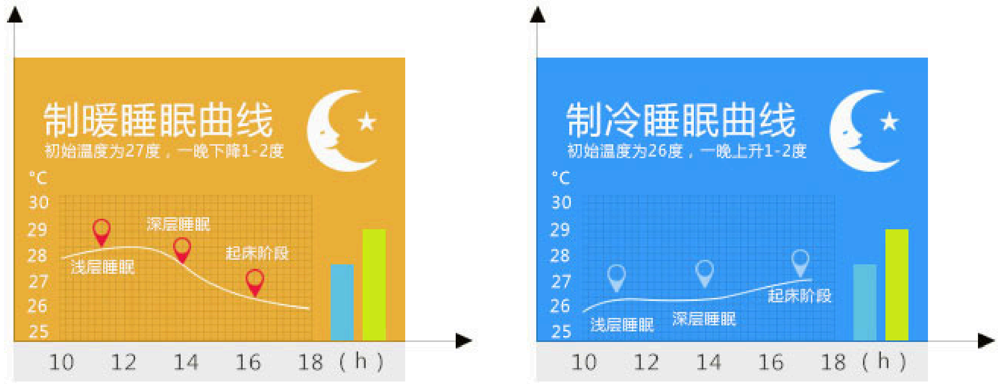

Figure 5.8 Temperature changes for “Smart stay”

Another outstanding feature is intelligent dehumidification, called “intelligent desiccant”, which means to maintain a suitable indoor humidity for creating comfortable indoor environment. Moreover, it is able to nebulize condensate water to realize almost no water drainage needed during the usage. And the filter is able to disassemble and wash directly.

Type	**TCL KY-35/KY**
Dimensions (w*d*h mm)	435*350*715
Weight (kg)	29
Price (CNY)	2699
Rated Voltage (V)	220
Rated Power (W)	1200
Cooling function	Yes
Heating function	Yes
Dehumidifying function	Yes
Air filtration function	No
Technology	Constant frequency
Energy Efficiency Index	3
Cooling for rooms up to (m^3)	22
Heating for rooms up to (m^3)	15
Rate Power for Cooling (W)	1200
Rate Power for heating (W)	1100
Fan speed	3
Circulating Air (m^3/h)	350
Maximum sound power level (dB)	50
Rated refrigerating capacity (w)	3500
Rated heat capacity (w)	-
EER	-

Refrigerant gas	R410A
Hose diameter (mm)	-
Hose length (mm)	1500
Anti dust filter	Yes
Remote control	Yes
Display	Yes
Timer	24h

Table 5.2 Features of TCL KY-35/KY

5.2.3 Gree

Gree Electric Appliances Inc. of Zhuhai is a Chinese major appliance manufacturer, which is the world's largest residential air-conditioner manufacturer. The product KY-36N entered the market since 2011, but it still occupied a large proportion of PACs market share.

Figure 5.9 Gree KY-36N

The product's performance is remarkable in dehumidifying, because circulating air volume is up to 420 m^3 a day. Other reason of maintaining market share of this product is the long period of guarantee, which is six year. In additional, the Gree also provides on-site repair to make sure to satisfy customer.

Type	Gree KY-36N
Dimensions (w*d*h mm)	500*460*810
Weight (kg)	45
Price (CNY)	2549
Rated Voltage (V)	220
Rated Power (W)	1200
Cooling function	Yes
Heating function	No
Dehumidifying function	Yes
Air filtration function	Yes
Technology	Constant frequency
Energy Efficiency Index	-
Cooling for rooms up to (m^3)	25
Heating for rooms up to (m^3)	-
Rate Power for Cooling (W)	1380
Rate Power for heating (W)	-
Fan speed	3
Circulating Air (m^3/h)	420
Maximum sound power level (dB)	54
Rated refrigerating capacity (w)	3600
Rated heat capacity (w)	-
EER	2,61
Refrigerant gas	R410A
Hose dimension (l*w mm)	190*55
Hose length (mm)	1500
Anti dust filter	Yes
Remote control	Yes
Display	Yes
Timer	24h

Table 5.3 Features of Gree KY-36N

5.3 The HVAC products in Japan's market

The situation in Japan's market is very similar to Chinese market. The PAC products only take few shares in residential area. Alike Chinese market the portable products specifically use for air purification and dehumidifying, have been paid more attention by householders.

5.3.1 Corona

Corona Corporation manufactures and sells “kerosene” heating appliances in Japan. Its products include kerosene fan heaters and portable kerosene heaters, as well as household appliances, such as room air conditioners. The company was founded in 1937. And the product CDM-1017 was the second best seller in 2017 in Japan.

Figure 5.10 Corona CDM-1017

Except to cool and dehumidify the space, it also can dry clothes with setting the air filter to the direction of clothes. Moreover, it is capable to auto-shutdown, when the container (5.8L) is full of water. And the capability of dehumidification per day is 10L with 60Hz and 9L with 50Hz.

Type	Corona CDM-1017
Dimensions (w*d*h mm)	386*250*600
Weight (kg)	13
Price (JPY)	29500
Rated Voltage (V)	100
Rated Power (W)	230
Cooling function	Yes
Heating function	No
Dehumidifying function	Yes
Air filtration function	Yes
Technology	-
Cooling for rooms up to (m^3)	32
Rate Power for Cooling (W)	-

Fan speed	3
Air dehumidification (L/day)	10
Maximum sound power level (dB)	38
Rated refrigerating capacity (w)	-
EER	-
Refrigerant gas	-
Hose diameter (mm)	-
Hose length (mm)	950
Anti dust filter	Yes
Remote control	No
Display	No
Timer	6h

Table 5.4 Features of Corona CDM-1017

5.3.2 Toyotomi

Toyotomi Corporation is a leading Japanese manufacturer of kerosene-fired appliances and electrical home appliances. Its PAC product TAD-22HW has use the technology of dual hose. With two hoses, one is used for drawing out heat and the other is used for bringing in cool air. Some consider these to be the best portable air conditioners to spend your money on. With this method there is no negative pressure created in the room therefore making it more efficient at cooling.

Figure 5.11 Toyotomi TAD-22HW

Another highlight is using carbon filter to purify indoor air. And the same with TCL, it is able to nebulize condensate water to realize almost no water drainage needed during the usage. And the filter is able to disassemble and wash directly.

Type	Toyotomi TAD - 22 HW
Dimensions (w*d*h mm)	440*320*690
Weight (kg)	26
Price (JPY)	42099
Rated Voltage (V)	100
Rated Power (W)	730
Cooling function	Yes
Heating function	Yes
Dehumidifying function	Yes
Air filtration function	Yes
Technology	-
Cooling for rooms up to (m^3)	53
Heating for rooms up to (m^3)	-
Rate Power for Cooling (W)	690
Rate Power for heating (W)	730
Fan speed	3
Air dehumidification (L/day)	42

Maximum sound power level (dB)	38
Rated refrigerating capacity (w)	2200
Rated heat capacity (w)	1900
EER	-
Refrigerant gas	R410A
Hose diameter for drawing out (mm)	130
Hose length for drawing out (mm)	1200
Hose diameter for bringing in (mm)	110
Hose length for drawing out (mm)	1200
Anti dust filter	Yes
Remote control	Yes
Display	Yes
Timer	12h

Table 5.5 Features of Toyotomi TAD-22HW

5.3.3 Bianco

Other popular product in Japanese market is Bianco EJ-CA035. This PAC is able to dehumidify the room with the capacity of 24L per day. As there are many rainy days in Japan, the dehumidify function of this product, are able to grantee to dry clothes inside room.

Figure 5.12 Bianco EJ-CA035

The product has been designed easy to use inside house and cooling range is from 15°C to 31°C. Auto mode has been set to automatically change to air filtration mode if the temperature is under 24°C and if the temperature is over 24°C, the PAC will automatically change to cooling mode.

Type	Bianco EJ-CA035
Dimensions (w*d*h mm)	310*310*640
Weight (kg)	21
Price (JPY)	33000
Rated Voltage (V)	100
Rated Power (W)	710
Cooling function	Yes
Heating function	No
Dehumidifying function	Yes
Air filtration function	Yes
Technology	-
Cooling for rooms up to (m^3)	-
Rate Power for Cooling (W)	710
Rate Power for heating (W)	-
Fan speed	-
Rated dehumidification capacity (L/day)	24
Maximum sound power level (dB)	52
Rated refrigerating capacity (w)	-
EER	-
Refrigerant gas	-
Hose diameter	150
Hose length	1600
Anti dust filter	Yes
Remote control	Yes
Display	Yes
Timer	24h

Table 5.6 Features of Bianco EJ-CA035

List of Figure

List of Table

Acroyms and abbreviatious

AC	air conditioner
BCD	building climate demarcation
BERC	Building Energy Research Center
BES	building energy saving
CBEM	China Building Energy Model
CO2	carbon dioxide
CV	constraint value
DHW	domestic hot water
ECL	Energy Conservation Law
EDMC	the Energy Data and Modelling Center, Japan
EPBD	Energy Performance of Buildings Directive
EU	European Union
EUI	energy use intensity
FAPC	floor area per capita
HEMS	homeenergy management system
hh	household
HSCW	hot summer and dold winter
HSWW	hot summer and warm winter
HVAC	heating, ventilation and air-conditioning
LPG	Liquefied petroleum gas
LV	leading value
MEPS	Minimum Energy Performance Standard
METI	Ministry of Econom, Trade and Industry
MLIT	Ministry of Land, Infrastructure and Transport
MOHURD	Ministry of Housing and Urban-Rural Development of the People's Republic of China
NDRC	National Development and Reform Commission
NEA	National Energy Administration
NUH	northern urban heating
nZEB	nearly Zero Energy Building
NZEB	Net Zero Energy Building
P&C	public and commercial
PAC	portabile air conditioner
PCS	Personal Comfort System
RR	rural residential
SC&C	severe cold and cold
SHFC	China Household Finance Survery
UHECS	Urban Household Energy Consumption Survey

UR	urban residential
ZEB	zero energy builidng
ZEH	zero energy house

Main references

BERC (2017), 2017 Annual Report on China Building Energy Efficiency, Beijing: China Building Industry Press

CBEU (2017), China Building Energy Use 2017, Beijing: China Architecture & Building Press

EDMC (2017), Handbook of Japan's & World Energy & Economic Statistics, The Energy Conservation center, Japan

ENEA (2017), Energy Efficiency Annual Report 2017, ENEA, Italy

Eurostat (2017)

Guo, Yan, Peng, et al. (2015), Investigation and analyses of residential heating

in the HSCW climate zone of China: Status quo and key features , Building and Environment, 94, 532-542.

Hu (2013), Research on Residential Building Energy Consumption of China's Urban Area and Comparison with Developed Countries , master thesis, Tsinghua University, China.

Hu, Yan, Guo, et al. (2017). A survey on energy consumption and energy usage behavior of households and residential building in urban China. Energy and Buildings, 148, 366-378.

IEA (2017), World Energy Balances: Overview (2017 edition) , OECD/IEA, Paris.

IEA (2016), Energy Efficiency in China, OECD/IEA, Paris

ISO (2013), ISO 12655:2013, Energy performance of buildings: Presentation of

measured energy use of buildings.

Lin, Jiang, Yan, et al. (2015) Analysis on energy consumption and CO2 emission in

China building construction. Energy of China, 37(3), 5-10.

Liu, Han, Luo, et al. (2003), Investigation and Analysis on China's Residential

Lighting Electric Consumption. Journal of Lighting Engineering, 14(4), 45-47.

Liu. (2008), A best practice in sustainable development: GLP in China. 2008

academic annual conference held by China Association for Science and Technology.

MILT (2017), 2017 White paper and Annual reports, Japan

MILT (2016), FY2016 Annual Report on Energy (Energy White Paper), Japan

MOC (1993), Standard of climate regionalization for architecture (GB50178/93),

Beijing.
MOHURD (2016), Standard for Energy Consumption of Buildings (GB/T51161-2016) , Beijing.
MOHURD et al. (forthcoming), Explanation of the Standard for Energy Consumption of Building.
NRCAN (2017), Energy Use Data Handbook Tables, NRCAN, http://oee.nrcan.gc.ca/corporate/statistics/neud/dpa/showTable.cfm?type=HB&sector=res&juris=00&rn=1&page=0
Shan, Wang, Li, etc. (2015). Energy and environment in Chinese rural buildings: Situations, challenges, and intervention strategies. Building and Environment, 91, 271-282.
State Council (2008), Energy Saving Regulations for Civil Constructions, Beijing.
Statistics Japan (2017), JAPAN STATISTICAL YEARBOOK 2017, http://www.stat.go.jp/data/ nenkan/index1.htm
WB (2017), Statistics database, WB, http://data.worldbank.org/
WEC (2013), World Energy Perspectives, Energy efficiency policies 2013, WEC.
WEC (2016), World Energy Perspectives, Energy efficiency policies 2016, WEC.
Xinhua News Agency (2016), The 13th Five-year Plan for Economic and Social Development of the People's Republic of China (2016–2020) . Beijing
Yan, Hong, Li, et al. (2017). A thorough assessment of China's standard for energy consumption of buildings. Energy and Buildings, 143, 114-128.
Zhang, Yang, Jiang, et al. (2010). Comparative analysis of energy use in China building sector: current status, existing problems and solutions. Frontiers of Energy and Power Engineering in China, 4(1), 2-21.