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SCHOOL OF ARCHITECTURE, URBAN PLANNING, CONSTRUCTION ENGINEERING

MASTER PROGRAM IN
BUILDING AND ARCHITECTURAL ENGINEERING

Zhong Guo Jin Ling Neng Hao Jian Zhu-Nearly zero energy building in China - Part 2

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Abstract

Building energy consumption accounts for a large proportion of total energy and carbon emissions over the world. In order to reduce building energy consumption and achieve sustainable development of buildings, nearly zero energy building (NZEB), as a future building energy target, has received extensive attention.

In January 2019, the Ministry of Housing and Urban-Rural Development, PRC issued GB/T51350-2019 "Technical standards for nearly zero-energy buildings " in China which based on the five climate zones in China: severe cold, cold, hot summer cold winter, hot summer warm winter and temperate.

The 2022 winter Olympic Games will be held in Beijing, we working within a multi-sector team to complete a variety of tasks associated with energy retrofit and high performance building consulting in Mountain press center.

This project combines natural conditions to optimize the building design, and takes the energy consumption level of GB50189-2015 " Design standards for energy efficiency of public buildings" as the baseline. By optimizing the efficiency of lighting and equipment, optimizing the performance of the envelope, high-efficiency air conditioner and heat recovery system. The comprehensive value of building energy consumption of the baseline is 171.23kWh/m²·a, the comprehensive value of building energy consumption of the design case excluding renewable energy is 79.55 kWh/m²·a, the average annual photovoltaic power generation is expected to be 336,290 kWh, and the annual design case of comprehensive energy consumption is 60.36 kWh/m²·a. The building body energy saving rate is 53.54%, the building comprehensive energy saving rate is 64.75%. The building renewable energy efficiency is 24.12%.

This project is a demonstration to promote the application of low-carbon technologies, effectively control greenhouse gas emissions, and make the Beijing winter Olympic Games an important platform for China to show its participation in the construction of global ecological civilization. And we hope that the above research and study can provide references for the further development of NZEB in cold region in China.

Key words: Nearly zero energy building, China, Climatic design, Winter Olympic games, Large office building.

Contents

1 Introduction

1.1 The relevance of the research

1.1.1 Problem identification
The buildings and buildings construction sectors combined are responsible for 36% of global final energy consumption and nearly 40% of total direct and indirect CO_2 emissions (IEA,2017). In China, the building sector consumed approximately 20% of the primary energy and approximately 23% of the electricity consumed in 2015 (China building energy consumption report 2017)

Many developed countries have proposed goals and polices for zero energy buildings (ZEB), also China is going to construct ZEB nowadays. There is no doubt that the development of ZEB will restructure the energy mix in the building sector. (Yang et al.2019)

1.1.2 Preliminary topic
The prospective of low-/zero-carbon building in China.

1.1.3 Preliminary library search and analysis

Figure 0.1.Search on web of science

In order to have a more comprehensive understanding of zero-carbon buildings and to analyze the feasibility of zero-carbon buildings and even negative-carbon buildings in China, we conducted a search on the web of science. The key words are "low-carbon buildings", "zero-carbon buildings" and "negative-carbon buildings". The time span of the papers published set to ten years (2009-2019).

Based on the relevance of the topics, we identified more than 3,000 papers and analyzed them via Bibliometrix.

Figure 0.2.Annual Scientific Productions
(Source from: Bibliometrix)

Because the statistics for 2018 and 2019 are not yet complete, we only summarize the Annual Scientific Productions between 2009 and 2017. According to the figure 1.2, we can see that in the past 8 years, the number of publications of related topics has increased year by year.

Figure 0.3.Most Productive Country
(Source from: Bibliometrix)

Figure 1.3 shows the countries with most publications. Chinese have the most research on zero-carbon buildings. As a developing country, China constructs a large number of new buildings each year and set the goal of reducing 40–45% carbon emission in 10 years(Wu et al.2017). At the same time, there is a lot of research on zero-carbon building in the UK, because the UK government has set ambitious targets to achieve "zero carbon" for new homes from 2016 and for non-domestic new buildings from 2019(Pan et al.2014).

Figure.0.4 Three field plots
(Source from: Bibliometrix)

Three Field plots was the relationship among authors, topics and publications. From this figure, we could know the popular topics for authors are "energy efficiency", "life cycle assessment", "ZCB" and so on. The most published journal is "Energy and building" and "building research and information".

Figure 0.5 Keyword co-occurrence
(source from: Bibliometrix)

Figure 5 shows the frequency of occurrence of keywords and the connections between them. Through this figure, we have an understanding of the general content and topics of these 3,000 articles, Performance, design, life cycle assessment and energy are the most frequently mentioned keywords.

Figure 0.6 Categories of papers

1.1.4 Our primary classification

We imported nearly 3000 papers into Mendeley (a reference management software), after reading the title of all the articles, we found only 1905 papers are meaningful topics for us. And we sorted them into 8 categories according to different disciplines.

	Environment (625)	Urban (356)	Building (642)	Materials (99)	Transportation (99)	Construction (184)	Energy (309)	Economy (204)
Environment (625)		135	236	71	64	133	158	79
Urban (356)	131		94	38	50	28	59	52
Building (642)	317	119		45	54	227	277	66
Materials (99)	59	13	57		9	62	68	6
Transportation (99)	45	77	30	15		24	38	30
Construction (184)	116	32	135	88	16		121	36
Energy (309)	146	45	228	41	7	70		29
Economy (204)	51	57	97	42	12	76	118	

Figure 0.7 Relationship between categories

Because each article may be involved into different categories, we analyze the relationship among the eight categories as *Figure1.7 shows.*

1.1.5 Our Secondary classification

In order to understand the content of the papers in each category in more detail, we analyzed the keywords of each category through Bibliometrix, and selected the top 20 most frequently appearing keywords, using word cloud to show the frequency of each keyword. The higher frequency of each keyword has larger size as it displays in the word cloud, and then we sort out the category again via selecting the top 6-9 keywords with the highest frequency keywords under each category.

Environment (625)	
Energy	42
Emission	37
Performance	33
Climate change	30
Consumption	28
Life cycle assessment	27
Mangement	24
Carbon	23
Impact	23

Left: Figure 0.8 *Word cloud of "Environment" (source from: Bibliometrix)*

Right: Table 1.1 *The frequency of word*

We first analyze from the most macroscopic perspective—environment. The most frequent keywords are "energy" and "carbon emissions". The energy aspect mainly refers to the impact of energy consumption on the environment. We are most concerned about the impact of carbon emissions on the environment. By reading the literature, we understand the current state of carbon emissions at domestic and abroad, the goals and main strategies for reducing the carbon emissions.

Urban (356)	
City	23
Politics	13
Energy	14
Climate change	12
Policy	12
Building	10
Governance	10
Impact	10
Emission	9

Left: Figure1.9 Word cloud of "urban" (source from: Bibliometrix)

Right: Table 1.2 The frequency of word

Then we analyzed the keywords of "urban", we found that the most frequent keywords are "energy", "politics", "policy" and "climate change", which shows that urban carbon emissions are closely related to government politics and decision-making, it is different from building projects .Because the direction of our thesis is zero carbon building, so we will not pay too much attention to this classification.

Builidng (642)	
Performance	54
Energy	49
Life cycle assessment	37
Emission	34
Consumption	29
Design	29
China	28
Efficiency	25
Model	25

Left: Figure1.10 Word cloud of "building" (source from: Bibliometrix)
Right: Table 1.3 The frequency of word

When it comes to building, the researchers are most concerned about its performance. High performance can reduce the energy of the building during operation phase and it has a very important impact on reducing operational emission. It is should be noticed that, with the increase of high-performance buildings, the operational emissions are gradually reduced, and the embodied emission are more and more worthy of attention. Therefore, a lot of literatures tend to discuss carbon emissions from the perspective of the whole life cycle. We have read a lot of literatures about life cycle assessment, and compare various methods and tools, decided to design our zero-carbon buildings from this perspective.

Materials (99)	
Life cycle assessment	12
Performance	10
Energy	7
Concrete	6
Building	6
Emission	5
Wood	5
Carbon	4
Embodied energy	4

Left: Figure1.11 Word cloud of "materials" (source from: Bibliometrix)
Right: Table 1.4 The frequency of word

The most important part of reducing carbon emissions is the use of building materials. A lot of literatures compare the timber structure and concrete structure buildings and find that wood-framed buildings have significant advantages. Many buildings achieve the goal of zero-carbon construction through prefabricated wood and biomass.

Transportation (99)	
Transport	7
Climate change	5
Built environment	4
Behavior	4
System	4
Air porlution	3
CO2 emission	3
Walking	3
Travel	3

Figure1.12 Word cloud of "transportation" (source from: Bibliometrix)
Right: Table 1.5 The frequency of word

Transportation also accounts for a large proportion of carbon emissions. Even in the life cycle assessment of buildings, the carbon emissions from the transportation of raw materials cannot be ignored. The most frequent keywords are transportation, climate change, building environment and systems. Most of the related articles mentioned issues such as increased carbon emissions, air pollution, and climate change caused by traffic problems.

Construction (184)	
Performance	76
Building	57
Energy	40
Consumption	35
Design	32
Impact	27
Life cycle assessment	24
Residential building	23
Model	23

Fig 1.13 Word cloud of "construction" (source from: Bibliometrix)
Right: Table 1.6 The frequency of word

From the perspective of the entire life cycle of building carbon emissions, it is divided into several stages of production, transportation, construction, operation, demolition and recycling. The carbon emission calculation in the past mostly only counts the two stages-production and operation. The construction phase is difficult to count, but there are a large number of papers indicating that there are many carbon emissions during the construction phase, so we will read the literature in this classification and find ways to calculate carbon emissions during the construction phase. The keywords with the highest frequency of this classification are "building", "energy" and "consumption".

Energy (309)	
Performance	82
System	50
Energy	44
Design	39
Consumption	36
Building	32
Carbon	28
System	26
Efficiency	20

Left: Figure1.14 Word cloud of "energy" (source from: Bibliometrix)
Right: Table 1.7 The frequency of word

Low carbon or zero carbon are often related with energy consumption because the energy consumption during the operational phase is the main part of the carbon footprint of the building's life cycle. Low-carbon buildings are based on energy efficient buildings, so energy performance is very important. It can be seen from the Word cloud, the highest frequency keywords of energy-related is "performance" and "energy consumption", and the frequency of "performance" has reached a large part, which shows that when authors mention building energy, performance is the most important part and has been received attentions.

Economy (204)	
Policy	16
Climate change	14
Energy	13
Building	10
Emission	8
Performance	7
Sustainability	7
Management	6
System	6

Left: Fig 1.15 Word cloud of "economy" (source from: Bibliometrix)
Right: Table 1.7 The frequency of word

In the articles related to low-carbon buildings or zero-carbon buildings, some mentioned economy, and the keywords related to the economy are "climate change", "policy" and "energy". The impact of climate change has raised concerns about carbon emissions. A lot of countries have begun to reduce energy consumptions and carbon emissions through various policies and economic means. Building carbon emissions are a very important part of this, and we can use this classification of papers to understand the policies of each country about low-carbon economy

Low/Zero/Negative carbon building

Environment
- Energy
- Emission
- Performance
- Climate change
- Consumption
- Life cycle assessment
- Management

Urban
- City
- Politics
- Energy
- Climate change
- Policy
- Buildng
- Governance

Building
- Performance
- Energy
- Life cycle assessment
- Emission
- Consumption
- Design
- China

Materials
- Life cycle assessment
- Performance
- Energy
- Concrete
- Building
- Emission
- Wood

Transportation
- Transport
- Climate change
- Built Environment
- Behavior
- System
- Air polution
- CO2 Emission

Construction
- Performance
- Building
- Energy
- Consumption
- Design
- Impact
- Life cycle assessment

Energy
- Performance
- System
- Energy
- Design
- Consumption
- Building
- Carcon

Economy
- Policy
- Climate change
- Energy
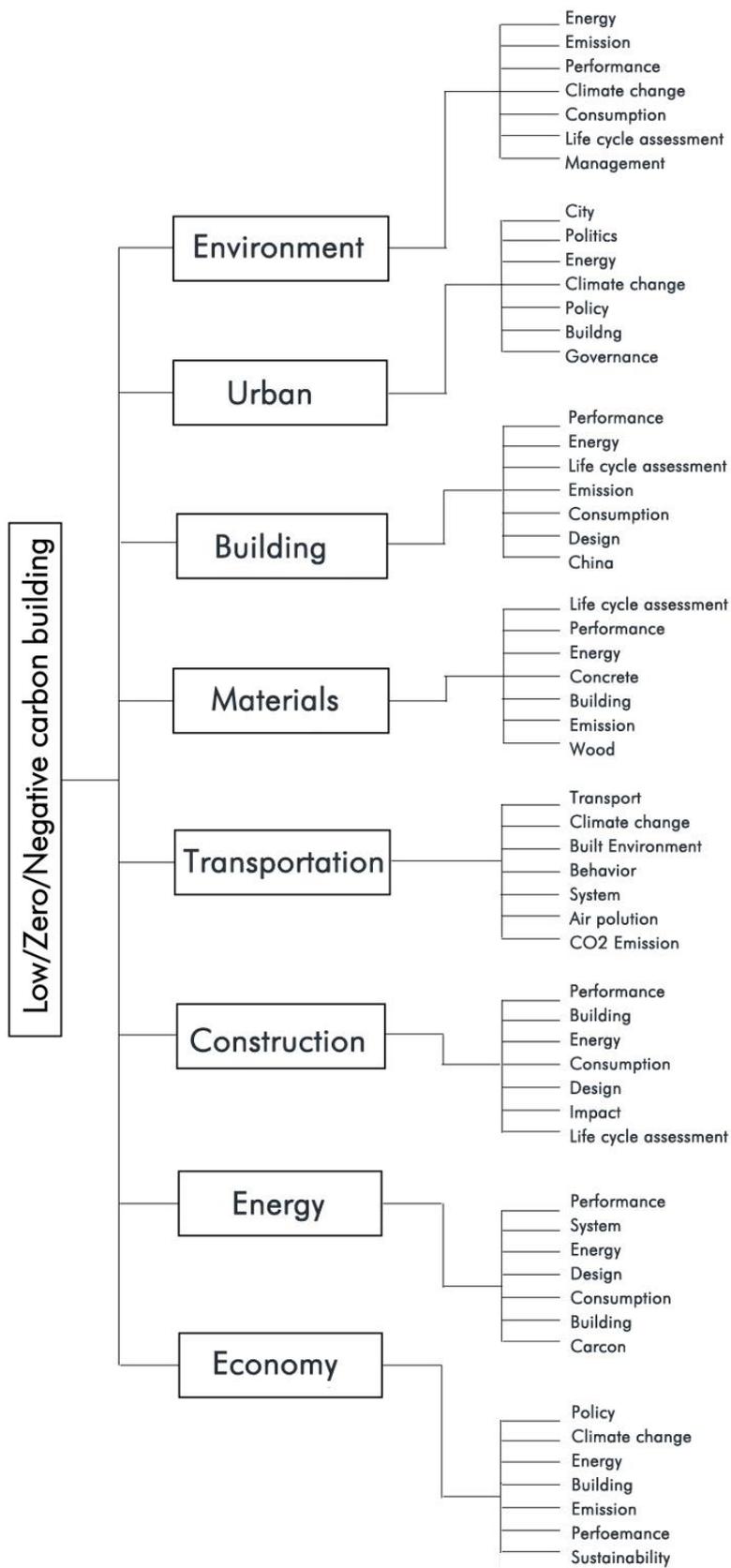- Building
- Emission
- Perfoemance
- Sustainability

Fig 1.16 Classifications of paper search

1.2 The aim of study

After completing the classification literature, we found that the number of publications on relevant topics in zero/low carbon building in China was the first. We are also concerned about what China has done in the past to develop low-carbon buildings and what the government will do in the future. Thus, we decided to start analysis China's relevant policies first.

Then we found that the NZEB investigation started earlier and emerged more rapidly in developed countries. And also, since 2010, with the stimulation of advanced ZEB and effective efforts to energy saving and emission reduction, NZEB has been concerned as an effective approach to the building energy reduction in China. On 24 January of 2019, the Ministry of Housing and Urban-Rural Development, PRC issued GB/T51350-2019 "Technical standards for nearly zero-energy buildings" in China which based on the five climate zones in China: severe cold, cold, hot summer cold winter, hot summer warm winter and temperate.

The 2022 winter Olympic Games will be held in Beijing, which is in cold region, and it will use low-carbon energy and build low-carbon venues. During my internship in China architectural design and research institute, I was lucky to participate in the project of Yanqing mountain press center of the winter Olympics, working within a multi-sector team to complete a variety of tasks associated with energy retrofit and high performance building consulting in this project.

This project combined with the natural conditions of the site to optimize the building design, optimize the thermal performance of the project envelope structure, through the regional cold and heat source system, the use of high-efficiency air conditioning units, the setting of a reasonable heat recovery device and solar photovoltaic system, to achieve the goal of nearly zero energy building.

Through the strategy of this project and the comparison of energy consumption on the baseline and the design plan, we have achieved the goal of nearly zero energy consumption. It is a demonstration to promote the application of low-carbon technologies, effectively control greenhouse gas emissions, and make the Beijing winter Olympic Games an important platform for China to show its participation in the construction of global ecological civilization.

Finally, we hope that the above research and study can provide references for the further development of NZEB in cold region in China.

2 Building energy efficiency policies

2.1 Global and China's energy consumption and comparison

Global primary energy consumption grew rapidly in 2018 at a rate of 2.9% which almost double its 10-year average of 1.5% per year, and the fastest since 2010 *(BP Statistical Review – 2019 Global energy market in 2018)*. As reported, the global demand for all fuels increased but growth was particularly strong in the case of gas (168mtoe, accounting for 43% of the global increase) and renewables (71mtoe, 18% of the global increase). Coal consumption grew by 1.4%, double its 10-year average rate. Its share in primary energy fell to 27.2%, the lowest in 15 years. Non-fossil fuels' share in primary energy in 2018 was 15.3%, the highest in recent history.
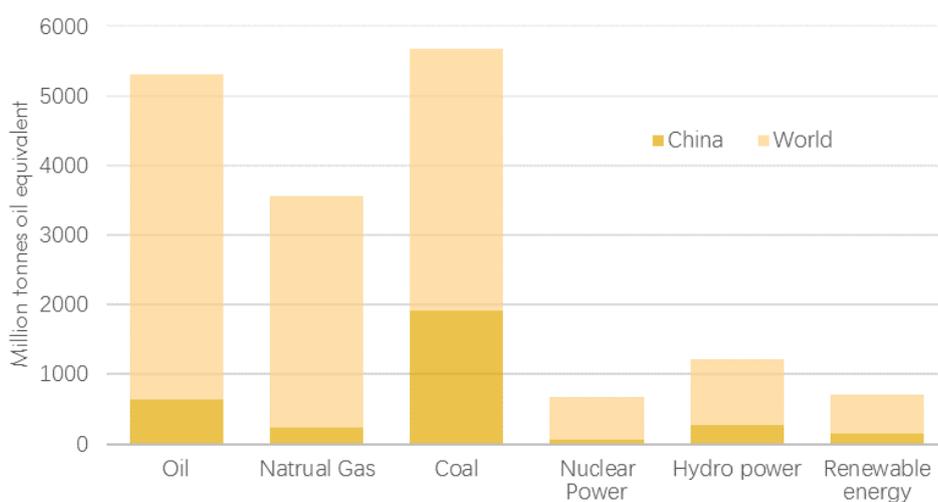

Figure 2.1 The energy consumption of world and China in 2018[1]
(BP Statistical Review of World Energy 2019)

Figure 2.2 The energy consumption of world and China from 2008 to 2018
(BP Statistical Review of World Energy 2019)

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[1] The graphs by author, data form *BP Statistical Review of World Energy 2019*

As for China, despite slower economic growth, China remained the world's largest energy consumer, accounting for 24% of global energy consumption and contributing 34% of global energy demand growth in 2018. China was still the largest contributor to global growth for the 18th consecutive year. the primary energy demand rose by 4.3% in 2018, the highest since 2012. Gas consumption increased by 18% in 2018, accounting for 22% of global gas consumption net growth. The share of coal in China's primary energy mix declined to 58% in 2018 from 60% in 2017 and 72% just 10 years ago.

Figure 2.3 the energy composition of China in 2008 and 2018
(BP Statistical Review – 2019 China's energy market in 2018)

From these two pie charts, among these 10 years China's energy mix continued to evolve. While coal remained the dominant fuel, its share of total energy consumption in 2018 (58%) hit a historical low. Renewables consumption grew by 29% in 2018, accounting for 45% of global renewables consumption growth. Among non-fossil fuels, solar consumption grew the fastest (+51%), followed by wind (+24%) and biomass & geothermal (+14%). Hydro grew by 3.2%, nearly one third the 10 years average growth of 9.2%. China's nuclear power generation increased by 19%, above the 10-year average growth of 15%. China accounted for 74% of the global nuclear power increment.

2.2 Energy consumption in Chinese building sector

According to the intergovernmental Panel on *Climate Change Fifth Assessment Report (IPCC, 2014)* buildings accounted for 32 % of total global final energy use, until 2017 buildings and construction together account for 36% of global final energy (*Global status report 2017-World Green Building Council*).

As for China*, a research report from the building energy conservation center of Tsinghua university*[2] , they reported since 2001, both total energy consumption and electricity consumption in China's building sector increased significantly. In 2016, the total building

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[2] *China Building Energy Use, 2018*

commercial energy consumption was 896 million tons of coal equivalent (Mtce) accounting for about 20% of the total primary energy consumption.

2.2.1 Building energy consumption of China

In 2016, China's total energy consumption in construction was 896 million tons of standard coal, accounting for 20.62% of the country's total energy consumption. China's building energy use is categorized using three sub-sectors based on their own influencing factors and characteristics. As the data shows (Figure 2.4), public buildings consume 346 million tons of standard coal, accounting for 38.53% of the total building energy consumption. Urban residential buildings consumed 339 million tons of standard coal, accounting for 37.71%; Rural residential buildings consumed 214 million tons of standard coal, accounting for 23.76%.

Figure 2.4 Building energy consumption in China in 2016[3]
(China building energy consumption report 2018)

Figure 2.5 China's total building area in 2016
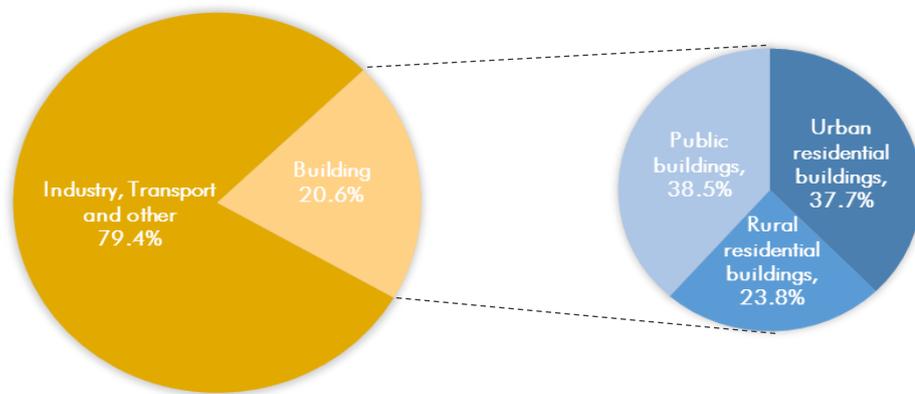*(China building energy consumption report 2018)*

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[3] Data from China building energy consumption report 2018, graphs by author

In recent years, China's rapid urbanization development, a large number of people from the countryside into the city. Rapid urbanization drives the continuous development of the construction industry, and the scale of China's construction industry continues to expand. The key reasons responsible for huge distinctions in energy intensities could be different lifestyles and energy consuming behavior.

In 2016, China's total building area reached 63.487 billion m^2 as Fig.2.5 illustrates, the public building area was 11.506 billion m^2, accounting for 18.12 %. Urban residential buildings area was 27.864 billion m^2, accounting for 43.89%; Rural residential buildings were 24.117 billion square meters, accounting for 37.99% of the total. Among them, residential buildings account for about 2/3 and public buildings account for 1/3.

The continuous growth of the scale of construction mainly from two aspects of drive the energy consumption growth: on the one hand, the growing construction area for the future brought a lot of building energy consumption demand, more buildings will need more energy to satisfy the heating, ventilation, air conditioning, lighting, kitchen, living hot water, and other services function. On the other hand, large-scale construction activities carried out using a large number of building materials, building materials production, leading to the mainland the source consumption. Therefore, the large-scale construction of China's buildings and infrastructure is an important reason for the continuous growth of China's energy consumption. The construction industry includes the construction of civil buildings, productive buildings and infrastructure such as roads, railways and dams. The energy consumption of the construction industry brought by the construction of new buildings and infrastructure can be accounted and analyzed from the production and transportation of building materials to the whole construction process. The energy consumption of building materials is the most important component of the construction energy consumption of the construction industry, among which the production energy consumption of steel and cement accounts for more than 80% of the total construction energy consumption of the construction industry.

Figure2.6 China's net energy intensity in 2016(Kgce/m²)[4]

(China building energy consumption report 2018)

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[4] Kilogram standard coal equivalent per square meters

From 2001, the total energy consumption increased less than 3 times and energy use intensity (EUI) about one third. In terms of energy intensity per unit area, the energy intensity of public buildings is the highest among the three types of building energy, which has been increasing in recent years. In 2016, the energy consumption per unit area of public buildings was 30.11Kgce/m^2, 2.5 times that of urban residential buildings (12.17Kgce/m^2) and 3.4 times that of rural residential buildings (8.86Kgce/m^2). The energy intensity per unit area of the three types of buildings here is the coal consumption method for power generation.

The electricity consumption per unit area of public buildings was 62.74 kWh/m^2, 3.8 times that of urban residential buildings (16.40kWh/m^2) and 3.9 times that of rural residential buildings (15.97kWh/m^2).

Figure2.7 China's net energy intensity in 2016(kWh/m^2)
(China building energy consumption report 2018)

2.2.2 Building energy consumption variation from 2000 to 2016

(1) Total energy consumption

The total energy consumption of buildings shows a continuous growth trend, but the average annual growth rate slowed down significantly from 2006 to 2016.The consumption of coal from 288 million tons in 2000 to 899 in 2016, there is an increase of about three times, with an average annual growth of 7.37%. Compared with 2000-2005, the growth rate of building energy consumption decreased significantly from 2006 to 2016.

The annual growth rate of building energy consumption during the tenth five-year plan (2000-2005) period was about 12%, while the growth rate of another five-year plans was around 5%, down by more than 50%. To some extent, this reflects China's efforts to promote building energy conservation since the 2006.

2000 to 2016, public building energy consumption (including heating energy consumption) accounted for 34% to 39% of the total building energy consumption, urban residential

building energy consumption (including heating energy consumption) was 38% to 42%, and rural building energy consumption was stable at 23% to 24%.

(2) Public building energy use intensity

Energy consumption per unit area of public buildings increased year by year, from 21.54Kgce/m^2 in 2001 to 27.91Kgce/m^2 in 2005, with an average annual growth of 6.7%. From 2005 to 2010, energy consumption per unit area of public buildings was generally stable. Since the 12th five-year plan (2010-2015), the energy consumption per unit area of public buildings has been decreasing year by year, from 31.30Kgce/m^2 in 2011 to 28.72Kgce/m^2 in 2015, and the energy consumption per square meter has decreased by 2.58Kgce.

Electricity consumption per unit area of public buildings has maintained an increasing trend. In terms of energy intensity per unit area, the energy intensity of public buildings is the highest among the three types of buildings. The electricity consumption intensity per unit area of public buildings has been increasing which is the main reason for the increase of total energy consumption intensity. Electricity consumption per unit area of public buildings increased 2.4 times from 26.42kWh/m^2 in 2000 to 62.74kWh/m^2 in 2016.

(3) Urban residential building energy use intensity

From 2000 to 2016, the energy consumption per unit area of urban residential buildings was stable, and the decline trend was obvious after 2007. In 2016, the energy consumption per unit area of urban residential buildings was 12.17kgce/m2, 0.87kgce/m2 higher than that of 2000. With the development of urbanization and the improvement of people's living standards, the electricity consumption per unit area of urban residential buildings shows a trend of increasing year by year, from 9.31kWh/m^2 in 2000 to 16.4kWh/m^2 in 2016, with an increase of about 1.76 times. The proportion of electricity in household energy is increasing.

(4) Rural residential building energy use intensity

The energy consumption per unit area of rural residential buildings has risen steadily, and the electricity consumption per unit area has risen rapidly. From 2000 to 2016, the energy intensity of rural residential buildings increased year by year. Energy consumption per unit area increased from 3.51Kgce/m^2 in 2000 to 8.86Kgce/m^2 in 2016, with an increase of 2.5 times and an average annual growth of 5.96%. The electricity consumption per unit area increased rapidly, from 2.62kWh/m^2 in 2000 to 15.97 kWh/m^2 in 2016, with an increase of 6.1 times and an average annual growth of 12.0%. Electricity has gradually become the main use of rural households.

2.2.3 Building energy consumption of provinces

From the perspective of different provinces, the total energy consumption of urban buildings varies greatly in 2015. The top three in total energy consumption are Shandong, Guangdong and Jiangsu, while the bottom three are Hainan, Qinghai and Ningxia respectively. Among them, urban population, total GDP and climate zone are the three factors that have the largest impact on the total energy consumption of urban buildings.

Figure2.8 Total energy consumption of urban civil buildings by province (excluding rural areas) in 2015 (China building energy consumption report 2017)

Ranking	Province	Climate zone	Total Energy consumption (mtce)	Population (million)	Energy consumption per person(Kgce/person)	Urbanization rate	GDP(trillion CNY)
Top1	Shangdong	Cold	61.82	61.46	1005.86	61.18%	9.73
Top2	Guangdong	Hot summer, warm winter	55.73	80.22	694.71	70.70%	7.65
Top3	Jiangsu	Hot summer, cold winter	43.18	55.24	781.68	68.80%	9.26
Bottom3	Ningxia	Cold	4.3	3.95	1088.61	57.98%	0.45
Bottom2	Qinghai	Severe cold	4.02	3.18	1264.15	53.07%	0.26
Bottom1	Hainan	Hot summer, warm winter	3.26	5.37	607.08	58.04%	0.35

Table 2.9 Energy consumption comparison of the top three and the bottom three

From the above table, it can be concluded that the biggest factor affecting the energy consumption of per person of all provinces in China should depend on the climate zone of this province. Even Qinghai as the province with the second-lowest total energy consumption, it still has high energy consumption of per person, the main reason is in the severe cold zone.

2.3 Carbon dioxide emission in Chinses building sector

According to the *BP Statistical Review of World Energy 2019, global* CO2 emissions increased by 2.0% in 2018, their highest rate for seven years and double its 10-year average growth. China's CO_2 emissions from energy use increased by 2.2% in 2018, a significant rebound from the 0.5% p.a. growth of previous five years.

Global status report 2017 published there is 39% of energy-related carbon dioxide (CO_2) emissions when upstream power generation, In 2016, China's building carbon emissions accounted for 19.4% of the country's energy emissions.

Figure 2.10 carbon dioxide emissions of world and China from 2008 to 2018
(BP Statistical Review of World Energy 2019)

2.3.1 Building carbon dioxide emission of China

In 2016, China's total carbon emissions from buildings were 1.96 billion tons of CO_2, including 743 million tons from public buildings, accounting for 37.9% of the total carbon emissions from buildings. The carbon emission from urban residential buildings was 809 million tons of CO_2, accounting for 41.3%. The carbon emission of rural residential buildings was 408 million tons of CO2, accounting for 20.8%.

Figure 2.11 Building carbon dioxide emission in China in 2016
(China building energy consumption report 2018)

In terms of the carbon emission per unit area, the carbon emission intensity per unit area of public buildings is the highest among the three types of building, and it has been growing in recent years.

In 2016, the carbon emission intensity per unit area of public buildings was 64.61 $KgCO_2/m2$, 2.2 times that of urban residential buildings ($29.04 KgCO_2/m^2$) and 3.8 times that of rural residential buildings ($16.92 KgCO_2/m^2$).

From the carbon emission coefficient of unit energy consumption, the carbon emission coefficient of unit energy consumption of urban residential buildings in 2016 was 2.39 $kgCO_2/Kgce$, higher than public buildings ($2.15 KgCO_2/Kgce$) and rural residential buildings ($1.91 kgCO_2/Kgce$).
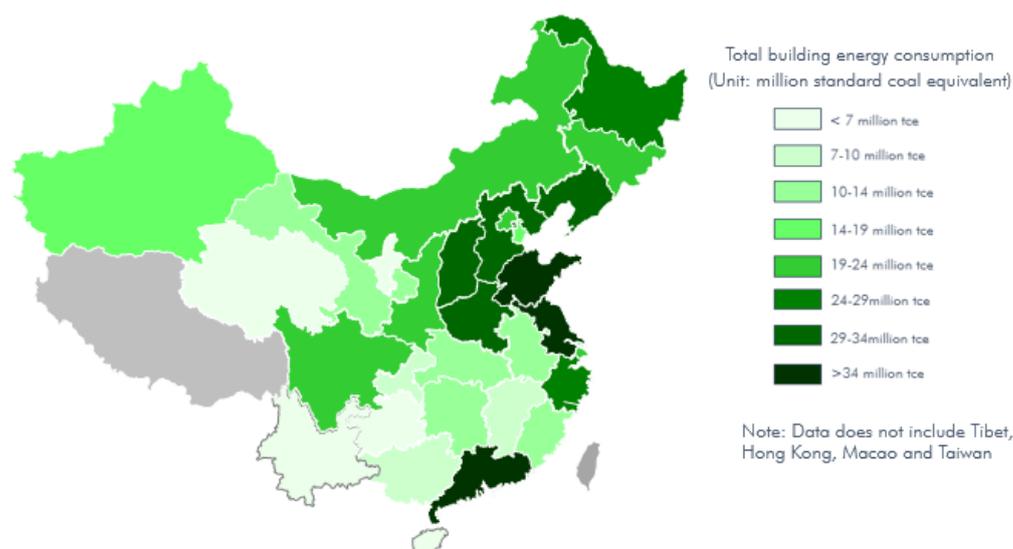

Figure 2.12 Total carbon emission of urban civil buildings by province in 2016 (excluding rural areas)
(China building energy consumption report 2018)

In 2016, the top three provinces and cities in terms of urban building emissions were 127.99 million tons of CO_2 in Shandong, 11.05 million tons of CO_2 in Guangdong, and 90.76 million tons of CO2 in Hebei. The next three provinces and cities were 7.93 million tons of CO_2 in Hainan, 10.28 million tons of CO_2 in Qinghai, and 10.48 million tons of CO_2 in Ningxia. Population, economy and climate are the main factors that lead to the differences of related indexes of building carbon emission in different provinces. For every 10,000 yuan increase in per capita GDP, the per capita CO_2 emission of urban areas will increase by about 90kg. For every 1000 yuan increase in output per unit area of public buildings, its electricity carbon emissions will increase by about $11.5 kgCO_2$. The carbon emission intensity of residential buildings in northern cities and towns (52.4 $kgCO_2/m2$) is four times that of non-heating areas (13.37 $kgCO_2/m2$), and the carbon emission of residential buildings per capita is 2.66 tons, twice that of non-heating areas (1.32 tons).

In order to better understand the flow of building energy to carbon emissions, the following Sankey diagram briefly analyzes the energy flow of China's buildings in 2016. Electricity is the main source of building carbon emissions accounting for 46%. Carbon emissions from northern heating accounted for 25%. Fossil fuels such as coal and natural gas account for 28% of emissions.

Figure 2.13 China's building energy flow in 2016

The carbon emission intensity of public buildings is much higher than the national and other residential building intensity levels, which is about 2.09 times of the national intensity level. In 2016, China's comprehensive carbon emission factor is 2.18 $kgCO_2/kgce$, that is, every 1kg of standard coal consumed releases 2.18kg of carbon dioxide on average

2.3.2 Building CO2 emission variation from 2000 to 2016

(1) The characteristic of periodical change of carbon emission per unit area of public buildings is obvious. From 2000 to 2005, carbon emission per unit area of public buildings increased rapidly year by year, from 49.46$kgCO_2/m^2$ in 2000 to 62.47 $kgCO_2/m^2$ in 2005, with an annual growth rate of 4.8%. From 2006 to 2010, the growth rate of carbon emission per unit area of public buildings slowed down, from 65.19$kgCO_2/m^2$ in 2006 to 69.1$kgCO_2/m^2$ in 2010, with an annual growth rate of 1.46%. From 2011 to 2016, the carbon emission per unit area of public buildings showed a declining trend year by year, from 74.06 $kgCO_2/m^2$ in 2012 to 62.40 $kgCO_2/m^2$ in 2015, and the carbon emission per square meter decreased by 11.66 $kgCO_2/m^2$.

(2) The carbon emission per unit area of urban residential buildings remains stable overall. In 2016, the carbon emission per unit area of urban residential buildings is 29.04 $kgCO_2/m^2$, 1.66 $kgCO_2/m^2$ higher than that in 2000. After 2012, the decline trend is obvious.

(3) From 2000 to 2016, the carbon emission intensity per unit area of rural residential buildings increased year by year. Carbon emission per unit area increased from 7.61 $kgCO_2/m^2$ in 2000 to 16.92 $kgCO_2/m^2$ in 2016, with an annual growth rate of 5.12%. The change of carbon emission intensity per unit area of rural residential buildings is mainly

affected by the following factors: 1) substantial improvement of rural living conditions leads to rapid growth of energy demand per unit area; 2) the proportion of rural non-commodity energy consumption decreases; 3) rural building energy conservation and emission reduction work lags behind, and there is no clear path to emission reduction.

Figure 2.14 China's building carbon emission comprehensive factor (carbon emission per unit building energy consumption, $KgCO_2/Kgce$)
(China building energy consumption report 2018)

From 2000 to 2012, the comprehensive carbon emission factor of buildings in China was relatively stable. China's comprehensive carbon emission factor for buildings showed a significant downward trend after the turning point in 2012. In 2016, the overall carbon emission factor decreased by 9.5% compared with 2012.

Remarkable achievements have been made in building energy conservation since 2012. 241 million tons of CO_2 emission reduction has been achieved due to the reduction of building carbon emission factor and energy intensity. *(China building energy consumption report 2018)*

2.4 Overview the building energy efficiency policies in China

2.4.1 Three stages from 1980 to 2010: 30%-50%-65%

China from last century 80s, begin to establish corresponding building energy conservation standard for civil building, can divide roughly.

There are three stages:

(1) Stage 1: In 1982, with support from the Ministry of Construction (MoC), the first study related to building energy efficiency in China, 'Study on energy conservation of heating for residential buildings in North China', was launched. As a result, in August 1986, the MoC officially issued the standard Energy Conservation Design Standard for Heating Residential Buildings JGJ [5]26–86. Through a thorough study monitoring building energy consumption and building components, the goal of the standard was a 30% decrease in heating energy consumption compared to the baseline buildings built in the early 1980s. It became known as the first step of energy efficiency goal, which was 30 percent.

(2) Stage 2: On December 7, 1995, the ministry of construction approved and issued the "civil building energy conservation design standard (heating residential buildings)" JGJ26-95, requiring the heating energy consumption to be reduced by 50% on the basis of the local general design of residential buildings in 1980 and 1981. It was the second step for energy saving (50% energy saving).

Subsequently, considering that each climate zone would affect energy efficiency, GB50178-93 Code for thermal design of civil buildings was introduced in 1993

Then, the technical specification for energy-saving renovation of residential buildings with existing heating system JGJ129-2000 was issued successively.

Design standards for energy conservation of residential buildings in hot summer and cold winter areas JGJ134-2001

Design standards for energy conservation of residential buildings in hot summer and warm winter areas JGJ75-2003

Finally, the first national standard for public buildings GB50189-2005" Design standard of energy efficiency of public building" was published in 2005 which request the public building also should take 50% energy-saving as the goal.

 (3) Stage 3: Save more 30 percent of the energy in the second stage, on top of the 50 percent saving in the second stage, which is the goal of 65 percent energy saving. At present, many regions in China have been promoting the goal of 65% energy saving in the third stage of building energy saving. The industry standard *"Energy saving design standard for residential buildings in severe cold and cold areas" (JGJ26-2010)* was announced on March

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[5] JGJ is abbreviations of technical standard for building construction

18, 2010 and implemented on August 1, 2010, stipulating that residential buildings in severe cold and cold areas should achieve 65% energy saving.

2.4.2 Next stage to 2030: Nearly zero energy building

In 2016, GB50189-2016 *"Design standard of energy efficiency of public building"* was update with the goal of further reducing building energy consumption by 30% based on GB50189-2005, which means the same goal of 65%. After three decades of development, China has accomplished its three-step '30%-50%-65%' plan for building energy efficiency proposed in the early 1980s.

Established in 2009, the US-China Clean Energy Research Center Building Energy Efficiency Consortium aims to promote nearly-ZEBs and ZEBs (Zero energy building). Through pilot studies from 2011 to 2014, scientists and researchers from both China and the United States jointly designed and built the first demonstration of a nearly-ZEB in China, specifically the nearly-ZEB China Academy of Building Research (CABR-NZEB). Adhering to the principle of 'passive building, proactive optimization, economic and pragmatic', ambitious annual energy consumption goals were set for the CABR-NZEB during the design stage: provide heating in winter with zero fossil fuel use, reduce summer cooling energy by 50%, reduce lighting energy by 75% and reduce total energy consumption by more than 80% from the average level.(Yang et al.2019)

With the stimulation of advanced Zero energy building (ZEB) and effective efforts to energy saving and emission reduction, nearly ZEB has been concerned as an effective approach to the building energy reduction in China (Xu et al., 2016). Driven by the national policies explicitly launched by the central government and the promising demonstration effects of pilot projects, local governments have also initiated NZEB design standards or technical guidelines as well as a series of incentives.

Policies should be formulated in a coordinated way to combine energy efficiency with renewable energy use to achieve zero net energy development in China (Feng et al., 2016). China adopts a top-down development strategy to promote ZEB. On February 6, 2016, Several Opinions on Further Strengthening Urban Planning and Construction Management is the first time that China has clearly developed ZEB in national documents. A national research project to support building energy efficiency towards a higher level (NZEB Technology System and Key Technology Development) is implemented in September 2017, whose focus is mainly on theory and indicator system, key technology products, design and construction evaluation and integration and demonstration.

At present, it is difficult for China to directly move from the current building code to the ZEB level. Nearly ZEB is a realizable way to address the current energy and environmental issues. Nearly ZEB are going to be the next energy-efficient direction in China's real estate market. The market of nearly ZEB is currently small, but it is booming as the technology roadmap becomes clear. China still has a large ZEB market to be explored.

Figure 2.9 Roadmap of nearly zero energy building standard in China

The first national standard nearly Zero Energy Buildings Technology Standard *GB/T 51350-2019* could lead the development of energy saving in China in the next 10–15 years. The entire process of building design, construction, and operation management will be fully clarified. The standard has released and implemented in 2019. It is China's first official ZEB national standard. Another national standard (Detection and Evaluation Standard for Nearly Zero Energy Building) is released to evaluate the performance of nearly ZEB in China. All the nearly ZEB should be tested on the performance after a full year operation.

Researchers in China has proposed a roadmap for 2016-2030 building codes upgrading: 30% of new buildings reach nearly zero energy by 2030, 30% of existing buildings are converted to nearly zero energy by 2030, and 30% of energy consumption in the building sector are from renewable energy sources by 2030 (*Liu et al. 2019*). Roadmap of Chinese building energy efficiency standard to ZEB is shown in Figure 2.9

2.5 Nearly Zero Energy Building

2.5.1 Definition
Since the energy consumption of building cause more and more attention, for now, NZEB is starting at a rapid developing stage in the world.

The term "zero energy building" is not a recent phenomenon, dating back to 1976, when Torben V of the technical university of Denmark Esbensen et al. conducted theoretical and experimental research on using solar Energy to heat buildings in winter in Denmark, and proposed the term "Zero Energy House" for the first time. *(Torben V.Esbensen 1977, Dimensioning of the solar heating system in the zero energy house in Denmark)*

In the recast Energy Performance of Buildings Directive (EPBD, 2010/31/EU), the term Nearly Zero-Energy Building (commonly abbreviated as NZEB) was introduced and defined as a "nearly zero-energy building means a building that has a very high energy performance. The nearly zero or very low amount of energy required should be covered to a very significant

extent by energy from renewable sources, including energy from renewable sources produced on-site or nearby" (Art. 2).

An important definition around zero energy buildings (ZEBs) is that of the US Department of Energy (DOE). A ZEB building is: "An energy efficient building where, on a source energy basis, the actual annual delivered energy is less than or equal to the on-site renewable exported energy" *(US Department of Energy, A Common Definition for Zero Energy Buildings, 2015)*

As for China, Chinses use 近(Jin) 零(Ling) 能(Neng) 耗(Hao) 建(Jian) 筑(Zhu) stand for nearly zero energy building, the definition from *Technical standard for nearly zero energy buildings GB/T 51350-2019 is*:" Buildings can adapt to climate characteristics and site conditions, and through passive building design to maximize the reduction of building heating, air conditioning, lighting demand, and through active technical measures to maximize the efficiency of energy equipment and system, make full use of renewable energy, with the minimum energy consumption to provide a comfortable indoor environment."

It can be seen that the definition of NZEB is different for each country/region. In this chapter, we will discuss the policies adopted by different countries (mainly asia-pacific regions) regarding NZEB. In the following chapter, we will learn and analyze the NZEB demonstration projects of each country. The purpose is to find and compare The efficiency strategies and demonstrate The feasibility of NZEB in difference climate zone in China.

In order to promote the development of near zero carbon building in China and improve the near zero carbon building code, some reference information is provided.

2.5.2 The policies and program in Pacific Rim area[6]

Through the comparison of climate, we find that the representative cities of China's five climate zones can all find corresponding cities with similar climate in developed countries. We are happy to compare and learn the design strategies and development policies of NZEB project in these cities, which will benefit both the China's new building construct work and existing building retrofit work in both developed and developing economies.

(1) Canada

The national target for Canada's public facilities is to reduce greenhouse gas emissions by 17 percent from the 2005 levels by 2020. Among the proposals for the 2016-2019 cycle is a proposal for public facilities to reduce greenhouse gas emissions by 30 percent from 2005 levels by 2030. The Federal Buildings Initiative (FBI) is a voluntary program that helps facilitate

(2) China

In 2017, China State Council issued the "13th Five Year Comprehensive Work Plan for Energy Conservation and Emission Reduction" (the "Work Plan") for the 2016-2020 period

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[6] *The Pacific Rim refers to the geographic area surrounding the Pacific Ocean. The Pacific Rim covers the western shores of North America and South America, and the shores of Australia, eastern Asia and the islands of the Pacific. (From WIKIPEDIA)*

which sets forth implementation guidelines for energy conservation and emissions reductions , 30% of new buildings reach nearly zero energy by 2030, 30% of existing buildings are converted to nearly zero energy by 2030, and 30% of energy consumption in the building sector are from renewable energy sources by 2030.

 (3) Korea

On July 17 2014, Ministry of Land, Infrastructure and Transport issued The Activation Plan of ZEB Corresponding to Climate Change on the 11th General Meeting of the Presidential Advisory Council on Science and Technology (PACST) which clearly analyzed the barriers and obstacles of ZEB promotion setting up the future roadmap step by step. The plan also showed the corresponding financial policy and subsidy for pilot projects, work distribution and calculation of the expected social, environment and economy effect.

(4) Japan

The program "Committee on Realization and Generalization of ZEB" was organized in 2009 in order to examine the roadmap to realization and generalization of Zero Energy Building (ZEB). By introducing energy saving measures for buildings, this committee proposed to realize ZEB as the standard for new buildings by 2030.

(5) United State America

The timeline and means for achieving the stated goal of zero net energy grinding building can be summarized as follows: All plans for new Federal buildings should achieve Zero Net Energy By 2030.

2.6 Summary

In China, NZEB is an emerging innovative building type that plays an important role in building energy efficiency and has the potential to alleviate the country's energy pressure.

China will fully begin the construction of NZEB from 1st of September, 2019, Plan is 30% of the new buildings reach nearly zero energy by 2030, 30% of existing buildings are converted to nearly zero energy by 2030, And 30% of energy consumption in the building sector are from renewable energy sources by 2030.

However, NZEB is no longer a new topic for other developed countries. Our goal is to provide more references and information for China's future NZEB by comparing the mature NZEB architectural design strategies of China and developed countries.

Although China's existing standard nearly Zero Energy Buildings Technology standard GB/T 51350-2019 provides some reference indexes for construction, it is still an urgent problem to learn and solve how to establish key technologies suitable for local climate conditions due to China's vast territory.

The following chapter will introduce the principles of architectural climate zoning in China. According to the climate zoning, we will find cities in developed countries with similar climates to learn the design strategies of NZEB in developed countries.

3 Climate regionalization in China

3.1 Main climate types in China

China has a vast territory and has the third largest land area in the world, the parts of the continent spanning up to 35 latitudes, most of which are located in subtropical and temperate regions. China is located on the Eurasian continent, and near the Pacific Ocean. It is greatly influenced by the distribution of land and sea. Due to the different geographical latitude, topography and other conditions, the climate varies greatly, the northwest region is a dry continental climate, while the southeast region is a monsoon area influenced by the sea and land interactions,forming a variety of climate in China.

There are different types of climate zones according to the different objects, climate zones can be divided into agriculture climate zoning, building climate zoning, aviation climate zoning; It can be divided into global climate regionalization, national climate regionalization and regional climate regionalization.

China's climate zoning has been carried out for nearly a century, during which there are three stages:

The 1930s to the 1940s was the beginning of China's climate zoning. The methods used here draw on the climate classification method of Europe and the United States and combined the natural types to define the regional types of climate.

From the 1940s, on the basis of the most representative regionalization compiled by the Chinese academy of sciences and the Chinese meteorological bureau, the principle of climate regionalization according to the three-level system of temperature zone, dry and wet zone and climate zone was formulated , which revealed the characteristics of China's climate regions at that time.

Third stage since the early 1980s, climatic regionalization pays more attention to the climate and the natural landscape and other natural geographical feature match instead of agricultural production, and the division method is identified as the national standard.

According to the classification rules of global climate types, the main climate types in China are:

(1) Tropical monsoon climate, including southern Taiwan province, Leizhou peninsula and Hainan island. Annual accumulated temperature ≥8000°C, the average temperature of the coldest month ≥16°C, the average temperature of the annual extreme minimum temperature for many years ≥5°C, the average temperature of the extreme minimum temperature generally ≥0°C, no frost all the year.

(2) Subtropical monsoon zone, northern China and southern China belong to this type of climate. Annual accumulated temperature between 4500°C and 8000°C, the average temperature of the coldest month between -8°C and 0°C, which is the transition zone between the tropical zone and the temperate zone. The temperatures in summer are quite high (at least 30 days, the average temperature ≥25°C), and the temperatures in winter are quite low.

(3) Temperate monsoon zone, Inner Mongolia, northern Xinjiang and other places belong to this type of climate. Annual accumulated temperature <1600°C to 3400°C, the average temperature in the coldest month between -28 and 8°°C, the average temperature in summer is still ≥22°C, but ≥25°C is very rare.

(4) Temperate continental zone includes temperate desert climate, temperate grassland climate and sub-cold coniferous climate.

(5) Alpine-cold zone, Qinghai-Tibet plateau and some high mountains belong to this type of climate. Annual accumulated temperature <2000°C, the daily average temperature is below 10°C, and the hottest temperature <5°C, even <0°C. The daily temperature range is large and the annual temperature range is small, but the solar radiation is strong and sunlight is sufficient. (Source from: Lv et al,2018 [in Chinses])

Figure3.1 China weather map
(https://www.chinadiscovery.com/weather.html)

3.2 Köppen climate regionalization in China

Köppen climate classification is one of the most widely used and influential climate classifications in the world. It takes temperature, precipitation and seasonal changes as the basis of classification, takes monthly average temperature and precipitation as the classification index, and refers to vegetation distribution to determine the boundary index value between climate types, and divides the world into 5 basic climate zones and 12 major climate types with climate sub-type.

Köppen climate classification has the advantages of strict standards, clear boundaries and convenient application. It can determine the climate type according to the simple temperature and precipitation index, and is basically suitable for tundra, forest, grassland, desert and other landscape zones, so it is widely used by scholars around the world. However, Köppen climate classification has its drawbacks. This is mainly reflected in the unreasonable division of dry zones and the neglect of vertical changes in temperature and precipitation

and zonal differences in horizontal latitude.

Based on the Köppen climate classification, the 4 main climate zones in china are Dry zone(B), Warm zone(C), Cold temperate zone(D) and Polar zone dominated by upland climate(E). The main 6 climatic types are Grassland climate (Bs), Desert climate (Bw), Dry winter warm climate (Cw), Warm humid climate (Cf), Winter dry, cold and warm climate (Dw), Tundra climate (ET).

Mainland China can be divided into the following major climatic zones:

(1) The southern warm region: south to the Qinling mountains and Huaihe river, and east to the Qinghai-Tibet plateau, the main climate sub-types are Cfa, Cwa and Cwb

(2) The northern cold and warm region: north to the Qinling mountains and Huaihe river, east to the northern Inner Mongolian plateau, east to the southern Aihui -- Tengchong line northern cold and warm area, the main climate subtypes are Dwa, Dwb, Dwc.

(3) The northwest arid region: north to the Qinghai-Tibet plateau, west to the northern Inner Mongolia plateau (inclusive) and west to the southern Aihin-Tengchong line, the main climate subtypes are Bsk and Bwk.

(4) The Qinghai-Tibet plateau region which is dominated by upland tundra climate, with Bsk and ETH as the main climate sub-types. (Zhu et al, 2015)

Figure3.2 Köppen-Geiger climate classification map for China(Source from: Present and future Köppen-Geiger climate classification maps at 1-km resolution, Beck et al, 2018)

3.3 Building design thermal zoning in China

The relationship between external climate and building system is getting closer and closer. The climate of the building area affects the orientation, spacing and layout of buildings, the design of envelope structure, indoor thermal comfort, application of passive technology,

HVAC system and equipment selection, etc.

These five climate types reflect the climate types of China at the global scale, and have guidance and reference for China's own building climate zones, but the building climate zones cannot be completely copied. According to different climatic conditions in China, the energy conservation design of buildings in different regions has different methods. Therefore, it is necessary to carry out more specific climatic zoning of buildings.

At present, there are only two standards for building zoning in China's industry: Building climate zone from GB50178-93 "*Building climate zoning standard*" and Thermal design zone from GB50176-16 "Civil construction thermal design code".

Building climate zone reflects the relationship between buildings and climate, mainly reflects the temporal and spatial distribution characteristics of the basic meteorological elements and their direct effects on buildings, showing the close relationship between buildings and climate.

The thermal design zone reflects the relationship between thermal design and climate, which mainly reflects the influence of meteorological basic elements on the thermal insulation design of buildings and envelope structures. Building thermal design zoning is to make civil building thermal design and regional climate, to ensure the basic indoor thermal environment requirements, in line with the national policy of energy conservation, improve efficiency.

Figure3.3 China climate regions defined by the Ministry of Construction
(Source: Huang et al.2007)

GB50176-16 "*Civil construction thermal design code*" uses the average temperature of the coldest month (January) and the hottest month (July) of the year as the main index of the partition, the days of annual average temperature ≤5°C and ≥25°C as the auxiliary index, China is divided into severe cold, cold, hot summer and cold winter, temperate, hot summer and warm in winter, and puts forward the corresponding design requirements.

Table. 3.1 The zoning index and design principle of building thermal design

Building Thermal Zoning in China			
Zoning name	Zoning Indicator		Design Principle
	Main Indicator	Auxiliary Indicator	
Server Cold	$t_{min,m} \leq -10℃$	$145 \leq d_{\leq 5℃}$	Must fully meet the requirements of winter insulation, generally do not consider the heat prevention in summer
Cold	$-10℃ < t_{min,m} \leq 0℃$	$90 \leq d_{\leq 5℃} < 145$	Thermal insulation requirements should be met in winter, and some areas should take into account heat prevention in summer
Hot summer, Cold winter	$0℃ < t_{min,m} \leq 10℃$	$0 \leq d_{\leq 5℃} < 90$	It must meet the requirements of heat prevention in summer and take into account heat prevention in winter
	$25℃ < t_{max,m} \leq 30℃$	$0 \leq d_{\geq 5℃} < 110$	Must fully meet the requirements of heat prevetion in summer, generally do not consider winter insulation
Hot summer, Warm winter	$10℃ < t_{min,m}$	$100 \leq d_{\geq 5℃} < 200$	Must fully meet the requirements of heat prevention in summer, generally no need to consider winter insulation
	$25℃ < t_{max,m} \leq 29℃$		
Temperate	$0℃ < t_{min,m} \leq 13℃$	$0 \leq d_{\leq 5℃} < 90$	Some areas should consider winter insulation, generally do not consider the heat prevention in summer
	$18℃ < t_{max,m} \leq 25℃$		

- $-t_{min,m}$: Mean temperature of coldest month;
- $-t_{max,m}$: Mean temperature of hottest month;
- $-d_{\leq 5℃}$: The number of days when the daily average temperature is less than or equal to 5°C;

3.4 Summary

As the code reported above, the basic design principles are different for different zones. Cold zones need to be designed to winter insulation and keep warm as much as possible, while hot zones need to pay more attention to excessive solar radiation.

It can be known that although the standards can give designer some suggestions and coefficient indicators, China has a wide area spanning multiple climatic zones, and the characteristics of the five climate zones are quite different. Therefore, it is of practical significance to formulate the corresponding NZEB specifications according to the climatic zones, and to list the detailed design strategies that can be adopted.

For example, if you want to design a building in the severe cold zone (i.e., Harbin) where the temperature is minus 25 degrees Celsius, you can refer to a building in Quebec that has a Mediterranean climate and can only reach minus 5 degrees Celsius.

In the following chapters, we selected cities in five climate zones in China, and found cities with similar climates in developed countries. We will start with a simple climate analysis and then compare the design strategies of the NZEB demonstration buildings in the city.

It is important to note that we also tried to seek can reference NZEB buildings in Europe, considering the NZEB European architecture development is already very mature, but because of the influence of the European Mediterranean climate, most countries don't have very hot weather in summer, but in China in addition to the Temperate zone, most of the city will be more than 25 degrees Celsius in the summer. So, in order to compare the climate of more familiar cities, we locked in the scope of the Pacific region.

4 Methodology

China shows the determination to reduce carbon emissions and achieve nearly zero energy buildings recent years. Due to the limitation of China's current construction technology, nearly zero energy not means the real energy consumption will be reduced to zero, but to adapt to the climate characteristics and site conditions, through the passive building design greatly reduce building heating, cooling, lighting requirements, through active technical measures greatly improve the efficiency of energy equipment and system, make full use of renewable energy, with minimal energy consumption to provide comfortable indoor environment, and the indoor environment parameters meet the requirements of standards.

In order to accurately calculate the energy consumption of this complex building, we used AutoCAD, Rhino, Grasshopper, Ladybug, Honeybee and other tools.

Honeybee connects the visual programming environment of Grasshopper to four validated simulation engines. As it can be seen in Figure, Honeybee connects Grasshopper to widely used simulation engines like EnergyPlus, OpenStudio, Radiance and Daysim - which evaluate building energy consumption, comfort, and daylighting. These plugins enable a dynamic coupling between the flexible, component-based, visual programming interface of Grasshopper and validated environmental data sets and simulation engine which and creates a graphical, user friendly interface for simulations. EnergyPlus is the main simulation engine used in this study linked to Grasshopper via Honeybee.

We draw the lines of three layers plan through AutoCAD, then imported it into Rhino, and extrude the blocks through Grasshopper to form Honeybee zones. And then we defined the properties of the building materials, input the schedules of occupant, lighting and equipment. Importing and analyze standard weather data of the selected location in Grasshopper through ladybug, and create the HVAC system, calculate energy consumption for heating, cooling, ventilation and lighting of the building through EnergyPlus.

Figure4.1 Ladybug and Honeybee work scheme
(Source: http://www.grasshoppper3d.com/group/ladybug

Methodology

Climate & Basic Setting

Architecture Modelling

Taken press conference hall as an example

Weather file. epw

Climate & Basic Setting

Simplified plans. dxf

Architecture Modelling

JGJ67-2006
ISO17772-1
DB11/687-2015

Energy Modelling

Result Analysis

GB/ T5130-2019

No

NZEB?

Yes

Stop

1st Floor
① Press conference hall
② Exhibition reception center
③ Lobby
④ Restaurant
⑤ Closed office
⑥ Conference room
⑦ VIP lounge
⑧ VIP reception

1st floor

Ground Floor
① Press conference hall
② Exhibition reception center
③ Lobby
④ Restaurant
⑤ Closed office
⑥ Rest room

Ground floor

Underground Floor
① Parking lot
② Warehouse
③ Equipment room

Underground floor

Energy Modelling

Taken press conference hall as an example

Lighting and equipment schedule

Occupancy schedule

0	0.00
1	0.00
2	0.00
3	0.00
4	0.00
5	0.00
6	0.00
7	0.00
8	0.00
9	0.00
10	0.00
11	0.00
12	0.00
13	0.00
14	0.00
15	0.00
16	0.00
17	0.00
18	0.00
19	0.00
20	0.00
21	0.00
22	0.00
23	0.00

0	0.00
1	0.00
2	0.00
3	0.00
4	0.00
5	0.00
6	0.00
7	0.00
8	0.00
9	0.50
10	0.80
11	0.90
12	0.80
13	0.00
14	0.70
15	0.80
16	0.80
17	0.70
18	0.00
19	0.00
20	0.00
21	0.00
22	0.00
23	0.00

0	0.00
1	0.00
2	0.00
3	0.00
4	0.00
5	0.00
6	0.00
7	0.00
8	0.00
9	0.50
10	0.50
11	0.50
12	0.50
13	0.00
14	0.50
15	0.50
16	0.50
17	0.50
18	0.00
19	0.00
20	0.00
21	0.00
22	0.00
23	0.00

AnnualSchedule — VER 0.0.62 JUL_28_2017

_sun, _mon, _tue, _wed, _thu, _fri, _sat, holiday_, coolDesignDay_, heatDesignDay_, ------------, _scheduleName, schedTypeLimits_, _runIt

readMe!, ----------, schedule, ----------, weekSched, schedIDFText

Conference_Occupancy

Toggle True

Cooling setpoint schedule

Heating setpoint schedule

0	5
1	5
2	5
3	5
4	5
5	5
6	5
7	5
8	5
9	5
10	5
11	5
12	5
13	5
14	5
15	5
16	5
17	5
18	5
19	5
20	5
21	5
22	5
23	5

0	16
1	16
2	16
3	16
4	16
5	16
6	16
7	16
8	16
9	
10	20
11	20
12	20
13	16
14	20
15	20
16	20
17	
18	16
19	16
20	16
21	16
22	16
23	16

AnnualSchedule — VER 0.0.62 JUL_28_2017

_sun, _mon, _tue, _wed, _thu, _fri, _sat, holiday_, coolDesignDay_, heatDesignDay_, ------------, _scheduleName, _schedTypeLimits_, _runIt

readMe!, ----------, schedule, ----------, weekSched, schedIDFText

Conference_heating

Temperature

Toggle True

Taken press conference hall as an example

Gene pool contains a collection of variables

24 defined values to generate occupancy of each hour on Sunday

Gene pool contains a collection of variables

24 defined values to generate occupancy of each hour on Monday to Friday

Gene pool contains a collection of variables

24 defined values to generate occupancy of each hour on Saturday

EnergyPlus Annual schedule

Add to EnergyPlus library

EnergyPlus Annual schedule

24 defined values to generate temperature set point of each hour on Monday to Saturday

Gene pool contains a collection of variables

24 defined values to generate temperature set point of each hour on Sunday

Gene pool contains a collection of variables

Schedule name

Conference occupancy

Conference lighting

Conference electricity

Schedule name

Conference heating

Conference cooling

Taken press conference hall as examples

Sys11_Fan Coil Units + DOAS

Airloop

Diagram labels (top figure): AvailabilitySchedule, DCV, DemandControlledVentilationNoFail, Name, SystemOutdoorAirMethod, Toggle True, ZoneSun, TemperatureAndHumidityRatio, ControlVariable, Brep, AvailabilitySchedule InWaterTemp OutWaterTemp, AvailabilitySchedule, AvailabilitySchedule FanTotalEfficiency MotorEfficiency Name PressureRise, MaximumOutdoorAirFlowRate, params Ctrl, params Ctrl, MechVentCtrl params OACtrl, AvailabilitySchedule P, params Coil ToWaterLoop, params AT, ref n objs, OA_Fan 500, params Coil ToWaterLoop, ref n objs ToWaterLoop, params Coil ToWaterLoop, ref n objs ToWaterLoop, params Fan, coilH coilC fan params 4PipeFanCoil, _HBZones AirTerminal Equipment Zones Sizing params, ExStream HeatRecovery OAStream Controller OA, _ctrl params Coil ToWaterLoop, params Coil ToWaterLoop, Efficiency Name PressureRise, AvailabilitySchedule P, params Fan, params Humidifier, _Temp var SPM, _min _max SPM, _min _max SPM, B1 B2 Branches, VentilationRequirement, typeOfLoad params, params Sz, Merge D1-D9 R, supply demand sizing params AirLoop, AirLoops PlantLoops VRFSystems HVACSystem

Lower flowchart:

- In/Our water temp → Heating coil
- Available schedule → Heating coil
- Available schedule → Water cooling coil
- Heating coil → Heating coil
- Water cooling coil → Cooling coil
- Available schedule, Fan total efficiency, Motor efficiency, Pressure rise → Fan
- VAV system no reheat → Air terminal
- Heating coil → Air terminal
- Fan → 4 Pipe fan coil
- 4 Pipe fan coil → Thermal zone
- Mechanical ventilation controller → Outdoor air system controller → Outdoor air system
- Temp & Humidity ratio controller → Water cooling coil
- Available schedule → Water cooling coil
- Available schedule → Heating coil
- Fan efficiency, Pressure rise → Fan variable volume
- Humidifier steam electric
- Available schedule → Setpoint manager schedule
- Thermal zone → Air loop branch
- Ventilation on requirement → Type of load
- Cooling or heating supply source → Air loop
- Zone branch and other HVAC component → Air loop
- HVAC component
- Air loop → HVAC system

Climate & Basic Setting

Weather file. epw

Architecture Modelling

Simplified plans. dxf

JGJ67-2006
ISO17772-1
DB11/687-2015

Energy Modelling

Result Analysis

GB/ T5130-2019

No

NZEB?

Yes

Stop

1. Thermal Zone Classification

Press conference hall
Exhibition reception center
Lobby
Office
Conference
Restaurant
VIP reception
Lounge
Corridor
Warehouse
Toilet
Core tube

2. Thermal Template

Operative temperature
Relative humidity
Ventilation air flow rate
Relative humidity
Internal gain
Heating & cooling Set point
Usage schedule

3. Materials Template

Roof
Wall
Floor
Exposed floor
Window

4. HVAC system

Air loop
Plant loop

The flowchart contains the following text elements:

Input documents (left column):
- Weather file. epw
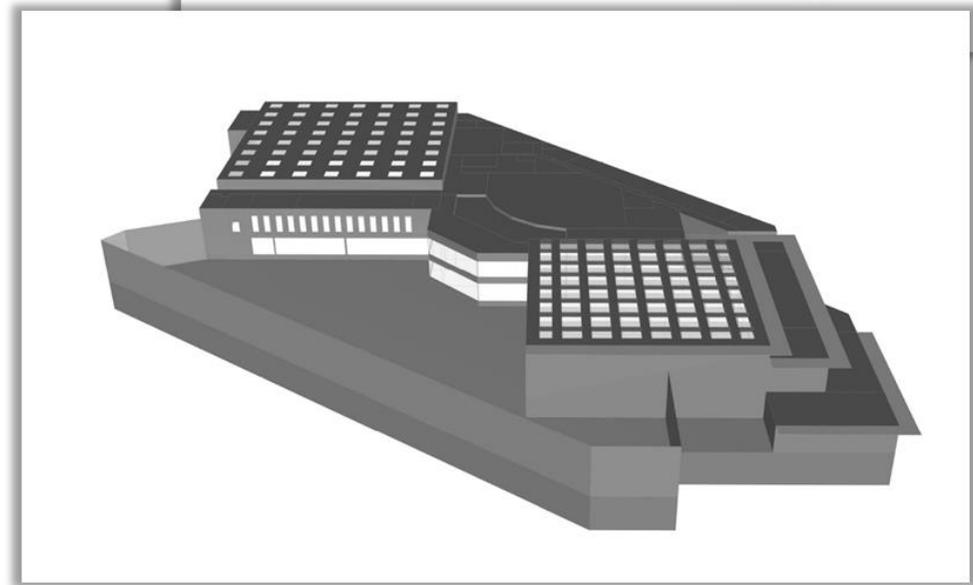- Simplified plans. dxf
- JGJ67-2006 ISO17772-1 DB11/687-2015
- GB/ T5130-2019

Process boxes (center column):
- Climate & Basic Setting
- Architecture Modelling
- Energy Modelling
- Result Analysis
- NZEB?
- No
- Yes
- Stop

Output branches (right):
- Zone energy use

Energy end use for heating, cooling, humidification. Electricity for lights and plug loads and auxiliary.

Comprehensive energy consumption in difference cases.

- Zone comfortable metrics

Operative temperature

Relative humidity

The building comprehensive energy saving rate should be higher than 60%, the energy saving rate of building body should be higher than 30%, The compr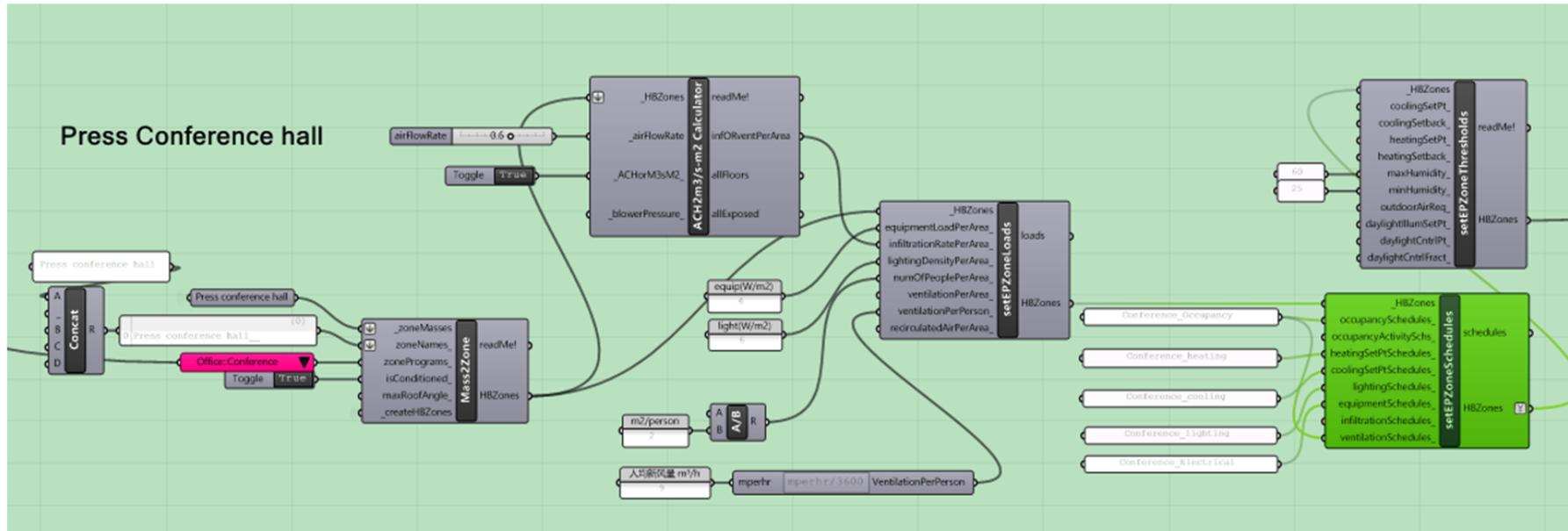ehensive value of building energy consumption of nearly zero energy public building in Beijing should be lower than 73kWh/m²·a, and the equivalent electricity should be lower than 28kWh/m²·a.

Utilization of renewable energy should be higher than 10%

5 Mountain Press Center of Beijing 2022 winter Olympics games

5.1 Project overview

Figure 5.1 Project rendering

The project is located in the southern district of Yanqing competition area of Beijing 2022 winter Olympic Games and winter Paralympic Games. It includes the press conference hall, news media working area, multi-functional activity area, rest area and other functional areas, and is closely connected with the traffic facilities of the competition area. It can provide international and professional services for news media and journalists during the competition. The total construction area of the project is 17,528m², and the total land area is 22,960m ². One floor underground, two floors above ground, the height of the building is 15.3m and the buried depth of the basement is 6.5m.

Figure 5.2 Elevation

1st Floor
① Press conference hall
② Exhibition reception center
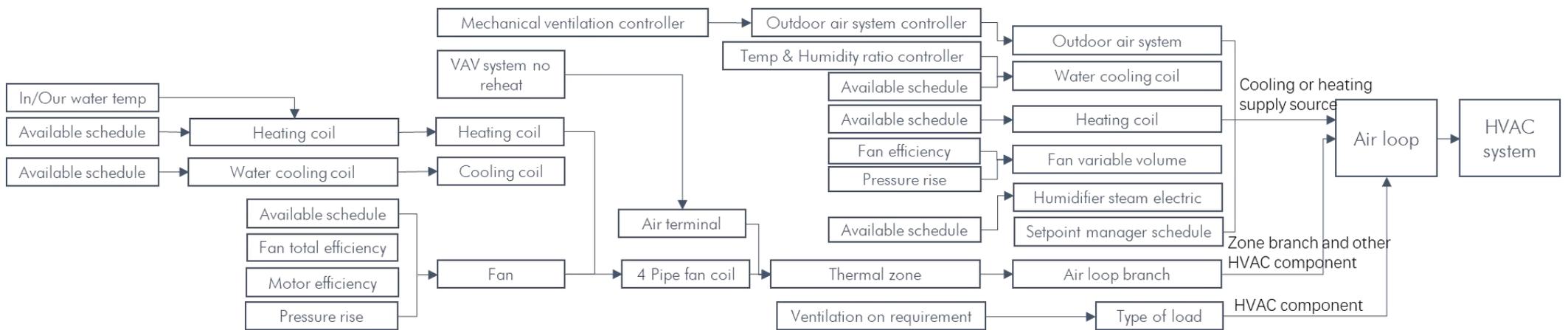③ Lobby
④ Restaurant
⑤ Closed office
⑥ Conference room
⑦ VIP lounge
⑧ VIP reception

Ground Floor
① Press conference hall
② Exhibition reception center
③ Lobby
④ Restaurant
⑤ Closed office
⑥ Rest room

Underground Floor
① Parking lot
② Warehouse
③ Equipment room

1st floor

Ground floor

Underground floor

Figure 5.3 Plan of underground floor, ground floor and first floor

5.2 Site climate design

- **Location**

Figure 5.4 Location of Beijing

Yanqing district belongs to Beijing, the capital of the People's Republic of China.

Coordinates: 39°55'N,116°23'E

Building thermal design zone: Cold

Köppen climate classification: Monsoon-influenced humid continental climate (Dwa)

- **Temperature**

Beijing Yanqing has a humid continental climate, characterized by hot, humid summers due to the East Asian monsoon, and cold, windy, dry winters that reflect the influence of the vast Siberian anticyclone. The annual average temperature is 11.5°C, the monthly average temperature of January is -5.5 °C and that of July is 26.6 °C.

Figure 5.5 Monthly average dry bulb temperature and psychrometric chart of Beijing

- **Relative humidity**

Spring can bear witness to sandstorms blowing in from the Gobi Desert across the Mongolian steppe, accompanied by rapidly warming, but generally dry, conditions. Autumn, similar to spring, is a season of transition and minimal precipitation. Precipitation averages around 570 mm annually, with close to 75% of that total falling from June to August. Beijing experiences extreme seasonal variation in the perceived humidity, with dry winter and spring which the monthly average relative humidity could achieve around 40%. And relatively wet summer and autumn with the monthly average relative humidity no more than 80%.

Figure 5.6 Monthly average participation and relative humidity of Beijing

According to the climatic characteristics of the cold zone and the site temperature and humidity, The energy conservation design principle of this project should focus on solving the problem of overcooling in winter. Meet the thermal insulation requirement and increase indoor humidity appropriately in winter, properly ventilate in middle season are the principle consideration.

Build most of the building area below the overlaying soil, only a small part of the building body is exposed to the outside, which reduces the heat loss caused by the external wall as much as possible and helps to reduce the heating energy consumption of the building.

- **Wind**

Figure 5.7 Windrose in summer and winter, and windspeed of Beijing

In summer, it was dominated by southeast wind, with the maximum wind direction and average wind speed about 4.0m/s. In winter, it is mainly dominated by west-northwest wind, with the maximum wind direction and average wind speed of about 5.3m/s. From the wind environment, it can be seen that the overall outdoor wind speed of the site is relatively high. It is not conducive to the wind environment control of the outdoor site in winter, and the building should take more consideration of wind protection design in winter, but the favorable season of natural ventilation is concentrated in summer from May to September and transition season. Opening Windows in these months can make full use of natural ventilation for passive refrigeration, which is conducive to reducing the opening time of air conditioning.

According to the analysis of meteorological wind roses, the dominant wind direction in summer is southwest (SE) and the dominant wind direction in winter is west-northwest (WNW). Therefore, for the ground part of the building, natural ventilation mode should try to use the dominant wind direction in summer for natural ventilation, therefore, the construction of main direction towards the south by east 33 ° or so, can make the most of the leading wind of natural ventilation in order to reduce air conditioning usage time, at the same time, the construction of the northwest edge by setting the porch, arc curtain wall, gable, etc, from design, to reduce the winter cold wind.

Figure 5.8 Schematic diagram of site ventilation

The ventilation design of the passive building, on the one hand, aims to disperse the heat from the solar radiation into the room during the winter days to other indoor (north room), as far as possible store more heat, on the other hand in summer night, to fully mobilize outdoor cool air, heat to the indoor high heat storage wall, storage cold load. The high air tightness of passive buildings can not only reduce the heat and cold load loss caused by air infiltration, but also play an important role in ventilation design.

Optimize the natural ventilation organization, design the natural ventilation air passage reasonably, adopt the natural ventilation measure in the middle season. Reduce the duration of active cooling measures, thereby reducing energy costs.

● Solar radiation

According to the above figure, sunshine in Beijing, the highest value could reach to 700Wh/m², and the monthly daily total direct normal radiation could reach above 3500Wh//m² in September and October. In summer from June to August, solar radiation is not as high as that in winter.

Figure 5.9 Direct normal radiation of Beijing

Based on the site selection of the current building, the solar radiation in winter and summer of the building site was simulated. In winter, the land slope of the south side of the site, and the solar heat gain is relatively abundant, while the north side is relatively flat, and the solar heat gain is relatively insufficient. Due to the high relative value of solar altitude angle in summer, heat gain in summer is relatively uniform except for the steep slope on the east side of the site. So we can think about solar renewable energy on the site, and also need to consider the heat protection in summer, and design shading system in the appropriate place.

Figure 5.10 Direct solar radiation in winter and summer

The main orientation of the facade of this project is southeast, and the sun visor is a tool for adjusting the solar radiation. In summer, the sun with a high altitude Angle will fall on the top of the sun visor, shielding the sun from entering the room. Winter solar Angle lower solar radiation will shoot into the low Angle of sunlight, for indoor heating.

Based on the local weather data of temperature and humidity, the solar shading analysis was carried out on the facade facing 33° southeast, and the conclusion was drawn that when the solar height Angle of the shading system was 70°, the main orientation facade met most of the comfort requirements.

Figure 5.11 Main orientation shading analysis in summer and winter

The transparent southeast envelope of the project adopts overhanging shading measures to reduce solar radiation on the building. The influence of cooling load, then reduce the cooling load of indoor air conditioning, reduce the building energy cost.

The solar radiation distribution of the glass surface of the building in winter and summer is analyzed respectively through the radiant heat gain analysis of the external Windows of the building, and passive heating is conducted in winter by means of the solar radiation distribution of the glass surface of the building through the Windows of the south elevation with low incident Angle.

Figure 5.12 Solar thermal analysis diagram of exterior window elevation in summer and winter

5.3 The Path to Nearly Zero Energy Building

Mountain press center is located in the southern district of Yanqing competition area of Beijing 2022 winter Olympic games and winter Paralympic games, which is closely connected with the transportation facilities of this competition area. Because of the large building area and dozens of rooms in the project, the simulation model is complex. Therefore, in the first step, we mainly analyze the two rooms with main functions —— Press conference hall and Exhibition reception center.

5.3.1 Baseline

5.3.1.1 Model Description

Figure 5.13 Press conference hall

The press conference hall is one of the most important functional areas of the mountain press center, which can provide event news release during the competition and provide international and professional services for news media and journalists.

Figure 5.14 Exhibition reception center

The exhibition reception center can provide reception for large national and international groups during the competition and as an exhibition of Olympic culture venues after competition.

Table 5.1 Information of model

Press conference hall			Exhibition reception center		
Length	m	34.2	Length	m	41.3
Depth	m	34.2	Depth	m	42.6
Height	m	12	Height	m	12
Gross wall area	m²	1169.6	Gross wall area	m²	1759.4
Volume	m³	14036	Volume	m³	21112.6
Window-wall ratio	\	20%	Window-wall ratio	\	0%
Skylight-roof ratio	\	36%	Skylight-roof ratio	\	18%

The Press conference hall is a square cube facing southwest, with length and width of 34.2m and height of 12m.The main envelope structure is a thermal insulation stone gabion wall and high-performance glass curtain wall. The window-wall ratio is 0.2. The roof is designed with high side windows for natural lighting, and the skylight-roof ratio is 0.36.

The exhibition reception center is a rectangular plane, 41.3 meters long, 42.6 meters wide, and 12 meters high. The main structure is The main structure is the exposed concrete coating wall (including thermal insulation). Because most of the parts are underground, there is no window on the external wall. Lighting is achieved through circular skylights. The ratio of skylight to roof is 0.18.

5.3.1.2 Construction Template

In the first design stage, we set the construction template of the baseline based on "Energy conservation design standard of Beijing public buildings DB11/687-2015".

Table 5.2 Insulation performance of non-transparent enclosure structure component

Insulation performance of non-transparent enclosure structure components				
Component	Insulation Materials	Insulation width [mm]	U [W/m²·K]	Construction
External wall overground	Rock wool	105	0.38	200mm aerated concrete block wall
External wall underground	Extruded polystyrene board	115	0.38	300mm concrete wall
Internal wall	Rock wool	25	1.5	120mm aerated concrete block wall
Roof	Extruded polystyrene board	135	0.33	150mm concrete floor
External door	\	\	3	\
Internal door	\	\	3	\
Basement floor	Rock wool	88	0.45	150mm concrete floor

Table 5.3 Insulation performance of transparent enclosure structure component

Insulation performance of transparent enclosure structure components				
Component	Composition	U [W/m²·K]	SHGC	Construction
Skylight window	Glazing	2	0.35	4(low-e)+16Air+4(low-e)mm double glass
	Frame	\	\	Wood clad aluminum window frame
	All	2		High strength plastics
External window	Glazing	2.8	0.35	4+16Air+4mm double glass
	Frame	\	\	Wood clad aluminum window frame
	All	2.7	\	\

5.3.1.3 Thermal Template

We create only one thermal templates for analysis. According to office building design regulations JGJ67-2006 related number of people index requirements, the number of users of Press conference hall is 520, and the number of users of exhibition reception center is 1200. Because the news media release has periodic, irregular and temporary characteristics, the press conference hall is treated as a meeting room and exhibition reception center is treated as an exhibition room for energy simulation analysis.

There is no detailed user occupancy schedule for meeting room and exhibition in the current regulations of China, we got the reference from ASHRAE and ISO17772-1:2017 "Energy performance of buildings —Indoor environmental quality—Part1: Indoor environmental input parameters for the design and assessment of energy performance of building".

- Indoor environmental quality

Table 5.4 Categories of Indoor environmental quality

Categories of indoor environmental quality	
Category	Level of expectation
IEQI	High
IEQII	Medium
IEQIII	Moderate
IEQIV	Low

From the table of indoor environmental quality categories, we could treat the press conference hall and exhibition reception center as the medium level IEQ$_{II}$.

- Temperature

Table 5.5 Categories of operative temperature

Type of building/space	Category	Operative temperature[℃]	
		Minimum for heating (winter season), approximately 1,0 clo	Maximum for cooling (summer season), approximately 0,5 clo
Resudential building, other spaces(untility rooms, storages ect.) Standing-walking activity~1,5 met	I	18,0	
	II	16,0	
	III	14,0	
Offices and spces with similar activity (single iffices,oen plan offices, conference rooms,auditorium, cafeteria,restaurants,class rooms), class rooms, Sedentary activity~1,2 met	I	21,0	25,5
	II	20,0	26,0
	III	19,0	27,0
	IV	18,0	28,0
Note A50% relative humidity level and low air velocity level(<0,1 m/s) is assumed			

For design of buildings and dimensioning of room conditioning systems the thermal comfort criteria (minimum room temperature in winter, maximum room temperature in summer) shall be used as input for heating load and cooling load calculations. The heating and cooling setpoint of templates could be 20°C and 26°C separately. And during the unoccupied period, the heating and cooling setpoint of templates could be 16 and 32°C.

- Relative humidity

Table 5.6 Recommended design criteria for relative humidity

Example of recommended design criteria for humidifity in occupied spaces if humidification ot dehumidification systems are installed			
Type of building/space	Category	Design relative humidity for dehumidification, %	Design relative humidity for humidification, %
Spaces where humidity criteria are set by human occupancy.(Special spaces, such as museums, churches stc.may require other limites)	I	50	30
	II	60	25
	III	70	20
Besides it is recommended to limit the absolute humidity to 12g/kg			

For buildings with no other humidity requirements than human occupancy, humidification or dehumidification is usually not needed, the values in the table recommended as design value under design conditions, and we use the value for energy modelling in the relative humidity is between 25% and 60%.

- Ventilation

Table 5.7 Recommended design criteria for total ventilation, supply air flow

Criteria based on pre-defined supply ventilation air flow rates: Total ventialtion(1), Supply air flow(2) and(3)					
Category	Total ventiation in-cluding air infiltration(1)		Supply air flow per person(2)	Supply air flow based on perceived IAQ for adapted person(3)	
	l/s,m^2	ach	l/s·per	qp l/s(per person)	qb l/s(m^2)
I	0,49	0,7	10	3,5	0,25
II	0,42	0,6	7	2,5	0,15
III	0,35	0,5	4	1,5	0,1
IV	0,23	0,4			

The indoor air quality is then expressed as the required level of ventilation or CO_2 concentrations. It is general accepted that the indoor air quality is influenced by emission from people and their activities (bio effluent, smoking), from building and furnishing, and from the HVAC system itself. The two last sources are normally called the building components. The required ventilation is based on health and comfort criteria. In most cases the health criteria will also be met by the required ventilation for comfort.

The basic calculation should be considered as below:

Total ventilation rate for a room is calculated from the following formula

$$q_{tot} = n \cdot q_p + A \cdot q_b$$

Where:

- q_{tot} — total ventilation rate of the room, l/s
- n — design value for the number of the persons in the room,
- q_p — ventilation rate for occupancy per person, l/s, pers
- A — room floor area, m^2
- q_b — ventilation rate for emissions from building, l/s,m^2

We use Table I.6 from ISO 17772-1 to decide the total ventilation rate of room, and we set the total ventilation including air infiltration is 0.6ach, and the supply air flow for adapted person is 2.5l/s(per person).

- Internal gain

Table 5.8 Recommended design criteria for operation time, internal gain and setpoint

	Parameter	Value	Unit
Operation time	Hour at days, START	7	hours
	Hour at day, END	18	hours
	Breaks, indside range	0	hours
	days/week	5	days
	hours/year	2868	hours
Internal gain	Occupanyts	2	m²/pers
	Occupanyts(Total)	8,3	W/m²
	Occupanyts(Dry)	5	W/m²
	Appliances	12	W/m²
	Lighting		
	Moisture production	30,00	g/(m²,h)
	CO2 prodution	9,35	l/(m²,h)
Setpoints	Min T,op in unoccupied hours	16	°C
	Max T,op in unoccupied hours	32	°C
	Min T,op	20	°C
	Max T,op	26	°C
	Ventilation rate (min)	3,8	l/(s·m²)
	Ventilation rate for CO2 emission	5,11	l/(s·m²)
	Max CO2 concentratioin (above outdoor)	500	ppm
	Min. relative humidity	25	%
	Max. relative humidity	60	%
	Lighting illuminance in working areas	100	lux

For people occupancy profile, we consider the floor area 2m²/person for meeting room. The non-heated zone is not considered to have a stable presence of people inside because people are usually present for very short time. It is assumed that the occupant produce 5W/m² internal gains, and the appliances we consider is 12W/m². We plan to choose the fluorescent linear light with power of 24W/m and lay it around the square sky light with the total quantity of 647m. According to the total flat area of 1169.6m², the indoor lighting power density can be obtained as 13.3W/m².

In exhibition room, we consider the floor area 5m²/person, and plan to choose compact fluorescent spotlight with power of 4W and lay it around the circular skylight with total quantity is 25*180, according to the total floor area of 1759.4m², the indoor lighting power density can be obtained as 10.2 W/m².

- Usage schedule

The usage schedule plan of occupant, lighting and appliance shows as showing in the following tables.

Table 5.9 Recommended design criteria for occupant schedule

h	Weekdays			Saturday			Sunday and holiday		
	Occupants	Appliances	Lighting	Occupants	Appliances	Lighting	Occupants	Appliances	Lighting
1	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0
9	0,5	0,5	0,5	0	0	0	0	0	0
10	0,8	0,8	0,8	0	0	0	0	0	0
11	0,9	0,9	0,9	0	0	0	0	0	0
12	0,8	0,8	0,8	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0
14	0,7	0,7	0,7	0	0	0	0	0	0
15	0,8	0,8	0,8	0	0	0	0	0	0
16	0,8	0,8	0,8	0	0	0	0	0	0
17	0,7	0,7	0,7	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0

(Table header spanning title: Energy calulation)

Since the press conference hall has been treated as a meeting room, on weekdays we assumed that at 9:00 AM, 50% occupants are already been here, at 10:00 AM, 80% occupants are in, while at 11:00 AM 90% occupants are present. There is a lunch break at 13.00 PM. At 18:00 people work off and go home, we consider no occupants in the meeting room. On Saturday, we also see it as a 50% occupancy during working hours, depending on the actual situation. We consider the usage schedule of appliance and lighting are the same as the occupants.

Since there is no usage schedule for exhibition in ISO17772-1:2017, we checked the ASHRAE, and found the occupant, lighting and equipment scheduling of exhibition. on weekdays except Monday, we assumed that at 10:00 AM, 30% occupants are already been here, at 11:00 AM, 50% occupants are in, while at 12:00 PM 90% occupants are present, at 16:00 PM 70% occupants are here and at 17:00 AM 50%, from 18:00 to 19:00, occupants started to leave. Because of the special nature of the exhibition hall, It will still be in use on weekends and will only be closed on Mondays.

Figure 5.15 Occupant, lighting and equipment usage schedule of Press conference hall

Figure 5.16 Occupant usage schedule of Exhibition reception center

Figure 5.17 Lighting and equipment usage schedule of Exhibition reception center

● Heating and cooling

Instead of simple on-off system, in our project heating and cooling plants are modelled to have a set point and setback temperature.

Heating and cooling setback temperature can be used to keep occupied spaces conditioned to avoid frost and overheating during periods when the building is not occupied. Internal comfort temperature for winter is defined at 20°C, and for summer is 26°C. For the cooling plant we set a maximum temperature of 32°C, during 9:00 AM and 17:00 PM the temperature is set at 26°C(For Exhibition reception center is during 10:00 AM and 19:00 PM). For the heating plant the setback temperature before and after working hours is set at 5°C, and for cooling is set at 37°C. This profile can decrease energy consumption.

Figure 5.18 Heating and cooling system profile of press conference hall

Figure 5.19 Heating and cooling system profile of exhibition reception center

5.3.1.4 End use of baseline

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
■ Heating	28.93	17.70	11.07	1.22	0.00	0.00	0.00	0.00	0.01	2.74	13.22	22.79
■ Auxiliary	1.30	0.83	1.18	1.46	1.68	1.09	1.25	0.91	0.56	1.11	0.83	1.05
■ Humidification	4.19	3.05	2.25	2.24	0.50	0.03	0.01	0.06	0.08	0.38	2.10	3.33
■ Light and equipment	3.55	3.26	3.70	3.36	3.70	3.55	3.50	3.70	3.50	3.55	3.55	3.50
■ Cooling	0.00	0.00	0.02	0.05	2.00	5.53	6.18	5.59	2.89	0.67	0.00	0.00

	Natural gas	Electricity
■ Heating	97.69	
■ Auxiliary		13.24
■ Humidification		18.21
■ Light and equipment		42.43
■ Cooling		22.94

Figure 5.20 End use _ press conference hall of baseline

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
■ Heating	19.02	10.17	4.98	0.54	0.00	0.00	0.00	0.00	0.01	1.32	6.74	15.12
■ Auxiliary	1.12	0.85	0.80	1.00	0.93	1.07	1.12	0.98	0.63	0.65	0.82	1.03
■ Humidification	2.63	1.87	1.50	1.99	0.56	0.00	0.00	0.04	0.06	0.26	1.35	2.14
■ Light and equipment	3.55	3.26	3.65	3.55	3.52	3.52	3.55	3.65	3.52	3.55	3.52	3.68
■ Cooling	0.00	0.00	0.00	0.00	0.60	2.08	2.11	2.11	0.97	0.08	0.00	0.00

	Natural gas	Electricity
■ Heating	57.91	
■ Auxiliary		11.00
■ Humidification		12.40
■ Light and equipment		42.53
■ Cooling		7.96

Figure 5.21 End use_ exhibition reception center
of baseline

From the press conference hall and exhibition reception center end use of baseline, we can see that the most energy needs in this project are heating loads, lighting and equipment loads, and the cooling loads are low, especially in the exhibition underground without windows. Otherwise, the end use for press conference hall is higher than which for exhibition reception center, that is because the design occupancy in press conference hall is 2m^2/person, in exhibition reception center is 5m^2/person.

5.3.2 Efficient lighting and equipment

According to the national standards to determine the power density of building lighting, reasonable layout of the number and location of lighting lamps. Indoor lighting power density (LPD) values conform to the national standard "building lighting design standard" GB50034 city night scene illumination design specification and the relevant provisions of the JGJ/T163, rooms and public areas of the intensity of illumination, intensity of illumination evenness, unified glare value, color rendering index commonly indexes meet the building lighting design standard "GB50034-2013" requirements. According to the function, nature, ambient area brightness, surface decoration material determine illumination and brightness standard value.

In order to reduce reactive power loss and meet the requirement of energy saving evaluation, we plan to use LED lamps with the same illumination and lighting effect instead of fluorescent lamps. LED lamps should meet the following requirements: straight tube lamp system efficiency ≥80lm/W, down lamp system efficiency ≥75lm/W; power factor of driving power supply ≥0.9, conversion efficiency of driving power supply ≥80%;

In conference press hall of baseline, we choose the fluorescent linear light with power of 24W/m and lay it around the square sky light, in the design case1, we use the LED lamps with the same illumination and light efficiency, and the power is only 11W/m with the same total quantity of 647m. And the Indoor lighting power density can be reduced from 13.3W/m² to 6W/m².

In exhibition room of baseline, we choose the compact fluorescent spotlight with power of 4W and lay it around the circular skylight with total quantity is 25*180, here we plan to use the LED spotlight with power of 2W which has the same illumination and lighting effect, according to the total floor area of 1759.4m² , the indoor lighting power density can be reduced from 10.2W/m² to 5.1W/m².

Table 5.10 Indoor lighting of baseline and design case1

Conference press hall	Light	Lamp power [W/m]	Indoor lighting power density [W/m²]
Baseline	Linear Fluorescent Lamps	24	13.3
Design case1	Linear LED Lamps	11	6

Exhibition reference center	Light	Lamp power [W]	Indoor lighting power density [W/m²]
Baseline	Compact fluorescent spotlight	4	10.2
Design case1	LED spotlight	2	5.1

By using LED linear lamps and LED spotlight instead of linear fluorescent lamp and compact fluorescent spotlight which has the same illumination and lighting effect, and efficient equipment, the lighting and equipment energy end use were reduced by more than half. Meanwhile, due to the decrease of internal gain, heating loads increased slightly, and cooling loads decreased. According to energy conversion factor for electricity in China, we can conclude that 58-68kWh/m², or 18.2%-22.1% of annual comprehensive energy consumption can be reduced by using high efficiency lighting and equipment in this project.

Figure 5.22 End use _ press conference hall of design case

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Heating	30.47	18.52	11.58	1.31	0.01	0.00	0.00	0.00	0.02	2.91	13.96	24.17
Auxiliary	1.33	0.84	0.88	1.21	1.45	0.95	1.08	0.79	0.49	0.95	0.74	1.09
Humidification	4.21	3.09	2.20	2.19	0.43	0.03	0.01	0.06	0.08	0.37	2.12	3.37
Light and equipment	1.48	1.36	1.54	1.40	1.54	1.48	1.46	1.54	1.46	1.48	1.48	1.46
Cooling	0.00	0.00	0.01	0.04	1.77	5.05	5.68	5.11	2.47	0.42	0.00	0.00

Annual end use [kWh/m²]

	Natural gas	Electricity
Heating	102.93	
Auxiliary		11.79
Humidification		18.14
Light and equipment		17.68
Cooling		20.54

Conversion factor in China	
Natural gas	1.25
Electricity	2.60

	Heating	Cooling	Light and equipment	Humidification	Auxiliary
Baseline	122.11	59.65	110.33	47.35	34.43
Design case1	128.67	53.40	45.97	47.17	30.66

	Baseline	Design case1
Total	373.87	305.87

Figure 5.23 Comprehensive energy _ press conference hall of baseline and design case1

Figure 5.24 End use _ exhibition reception center of design case1

Conversion factor in China	
Natural gas	1.25
Electricity	2.60

Figure 5.25 Comprehensive energy _ exhibition reception center of baseline and design case1

5.3.3 High performance building envelope

High performance building envelope components can not only better meet the requirements of heat preservation, heat insulation, light transmission and ventilation, but also reduce energy consumption while maintaining a good indoor physical environment, achieving the purpose of energy conservation and emission reduction.

Including external wall insulation technology, high performance glass technology.

- **External wall insulation technology**

The main technical idea of passive building is that, on the one hand, the building envelope with high thermal insulation and air tightness can resist the influence of outdoor low temperature in winter, solar radiation in summer and outdoor high temperature on indoor thermal environment.

On the one hand, the building envelope wall is made of high heat storage material on the indoor side, so as to realize the goal of using solar energy for heating in winter and ventilation for cooling in summer.

Here we enhance the insulation performance by increasing the thickness of the insulation. The main way of exterior wall insulation technology is to make use of external insulation materials with a thickness of 150-200mm or more and highly air-tight enclosure structure, which is mainly used to resist the influence of outdoor low temperature in winter, solar radiation in summer and outdoor high temperature on indoor thermal environment. Generally speaking, the roof, outer wall, basement floor, underground wall and the non-transparent outer protective structure shall be completely covered with thick insulation materials, and the structural thermal bridge formed by beams, plates and columns shall not appear, and dew and mildew shall not occur.

For the inevitable hot bridge caused by metal connections to take blocking hot bridge facilities. This kind of construction makes the whole outer protective structure play the role of heat preservation in winter and heat insulation in summer. In the process of building design and construction, it is necessary to deal with all kinds of nodes.

Table 5.11 Insulation performance of non-transparent enclosure structure components

Insulation performance of non-transparent enclosure structure components				
Component	Insulation Materials	Insulation width [mm]	U [W/m²·K]	Construction
External wall overground	Rock wool	250	0.162	200mm aerated concrete block wall
External wall underground	Extruded polystyrene board	250	0.175	300mm concrete wall
Internal wall	Rock wool	150	0.251	120mm aerated concrete block wall
Roof	Extruded polystyrene board	250	0.177	150mm concrete floor
External door	\	\	0.8	\
Internal door	\	\	1.2	\
Basement floor	Rock wool	100	0.397	150mm concrete floor

- High performance glass technology

In winter, we can make full use of the solar radiation through the windows to heat the room, and at the same time, we can reduce the heat transfer and heat dissipation of the windows through the good insulation performance of the three layers of glass. Summer, through the use of good shading design and far infrared reflection glass, shade, reflect the outdoor sun and high temperature radiation. Low-e glass windows and shading design not only utilize solar energy in winter, but also prevent solar radiation in summer and enhance natural lighting.

Table 5.12 Insulation performance of transparent enclosure structure components

Insulation performance of transparent enclosure structure components				
Component	Composition	U [W/m²·K]	SHGC	Construction
Skylight window	Glazing	0.75	0.5	6(low-e)+16Ar+6+16Ar+6mm tempered hollow low-e glass
	Frame	\	\	Wood clad aluminum window frame
	All	0.8		High strength plastics
External window	Glazing	0.75	0.5	6(low-e)+16Ar+6(low-e)+16Ar+6mm tempered hollow double low-e glass
	Frame	\	\	Wood clad aluminum window frame
	All	0.8	\	\

The construction part of this project is implemented according to the three-star standard of green building in China. It is oriented to the goal of nearly zero-energy building and adheres to the principle of reducing carbon emissions by reducing energy consumption of conventional buildings. Therefore, the thermal performance of the structure is improved compared with DB11/687-2015 of Beijing public building energy conservation design standard (Baseline) .

Table 5.13 Comparison of insulation performance

Comparison of insulation performance		
Component	U value of baseline [W/m²·K]	U value of design case2 [W/m²·K]
External wall overground	0.38	0.162
External wall underground	0.38	0.175
Internal wall	1.5	0.251
Roof	0.33	0.177
External door	3	0.8
Internal door	3	1.2
Basement floor	0.45	0.397
Sktlight window	2.0	0.8
External Window	2.7	0.8

By increasing the insulation thickness of enclosure structure and change the glass material of window, reduce the thermal transmittance, and greatly reduce the heating loads, at the same time cooling loads and humidification loads are increased slightly. From the perspective of annual comprehensive energy consumption, it decreased by 36-70kwh/m², or 17.4%-22.8%.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
■ Heating	12.74	8.00	4.99	0.52	0.04	0.00	0.00	0.00	0.00	1.23	5.96	10.34
■ Auxiliary	0.40	0.33	0.56	0.67	0.74	0.54	0.57	0.48	0.35	0.46	0.38	0.36
■ Humidification	4.49	3.47	3.18	3.87	1.24	0.05	0.01	0.10	0.27	0.59	2.52	3.75
■ Light and equipment	1.48	1.36	1.54	1.40	1.54	1.48	1.46	1.54	1.46	1.48	1.48	1.46
■ Cooling	0.00	0.00	0.03	0.06	2.06	5.39	5.93	5.45	3.03	0.78	0.01	0.00

	Natural gas	Electricity
■ Heating	43.82	
■ Auxiliary		5.84
■ Humidification		23.53
■ Light and equipment		17.68
■ Cooling		22.75

Figure 5.26 End use _ press conference hall of design case2

Conversion factor in China	
Natural gas	1.25
Electricity	2.60

	Heating	Cooling	Light and equipment	Humidification	Auxiliary
■ Baseline	122.11	59.65	110.33	47.35	34.43
■ Design case1	128.67	53.40	45.97	47.17	30.66
■ Design case2	54.78	59.14	45.97	61.17	15.19

	Baseline	Design case1	Design case2
Total	373.87	305.87	236.26

Figure 5.27 Comprehensive energy _ press conference hall of baseline and design case1,2

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Heating	12.97	7.52	3.86	0.40	0.00	0.00	0.00	0.00	0.00	0.94	4.84	10.79
Auxiliary	0.63	0.55	0.56	0.45	0.30	0.32	0.34	0.31	0.23	0.39	0.57	0.62
Humidification	2.84	2.21	1.94	2.83	0.86	0.00	0.00	0.10	0.19	0.37	1.63	2.47
Light and equipment	1.46	1.34	1.50	1.46	1.44	1.44	1.46	1.50	1.44	1.46	1.44	1.51
Cooling	0.00	0.00	0.00	0.00	0.53	1.94	2.05	2.01	0.82	0.08	0.00	0.00

	Natural gas	Electricity
Heating	41.32	
Auxiliary		5.28
Humidification		15.43
Light and equipment		17.43
Cooling		7.44

Figure 5.28 End use _ exhibition reception center of design case2

Conversion factor in China	
Natural gas	1.25
Electricity	2.60

	Heating	Cooling	Light and equipment	Humidification	Auxiliary
Baseline	72.38	20.69	110.57	32.23	28.61
Design case1	84.07	18.21	45.32	30.96	27.45
Design case2	51.65	19.34	45.32	40.12	13.72

	Baseline	Design case1	Design case2
Total	264.48	206.02	170.16

Figure 5.29 Comprehensive energy _ exhibition reception center of baseline and design case1,2

5.3.4 Efficient HVAC system

To reduce energy consumption of building operation facilities, we should improve the efficiency of heating, cooling and ventilation system.

In our baseline, HVAC system is benchmark system—Fan coil + DOAS system.

A dedicated outdoor air system (DOAS) is a type of heating, ventilation and air-conditioning (HVAC) system that consists of two parallel systems: a dedicated system for delivering outdoor air ventilation that handles both the latent and sensible loads of conditioning the ventilation air, and a parallel system to handle the (mostly sensible heat) loads generated by indoor/process sources and those that pass through the building enclosure. Traditional HVAC systems, such as variable air volume (VAV) systems serving multiple zones, have potential problems in terms of poor thermal comfort and possible microbial contamination. Depending on the environment and the parallel system involved, in a DOAS setup the outdoor air system will handle some of the sensible load in addition to the latent load, and the parallel system will handle the remaining sensible load. The main point of a DOAS system is to provide dedicated ventilation rather than ventilation as an incidental part of the process of conditioning interior air.

The building has a dedicated outside air system (DOAS), using 100% outside air in Press conference hall and Exhibition hall, demand controlled ventilation based on CO2e sensors.

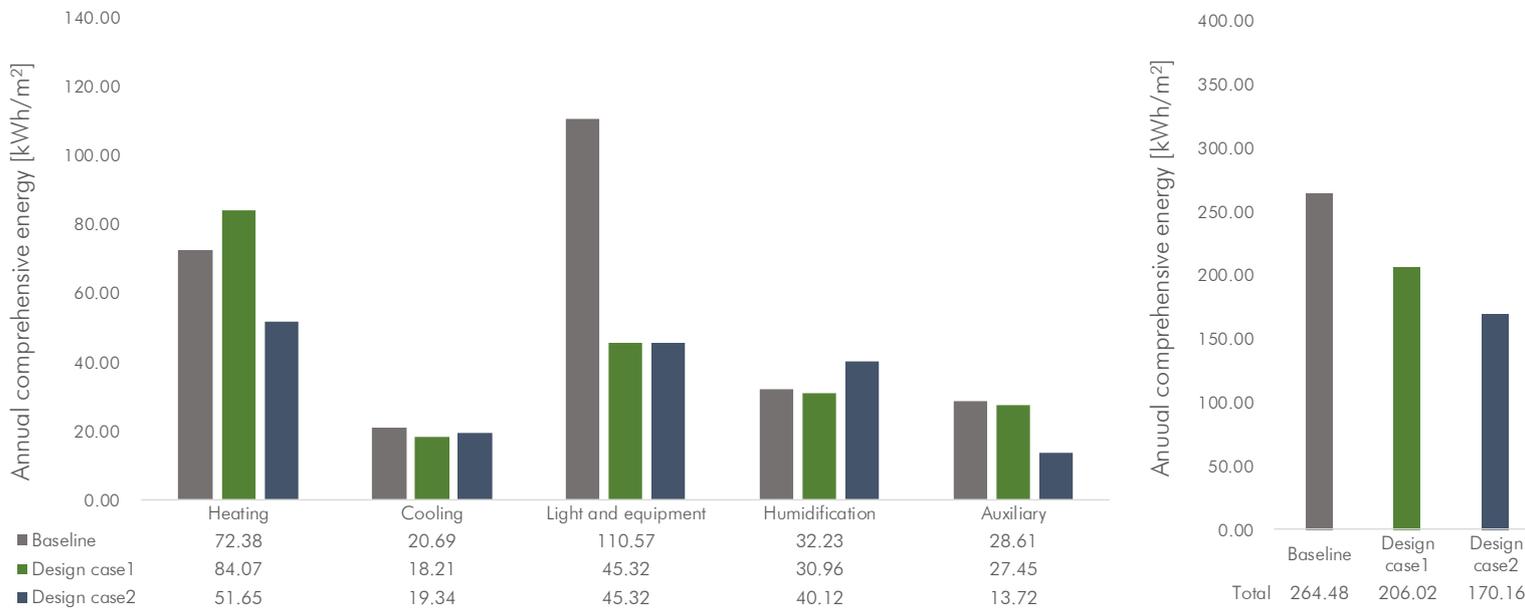The DOAS system delivers 30% more ventilation air than required by code and uses MERV 13 filters to filter out contaminants. Increasing the efficiency of filtration, especially for small particles, greatly improves indoor air quality. Nine eight-foot Essence and four Fans that efficiently promote air flow within the office.

The project is equipped with a low-temperature floor radiant heating system in the foyer on the first and second floors. Hot water from the air-conditioning system is mixed with water to obtain floor radiant heating hot water. The temperature of supply and return water is 45/35℃. The system is connected with the indoor buried pipe through the water distributor. PE-RT pipe is adopted as the pipe material, and the pipe layout adopts the rotary folding type.

Figure 5.30 Comparison between forced air heating and radiant floor heating (How does Underfloor Heating work, Daikin)

Fan-coil + DOAS are still used in the designing high efficient HVAC systems, and add the ground source heat pump system with COP values of 3.7 and 4.5 was used simultaneously, the heat recovery system which the efficiency is 0.75.

The use of high-efficiency heating and cooling equipment can effectively reduce the consumption of electric energy and further reduce the carbon emission of buildings.

(1) Ground source heat pump

This project mainly adopts the heat exchange system form of vertical buried pipe, with low operation and maintenance cost, small floor space, and no auxiliary heat source in winter. The heat pump unit adopts GSG water source screw unit, which has large cooling capacity and high efficiency, and is suitable for large public buildings.

Figure 5.31 Geothermal work process (Let your dirt warm your home - the magic of geothermal heating, Ewan Sargent, 2016)

Through the use of geothermal heat pump instead of gas boiler, the source of heating loads mainly for geothermal, and energy consumption is electricity. However, the previous optimization of the envelope has significantly reduced the heating loads, it is not so obvious in this design case, at the same time cooling loads are increased. Overall, the annual comprehensive energy consumption can be reduced by 7-27.6kWh/m² in this project.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Auxiliary	0.17	0.11	0.20	0.50	0.94	1.12	1.18	1.05	0.67	0.30	0.11	0.13
Humidification	3.64	3.10	3.11	3.64	0.81	0.09	0.02	0.10	0.26	0.59	2.32	3.32
Light and equipment	1.48	1.36	1.54	1.40	1.54	1.48	1.46	1.54	1.46	1.48	1.48	1.46
Heating	2.94	2.01	1.38	0.22	0.01	0.00	0.00	0.00	0.01	0.41	1.54	2.67
Cooling	0.00	0.01	0.28	1.59	3.69	4.90	5.33	4.70	2.63	0.73	0.03	0.00

	Annual
Auxiliary	6.49
Humidification	21.00
Light and equipment	17.68
Heating	11.19
Cooling	23.88

Figure 5.32 End use _ press conference hall of design case3

Conversion factor in China	
Natural gas	1.25
Electricity	2.60

	Heating	Cooling	Light and equipment	Humidification	Auxiliary
Baseline	122.11	59.65	110.33	47.35	34.43
Design case1	128.67	53.40	45.97	47.17	30.66
Design case2	54.78	59.14	45.97	61.17	15.19
Design case3	29.10	62.10	45.97	54.61	16.87

	Baseline	Design case1	Design case2	Design case3
Total	373.87	305.87	236.26	208.66

Figure 5.33 Comprehensive energy _ press conference hall of baseline and design case1,2,3

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Auxiliary	0.19	0.11	0.07	0.17	0.41	0.59	0.72	0.58	0.34	0.08	0.08	0.16
Humidification	3.02	2.47	2.21	3.06	0.62	0.00	0.00	0.04	0.17	0.43	1.87	2.79
Light and equipment	1.46	1.34	1.50	1.46	1.44	1.44	1.46	1.50	1.44	1.46	1.44	1.51
Heating	3.11	2.03	1.22	0.21	0.01	0.00	0.00	0.00	0.01	0.36	1.44	2.83
Cooling	0.00	0.00	0.00	0.50	1.85	3.00	3.95	3.02	1.44	0.15	0.00	0.00

	Annual
Auxiliary	3.49
Humidification	16.69
Light and equipment	17.43
Heating	11.22
Cooling	13.91

Figure 5.34 End use _ exhibition reception center of design case3

Conversion factor in China	
Natural gas	1.25
Electricity	2.60

	Heating	Cooling	Light and equipment	Humidification	Auxiliary
Baseline	72.38	20.69	110.57	32.23	28.61
Design case1	84.07	18.21	45.32	30.96	27.45
Design case2	51.65	19.34	45.32	40.12	13.72
Design case3	29.16	36.16	45.32	43.39	9.09

	Baseline	Design case1	Design case2	Design case3
Total	264.48	206.02	170.16	163.12

Figure 5.35 Comprehensive energy _ exhibition reception center of baseline and design case1,2,3

(2) Heat recovery system

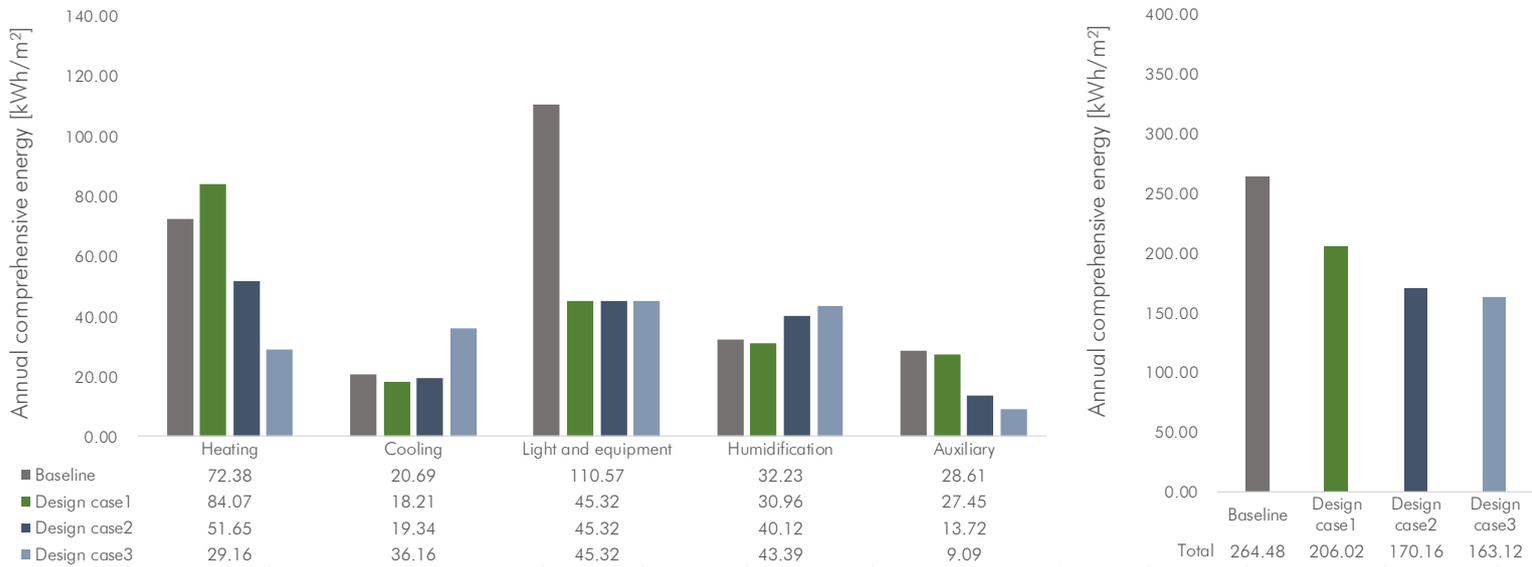Heat recovery is a method which is increasingly used to reduce the heating and cooling demands (and thus energy costs) of buildings. By recovering the residual heat in the exhaust gas, the fresh air introduced into the air conditioning system is pre-heated (pre-cooled), and the fresh air enthalpy is increased (reduced) before the fresh air enters the room or the air cooler of the air conditioning unit performs heat and moisture treatment.

The air conditioning system of the project mainly adopts the fan coil + DOAS system with a Fixed plate heat recovery system. The plate heat recovery system has the advantages of ① No moving parts hence high reliability; ②High heat transfer coefficient; ③No cross contamination; ④Frost control possible; ⑤Sensible and latent heat recovery.

The fresh air unit adopts the combined heat recovery type fresh air unit, which is controlled by different regions. The fresh air is fed into the service area independently, and the heat recovery efficiency meets the standard requirements.

The heat recovery is getting a necessity due to an increasing energy cost for treatment of fresh air. The main purpose of heat recovery systems is to mitigate the energy consumption of buildings for heating, cooling and ventilation by recovering the waste heat. In this regard, stand alone or combined heat recovery systems can be incorporated into the residential or commercial buildings for energy saving.
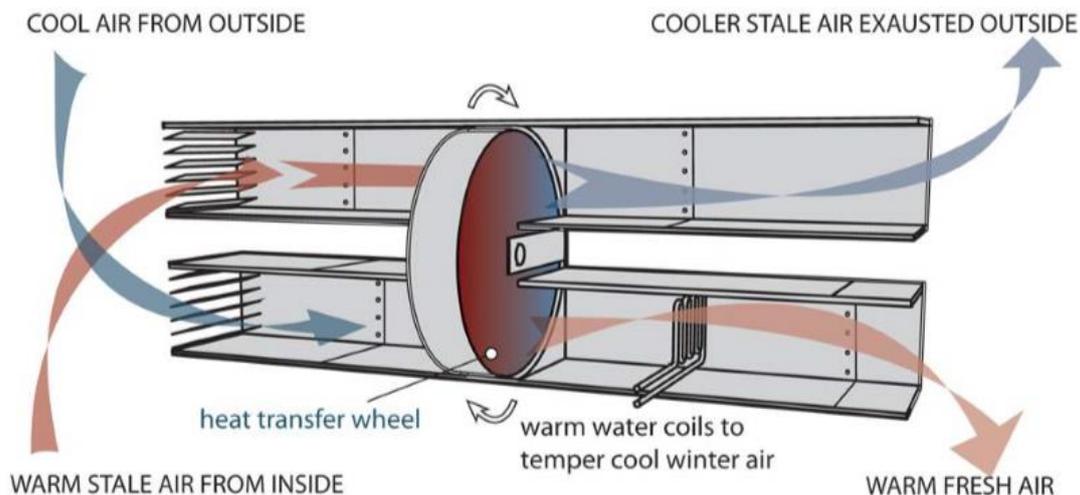

Figure 5.36 Hear recovery system (Living proof-Bullitt center, Robert B. Peña, 2013)

Through the heat recovery system, cooling, heating and humidification loads can be effectively reduced again. In this design case, we designed the heat recovery system with 75% efficiency, and reduce 22.5-24.4kWh/m², or 11.7%-13.8% annual comprehensive energy consumption.
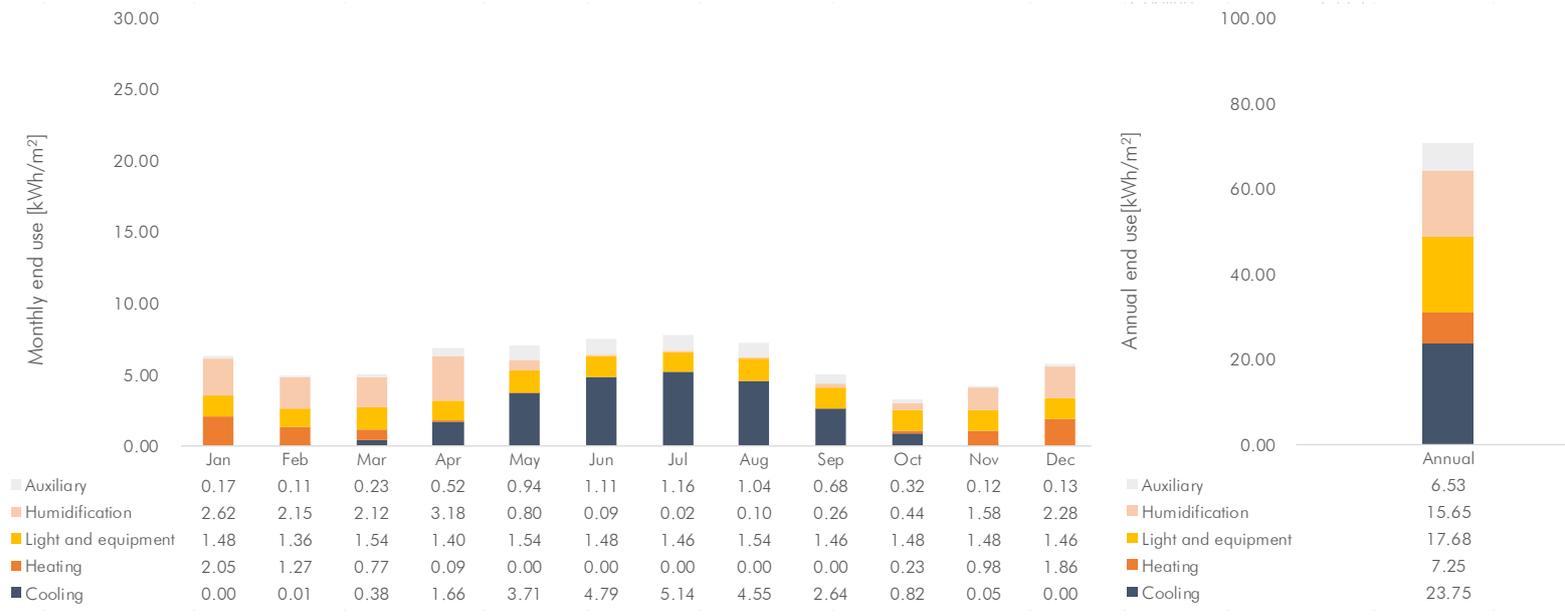
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Auxiliary	0.17	0.11	0.23	0.52	0.94	1.11	1.16	1.04	0.68	0.32	0.12	0.13
Humidification	2.62	2.15	2.12	3.18	0.80	0.09	0.02	0.10	0.26	0.44	1.58	2.28
Light and equipment	1.48	1.36	1.54	1.40	1.54	1.48	1.46	1.54	1.46	1.48	1.48	1.46
Heating	2.05	1.27	0.77	0.09	0.00	0.00	0.00	0.00	0.00	0.23	0.98	1.86
Cooling	0.00	0.01	0.38	1.66	3.71	4.79	5.14	4.55	2.64	0.82	0.05	0.00

	Annual
Auxiliary	6.53
Humidification	15.65
Light and equipment	17.68
Heating	7.25
Cooling	23.75

Figure 5.37 End use _ press conference hall of design case4

Conversion factor in China	
Natural gas	1.25
Electricity	2.60

	Heating	Cooling	Light and equipment	Humidification	Auxiliary
Baseline	122.11	59.65	110.33	47.35	34.43
Design case1	128.67	53.40	45.97	47.17	30.66
Design case2	54.78	59.14	45.97	61.17	15.19
Design case3	29.10	62.10	45.97	54.61	16.87
Design case4	18.84	61.75	45.97	40.69	16.99

	Baseline	Design case1	Design case2	Design case3	Design case4
Total	373.87	305.87	236.26	208.66	184.24

Figure 5.38 Comprehensive energy _ press conference hall of baseline and design case1,2,3,4

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Auxiliary	0.17	0.10	0.06	0.15	0.37	0.52	0.63	0.51	0.30	0.07	0.07	0.14
Humidification	2.33	1.88	1.61	2.54	0.53	0.00	0.00	0.03	0.15	0.31	1.39	2.10
Light and equipment	1.46	1.34	1.50	1.46	1.44	1.44	1.46	1.50	1.44	1.46	1.44	1.51
Heating	2.42	1.55	0.86	0.12	0.00	0.00	0.00	0.00	0.00	0.24	1.09	2.21
Cooling	0.00	0.00	0.00	0.46	1.67	2.61	3.43	2.60	1.29	0.14	0.00	0.00

	Annual
Auxiliary	3.12
Humidification	12.86
Light and equipment	17.43
Heating	8.49
Cooling	12.20

Figure 5.39 End use _exhibition reception center of design

Conversion factor in China	
Natural gas	1.25
Electricity	2.60

	Heating	Cooling	Light and equipment	Humidification	Auxiliary
Baseline	72.38	20.69	110.57	32.23	28.61
Design case1	84.07	18.21	45.32	30.96	27.45
Design case2	51.65	19.34	45.32	40.12	13.72
Design case3	29.16	36.16	45.32	43.39	9.09
Design case4	22.06	31.73	45.32	33.44	8.10

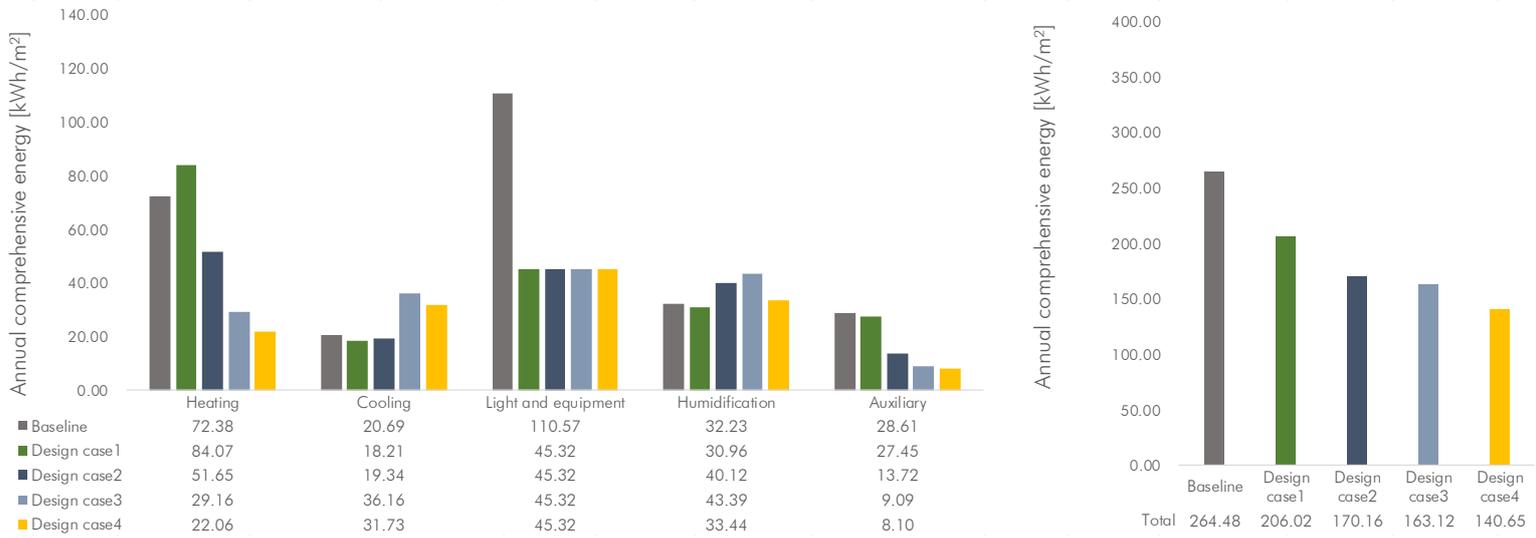|	Baseline	Design case1	Design case2	Design case3	Design case4
Total	264.48	206.02	170.16	163.12	140.65

Figure 5.40 Comprehensive energy _ exhibition reception center of baseline and design case1,2,3,4
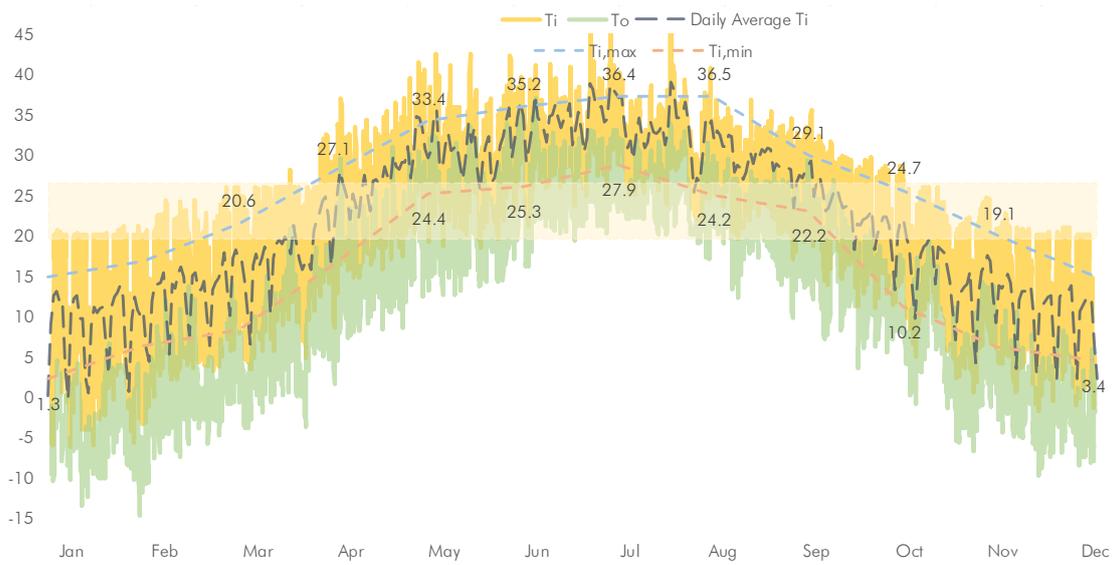
5.3.5 Indoor environment

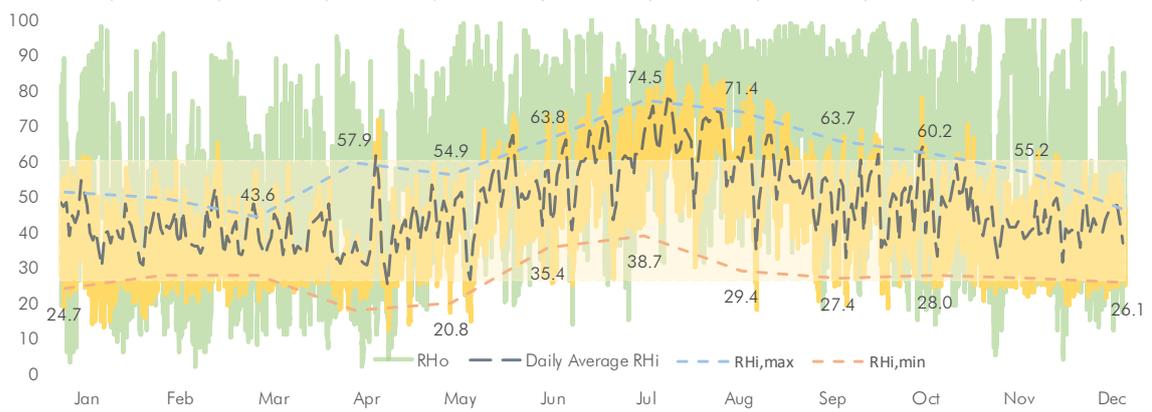*Figure 5.41 Indoor air temperature of press conference hall*

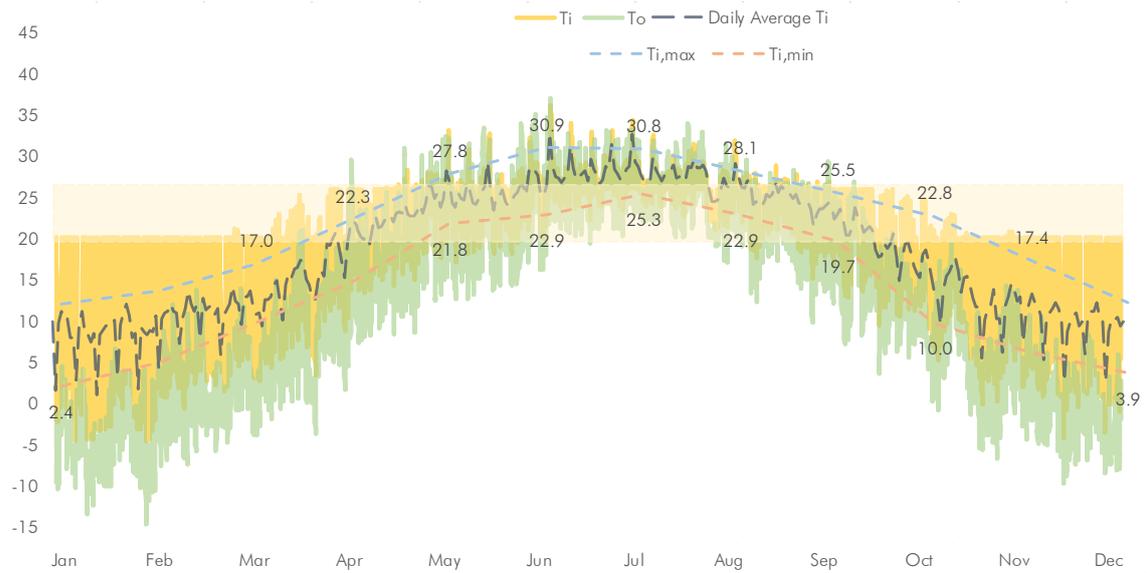*Figure 5.42 Indoor relative humidity of press conference hall*

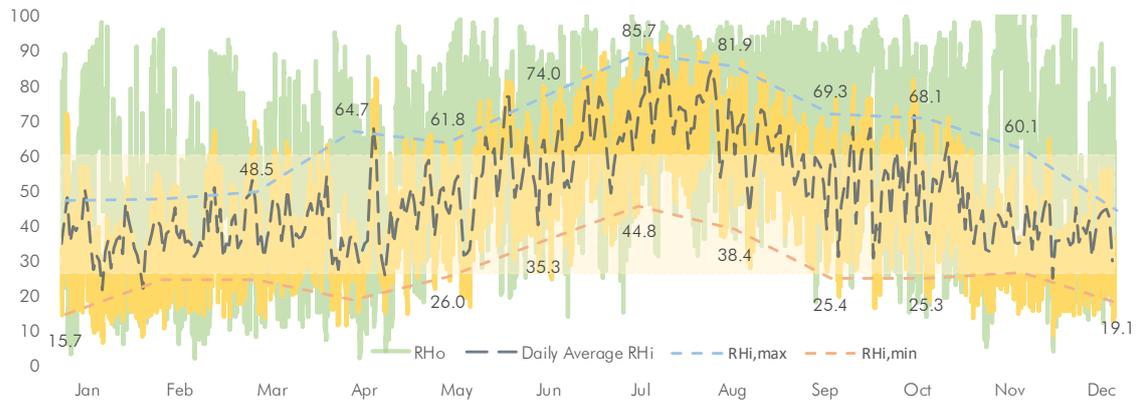*Figure 5.43 Indoor air temperature of exhibition reception center*

Figure 5.44 Indoor relative humidity of exhibition reception center

5.3.6 Thermal bridges

A thermal bridge is a short-cut for thermal energy. Heat will take the shortest route to escape to the outside. The consequences of thermal bridges are however more dire than just losing a few kilowatt-hours of warmth: the inner surface around a thermal bridge will get cold, which is why moisture in indoor air is likely to become sufficiently saturated to allow mold growth on these surfaces. That is why thermal bridges need to be designed out of well insulated building envelopes.

The linear thermal bridge Psi value indicates the additional heat loss incurred at linear thermal bridges. This is additional to the one-dimensional heat loss that can easily be calculated using U-values, and multiplying the thus obtained U-values with the area of building element in question. While U-value calculations give the loss factor for one-dimensional heat flow (from inside-out in one direction), for thermal bridge modelling, either looking for the effect of two-dimensional heat flow (at right angle joints), or the effect of gaps in the alignment of two or more elements, situations that cannot accurately enough be reflected with U-value calculations alone. Two-dimensional heat flow simulations for linear thermal bridges obtained in THERM are typically accurate enough for Passive House purposes.

The building should be designed without thermal bridge, it means the thermal bridge coefficient is very low. The thermal bridge coefficient must be determined by using finite element software — THERM.

High performance thermal insulation materials and broken bridge anchoring products are required for the non-thermal bridge structure to ensure that continuous thermal insulation layer is set in the peripheral protective structure, and the thermal bridge part of the building is marked and strengthened, such as the following parts:

Roof-wall corner bridge

The equations shown in the figure:

$$Psi = U_{therm} \times L_{custom} - U_{wall} \times (h_{w1}+h+s_i) - U_{roof} \times (L_R+s_w+s_i)$$

$$L_{custom} = L_R + h_{w1} + s_w + h + 2s_i$$

$$h_w = \max \{1.00; 3(s_i + s_w)\}$$

$$h_w = \max \{1.00; 3(s_i + h)\}$$

| Adiabatic surface
| Concrete slab
| Insulation layer
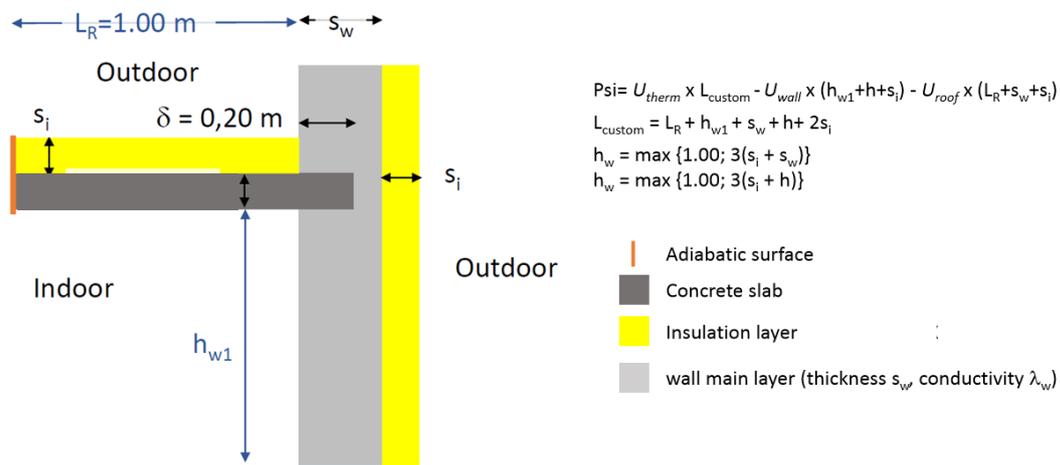| wall main layer (thickness s_w, conductivity λ_w)

Figure 5.45 Roof-Wall linear thermal bridge calculation method

ISO 10211:2007 requires to extend your model at least to the greater of 1 m and three times the thickness of the flanking element concerned each side of the joint or central element. After import the drawing of the element and set the materials and boundary condition, we could calculate the linear thermal bridge.
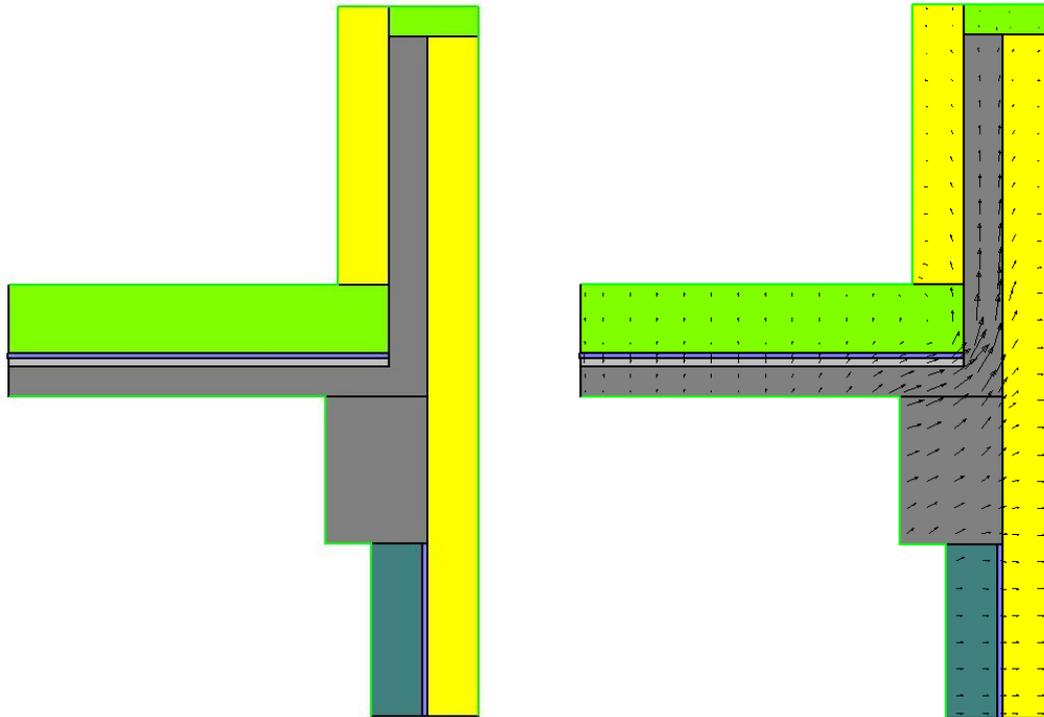
Figure 5.46 Roof-Wall thermal bridge section and heat flux

Table 5.14 Materials of Roof-Wall linear thermal bridge

Roof			
Composition	Thickness [mm]	Density [kg/m³]	K [W/m²·K]
Extruded polystyrene insulation layer	270	30	0.177
Polymer mortar	20	2140	
Composite light aggregate concrete	20	800	
Reinforced concrete roofing board	120	2400	
External wall			
Composition	Width [mm]	Density [kg/m³]	K [W/m²·K]
Double layer hydrophobic rock wool board	200	22	0.162
Polymer mortar	20	2140	
Aerated concrete block wall	200	1350	

Table 5.15 Boundary condition of Roof-Wall linear thermal bridge

Boudary condition		
Condtion	Temperature [°C]	Film coeffecient [[W/m²·K]
Exterior environment	-5.5	0.04
Interior environment	20.0	7.69

After set the thickness and the thermal conductivity of materials in Roof-Wall section, it is necessary to set the boundary condition. According to the monthly average lowest temperature in Beijing, we set the outdoor air temperature as -5.5℃, and the film coefficient is 25W/m²·K, indoor air temperature is 20℃, and the film coefficient is 7.69W/m²·K, the others has been set as adiabatic.After calculation, from the figure of the heat flux of Roof-Wall, we could see the heat flux in the reinforced concrete roofing board is higher than in the other part.
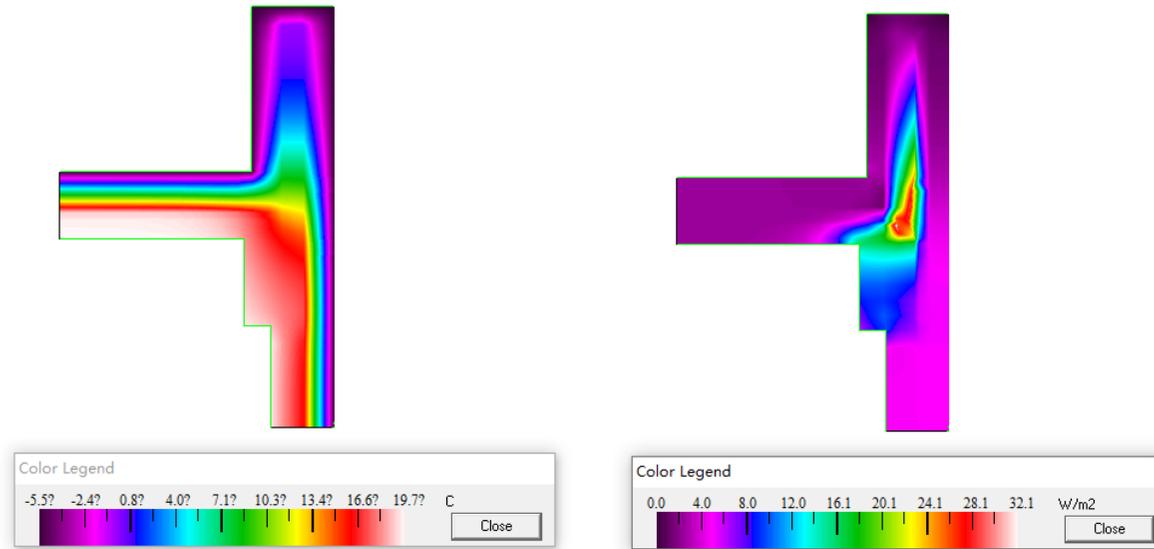
Figure 5.47 Temperature and heat flux of Roof-Wall section

The U_{therm} value must be compared with the flux through the whole L_{custom}.

$$Psi = U_{therm} \cdot L_{custom} - U_{wall} \cdot (h_w + h + s_i) - U_{roof} \cdot (L_R + s_w + s_i) \qquad (1)$$

$$L_{custom} = L_R + h_w + s_w + h + 2 \cdot s_i \qquad (2)$$

$$h_w = max\{1.00; 3(s_w + s_i)\} = max\{1.00; 3(0.22 + 0.2)\} = 1.26 \text{ m}$$

$$L_R = max\{1.00; 3(h + s_i)\} = max\{1.00; 3(0.16 + 0.27)\} = 1.29 \text{m} \qquad (3)$$

$$L_{custom} = 1.29 + 1.26 + 0.22 + 0.16 + 0.2 + 0.27 = 3.4 \text{ m}$$

$$Psi = 0.171 \cdot 3.4 - 0.162 \cdot (1.26 + 0.16 + 0.27) - 0.177 \cdot (1.29 + 0.22 + 0.2) = -0.0503$$

The Psi value is negative because the actual heat flux is less than that calculated using external areas. By contrast, the actual heat flux is more than that calculated on the basis of just the internal areas.

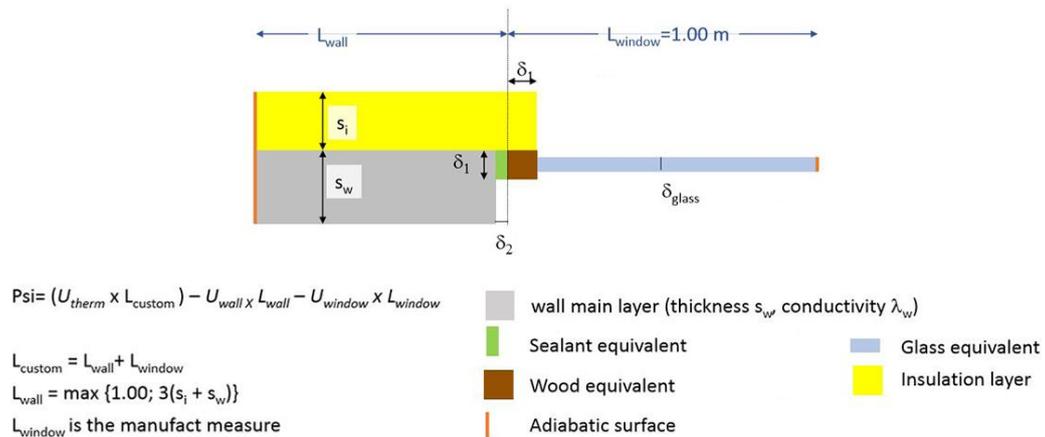## Wall-window external bridge

Figure 5.48 Wall-window linear thermal bridge calculation method

ISO 10211:2007 requires to extend your model at least to the greater of 1 m and three times the thickness of the flanking element concerned each side of the joint or central element. After import the drawing of the element and set the materials and boundary condition, we could calculate the linear thermal bridge.
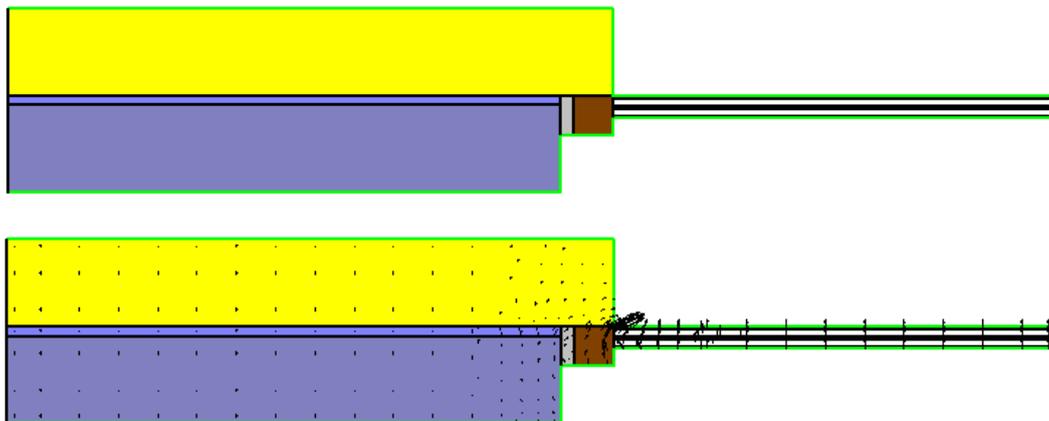

Figure 5.49 Wall-window thermal bridge section and heat flux

Table 5.16 Materials of Wall-window linear thermal bridge

External wall			
Composition	Width [mm]	Density [kg/m³]	K [W/m²·K]
Double layer hydrophobic rock wool board	200	22	
Polymer mortar	20	2140	0.162
Aerated concrete block wall	200	1350	

Envelope			
Composition	Thickness [mm]	SHGC	K [W/m²·K]
Tempered Low-e glazing	6		
Argon	16		
Tempered Low-e glazing	6	0.5	0.75
Argon	16		
Tempered glazing	6		
Wood clad aluminum window frame	\	\	0.8

Table 5.17 Boundary condition of Wall-window linear thermal bridge

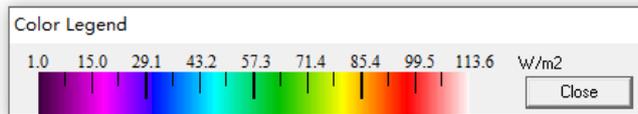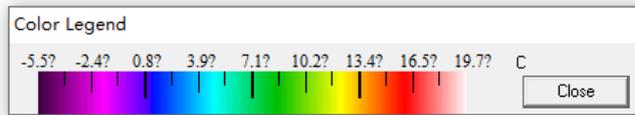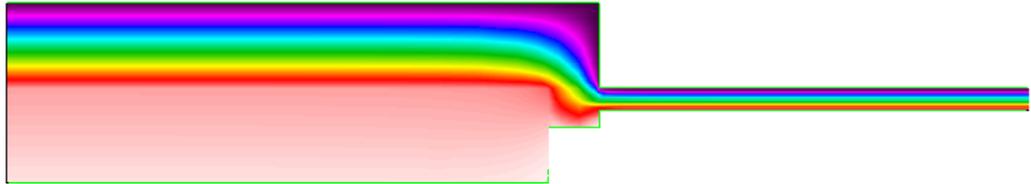| Boudary condition		
Condtion	Temperature [°C]	Film coeffecient [[W/m²·K]
Exterior environment	-5.5	0.04
Interior environment	20.0	7.69

Figure 5.50 Temperature and heat flux of Wall-window section

The U_{therm} value must be compared with the flux through the whole L_{custom}.

$$Psi = U_{therm} \cdot L_{custom} - U_{wall} \cdot L_{wall} - U_{window} \cdot L_{window}$$

$$L_{custom} = L_{wall} + L_{window}$$

$$L_{wall} = max\{1.00; 3(s_w + s_i)\} = max\{1.00; 3(0.22 + 0.2)\} = 1.26 \text{ m}$$

$$L_{window} = 1 \text{ m}$$

$$L_{custom} = 1.26 + 1 = 2.26 \text{ m}$$

$$Psi = 0.562 \cdot 2.26 - 0.162 \cdot 1 - 0.75 \cdot 1.26 = -0.163$$

The Psi value is negative because the actual heat flux is less than that calculated using external areas. By contrast, the actual heat flux is more than that calculated on the basis of just the internal areas.

5.3.7 Photovoltaic power generation

The wall and roof on the south side are the orientation that makes the best use of solar energy. The integrated design of building PV should be reasonably adopted in the building's outer protective structure. Photovoltaic panels can generate electricity and supplement it into the building's lighting or equipment system, so as to reduce the building's dependence on municipal electricity and reduce the electricity energy cost.

The survey of Yanqing solar energy resources in Beijing shows that solar energy resources in Beijing are relatively rich in resources. The annual sunshine is over 2800h and the annual total radiation is 1586.20kWh/m². The energy efficiency of 0.88 is stable, which provides favorable natural conditions for the utilization of solar energy in Yanqing area.

The photovoltaic application of mountain news center adopts grid-connected photovoltaic system scheme, and the photovoltaic group is a crystalline silicon module.

We use the tool—PVsyst to calculate the approximate annual photovoltaic power generation in this project. We choose the preliminary design, which is a rough estimation of the PV system energy yield, based on a few very general parameters, and set it as the Grid-connected system, for grid-connected systems, the energy is usually sold at a constant price all over the year. The relevant optimum is then to maximize the yearly energy.
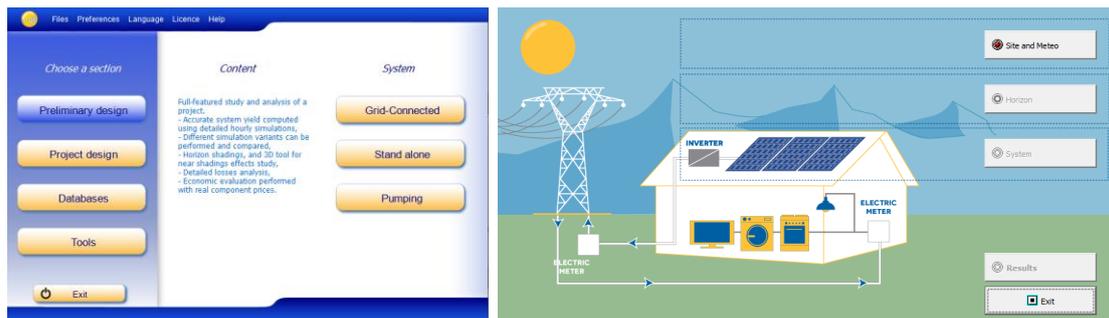

Figure 5.51 Photovoltaic system and project site
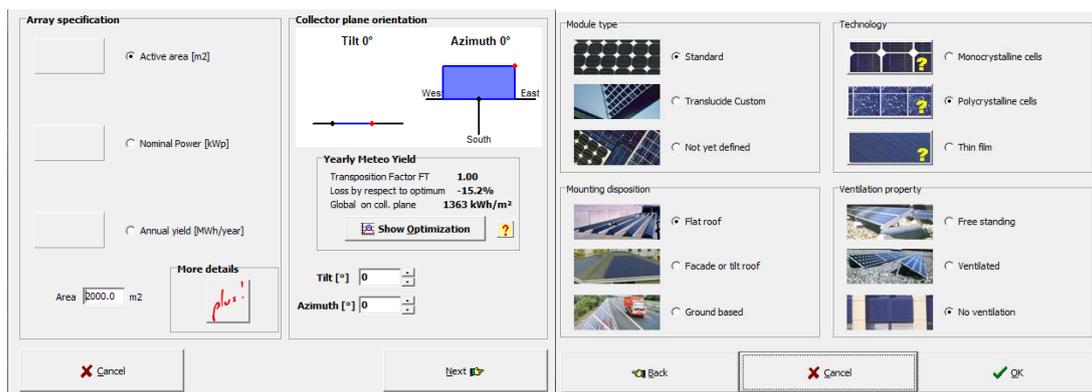

Figure 5.52 Photovoltaic collector plane orientation and module

Next, set the location in Beijing, for aesthetic consideration, these PV panels are paved on the shading system of the flat roof and overhanging, and both the tilt and azimuth are 0°.

The effective radiation area is 2000m². The we choose the standard polycrystalline cells on the flat roof without ventilation.
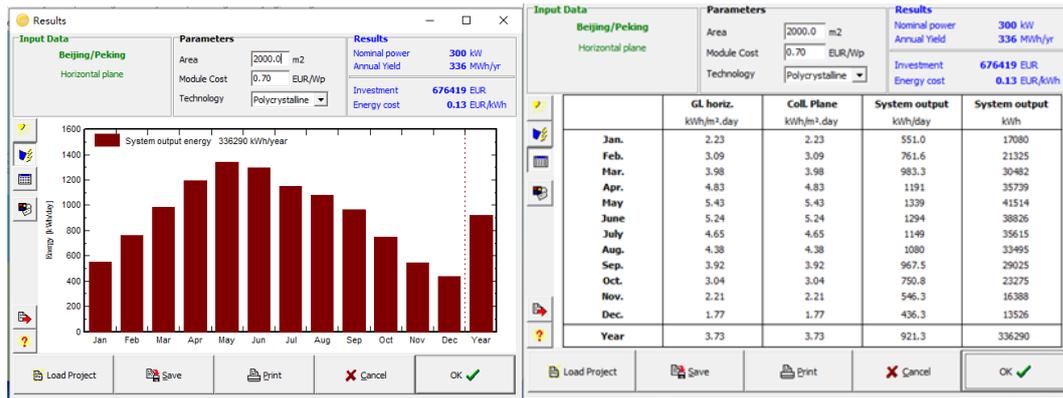
Figure 5.53 Photovoltaic system output energy result

On the basis of full consideration of photovoltaic system power generation efficiency, investment cost, architectural aesthetics and feasibility, the target of photovoltaic application in mountain press center is about 2000 m² of effective radiation area. The average annual photovoltaic power generation is expected to be 336,290 kWh.

5.4 The result of Nearly Zero Energy Building

According to GB/ T51350-2019 "Technical standard for Nearly zero energy buildings". The comprehensive value of building energy consumption of nearly zero energy public building in Beijing should be lower than 73kWh/m²·a, and the equivalent electricity should be lower than 28kWh/m²·a. The building comprehensive energy saving rate should be higher than 60%, the energy saving rate of building body should be higher than 30%, and utilization of renewable energy should be higher than 10%.

	Heating	Cooling	Light and equipment	Humidification	Auxiliary
Baseline	34.30	14.33	89.86	29.69	7.72
Design case1	41.46	10.95	48.52	27.72	6.50
Design case2	23.00	11.75	43.16	17.21	2.24
Design case3	8.06	12.75	43.16	19.93	3.28
Design case4	5.43	12.48	43.16	15.33	3.15

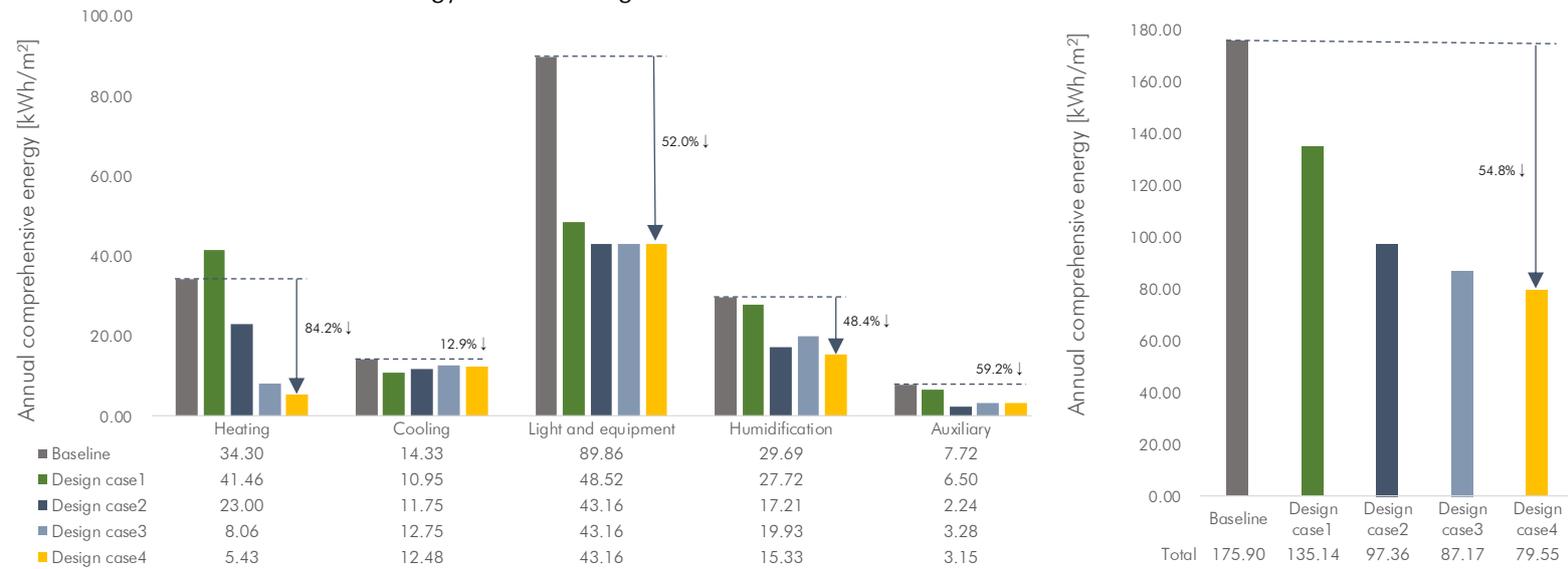|	Baseline	Design case1	Design case2	Design case3	Design case4
Total	175.90	135.14	97.36	87.17	79.55

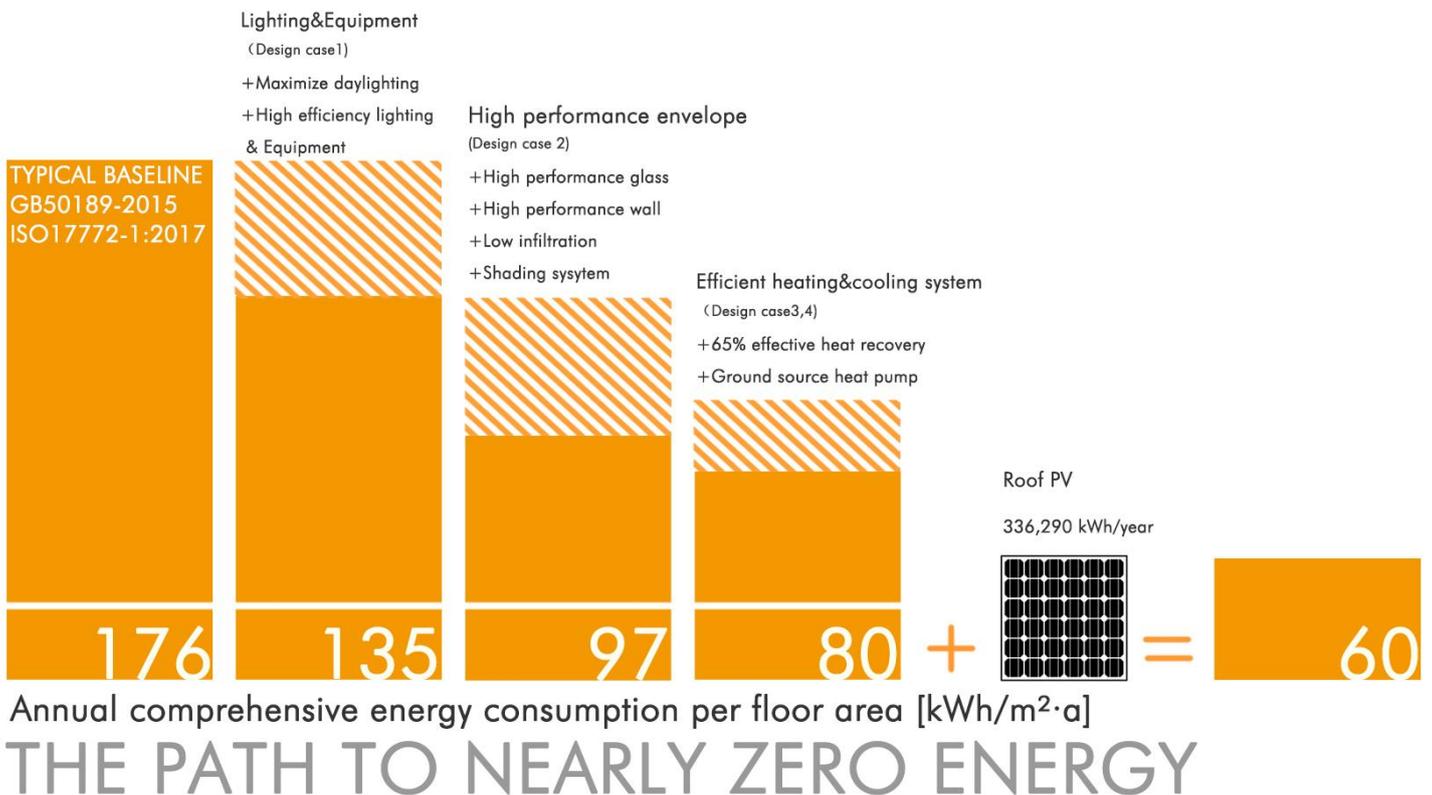Figure 5.54 Comprehensive energy _ Mountain press center of baseline and design case1,2,3,4

Figure 5.55 The path to nearly zero energy

Table 5.16 Comprehensive energy consumption of nearly zero energy public buildings

The comprehensive value of building energy consumption of nearly zero-energy public buildings (kWh/m²·a)								
City	Small office building	Large office building	Small hotel building	Large hotel building	Mall building	Hospital building	School building teaching building	School building library
Harbin	64	75	69	84	113	119	64	65
Shenyang	58	70	66	80	113	114	63	61
Beijing	59	73	71	85	127	123	74	65
Zhumadian	57	76	75	90	139	128	82	70
Shanghai	57	78	78	96	148	135	87	74
Wuhan'	55	77	77	90	148	131	81	71
Chengdu	55	76	76	87	149	135	86	73
Shaoguan	60	84	86	104	172	148	98	81
Guangzhou	65	92	95	119	197	173	112	94
Kunming	42	58	60	67	113	104	54	54

Table 5.17 Equivalent electricity energy consumption of nearly zero energy public buildings

Equivalent electricity consumption of building energy consumption of nearly zero-energy public buildings (kWh/m²·a)								
City	Small office building	Large office building	Small hotel building	Large hotel building	Mall building	Hospital building	School building teaching building	School building library
Harbin	25	29	27	32	43	46	25	25
Shenyang	22	27	25	31	43	44	24	23
Beijing	23	28	27	33	49	47	28	25
Zhumadian	22	29	29	35	53	49	32	27
Shanghai	22	30	30	37	57	52	33	28
Wuhan	21	30	30	35	57	50	31	27
Chengdu	21	29	29	33	57	52	33	28
Shaoguan	23	32	33	40	66	57	38	31
Guangzhou	25	35	37	46	76	67	43	36
Kunming	16	22	23	26	43	40	21	21

(1) The comprehensive value of building energy consumption is calculated as follows:

$$E = E_E - \frac{\sum E_{r,i} \times f_i + \sum E_{rd,i} \times f_i}{A}$$

E — Comprehensive value of building energy consumption;

E_E — The comprehensive value of building energy consumption excluding renewable energy generation;

A — Builidng area;

f_i — Energy conversion coefficient of type i energy;

$E_{r,i}$ — Type i annual renewable energy generation generated by the building body;

$E_{rd,i}$ — Type i annual renewable energy generation generated by the building surrounding.

The comprehensive energy consumption of Mountain press center:

$$E = 79.55 - \frac{336290}{17527.91} = 60.36 \ \frac{\text{kWh}}{\text{m}^2}$$

The Equivalent electricity of energy consumption of Mountain press center:

$$E' = 60.36 \div 2.6 = 23.22 \ \frac{\text{kWh}}{\text{m}^2}$$

Table 5.18 Nearly zero energy and public building efficiency targets

Nearly zero energy and public building efficiency targets						
Building comprehensive energy saving rate		≥60%				
Building energy consumption index	Energy saving rate of building body	Severe cold	Cold area	Hot summer cold winter	Hot summer cold winter	Temperate
		≥30%		≥20%		
	Building tightness (Air changes N50)	≤1.0		-		
Renewable energy efficiency		≥10%				

(2) When calculating the energy saving rate of building body, the comprehensive value of building energy consumption should not include the renewable energy, and should be calculated as to the following formula:

$$\eta_e = \frac{|E_E - E_R|}{E_R} \times 100\%$$

η_e — Energy saving rate of building body;

E_E — The comprehensive value of building energy consumption of the design case excluding renewable energy;

E_R — The comprehensive value of building energy consumption of the baseline.

The building body energy saving rate of the Mountain press center:

$$\eta_e = \frac{|79.55 - 175.90|}{175.90} \times 100\% = 54.87\%$$

(3) The building comprehensive energy saving rate calculated as to the following formula:

$$\eta_p = \frac{|E - E_R|}{E_R} \times 100\%$$

η_p — Building comprehensive energy saving rate;

E — The comprehensive value of building energy consumption of design case.

The building comprehensive energy saving rate of the Mountain press center:

$$\eta_e = \frac{|60.36 - 175.90|}{175.90} \times 100\% = 65.69\%$$

(4) Renewable energy efficiency calculated as to the following formula:

$$REP_p = \frac{\sum E_{r,i} \times f_i + \sum E_{rd,i} \times f_i}{E_R \times A} \times 100\%$$

The building renewable energy efficiency of the Mountain press center:

$$REP_p = \frac{336290}{79.55 \times 17527.91} \times 100\% = 24.12\%$$

From the above calculation of this project, we can see that the comprehensive value of building energy consumption of the baseline is 171.23kWh/m²·a, the comprehensive value of building energy consumption of the design case excluding renewable energy is 79.55 kWh/m²·a, and the annual design case of comprehensive energy consumption is 60.36 kWh/m²·a. The building body energy saving rate is 53.54%, the building comprehensive energy saving rate is 64.75%. The building renewable energy efficiency is 24.12%.

We can get the conclusion that this project reach the goal of Chinese Nearly zero energy building.

6 Conclusion

The 2022 winter Olympic Games will be held in Beijing. In order to reduce building energy consumption and realize sustainable development of buildings, the Mountain press center of the winter Olympic Games is designed with high performance and energy saving, so that the project can reach the goal of nearly zero-energy buildings and meet GB/T51350-2019 "Technical standards of Chinese nearly zero-energy buildings" which issued in 2019.

In order to achieve the goal of nearly zero energy consumption, firstly, based on GB50189-2015 "Energy saving design standards for public buildings", grasshopper was used to simulate the energy consumption of the two main rooms of the mountain news center - Press conference hall and exhibition reference center.

The result of the simulation is end use, according to the energy conversion factors for electricity in China, electricity is 2.6 and natural gas is 1.25. The analysis shows that the comprehensive energy consumption of baseline are 373.8 and 264.5kWh/m², the most energy needs in this project are heating loads, lighting and equipment loads, and the cooling loads are low.

In terms of cost, we first optimized the efficiency of lighting and equipment, by using LED linear lamps and LED spotlight instead of linear fluorescent lamp and compact fluorescent spotlight which has the same illumination and lighting effect, and efficient equipment, the lighting and equipment energy end use were reduced by more than half. Meanwhile, due to the decrease of internal gain, heating loads increased slightly, and cooling loads decreased. Overall, 58-73kWh/m² or 20%-22% of annual comprehensive energy consumption can be reduced.

Next, we increase the insulation thickness of enclosure structure and change the glass material of window, reduce the thermal transmittance, and greatly reduce the heating loads, at the same time cooling loads and humidification loads are increased slightly. From the perspective of annual comprehensive energy consumption, it decreased by 36-70kwh/m², or 17.4%-22.8%.

Through the use of geothermal heat pump instead of gas boiler, the source of heating loads mainly for geothermal, and energy consumption is electricity. However, the previous optimization of the envelope has significantly reduced the heating loads, it is not so obvious in this design case, at the same time cooling loads are increased. Overall, the annual comprehensive energy consumption can be reduced by 7-27.6kWh/m² in this project. Then, we add the heat recovery system with 75% efficiency, and reduce 22.5-24.4kWh/m², or 11.7%-13.8% annual comprehensive energy consumption.

Finally, we simulated the whole building and verified the results again. The annual comprehensive value of building energy consumption of the baseline is 171.23kWh/m², the comprehensive value of building energy consumption of the design case excluding renewable energy is 79.55 kWh/m²·a, the target of photovoltaic application in mountain press center is about 2000 m² of effective radiation area. The average annual photovoltaic power generation is expected to be 336,290 kWh, and the annual design case of comprehensive energy consumption is 60.36 kWh/m²·a. The building body energy saving rate is 53.54%, the building comprehensive energy saving rate is 64.75%. The building renewable energy efficiency is 24.12%.

The project is a demonstration project to promote the application of low-carbon technologies, effectively control greenhouse gas emissions and make the Beijing winter Olympic Games an important platform for China to participate in the construction of a global ecological civilization. It is hoped that the above research will provide reference for further development of Nearly zero energy building in the cold zone of China.