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High Impact Opportunities for Energy Efficiency in China

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清華大学
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HIGH IMPACT OPPORTUNITIES FOR ENERGY EFFICIENCY IN CHINA

CHINA ENERGY EFFICIENCY SERIES

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CONTENTS

LIST OF ABBREVIATIONS

ASHP	Air source heat pump
BEV	Battery electric vehicles
C2E2	Copenhagen Centre on Energy Efficiency
CDQ	Coke dry quenching
CO_2	Carbon Dioxide
CCPP	Combined Cycle Power Generation Technology
DTU	Technical University of Denmark
EMC	Energy Management Contract
ERI	Energy Research Institute of the National Development and Reform Commission of China
ESCO	Energy service company
EV	Electrical vehicle
GCE	Grams of coal equivalent
GDP	Gross Domestic Product
GHG	Greenhouse gas
HIO	High Impact Opportunity
HCV	Heavy-duty commercial vehicles
HEV	Hydrogen fuel battery vehicle
KWH	Kilowatt-Hour
M^2	Square meter
MITT	Ministry of Industry and Information Technology
MOHURD	Ministry of Housing and Urban-Rural Development
MOST	Ministry of Science and Technology
MOT	Ministry of Transportation
MRV	Measurable, reportable and verifiable
MTCE	Million tonnes of coal equivalent
NBS	National Bureau of Statistics
NDRC	National Development and Reform Commission
NEA	National Energy Agency
NPV	Net present value
O&M	Operation and maintenance
PCN	Project Concept Notes
PHEV	Plug-in Hybrid Electric Vehicle
RMB	Renminbi
SEFORALL	Sustainable Energy for All
TSINGHUA 3E	Institute of Energy, Environment and Economy at Tsinghua University
UNEP	United Nations Environmental Program

LIST OF TABLES

FOREWORD

Improving energy efficiency is critical to achieving the ambitious goals of the Paris Agreement under the UN Framework Convention on Climate Change. Most global and regional studies show that enhanced energy efficiency policies and actions can dramatically reduce energy use and associated greenhouse gas emissions. This is reflected in the fact that 167 countries included action on enhanced energy efficiency in the Intended Nationally Determined Contributions they submitted as the foundation for the Paris Agreement.

Energy efficiency delivers not only reductions in energy consumption and emissions, if implemented properly, it will also provide opportunities for many economy-wide benefits, such as improved health and well-being, cleaner air and more jobs.

In spite of the political ambition and potential for deriving multiple benefits from action, there are many common barriers and market failures that often prevent countries from moving at the expected pace in implementing the actions on energy efficiency that have been identified. Many of these barriers and failures need to be overcome in by individual countries and cities, but best practice examples of proven solutions are extremely useful in showing what works and how it can be made to happen. This report presents an analysis of energy-efficiency opportunities and actions in a number of key sectors in China aimed at inspiring other countries. The assessment highlights some of the conditions for success that will be essential for replication in other parts of the world.

In terms of the future growth of energy and related greenhouse gas emissions, China and India stand out from other countries due to their rapid economic development, large populations, rapid urbanization and growing industrial sectors. Both countries are focused on decoupling both energy use and emissions from economic growth. In their Intended Nationally Determined Contributions, submitted under the Paris Agreement, both countries have included strategies to pursue improved energy efficiency across the main sectors of their economies.

This report is part of the China and India Energy Efficiency series that has emerged from the High Impact Opportunities studies that the UNEP DTU Partnership has supported in China and India. In China, the study was carried out by the Energy Research Institute under the National Development and Reform Commission and the Institute of Energy, Environment and Economy at Tsinghua Institute. The other two reports published on China are under the study : Best Practice and Success Stories on Energy Efficiency in China, and Enhancing Energy Efficiency in China - Assessment of Sectoral Potentials. All the reports can be downloaded for free at www.energyefficencycentre.org.

China is the second-largest economy in the world and the biggest greenhouse gas emitter. Whether it can continue the rapid improvements to its energy efficiency, and how, are critical not only to fulfilling the country's international climate targets and domestic five-year plan targets, but also key to realizing the global goals of climate change and clean and sustainable energy development.

This report, High Impact Opportunities for Energy Efficiency in China, presents six High Impact Opportunities (HIOs) for improvements to energy efficiency in China in the transport, building, industry and power sectors. These HIOs have been selected from the long list of HIOs identified with economic and energy modelling by the same expert team in the report, Enhancing Energy Efficiency in China: Assessment of Sectoral Potentials. The six HIOs covered in this report concern waste heat recovery in the industrial sector, passive house and air source heat pumps for the building sector, high fuel economy for trucks for cargo transport and electric vehicles for passenger transport, and energy conservation transformations of coal-fired power plants. These HIOs are expected to have huge impacts on improving energy efficiency in China by 2050. They have been selected through stakeholder consultation and are based on four criteria: high technical maturity and great energy-efficiency potential; low current technical penetration rate, but great potential for promotion in the future; high returns for investment; and comprehensive and far-reaching impact.

The report also presents detailed project concept notes on how to speed up implementation of two of the HIOs for the building sector through pilot projects on a commercial scale.

I would like to thank the national experts and practitioners who have contributed the eight best practice and success stories included in this publication. I am sure that the publication will be of value to policy-makers, practitioners and researchers in the two countries, as well as providing inspiration to other countries on how to move forward with energy-efficiency policies and action paving the way to further gains in efficiency.

John Christensen
Director
UNEP DTU Partnership

EXECUTIVE SUMMARY

As the largest energy consumer in the world, energy efficiency and conservation have been prioritized in China to meet its fast-growing appetite for energy as a result of industrialization and urbanization, as well as to alleviate environmental pressure and tackle climate change. Evidence from analytical and case studies shows that High Impact Opportunities (HIO) for energy efficiency are not yet being fully utilized due to the complexity of coordination between economic development and energy efficiency in developing countries such as China.

Based on energy conservation potentials, cost effectiveness, application prospects and practical feasibilities, the report identifies six HIOs for further and faster energy efficiency improvements in China before 2050, including promoting industrial waste-heat recovery technologies, which would potentially save around 200 million tce of energy by 2050; promoting passive house and air source pump technologies, which would conserve energy use in the building sector by around 220 million tce and 50 million tce by 2050 respectively; upgrading the fuel economy of trucks and promoting electric vehicles, which have the potential to save around 45.94 million tce and 49.22 million tce respectively by 2050; and retrofitting conventional coal-fired power plants, which would save around 56 million tce by 2050.

To move forward in tapping these HIOs for energy efficiency, this report also draws up two project concept notes (PCN) on concrete energy-efficiency projects to be implemented at the local level. The first PCN describes how to promote passive houses in Beijing, the second to promote air source heat pump technologies in buildings in the Yangtze River region. Beijing has implemented the strictest energy-efficiency standards for buildings in China, yet the standards need to be upgraded extensively in response to the bad air pollution. The Yangtze River region has the potential to increase China's building energy consumption in the future in respect of heating supply in winter.

In the case of the first PCN, describing the promotion of passive houses, it is estimated that completely adopting passive houses in new buildings by 2030 would reduce energy use by 343 million tce annually (total floor area of new buildings: 30 billion m^2 in the whole of China), with a requirement for an additional investment of 17.88 trillion RMB. In the case of the second PCN, to promote air source heat pumps (ASHPs), it is estimated that completely adopting ASHP technologies would reduce energy use by 60-90 million tce, with a total investment of 1.0-1.2 trillion RMB (6 billion m^2 of existing buildings in the Yangtze River region). Despite the high upfront incremental investment, the potential net present value (NPV) of energy savings during the buildings' use life would exceed the costs set out in both PCNs.

China Shanghai the pearl tower and Pudong skyline at sunset.
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INTRODUCTION

Sheng Zhou

BACKGROUND

The Copenhagen Centre on Energy Efficiency (C2E2) is a collaboration between the Danish Government, the UN Environment Program (UNEP) and the Technical University of Denmark (DTU). C2E2 serves as the Energy Efficiency Hub of the United Nations Sustainable Energy for All (SEforALL) initiative. The SEforALL initiative is a multi-stakeholder partnership between governments, the private sector and civil society. It was launched by the United Nations Secretary General in 2011 to achieve three interrelated goals by 2030:

1. To ensure universal access to modern energy services;
2. To double the share of renewable energy in the global energy mix from 18% to 36%; and
3. To double the rate of improvements in energy efficiency from -1.3% to -2.6% annually.

In order to facilitate realization of the SEforALL goal on energy efficiency, C2E2 provides capacity-building, analytical and knowledge support to countries in respect of their actions to improve energy efficiency. With China's high and increasing importance in global energy issues, it has received more emphasis in relation to energy-efficiency improvements under the SEforALL initiative.

This report is part of the findings of the project, 'High Impact Opportunities for Energy Efficiency Improvement in China', which C2E2 initiated to facilitate and support further and faster energy-efficiency improvements in the country. The project was implemented by the Institute of Energy, Environment and Economy at Tsinghua University (Tsinghua 3E) and the Energy Research Institute (ERI) of the National Development and Reform Commission. The two institutions' strong expertise in energy-efficiency policies and energy-modelling in China, plus their close ties to Chinese ministries as the main think tanks on energy and climate policy-making, provide a strong basis for the study project. The project started in September 2015 and was completed in March 2017.

This project consists of three parts: (1) Best Practice and Success Stories on Energy Efficiency in China, (2) Report on Energy Efficiency Options in the Industrial, Building, Transportation and Power Sectors, and (3) Report on High Impact Opportunities and Project Concept Notes for Energy Efficiency in China. The first output provides a detailed overview of China's energy-efficiency policies and measures and includes eight Best Practice and Success Stories on Energy Efficiency in China. The second output includes an assessment of the energy-efficiency improvement potential of the key sectors of industry, building, transportation and power generation. The third output, which is dealt with in this report, focuses on the six high-impact opportunities (HIOs) and two Project Concept Notes (PCNs) for energy-efficiency improvements in China. This develops the criteria and methodology for choosing HIOs, taking into account the results of the first two reports and the opinions of the key stakeholders. The two PCNs will also be formulated in order to realize and implement two of the HIOs.

In order for the project's findings to address key issues on the energy policy-makers' agenda, the project included two workshops. The inception workshop, organized in January 2016, was aimed at discussing the main issues and opportunities for improvements in energy efficiency in key sectors with various ministries, industries and experts. The final workshop, organized in December 2016, focused on reporting the preliminary findings of the project to government ministries and other key stakeholders in energy-efficiency improvements and collecting feedback from them. Apart from these two big workshops, small-scale consultations were also carried out throughout implementation of the project.

Experts from the Copenhagen Centre provided guidance for the study regarding the overall design of the project, provided templates for each report, and reviewed and commented on the draft reports. The ERI and Tsinghua 3E use energy models to estimate the potential for energy-efficiency improvements in key sectors and to project the role of energy efficiency in fulfilling China's National Determined Contributions to global climate change mitigation.

SELECTION OF HIGH IMPACT OPPORTUNITIES FOR ENERGY EFFICIENCY

There are many different energy-efficiency technologies in different sectors of the Chinese economy (industry, power, building and transportation), based on sectoral technical-economic analysis and promotion potential. The criteria for HIO selection set by the research group include the following four factors: (1) high technical maturity and great energy-efficiency potential; (2) low technical penetration rate at present, but great potential for promotion in the future; (3) good profits for investment; (4) potential to improve the energy efficiency of the whole social system. The HIOs can be technical ones that focus on specific technology change, like promoting more efficient cars or power generating units, and structural ones that is about industrial process, product, and service structure change, like promoting public transit and switching from coal-fired power generation to natural-gas based power generation. Based on these criteria, the research group screened out six HIO technologies in the industry, building, transportation and power sectors according to analyses of their technical feasibility and energy-saving effects, i.e. their technical economy and prospects of promotion, as shown in Table 1:

Table 1. HIOs and PCNs

SECTOR	HIO	PCN
Industry	Waste-heat recovery	
Building	Passive house	X
	Air source heat pump	X
Transport	Upgrade fuel economy of trucks	
	Electric vehicles (EVs)	
Power	Energy conservation transformation of coal-fired power plant (including CHP)	

Of the six HIOs, one belongs to the industry sector, two to the building sector, two to the transportation sector and one to the power sector. Both PCNs belong to the building sector.

SELECTION OF PROJECT CONCEPT NOTES FOR ENERGY EFFICIENCY

To take forward HIOs for energy efficiency, the report includes two PCNs, in order to expand the funding channels for energy-efficiency projects at the local level.

The first PCN concerns the promotion of 100,000 m^2 (roughly one residential compound) of passive houses in Beijing. It is estimated that to construct a 100,000 m^2 passive house community in new buildings, the direct increased investment will be 59.6 million RMB, the indirect saving investment 19.4 million RMB, total energy savings 1144 tce, and the cost of energy saving 0.96 million RMB; i.e. the saving costs of avoiding district heat are 3.50 million RMB annually.

The second PCN concerns the promotion of air source heat pump technologies in buildings in the Yangtze River region accommodating a thousand households. It is also estimated that to promote a thousand households worth of ASHP heating and hot water in new building the total initial investment will be 16.7-19.7 million RMB, the total O&M of a thousand households being 2.3 million RMB. Total energy savings are 1000-1500 tce per hundred households, and the cost of energy savings 0.9-1.2 million RMB.

STRUCTURE OF THE HIGH-IMPACT OPPORTUNITIES CHAPTERS AND PROJECT CONCEPT NOTES FOR ENERGY EFFICIENCY

The report consists of eight chapters, six on the six HIOs, and two on the two PCNs. The six HIOs and two PCNs are explained in detail from Chapters 1 to 8.

- Chapter 1. HIO for Industrial Waste Heat Recovery Technologies
- Chapter 2. HIO for Promote Passive Houses
- Chapter 3. HIO for Air Source Heat Pump Technology
- Chapter 4. HIO for Upgrading the Fuel Economy of Trucks
- Chapter 5. HIO for Promoting Electric Vehicles
- Chapter 6. HIO for the Transformation of Coal-fired Power Plant
- Chapter 7. PCN for Passive Houses (100,000 m^2)
- Chapter 8. PCN for Air Source Heat Pump (1000 households)

Each HIO chapter consists four parts: 1) Background, 2) Technical description, 3) Obstacles, 4) Measures to promote, providing readers with an overview of key information about the HIO for energy efficiency in China.

Each PCN chapter provides much more detailed information, structured as follows:

- Introduction/Background
- Objectives
- What are the outputs, and are they measurable?
- Relationship to the country's energy efficiency improvement priorities
- Project Deliverables, e.g. Value/Benefits/Messages
- Project Scope and Possible Implementation
- Project Activities
- Timelines
- Budget/Resource Requirements
- Measurement/Evaluation
- Possible Complications/Challenges
- Responsibilities and Coordination

The 2010 China (Beijing) International Energy Saving and Environmental Protection Exhibition (EnerChina 2010) on June 15.

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CHAPTER 1

HIO FOR INDUSTRIAL WASTE HEAT RECOVERY TECHNOLOGIES

Guanyun Fu

1.1 BACKGROUND

China's industrial sectors possess lots of waste-heat resources, especially in the production processes of building materials, metallurgy, chemicals, papermaking, textiles and other industries. Among them, the waste-heat resources of the building materials industry account for more than 40% of fuel consumption, of the metallurgy industry more than 33%, and of the chemical, papermaking, textile and other industries approximately 15%. According to the findings of a 2010 survey conducted by the Energy Research Institute under the NDRC, the waste-heat sources OF seven industries (including steel, cement, glass, ammonia, caustic soda, calcium carbide and sulfuric acid) were as high as 280 million tce, accounting for 8% of total national energy consumed in the same year, potentially reaching 340 million tce in 2015. However, due to technical, system and concept constraints, only some of the potential waste-heat resources are being developed and utilized in China. Among the different industrial sectors, the steel and cement industries have higher utilization rates of waste-heat resources, while there is still much space for further improvements in other industries. In terms of waste-heat grades, high-grade heat resources have higher utilization levels, there being greater difficulties in the utilization of low- to medium-grade waste-heat resources (according to an investigation made by Energy Research Institute, 54% of industrial waste heat resources are 400°C middle- to low-temperature waste-heat sources, most of which are low-grade waste-heat sources with temperatures of 200°C and below). Strengthening the exploitation and utilization of China's industrial waste-heat resources would have significant future impacts on energy conservation and emissions reductions in industrial sectors.

1.2 TECHNICAL DESCRIPTION

There are three main approaches to using industrial waste heat. The first approach is to direct the use of waste-heat resources. The principle of this approach is relatively simple, namely using waste-heat resources directly for various purposes, including air preheating, dry, hot water or steam production, refrigeration and heat supply. The second approach is to convert waste heat into power for recovery, which is especially applicable for high-grade waste-heat resources. The best method of recycling is to convert waste heat into power or power generation. It is worth mentioning that, for low- to medium-grade waste-heat resources, it is also possible to realize power recovery by means of Rankine cycles, heat pumps and other methods. The third approach is the comprehensive utilization of waste-heat resources. Depending on quality, energy carriers and the pressure of waste-heat resources, through step-by-step and classified processing methods such as Gas Turbine Combined Cycle Power Generation Technology (CCPP), the latent heat of the fuel gas in the waste heat and sensible heat that the fuel gas carries itself can be utilized, thus maximizing the utilization of waste-heat resources.

Preliminary assessment indicates that industrial waste heat-recovery technologies that are more mature, have greater economic efficiency and greater promotion potential include coke dry quenching (CDQ), sintered ore waste-heat power generation, cement kiln pure low-temperature waste-heat power generation, blast furnace slag-water heating and other technologies. Cement kiln pure low-temperature waste-heat power generation technology has already become the standard configuration for newly built cement plants and is being used in more than 90% of existing cement plants. Therefore, there is not much room left for further improving this technology's penetration rate. In contrast, there is considerable room for improving the penetration rate of coke dry quenching (especially for independent coking plants), sintered ore waste-heat power generation, the fourth generation of grate coolers and other technologies. By 2050, the penetration rate of these technologies should reach 80% or even higher. Blast furnace slag-water heating generation technology has been used as a typical case of a combination of industry and city-based low-grade waste-heat recovery. It has been included in the Top Ten Chinese Best Energy Conversation Technologies and Practice List and is being rapidly promoted and applied in areas that need space heating in northern China.

The Yangtze River Industrial Park.

humphery/Shutterstock.com

1.3 OBSTACLES

(1) TECHNICAL OBSTACLES

From the technical point of review, industrial waste-heat resources are often scattered, intermittent and unstable. The energy carriers may be gas, solid or liquid, and some waste-heat carriers are explosive, toxic, dusty and adhesive. Especially with regard to energy quality, the grades of waste-heat resources in different sectors and with different energy carriers can be very different. Besides high-grade waste-heat resources, there also exist a large number of low- to medium-grade waste-heat resources (approximately half of waste-heat resources are below 400°C), which are relatively difficult to recycle, can only be used in small areas, and are not economic.

(2) INSTITUTIONAL OBSTACLES

There also exist some institutional barriers to the dissemination of industrial waste-heat recovery technologies: waste-heat power generation and heating are difficult to access, enterprise financing is difficult, etc. For example, projects that generate power from industrial waste heat still find it difficult to sell power to the grid. The causes include the management system and the fact that charging standards are less standardized for some enterprises, while the implementation of relative policies in different areas is inconsistent, etc. In some power output provinces especially, industrial waste-heat power-generation units need to pay small sums and other fees to obtain connection to the grid, meaning that industrial projects that generate power from waste-heat resources cannot be put into operation for a long time after completion, resulting in the idling of power generation units and waste heat being unnecessarily wasted. In addition, some standards for waste-heat resources are still imperfect or too old and cannot meet the healthy development needs of a waste-heat recovery market.

1.4 MEASURES TO PROMOTE

(1) Increasing the investment in and financial support to industrial waste-heat recovery. It is suggested that the government should increase the investment in and financial support to industrial waste-heat recovery. First, financial institutions should be encouraged to innovate green credit products and increase credit input to industrial waste-heat recovery projects. Another solution is to guide all kinds of venture capital enterprises, equity investment enterprises and international aid funds to increase investment in the field of industrial waste-heat recovery. Secondly, full use should be made of the model of the 'Energy Management Contract' (EMC) and to encourage energy-saving service companies to provide customized energy services for energy consumption enterprises, especially comprehensive energy service companies that have technology and equipment reserves in the field of industrial waste-heat recovery.

(2) Accelerating the construction of a standard system for industrial waste-heat recovery. A national energy conversation management department should organize and coordinate the relevant industry associations, standards formulation departments and industrial enterprises to accelerate the construction of a standard system capable of achieving the full and effective development and utilization of industrial waste-heat resources. First, arrangements should be made to design a structured, clear, and coordinated standard system for the data collection and utilization of industrial waste-heat resources. This system should be used to guide the making and revision of future standards, thus ensuring that the standards are coordinated and scientific, and avoiding conflicts and contradictions among different standards. Secondly, arrangements should be made to revise certain existing standards that are obsolete, such as Industrial Waste Heat Terminology, Classification, and Grading and Resources Calculation Methods. Thirdly, desperately needed standards for industrial waste-heat recovery should be drawn up as soon as possible. These should include general rules for industrial waste-heat recovery and for the selection of industrial waste-heat recovery devices, as well as to test thermal evaluation standards for industrial waste-heat recovery devices, specifications for power generation from waste heat, procedural designs in the steel, building materials and petrochemical sectors, manufacturing standards for waste-heat recovery devices, etc. In addition, it is also important to construct a system of guarantees for the implementation of industrial waste-heat recovery standards.

(3) Improving relevant policies to combine industrial waste-heat power generation units with the grid as soon as possible. A national energy conversation management department should organize and coordinate energy management departments, electricity regulation departments and power grid enterprises to develop scientific and reasonable management methods and standardize approval procedures and management fees for waste-heat power grid connection. In this way, unreasonable regulations that impede industrial waste-heat power grid connection can be cleaned up, thus creating good external conditions for industrial waste-heat power generation units to realize grid connection.

2 CHAPTER

HIO FOR PROMOTING PASSIVE HOUSES

Jianguo Zhang

2.1 BACKGROUND

Passive houses are buildings in which different energy-efficiency technologies are installed to establish an optimal envelope structure and indoor environment, maximize the thermal insulation, heat insulation performance and airtightness of the building, and minimize the requirements for heating supply and cooling. In addition, different passive building measures, such as natural ventilation, natural lighting, solar irradiation for heat gain and indoor non-heating supply heat source for heat gain are adopted to realize a comfortable indoor thermal and humid environment and lighting environment, minimize dependence on the active mechanical heating and cooling system, or completely remove such facilities.

Since the world's first passive house in the real sense was built in Darmstadt, Germany, in 1991, passive houses have demonstrated their huge room and potential for development. By the end of 2013, about 50,000 passive houses had been built globally, half of which are in Germany. Compared with the statutory minimum architectural energy consumption standard specified in Germany under the Architectural Energy Saving Regulations/EnEV2009, passive houses only consume 30%~50% (depending on the type of building) of the minimum energy consumption, while the incremental cost is only between 3% and 15% (depending on the type of building) higher than a standard new building. Up to now, the 'passive house' has become the building standard with the most extended coverage in Europe. Since 2009, the Ministry of Housing and Urban-Rural Development (MOHURD) has been carrying out 'China passive low-energy consumption building demonstration projects' in cooperation with the German Energy Agency. Some passive houses have been completed and occupied, and passive house pilot projects are under construction in different climatic zones all over the country. The Qinhuangdao 'Zaishuiyifang' pilot project shows a significant energy conversion effect. Compared with residential buildings as specified in local building codes that require '65% energy savings', energy consumption for heating can be reduced by about 70%, while the construction costs only increase by 12%.

At present, there is still a big gap between China and developed countries in per capita residential building area, and per capita public buildings are for tertiary industry employees. Assuming that China reached a similar level to that in developed countries at a corresponding stage of development in 2015, then the total building area would exceed 86 billion square meters, an increase of 30 billion square meters from the present level. In the next several decades, urban residential buildings will annually increase by more than one billion square meters on average. Therefore, in the huge new construction market of the future, the large-scale promotion of passive houses will bring significant energy conversion effects.

2.2 TECHNICAL DESCRIPTION

Technically, it is essential to adhere to the principle of 'giving the priority to passive design and perform active optimization for economic and practical results'. In addition to meeting local climatic and natural conditions on the construction site, the building sector should, through reasonable floor planning, effectively utilize natural lighting and natural ventilation to improve the heat insulation and airtightness performance of the building envelope, and adopt various passive technological means, including solar utilization techniques and indoor non-heating heat sources for heat gain, to achieve building energy efficiencies and provide a comfortable indoor environment.

The design concept and major technical points of passive houses are the following. First, buildings should have a compact form and small shape coefficient. Second, the thermal insulating properties of building envelopes should be optimized, the heat bridge effect being minimized without a thermal bridge. Third, buildings should have a high degree of airtightness so that heat loss caused by ventilation can be reduced and the build-up of condensation and mildew on building components can be avoided. Fourth, optimum orientation of buildings and windows should be aimed at, as well as reasonable shading measures to achieve the maximum use of solar in winter and its minimum use in summer. In addition, buildings will make full use of natural light, leading to significant substitution and reduction of artificial lighting. Fifth, in the transition period, buildings will use natural ventilation to adjust the indoor temperature and humidity as much as possible, thus improving comfort. Sixth, a fresh air system with an efficient heat (cold energy) recovery function will be adopted. This system can recover waste heat (cold energy) indoors, and the efficiency of the heat-recovery device should be above 75%, thus maintaining a good indoor air quality. Seventh, buildings should have a strengthened sound insulation and noise reduction function, significantly reducing the sound transmission through the pipe network and auxiliary channel. Finally, and eighth, renewable energy will be fully utilized. For example, the winter indoor heat requirement can be met from solar energy, and solar water heaters can be installed to meet the living hot water demand. In addition, when building passive houses, refined construction is needed to ensure that thermal insulation, airtightness, moisture proofing, water tightness and other measures are implemented as well.

The main energy-efficiency indicators of passive houses include the total primary energy consumption of the building (including heating, cooling, ventilation, lighting, hot water, auxiliary energy and household appliances), per area heating (cooling) annual requirement and airtightness. According to Germany's standards for passive houses, the total energy consumption of the building (primary energy) should not exceed 120kWh/m^2/year, the annual area heating (cooling) requirement should not exceed 15kWh/m^2/year, and airtightness should satisfy the requirement that n_{50} is less than 0.6/h (meaning that, when the indoor and outdoor pressure difference equals 50 Uncontrolled leakage through Pascal, uncontrolled leakage through gaps must be smaller than 0.6 of the total house volume per hour). Since China has a vast territory and a diverse climate, it is necessary to adjust the indicators for heating, cooling and primary energy consumption according to regional climate characteristics and building types.

2.3 OBSTACLES

China is confronted with the following major obstacles in popularizing passive houses. The first obstacle is recognition: due to the brief history of new building types in China, society as a whole has a low level of recognition of passive houses. The second obstacle is technical: integrated design concepts are generally needed to design passive houses, and specialized technical personnel for the design of passive houses are lacking. The third obstacle relates to standards: China's current building code mainly sets out the requirements for the thermal performance of the building envelope and special energy-consuming equipment such as heating and air-conditioning, but has not raised the requirements for the energy-efficiency level of whole buildings. The design of passive houses needs to evaluate the building's overall energy consumption performance. The fourth obstacle relates to building materials: energy-efficient building materials, such as high-performance windows and air-sealing products, are in short supply in the market right now, meaning that a relevant technology supply system has not yet been devised, such as a healthy roof system, an external wall-insulation system, doors and windows, etc. The fifth obstacle relates to construction: passive houses need refined construction, which means high requirements for the quality of construction personnel. However, most construction workers in China are migrant workers, and there is lack of well-trained, stable workers in the construction industry. The sixth obstacle relates to policy: current methods of calculating housing floor area and floor area ratios are not conducive to mobilizing the readiness of real-estate developers to build passive houses. According to current provision, the envelope of the external wall is treated as the boundary in calculating housing floor areas and floor area ratios, while passive houses have additional layers of insulation that are typically 10~20 cm thick. If, following current calculation methods, real estate developers wrongly calculate floor area ratios and consumers pay 3%~10% more for the increased building area owing to the existing of insulation layers, this will not be conducive to the market promotion of passive houses.

2.4 MEASURES TO PROMOTE

The practice results of existing pilot projects in China have shown that the popularization of passive houses under existing conditions can significantly reduce the energy consumption of buildings, in addition to improving the living environment, showing that passive houses are technically feasible and economically affordable. In order to promote passive houses, more measures need be taken in the future.

First of all, a clear strategy is needed. The promotion of passive houses should be included in the national building energy-efficiency improvement road map, and the government should encourage stakeholders to take action as soon as possible. Second, standards must be improved. By tracking the implementation of passive-house pilot projects in different climate zones and belonging to different building types, we can summarize the experience of different cases and accordingly develop different design standards, norms and construction methods suitable for China's various climate zones and building types. Third, awareness-raising and training should be strengthened. It is important to popularize the concept of 'integrated design' and the design methods of passive houses to improve awareness among energy conversion authorities, real-estate developers and architects of the potential, methods and benefits of building energy-efficiency improvements, to develop comprehensive building energy-efficiency assessment tools, to specify the qualifying requirements of passive house construction and to strengthen the training of construction workers. Fourth, technical support is needed. It will be necessary to enhance research into and the development of the relevant technologies and products of passive houses, improve the supply system of building material products and technologies of passive houses and to strengthen market supervision. Fifth, steps should be taken to strengthen the construction of innovative mechanisms to increase the readiness of real-estate developers to develop passive houses and increase the enthusiasm of consumers to buy them.

A construction site of residential buildings in China.

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CHAPTER 3

HIO FOR AIR SOURCE HEAT PUMP TECHNOLOGY

Jianguo Zhang

3.1 BACKGROUND

Heat pumps work by consuming energy, raising the heat at low temperature to a higher temperature and releasing it on demand. Air source heat pumps can extract heat from the outdoor air, as a fan drives the outdoor air through the heating device (the heat pump evaporator) installed outdoors and thus obtaining heat energy from outdoor air. Then, by means of the indoor heat exchanger (the heat pump condenser), heat is used to produce hot water and hot air for room heating. In actual operation, depending on the efficiency of the motor, compressor, heat exchanger and other components, the heating efficiency of the air source heat pump (ASHP) is about 3 to 4. To satisfy the same heating requirement, the electrical consumption of an air source heat pump is only a quarter to a third that of direct electric heating. Therefore, the energy conversation effect of air source heat pumps is significant.

Heating energy consumption is an important part of total building energy consumption. At present, the energy consumption of central heating by urban buildings in the north alone accounts for about a quarter of China's total building energy consumption. The Yangtze River region includes Shanghai, Anhui, Jiangsu, Zhejiang, Jiangxi, Hunan, Hubei, Sichuan and Chongqing, and has about 6 billion square meters of urban residential buildings and 200 million urban residents. But for a long time, the indoor temperature of residential buildings has generally been low in winter, and thermal comfort has been poor in the Yangtze River region. With improvements in living standards, the demand for improvements to indoor winter temperatures has increased. The heating energy consumption of this region will be a point of potential increase in China's building energy consumption in the future.

Although the heating requirements of residents in the Yangtze River region need solving, it is not feasible to adopt central heating similar to what occurs in northern China. Assuming that large-scale central heating is adopted in this region, where there are 6 billion square meters of urban residential buildings, the heating energy consumption intensity in winter is approximately 8 to 12 kgce/m². However, if air source heat pumps were adopted for heating, electricity consumption intensity falls to about 6 to 8 kWh/m² (equivalent to between 2 and 3kgce/m²), only a quarter of the figure for central heating, leading to energy conversation of about 50 million tce. Compared to direct electric heating, two thirds of electricity consumption can be saved, assuming that the heating efficiency of air source heat pumps (ASHP) is 3, leading to an energy consumption of about 24 million tce. From the perspective of what consumers actually pay for heating, for a residential unit of 100 square meters, the heating cost for a whole winter is about 1500 RMB with central heating, about 800 to 1000 RMB with a wall-hung gas boiler, and only 500 to 600 RMB with an air source heat pump. Thus, the promotion of air source heat pumps is technically feasible and economically reasonable, as well as having significant energy conversion potential.

3.2 TECHNICAL DESCRIPTION

Air source heat pump technology can be used to produce hot water or to heat buildings. At present, the air source heat pump used for heating buildings usually has three units: a large-scale air source heat pump water chiller-heater unit (air-water-heat pump system), a multi-split air-conditioning system, and a room air-conditioner. Owing to the convenience of access to heat, the air source heat pump is highly appropriate in China's many climate zones, being the top choice for heating buildings in regions where central heating is not possible. Since air source heat pumps can extract heat from the outdoor air directly, they can be easily installed locally, thus saving construction space. As long as the area is not extremely cold (an applicable outdoor temperature range of -10°C to 10°C), air source heat pumps can be used. There are various types of indoor terminal air source heat pumps, including floor radiation heating and direct delivery of hot blast by means of the device terminal or fan coil. When adopting floor radiation heating, it is already sufficient if the temperature of hot water produced by the heat pump reaches about 35°C, thus improving greatly the energy-using efficiency of air source heat pumps. What is more, floor radiation heating is easier to guarantee than the direct delivery of hot blast. Therefore, in respect of systematic energy conversion and indoor comfort, a system combining air source heat pumps with floor radiation has more advantages.

For cold areas, low-temperature heat-pump technology can also be used to improve reliability, safety and energy efficiency. For example, the air source heat pump technology based on a two-stage enhanced vapor inverter compressor has a broad range of application. This technology increases heating and cooling ability and the level of energy efficiency from -25°C to 54°C in the outdoor environment, and can be used for cooling in high-temperature areas and heating in low-temperature areas. Compared with conventional air source heat pump technology, this technology can only increase energy efficiency by 5% to 10% in rated heating conditions with an outdoor temperature of 7°C, but it will increase heating capacity by 50% to 100% and increase energy efficiency by between 5% and 20% when the outdoor temperature is -20°C. This technology is strongly adaptable to outdoor environmental temperatures and can be promoted and popularized in most parts of China.

3.3 OBSTACLES

There also exist some obstacles to the future promotion of air source heat-pump technology. The first obstacle is the applicability of the technology. In the Yangtze River region, for both cooling in summer and heating in winter, the requirements of the compression ratios of vapor compression refrigeration cycles are similar. Thus, this region is the most suitable area in which to share air source heat-pump technology in both winter and summer. However, when using air source heat pumps for heating in winter in this region, condensation may build up in the heat pump's outdoor evaporator. In cold areas, the heating efficiency of an air source heat pump will obviously decrease in winter when the environmental temperature is low, affecting its use effect. The second obstacle is the problem of the conditions supporting the technology. In order to solve the problem of heating buildings, one important precondition is that they should have good insulation and airtightness. However, insulation is poor in buildings that are suitable for air source heat pump heating, including residential buildings in the Yangtze River region and northern rural buildings. If the insulation and airtightness of buildings cannot be improved, it will be difficult to achieve the desired heating effect. The third obstacle relates to the business model. Unlike the central heating pattern in urban areas in northern China, air source heat-pump technology is household-based. In its daily operations and technical maintenance, there is a lack of professional technical support, thus affecting its use by consumers.

3.4 MEASURES TO PROMOTE

In order to promote air source heat-pump technology better, several measures suggest themselves, as in the following.

First of all, air source heat-pump technology should be included in renewable energy technologies and enjoy relevant support policies. Second, the range of applications of air source heat-pump technology should be defined. When this technology is used in different climate zones or for different purposes, the requirements for the performance of air source heat pumps differ. For hot summer/cold winter areas, air source heat pumps can be used for cooling in summer and heating in winter. For cold areas, they are mainly used for heating in winter, but for hot summer and warm winter areas, they are mainly used for cooling in summer. Third, air source heat pumps can be used to solve the problems of providing winter heating in the Yangtze River region and replacing coal burning by rural residents in the north. However, the precondition is to achieve improvements to the insulation and airtightness of buildings in order to reduce building energy demand. Fourth, it is important to enhance technology research and development by extending the range of application of air source heat-pump technology and further improving the energy efficiency of the device. Fifth, regional pilots of the peak-load regulation of the power system should be carried out. For example, the large-scale installation of air source heat pumps in northern rural regions will have a significant effect on the power supply of regional power grids. At the peaks or troughs of power demand, it is feasible to achieve cuts and increases respectively by stopping or starting air source heat pump units, but the effect of this needs exploring. Sixth, business models need to be developed and technical services guaranteed.

Air Source Heat Pumps Heating Cycle

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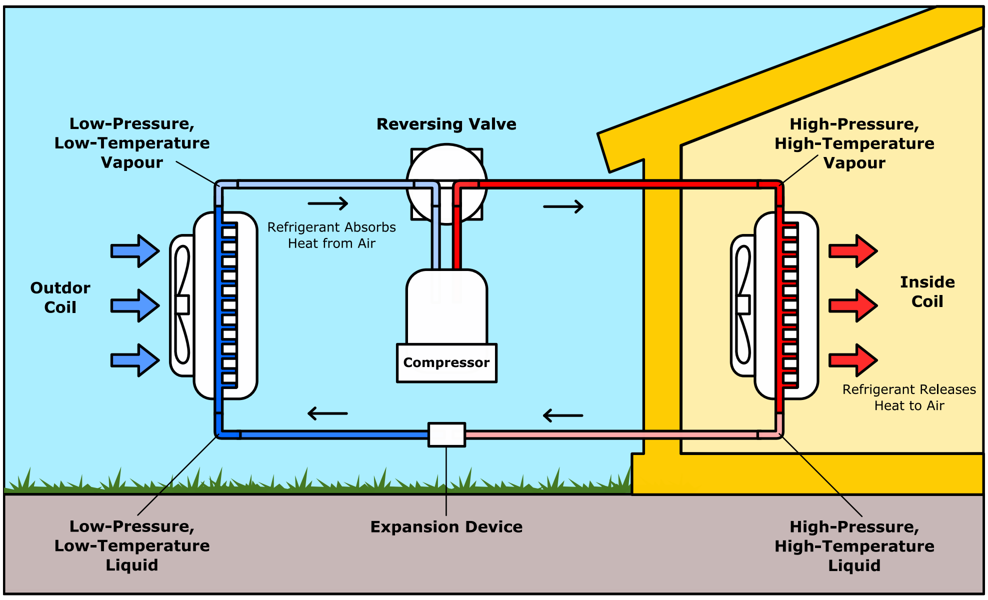

4

CHAPTER

HIO FOR UPGRADING THE FUEL ECONOMY OF TRUCKS

Wenjing Yi

4.1 BACKGROUND

According to statistics from the Ministry of Industry and Information Technology (MITT), China's automobile fuel consumption accounts for about half of total annual oil consumption, while 49.2% of total automobile fuel consumption is consumed by heavy-duty commercial vehicles (HCVs), even though they only account for 13.9% of China's total vehicle fleet. That is to say, although the number of HCVs in China is much lower than passenger cars, their fuel consumption is roughly equivalent to the fuel consumption of passenger cars. Therefore, the urgency of managing the fuel consumption of HCVs in China is much stronger than in any other country. If the fuel consumption of HCVs can decrease by 10% from its present level (the possession of HCVs uses the 2012 level, which is about 14 million), at least 9 million tons of gasoline and diesel can be saved annually, which is equivalent to the fuel consumption of more than 9 million household cars. The oil conversion effect is huge. According to MITT's survey of the present fuel consumption of hundreds of HCVs of major enterprises, the fuel consumption of China's HCVs is nearly 20% higher than similar vehicles in Japan and Europe. In addition, there exist different disparities between China's commercial vehicle production and developed countries' enterprises in the level of technologies that are closely related to fuel consumption. Relevant core technologies include engine combustion technology, electronic control technology, lightweight technology of the whole vehicle, high-pressure fuel-supply technology, multi-gear transmission technology and mastery of core components.

More than 90% of total HCV fuel consumption comes from trucks, i.e. heavy cargo vehicles. In order to promote energy conversion in China's transportation sector, reduce fuel consumption and guarantee energy security, the fuel economy of trucks must be regulated from the side of production so as to continuously increase the efficiency level of vehicles during the actual operation process from the source.

Heavy duty trucks stopped on the highway because of the traffic jam, on December 9, 2013, Tianjin, China.

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4.2 TECHNICAL DESCRIPTION

The fuel economy of heavy-duty commercial vehicles (of which the most important are trucks) has a significant effect on energy conversion and emissions reductions in the Chinese transportation sector. The Ministry of Transport (MOT) and Ministry of Industry and Information Technology (MITT) have issued a series of standards, including *Fuel Consumption Limits and Measurement Methods for Cargo Vehicles under Operation* (JT/719-2008), *Fuel Consumption Measurement Methods for Heavy-duty Commercial Vehicles* (GB/T 27840-2011), *Fuel Consumption Limits for Heavy-duty Commercial Vehicles* (the first stage) (QC/T 924-2011), *Fuel Consumption Limits for Heavy-duty Commercial Vehicles* (GB 30510-2014) and so on. The core standards are the last two.

Fuel Consumption Limits for Heavy-duty Commercial Vehicles (the first stage) (QC/T 924-2011), issued by MITT on December 31, 2011, has been implemented since July 1, 2012. It is a recommended standard for the automotive industry, but it is a mandatory standard for commercial vehicles with a maximum designed mass of more than 3500 kg that consume gasoline and diesel, including cargo vehicles, semi-trailer towing vehicles and buses. From July 1, 2012, products that fail to meet the requirements of these limits have not been included in the *Vehicle Manufacturers and Products Bulletin* and should not be marketed. MITT and MOT jointly conduct the supervision and management of fuel consumption detection for heavy-duty commercial vehicles. *Fuel Consumption Limits for Heavy-duty Commercial Vehicles* (GB 30510-2014) that are stricter than the first stage became a mandatory standard and have been implemented since July 1, 2014. The formulation of *Fuel Consumption Limits for Heavy-duty Commercial Vehicles* (the third stage) has already been in full swing since 2014, and has now been submitted to the State Council for approval.

4.3 OBSTACLES

Compared with developed countries, there is still a big gap in the efficiency level of trucks, as well as obstacles in the process of improving their fuel economy.

First, the standard for the limits on fuel consumption by trucks is not strict enough in China, and there are a lot of problems in enforcement. In the future, we should reinforce the formulation and implementation of the standard for these limits. The third-stage standard for these limits is aimed at closing the gap with Japan, Europe and other developed countries.

Secondly, there is a big gap between nameplate fuel consumption and actual fuel consumption in on-road conditions. The overloading and empty running of trucks in China are extremely serious at present, greatly affecting the fuel consumption trucks in on-road conditions. The management sector for transportation should adopt more effective ways to eliminate the overloading of trucks and guarantee the safety of on-road running.

Thirdly, the illegal modification of trucks is a very serious phenomenon in China, seriously affecting the efficiency of trucks. After such modifications, the actual load of trucks is much more than their marked loads, such that they can pay lower toll fees, purchase taxes and other fees. Although the state has issued appropriate rules, and multiple ministries will jointly regulate this phenomenon, truck modification is still very common. After being modified, the efficiency of overloaded trucks decreases sharply.

What is worse, truck production enterprises attach less importance to energy conservation technology, and technical research and development capability are limited. All these are important factors affecting the upgrading of fuel economy for trucks.

4.4 MEASURES TO PROMOTE

The following measures should be introduced: First, promote the timely issuing and updating of the new standard for the limits on HCV fuel consumption and closing the gap with the standards in developed countries. Second, enhance the ability of joint supervision and regulation among multiple ministries, including implementing strict regulations on truck manufacturers and prohibiting the sale of vehicles which do not meet the standard. Third, strengthen the joint regulation of illegal modification and overloading of trucks to improve their actual operating conditions. Fourth, promote research and development into a new generation of medium- to heavy-duty gasoline and diesel engine-efficiency improvement technologies, such as research on efficient clean-combustion technology, efficient post-processing systems, advanced air management technology, high-strength and low-friction design technology, efficient accessory technology, common control strategy, advanced sensing system integration technology, and so on. And fifth, encourage an environment in which truck manufacturers improve product standards on their own initiative and adopt the 'Leaders' plan to set good industrial examples.

CHAPTER 5

HIO FOR PROMOTING ELECTRIC VEHICLES

Wenjing Yi

An electric vehicle on display at the 9th China International Automobile Exhibition. on November 25, 2011 in Guangzhou, China.

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5.1 BACKGROUND

With the increase in the possession of civilian motor vehicles, China's refined oil consumption shows a rapid growth trend. In 2015, dependence on foreign oil exceeded 60%. Along with the increase in the demand for oil, the gap between supply and demand can only be satisfied through imports, which will further improve China's dependence on foreign oil, placing huge pressure on energy security. What is worse, the pollutant emissions caused by traditional diesel locomotives impose overload pressure on regional and city environments, and a vast area of mid-eastern China is suffering from smog. In addition, traditional cars cause greenhouse gas emissions, which have a negative effect on China's ability to address climate change and observe its international commitments. One kind of clean vehicle, electric vehicles (EVs), has a positive effect on solving urban environmental problems. What is more, with the increase in the share of renewable energy in power generation in the future, the low-carbon effect of electric vehicles will increase significantly, as well as leading to reductions in oil consumption, which will guarantee energy security.

Electric vehicles are a key technology in the new round of energy revolutions, and they have been identified as a key field for enhancing the core competitiveness of industry in Japan, the US, Europe and other developed countries. In order to realize leapfrog developments in its automobile industry, China has adopted electric vehicles as an important component of its strategic and emerging industries and has implemented various policies to promote the technical development, infrastructure construction, research and development of electric vehicles, thus promoting the development of the electric vehicle industry and the popularization of electric vehicles. China's policies in promoting the development of electric vehicles are mainly divided into four categories: macroscopic development goals and plans, financial subsidies for electric vehicles sold, development plans for infrastructure charging, and other relevant policies.

5.2 TECHNICAL DESCRIPTION

As the hotspot in the traffic field in recent years, electric vehicles now are in rapid development in all countries around the world. The total number of EVs globally has now exceeded one million. In 2015, China became the largest EV market in the world. The main driving force comes from policy support and subsidies. Electric vehicles mainly include battery electric vehicles (BEVs), plug-in hybrid electric vehicles (PHEVs) and hydrogen fuel battery vehicles (HEVs). BEVs are mainly driven by electricity. The engine system of PHEVs has both an electric motor and an internal combustion engine, so PHEVs are driven by oil or electricity as required. The main fuel of HEVs is hydrogen. The process of vehicle hydrogenation is much faster than charging, so the hydrogenation speed is basically equivalent to the refueling speed of traditional liquid fuel vehicles.

330,000 electric vehicles were sold in China in 2015, of which 250,000 were BEVs and 80,000 PHEVs. According to the survey, the main driving force in promoting the purchase of EVs is financial subsidies for small and medium-size cities, but for large cities, the restriction policy on purchases of traditional fuel vehicles is the main reason for consumers switching to electric vehicles.

5.3 OBSTACLES

Although the development of China's electric vehicle industry has achieved remarkable results, its foundation is still not solid, and there still exist some obstacles.

First, market-driven popularization is weak. At present, the development of the electric vehicle industry is mainly driven by policy support and mainly relies on tax incentives. However, this pattern can only accelerate industrial development in the short term, resulting in enterprises depending excessively on subsidies and product development deviating from actual market demand. Second, core technologies are still lacking. The technical level of China's own EV brands is poor, and the future pressure of competition will be huge. The quality of whole vehicle performance still cannot meet consumers' demands, and some of the core components are dependent on supplies from foreign enterprises. Third, charging infrastructure and support services are lagging behind. Although the state has issued relevant guidance on the construction of charging piles, the enthusiasm of local governments and industrial enterprises is not high. The operating and profit models are still not clear, and practice, which relies on network service platforms to enhance user experiences and value-added services, is still lacking. Fourth, the after-sales service and maintenance system is still lacking. Since battery repair and replacement requires professional devices, vehicle types differ greatly and the required investment in maintenance devices is high, general 4S shops do not want to provide maintenance services for consumers.

5.4 MEASURES TO PROMOTE

Financial subsidies should give way more to market forces. With the gradual withdrawal of financial subsidies, the government should develop more market tools to promote electric vehicles, for example, by means of carbon emissions trading systems and by encouraging enterprises to increase their efforts to promote electric vehicles.

Consumer demand should be guided, thus increasing the promotion of electric vehicles. At present, seven Chinese cities are implementing restrictions on purchases of traditional cars. In these cities, consumers' willingness to buy electric vehicles has increased significantly. Along with the surge in car possession, more and more cities will face increased air pollution and traffic jams. The guiding of consumers' preferences can improve the popularity of electric vehicles.

The charging environment ought to be optimized. The Ministry of Finance has issued an incentive policy for the construction of new energy vehicle-charging piles. In the future, the construction of charging piles will obviously accelerate, thus abolishing the key obstacle to electric vehicle popularization.

The technical level of electric vehicles should be improved and the costs reduced. Given continuous improvements in technology, the concerns over mileage because of imperfect battery technology will gradually be eliminated. Especially in low temperatures, repeated charging and low-power conditions, guaranteeing the normal driving of electric vehicles is a key issue to be resolved.

CHAPTER 6

HIO FOR THE TRANSFORMATION OF COAL-FIRED POWER PLANTS

Qingbing Pei

6.1 BACKGROUND

China's installed capacity structure has long been dominated by thermal power, and thermal power is based on coal-fired power. In 2015, installed capacity reached 1,508 GW in China: the installed capacity of thermal power was 990 GW, accounting for 65.7%; the installed capacity of coal-fired power was 884 GW, accounting for 89.3% of thermal power. In the same year, China's power generation reached 5.6 trillion kWh: thermal power generation was 4.1 trillion kWh, accounting for 73.2%, and coal-fired power generation was 3.76 trillion kWh, accounting for 91.7% of thermal power. Although the proportion of thermal power was 75.7% in 2005, it still occupies the dominant position.

Pollutant emissions caused by coal consumption are one important cause of air pollution. In China, power generation accounts for about half of all coal consumption. Therefore, accelerating the upgrading of coal-fired power plants is beneficial to easing resource constraints, realizing clean energy use and improving air quality.

The energy utilization efficiency of the Chinese power sector has been constantly improved in recent years. The gross coal consumption rate of power units over 6,000 kWh declined from 370 gce/kWh in 2005 to 319 gce/kWh in 2014, and the service power rate declined from 343gce/kWh in 2005 to 300 gce/kWh in the same year.

Nevertheless, there is still some room for improving energy efficiency in the power sector, and the energy conversion of coal-fired power plants is one of the main means of doing this. China's government issued *Full Implementation of Ultra Low Emission and Energy Conversation Transformation of Coal-fired Power Plants* in December 2015, stating that by 2020 coal-fired power plants should have fully implemented ultra-low emissions and energy conversions, significantly reducing coal consumption in power generation and pollution emissions. What is more, the gross coal consumption rate of existing coal-fired power units should be lower than 310 gce/kWh after conversion and lower than 300 gce/kWh for power units above 600,000 kWh (except for air-cooled units).

6.2 TECHNICAL DESCRIPTION

The transformation of coal-fired power plants involves two important methods. One is to transform the steam turbine's flow passage, recovery and utilization of residual heat from boiler fuel gas, using motor frequency conversion and other technologies to realize comprehensive energy conversions. The other method is the transformation of pure condensing units to realize cogeneration.

The comprehensive energy conversion of coal-fired power plants mainly applies to 300-600 MW subcritical and supercritical units. (1) Comprehensive technology for improving the performance of the turbine units of thermal power plants. This technology is mainly applied to existing steam turbine generator units commissioned with higher energy consumption. By optimizing the body and thermal systems of turbines, and analyzing equipment design and manufacture, power plant design and auxiliary machine configuration, equipment installation and overhaul, operation and maintenance, and their mutual relationships, turbine performance is comprehensively improved. (2) Technology of waste-heat in-depth recovery of thermal power plant exhaust gas comprehensive optimization system. This technology is applicable to the coal-fired units with actual exhaust gas temperatures higher than 120°C. The principle behind this technology is to install a gas cooler at the tail flue between the air pre-heater of the power station boiler and the electric precipitator, which will reduce the flue temperature to approximately 90°C. The recovered gas heat can heat compensated water from 70°C to approximately 110°C, thus pushing out low-pressure heater steam extraction and increasing the action of the turbine. (3) Vacuum-holding energy-efficiency system technology of thermal power plant condenser. This technology is applied to the generating unit of the water-cooled condenser system. By cleaning with a rubber ball, a turbine condenser vacuum-holding energy-efficient system can automatically eliminate the fouling of the condenser without stopping, thus improving unit performance and reducing the turbine's energy consumption.

The technology for the transformation of pure condensing units in order to realize cogeneration is mainly applied to 125-200MW pure condensing turbine units in the power sector. The technical principle is the holing extraction of pure condensing turbine units so as to enable the latter to provide the dual functions of pure condensing power generation and heat supply, thus improving energy efficiency.

6.3 OBSTACLES

There are two main obstacles to the comprehensive energy conversion of coal-fired plants. First, affected by the management model of enterprises, some power-generation enterprises focus more on production safety and environmental protection and less on energy conversation management. These enterprises suffer from a lack of global awareness of energy conversion and find it difficult to seek out comprehensive and systematic energy conversion opportunities. Secondly, some enterprises are limited by their research and development capability and capital, thus finding it difficult to promote advanced technologies that suit them.

There are three main obstacles to the transformation of pure condensing units to realize cogeneration. First, construction of an urban heat-supply network infrastructure is lagging behind. The enthusiasm of local governments and local heating power companies in constructing heat supply networks is not high, and the construction of such networks is not timely. Secondly, the pricing system for heating power and power is incomplete. Under the existing system, heat power plants and thermal power plants will bid to access the network under equal conditions, but combined heat and power generation and pure condensing thermal power generation units are usually disadvantageous in grid competition. Thirdly, while the demand for power increases slowly, the demand for heating increases continuously. Therefore, transforming pure condensing units to realize cogeneration will be subject to some restrictions.

6.4 MEASURES TO PROMOTE

(1) Coal-fired power plants establish enterprise energy-management systems, meaning that enterprises should base energy-conversion and energy-efficiency improvement plans on carrying out energy audits. Power generation authorities and associations implement energy-efficiency benchmarking for power generation enterprises. By means of carbon emissions trading systems and other means, power generation enterprises can obtain economic benefits, as well as improving energy efficiency.

(2) Implementation of the concept of systematic energy conversion, promoting engineering design optimization, and promoting integrated technology application. By strengthening engineering design and the feedback of construction and operational experience, the engineering design optimization level can be improved. The construction of coal-fired projects that apply integrated advanced energy conversion and emissions reductions technologies should also be encouraged.

(3) In the cities and industrial parks where conditions are ready, coal-fired units implement cogeneration. In the areas that have drawn up cogeneration development plans, local governments should create regional heat pipe network development plans adapted to the scale of development of cogeneration units. Heating system reform and improving heat price formation mechanisms should be encouraged.

Coal fired power station with cooling towers releasing steam.

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7

CHAPTER

PCN FOR PASSIVE HOUSES (100,000 M²)

Qin Zhang

7.1 INTRODUCTION

Passive houses are buildings in which different energy-efficient technologies and passive building measures have been introduced to establish the optimal envelope structure and realize a comfortable indoor thermal and humid environment, thus minimizing dependence on the active mechanical heating and cooling system or completely abolishing such facilities.

The world's first passive house was established in Darmstadt, Germany, in 1991. Since 2009, the Chinese Ministry of Housing and Urban-Rural Development (MOHURD) has also carried out 'China passive low-energy consumption building demonstration projects' in cooperation with the German Energy Agency. By 2016, more than thirty passive house pilot projects had been completed and more than seventy passive house pilot projects were under construction, covering most of China's climate zones. Some passive houses have been occupied and have shown significant energy-conversion effects. For example, the Qinhuangdao 'Zaishuiyifang' pilot project shows that, compared to residential buildings as specified in the local building code that imposes '65% energy savings' from the 1980-1981 average local building energy efficiency perofmrance level, energy consumption for heating can be reduced by about 70%.

At present, there still exists a big gap between China and developed countries in per capita residential building area and per capita public building area for tertiary industry. Assuming that China reached a similar level as developed countries at a corresponding stage of development in 2015, then the total building area will have exceeded 86 billion square meters, an increase of 30 billion square meters from the existing level. In the next several decades, urban residential buildings will increase annually by more than 1 billion square meters on average. Therefore, in the huge new building market of the future, the large-scale promotion of passive houses will produce significant energy conversion effects.

7.2 OBJECTIVES

Demonstrate the commercial feasibility of passive houses in China on a large scale.

Generally, although energy consumption will be saved significantly, the incremental investments and costs will also be considered carefully. Currently, passive houses are being piloted to demonstrate their technological feasibility. To facilitate the promotion of such building concepts on a large scale, the commercial feasibility of passive houses must be demonstrated in light of the specific situation in China, with its different climatic zones and alternative energy prices.

7.3 THE OUTPUTS AND THEIR MEASURABILITY

The proposed project outputs are the following:

- One passive house compound with a total floor area of 100,000 m².
- Assess the direct increased investments and costs compared with traditional residential building communities, such as building construction investments and municipal supporting facility investments.
- Assess the indirect saved investments and costs compared with traditional residential building communities, such as residential air-conditioning equipment, the pipe well area saving due to the heating system being abolished or simplified, rewards or subsidies from government, tax deductions and exemptions.
- Assess energy conservation and its cost compared with traditional residential building communities in light of the local energy price for heating supply and natural gas and electricity prices.
- Assess the indoor environment and living quality of passive houses, such as indoor temperature, indoor humidity, sound insulation and noise reduction.
- Assess the commercial feasibility of passive houses at the community scale and the feasibility of their promotion in China.

All the above outputs are measurable ex post. Here the **traditional residential building community** refers to buildings conforming to the local building code that imposes 'energy savings of 65%.

7.4 RELATIONSHIP TO THE COUNTRY'S ENERGY-EFFICIENCY IMPROVEMENT PRIORITIES?

The proposed projects are fully consistent with China's energy-efficiency improvement priorities. There is a high degree of possibility that passive houses will become extremely popular in the consumer market in the future.

A series of policies have been issued to promote passive houses. The State Council issued *Some Opinions on Further Strengthening the Management of Urban Planning and Construction* in February 2016, stating that China will develop passive houses and other clean energy-saving buildings. *The 13th Five-Year Plan for Housing and Urban-Rural Development* also emphasizes the promotion of passive houses. A number of provinces have issued specialized policies to promote passive houses.

Especially in order to mobilize the enthusiasm of real-estate developers to construct passive houses, the government has drawn up a relevant support plan, the first form involving an award or subsidy. For example, the government will grant awards according to the incremental cost of the passive house project in Shandong, and Hebei province has set up a specialized fund for subsidizing passive houses of ten RMB per square meter. The second form refers to the advantages of land purchases. In Baoding, real estate developers will pay 200,000 RMB less per acre of land when developing passive houses. What is more, under the same competitive conditions, the developers of passive houses enjoy a priority. The third form refers to the remission of some relevant fees. For example, passive house projects do not need to pay urban construction support fees in Dingzhou, Hebei province.

7.5 PROJECT DELIVERABLES, E.G. VALUE/BENEFITS/ MESSAGES

Generally, although energy consumption will be saved significantly, the incremental investments and costs will also be considered carefully. Currently, passive houses are being piloted to demonstrate their technological feasibility. To facilitate the promotion of such building concepts on a large scale, it is necessary to demonstrate the commercial feasibility of passive houses in light of the specific situation in China, with its different climatic zones and alternative energy prices.

The proposed project deliverables are the following:

- One passive house community of 100,000 m^2.
- Direct increased investments and costs compared with traditional residential building communities: 59.6 million RMB, 596 RMB/m^2. These data have been taken from the Qinhuangdao 'Zaishuiyifang' passive house pilot project. Although property prices in Beijing are much higher, building costs are similar.
- Indirect saved investments and costs compared with traditional residential building communities: 19.4 million RMB, 194 RMB/m^2.
- Energy conservation and its cost compared with traditional residential building communities as specified in local building codes imposing 'energy savings of 65%': 1,144 tce and 11.44 kgce per m^2: 3.5 million RMB and 35 RMB/m^2, without taking into account energy savings from cooling needs in summer.
- Indoor environment and living quality, such as indoor temperature, indoor humidity, sound insulation and noise reductions.
- The commercial feasibility of passive houses at the community scale and the feasibility of their promotion in China. If commercially feasible, explore the possibility of promotion on a large scale. If not commercially feasible, explore possible solutions and measures, such as subsidies and tax-preferential policies.

7.6 PROJECT SCOPE AND POSSIBLE IMPLEMENTATION

The proposed project will construct a passive house community. Key information concerning this is as follows:

Project scale: 100,000 m^2. Currently, the scale of the pilot passive house projects ranges from 6,000 to 15,000 m^2, roughly equivalent to one building. To demonstrate their commercial feasibility better, the project scale is 100,000 m^2, ten times the existing pilot project scale, and roughly equivalent to ten buildings or 1,000 households or families, or one residential community.

Project location: based on experience with the pilot passive house projects, the project will be located in northern China or a cold climate zone, where there is a huge energy-savings potential from the heating supply.

Project type: newly built or renovated, and renovation of existing buildings.

Project feasibility: the existing pilot projects have proved the technical feasibility of passive houses across different climate zones in China. Currently, urban residential buildings are increasing by more than 1 billion square meters per year on average, which is equal to 10,000 communities on the proposed project scale. The total of existing residential buildings exceeded 56 billion square meters in 2015, which implies a huge potential for retrofitting using passive house technology. Therefore, the proposed project is feasible and has huge potential.

Project implementation: the proposed project can be implemented by real-estate developers for newly built projects or third-party and energy-service companies (ESCO) for renovation or the renovation of existing buildings.

7.7 PROJECT ACTIVITIES

In brief, the construction principle for passive houses can be summarized as creating a building envelope with excellent insulation properties and efficient devices. Technically, it is essential to adhere to the principle of 'give a priority to passive design and perform active optimization for economical and practical results'.

Compared with traditional residential building communities, in order to achieve the expected energy conversion effects, it is essential to pay attention to the following key design points when carrying out passive house projects: 1) buildings should have a compact form and a small shape coefficient; 2) the thermal insulating properties of building envelopes should be optimized, and the heat bridge effect minimized without a thermal bridge; 3) buildings should be highly airtight; 4) the best orientation of buildings and windows and reasonable shading measures will be adopted to achieve the maximum use of solar in winter and the minimum use of solar in summer; 5) in the transition season, buildings will use natural ventilation to adjust indoor temperatures and humidity as much as possible, thus improving comfort; 6) a fresh air system with an efficient heat (cold energy) recovery function will be adopted so that a good indoor air quality (indoor temperature, indoor humidity, etc.) can be maintained; 7) buildings will have a strengthened sound insulation and noise reduction function; and 8) renewable energy will be fully utilized.

The main energy-efficiency indicators of passive-house communities include the total primary energy consumption of buildings (including heating, cooling, ventilation, lighting, hot water, auxiliary energy and household appliances) per area of heating (cooling) requirement annually. According to German standards for passive houses, the total energy consumption of the building (primary energy) should not exceed 120 kWh/m² per year, and the annual per area heating (cooling) requirement should not exceed 15 kWh/m² per year. Since China has a vast territory and a diverse climate, the indicators for heating, cooling and primary energy consumption should be adjusted according to regional climate characteristics and building types. According to China's passive-house design standard, the heating requirement should not exceed 18Wh/m² per year in the severe cold region or 15Wh/m² per year in the cold region, which is only a quarter of the standard of '65% energy savings' for the northern area.

Therefore, it is reasonable to conclude that consumers will prefer to buy passive houses, even though their construction costs are a little higher. It is obvious that passive houses enjoy a broad market prospect and a vast market demand.

7.8 TIMELINES (WHAT ARE THE TIMELINES, E.G. ONE QUARTER, ONE YEAR, MULTIPLE YEARS?)

Estimate: **two years** for newly built community; **half a year** for renovation and the renovation of existing buildings.

7.9 BUDGET/RESOURCE REQUIREMENTS

Compared with traditional residential building communities (satisfying the standard of 'energy savings of 65%'), additional investments or costs are estimated as follows:

1) DIRECT INCREASED INVESTMENT AND COSTS

Compared with traditional buildings, construction costs for passive houses are generally between 5% and 15% higher. Generally speaking, the main two causes are incremental pay for building materials with good insulation property that are used in the construction of the building envelope, and the construction of the heat recovery system (fresh air system). Taking the Qinhuangdao 'Zaishuiyifang' passive house pilot project as an example, according to information from the real-estate developer, the construction cost is 5,624 RMB/m², compared to the traditional construction cost of 65% energy-saving buildings of 5,028 RMB/. Although property prices in Beijing are much higher, building costs are similar. Given data availability, we take this data as our estimate.

Therefore, the direct increased investment and costs are 596 RMB/m², 12% higher than for traditional buildings. And the total direct increased investment of a 100,000 passive house community is **59.6 million RMB**.

2) INDIRECT SAVED INVESTMENT AND COSTS

Since there is no need to install a heat meter, air conditioner or pipe well for passive houses, heat supply stations, etc., the indirect saved investments and costs are estimated at about 194 RMB/m².

Therefore, the indirect saving investment and costs are 194 RMB/m². And the total indirect saving investment for a 100,000 passive house community is **19.4 million RMB**.

3) ENERGY CONSERVATION AND ITS COST

What is more, although the construction costs of passive houses are a little higher than for traditional buildings, the operating costs will decline significantly. Since passive houses do not rely on auxiliary heating or cooling systems, the building's energy consumption is fairly low, leading to a sharp decrease in energy costs. From the perspective of the full-life cycle, passive houses have long-term cost advantages and are cost-effective.

Compared with the statutory minimum architectural energy consumption standard specified in Germany's Architectural Energy Saving Regulations/EnEV2009, passive houses only consume 30%~50% (depending on the type of building) of the minimum energy consumption. According to China's passive house design standard, the per area heating requirement should not exceed 18Wh/m² per year in the severe cold region, nor 15Wh/m² per year in the cold region, which is only one quarter of the standard of 'energy savings of 65%' for the northern area (see section on HIO).

Taking the Qinhuangdao 'Zaishuiyifang' passive house pilot project as an example, the first passive house project in China, building energy consumption can be reduced significantly. Compared with traditional buildings that must satisfy the standard of 'energy savings of 65%', the total building area of this pilot project is 28,050 square meters. This can save 321 tons of coal consumption, which means 11.44 kgce/m².

Therefore, total energy savings are 1144 tce for a 100,000 passive house community, which is equal to 1600 tons of raw coal (one ton of raw coal equals 0.714 tce), and assuming the raw coal price is 600 RMB/tons of raw coal (http://www.cctd.com.cn/), the value of energy saving is **0.96 million RMB.** Alternatively, the heating supply price is generally 35 RMB/m² (price of district heating supply in Beijing), and the cost saved of avoiding district heat is **3.50 million RMB** annually.

As well as in the cold region, such as Hebei province and Shandong province, China has undertaken a series of pilot projects in different climate zones, all showing significant energy conversion effects. Harbin's 'Xi Shu Ting Yuan B4# Building' is the first passive house pilot project in the severe cold region, its per area heating requirement only being one-fifth of the overall energy-saving standard of Heilongjiang province. According to calculation results, when in actual operation, this project can reduce building energy consumption by more than 72%. Xinjiang's 'Xing Fu Bao' passive house project is the first to be certified in the northwest region, its per area gas consumption being about 1.5m³/m², which is only a tenth of that for general buildings, meaning that this project can reduce energy consumption by more than 90%. What is more, Hunan's 'Hui Nature City Park' project (the first passive house project in a hot summer/cold winter region), Fujian's 'Northern Mountain' project (the first passive house project in a hot summer/warm winter region), Qinghai's 'Li Shui Wan' project (the first passive house project on the Qinghai-Tibet Plateau) and other pilot projects all show significant energy conversion effects.

4) SUMMARY

Compared with traditional residential buildings (those satisfying the standard of 'energy savings of 65%'), the key indicators of passive houses are the following:

Table 2. Comparison between passive houses and traditional residential buildings

INDICATORS	DIFFERENCES
1. Direct increased investment	596 RMB/m²
2. Indirect saved investment	194 RMB/m²
3. Energy conservation	11.44 kgce/m² per year
4. Cost savings of energy conservation	35 RMB/m² per year

Based on the above indicators, the payback period is about (596-194)/35=11.5 years, which is modestly economically attractive.

In addition, if the indoor environmental quality, residential health and the municipal heating supply system are taken into account, passive houses will become more attractive.

7.10 MEASUREMENT/ EVALUATION

The evaluation summaries are the following:

- Total direct increased investment: 59.6 million RMB
- Indirect saved investment: 19.4 million RMB
- Energy conservation: 1600 tons of raw coal
- Cost savings of energy conservation: 3.5 million RMB
- Payback period: 11.5 years

Detailed information as in the above section.

7.11 POSSIBLE COMPLICATIONS/ CHALLENGES

When carrying out passive house projects, certain difficulties and obstacles may have to be faced.

First, the whole of society currently has a low recognition rate regarding passive houses, meaning that greater efforts are needed to strengthen promotion of the concept of the passive house and to make it known to more consumers. Second, there is a lack of specialized technical personnel for the design of passive houses. Third, there is the obstacle of the standards issue. Fourth, passive houses need refined construction, which means higher requirements for the quality of construction personnel. However, most construction workers are migrant workers in China, and there is lack of well-trained, stable workers in the construction industry. Fifth, energy-efficient building materials, such as high-performance windows and air-sealing products, are in short supply in the market currently, resulting in no relevant technology supply system having been formulated. The sixth obstacle is the policy issue. Current methods of calculating housing floor area and floor area ratio are not conducive to mobilizing the enthusiasm of real-estate developers to build passive houses (for detailed information, see the HIO on Passive Houses in Chapter 2).

The practice results of the existing pilot projects in China indicate that the popularization of passive houses under existing conditions can significantly reduce the energy consumption of buildings, in addition to improving the living environment, suggesting that passive houses are technically feasible and economically affordable. In order to promote passive houses, more measures need be undertaken in the future.

First of all, a clear strategy is needed. Passive houses should be promoted through the national building energy efficiency improvement road map, and the government should encourage stakeholders to take action as soon as possible. Second, standards must be improved. By tracking the implementation of passive house pilot projects in different climate zones and belonging to different building types, experience can be summarized, and accordingly different types of design standards, norms and construction methods that are suitable for China's different climate zones and different building types can be developed. Third, propaganda and training should be strengthened. It is important to popularize the concept of 'integrated design' and the design methods of passive houses, improve awareness of energy-conversion authorities, real-estate developers and architects to the potential, methods and benefits of improvements to building energy efficiencies, develop comprehensive building energy efficiency assessment tools, specify the qualification requirements for the construction of passive house construction, and strengthen the training of construction workers. Fourth, technical support is needed. The research and development of relevant technologies and products of passive houses must be enhanced, the supply system of building material products and technologies of passive houses improved and market supervision strengthened. Fifth, the construction of innovative mechanisms to mobilize the readiness of real-estate developers to develop passive houses and the enthusiasm of consumers to buy passive houses must be strengthened (detailed information in HIO chapter).

7.12 RESPONSIBILITIES AND COORDINATION

Stakeholders of passive houses include:

Supply side: real-estate developers for new residential building projects, or third-party and energy-service companies (ESCO) for renovation and the renovation of existing buildings, who will maximize their profits.

Demand side: house buyers or existing residents, who will minimize their costs or pay some additional costs for greater indoor quality.

Technical supply side: design and consulting units of passive house communities.

Government: policy, standards, subsidies or tax reductions.

Financial agency: investment and financial management, business model design.

On-going construction are seen around Beijing Central Business District (CBD).

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CHAPTER 8

PCN FOR AIR SOURCE HEAT PUMP (1,000 HOUSEHOLDS)

Sheng Zhou

Qin Zhang

8.1 INTRODUCTION

Air source heat pumps (ASHPs) can raise the heat at low temperature from the outdoor air to a higher temperature level, to be released in the outdoor air, in order to produce hot water and room heating. In its actual operation, ASHP technology is mainly used to produce hot water or to heat buildings. Given the efficiency of the motor, compressor, heat exchanger and other components, the heating efficiency of air source heat pumps (ASHP) is about 3 to 4. Compared with meeting the same heating requirement from direct electric heating, the electricity consumption of ASHPs is only a quarter to a third of that value. Therefore, its energy conversion effect is significant.

Heating energy consumption is an important part of total building energy consumption. At present, the energy consumption of central heating in urban buildings in northern China alone accounts for about a quarter of China's total building energy consumption. However, the Yangtze River region includes Shanghai, Anhui, Jiangsu, Zhejiang, Jiangxi, Hunan, Hubei, Sichuan and Chongqing, and has about 6 billion square meters (m^2) of urban residential buildings and 200 million urban residents. For a long time, without a heating supply, the indoor temperature of residential buildings has generally been low in winter, and thermal comfort is poor in this region. With the improvements to living standards, the demand for improvements to indoor temperatures in winter is increasing. Heating energy consumption in this region will represent a huge potential increase in China's building energy consumption in the future. Although the heating problems of residents in the Yangtze River region need solving, it is neither feasible nor economical to adopt central heating like that in the north of the country. Alternatively, ASHPs, direct electric heating and wall hung gas boilers are more feasible and realistic choices. Among them, ASHPs are more energy efficient, economic and environmental friendly. Compared with large-scale central heating or direct electric heating, if ASHPs are adopted in the Yangtze River region, they will create an energy conversion of about 24 million tce. Therefore, there will be a vast demand for ASHPs in the Yangtze River region in the future (detail information in HIO chapter). Besides a good energy consumption performance, ASHP water heaters can provide hot water at more stable temperatures and are more comfortable.

Another potential application of ASHPs is the residential demand for hot water, which has increased significantly in recent years and will continue to do so for a long time. Currently, as ASHP water heaters only account for 3% of the market, there is a vast development potential in the future.

8.2 OBJECTIVES

The objective of the project is to demonstrate the commercial feasibility of ASHPs in China.

Generally, ASHPs are currently being piloted to demonstrate their technological feasibility. To facilitate the promotion of the ASHP concept, its commercial feasibility on a large scale must be demonstrated in light of the specific situation in China, with its different climatic zones and alternative energy prices, especially in the Yangtze River region.

8.3 THE OUTPUTS AND THEIR MEASURABILITY

The proposed project outputs are the following:

- 1000 households with ASHPs for heating in winter and hot water all year
- Assess the increased investment and costs compared with traditional heating and hot water
- Assess the indirect saved investment and costs compared with traditional heating and hot water, such as air-conditioning equipment, the pipe well area saving due to the heating system being abolished or simplified, awards or subsidies from the government, tax deductions and exemptions.
- Assess energy conservation and its cost compared with traditional heating and hot water, and taking into account the local energy price for heating supply and natural gas and the electricity price.
- Assess the ASHP environment and living quality.
- Assess the commercial feasibility of ASHPs on a large scale and the promotion of their feasibility in China.

All the above outputs are measurable ex post. Here **traditional heating and hot water** refers to heating by central heating in north China, direct electric heating or wall-hung gas boilers in the Yangtze River region.

8.4 RELATIONSHIP TO THE COUNTRY'S ENERGY EFFICIENCY IMPROVEMENT PRIORITIES

A series of policies have been issued to promote ASHPs in China.

At the national level, the Ministry of Finance has issued relevant policies and granted financial subsidies to consumers when buying ASHP water heaters. In addition, the State Council issued an *Air Pollution Prevention Action Plan* in 2013, explicitly encouraging the application of ASHPs.

At the regional level, a number of provinces have included ASHPs in their renewable energy policies, including Hebei, Fujian, Zhejiang, Shandong, etc. Moreover, local governments are granting a large number of financial subsidies to promote ASHPs. For example, in adopting ASHPs, the subsidies residents receive can be up to 18,000 RMB per household in Beijing.

8.5 PROJECT DELIVERABLES

Generally, ASHPs are currently being piloted to demonstrate their technological feasibility. To facilitate promotion of the ASHP concept, the commercial feasibility of ASHPs on a large scale must be demonstrated in light of the specific situation in China, such as different climatic zones and alternative energy prices, especially in the Yangtze River region.

The proposed project deliverables are the following:

- 1000 households with ASHPs for heating and hot water.
- Direct increased investment and costs compared with traditional heating and hot water: between 16.7 million and 19.7 million RMB. Based on the publication and pilot project data, without future falls in prices with increased distribution and use, which is very uncertain at present.
- O&M: 2.3 million RMB annually.
- Energy conservation and its cost compared with traditional heating and hot water: 1000 to 1500 tce in total, and 1.0 to 1.5 tce per household. The cost savings are estimated at 0.9 million to 1.2 million RMB in total and 900 to 1500 RMB per household.
- ASHP indoor environment and living quality, such as indoor temperature, indoor humidity.
- The commercial feasibility of ASHPs on a large scale in China. If commercially feasible, explore the possibility of promotion on a large scale. If not commercially feasible, explore possible solutions and measures, such as subsidies and tax-preferential policies.

8.6 PROJECT SCOPE AND POSSIBLE IMPLEMENTATION

The proposed project is to construct 1,000 households with ASHPs for heating and hot water. Key information is the following:

Project scale: 1,000 households. Currently, the pilot ASHP project scales range from several households (8 households) to several buildings or student dormitories (786 rooms). To demonstrate better commercial feasibility in the Yangtze River region, the project scale is 1,000 households, ten times that of the pilot projects, and roughly equivalent to one residential building community of 1,000 households.

Project location: based on experience with the pilot ASHP projects, the project is located in the Yangtze River region, where there is a huge potential for ASHP energy savings from heating supply and hot water.

Project type: newly built or renovated and the renovation of existing buildings.

Project feasibility: based on the pilot projects, ASHPs are technically feasible across different climatic zones in China. Currently, urban residential buildings in Yangtze River region will average 6 billion square meters, which is equal to 600 million households, many more than the proposed scale of the project. Therefore, the proposed project is feasible and has promising potential.

Project implementation: the proposed project can be implemented by real-estate developers for newly built projects or third-party and energy service companies (ESCO) for renovation and the renovation of existing buildings.

8.7 PROJECT ACTIVITIES

The ASHP technology can be used to produce hot water or to heat buildings. At present, the ASHP technology used to heat buildings mainly consists three products: a large-scale ASHP water chiller-heater unit (air-water-heat pump system), a multi-split air-conditioning system, and a room air-conditioner. Owing to the convenience of access to heat, ASHPs enjoy strong applicability in China's many climatic zones, being the top choice for heating buildings in a region that central heating cannot cover. Since ASHPs can extract heat from the outdoor air directly, they can be easily installed locally, saving construction space. As long as the area is not extremely cold (applicable outdoor temperature range of -10 to 10°C), ASHPs can be used. The indoor terminal forms of ASHPs are various, including floor radiation heating and the direct delivery of hot blasts by means of the terminal device or fan coil. When adopting floor radiation heating, it is already satisfactory if the temperature of hot water produced by the heat pump reaches about 35°C. Thus, the energy-using efficiency of ASHPs has been greatly improved. What is more, it is easier to ensure floor radiation heating than the direct delivery of hot blast. Therefore, in the aspects of systematic energy conversion and indoor comfort, the pattern combining ASHPs with floor radiation has greater advantages.

For the proposed project, 1000 households with ASHPs for heating and daily hot water are being installed.

8.8 TIMELINES

Estimate: **two years** for newly built community; **half a year** for the renovation of existing buildings.

8.9 BUDGET AND RESOURCE REQUIREMENTS

Compared with traditional residential building heating and daily hot water, additional investments or costs are estimated as follows (Xiaoping Tang, 2016; Xiao-ning Chen, 2016; Heng Su, 2015):

1) INITIAL INVESTMENT AND COSTS

Heating component with floor heating terminal: as for the initial cost of purchasing an ASHP device, the overall price for a set of residential buildings of 100 square meters is about 13,700 RMB. An alternative option is direct electricity heating costing 3,000 RMB, while the price of a wall-hung gas boiler unit is 7,000 RMB. And there are about three air-conditioning units for cooling in summer. Therefore, the difference between the initial costs of the two models is small, while the design and installation of the ASHP device is simpler.

Hot water: As for the initial cost of purchasing an ASHP device for daily hot water, the general cost for one household is between 3,000 and 6,000 RMB. An alternative option is direct electricity heating, which costs between 500 and 2,000 RMB, while the price of a wall-hung gas boiler unit ranges from 2,500 to 5,000 RMB.

Therefore, the initial investment and cost is 13,700 RMB/household for ASHP heating and from 3,000 to 6,000 RMB/household for hot water. The total initial investment for 1,000 households is from **16.7 to 19.7 million RMB.**

2) OPERATING COSTS

As for operating costs, the situation differs in different climatic zones. Research shows that for the 'Liyang project' in Jiangsu province, which adopted floor radiation, the operating costs of ASHPs are more than 41% less than for wall-hung gas boilers and more than 59% less than for direct electric heating. When adopting radiator heating, the operating costs of ASHPs are more than 24% less than for wall-hung gas boilers and more than 55% less than for direct electric heating, implying that floor radiation heating is more energy efficient.

As for the maintenance costs, ASHP systems have obvious advantages. Since the water temperature of an ASHP is relatively lower, the service life of the water pump, mainboard and other core components is longer and more reliable. Thus, as long as the initial installation is reasonable, the later maintenance costs will be very low.

Heating component with floor heating terminal: about 2,030 yuan RMB annually with an ASHP. The alternative option is direct electricity heating costing 5,420 RMB annually, while the cost of a wall-hung gas boiler unit is 3,440 RMB annually.

Hot water: about 228 RMB annually with an ASHP. The alternative option is direct electricity heating costing 719 RMB annually, while the cost of a wall-hung gas boiler unit is 239 RMB annually.

Therefore, the O&M is 2,030 RMB/household for ASHP heating and 228 RMB/household for hot water, and the total O&M of 1000 households is **2.26 million RMB.**

3) ENERGY CONSERVATION AND ITS COST

Heating component with floor heating terminal: When the ASHP technology is used for building heating, it generates significant energy conversion effects. Taking the Yangtze River region as an example, the heating energy consumption intensity in winter is approximately 8~12 kgce/m² when adopting central heating similar to that in northern China, while the electricity consumption intensity is about 6~8 kWh/m² (equivalent to 2~3kgce/m²) when adopting ASHPs for heating. The energy consumption intensity of an ASHP is only a quarter of that of central heating. When compared with direct electric heating, two thirds of electricity consumption can be saved, assuming that the heating efficiency of ASHPs (COP) is 3.

Research also shows that the ASHPs of the 'Liyang project' in Jiangsu province produce about 5.44 kgce/m² annually in respect of winter heating supply. An alternative option is direct electricity heating producing 20.07 kgce/m² annually, while the price of a wall-hung gas boiler unit produces 14.53 kgce/m² annually.

Hot water: When ASHP technology is used to produce hot water, it shows a significant energy conversion effect. As shown in *The Research Report on the Development of China Air Source Heat Pump Industry 2015*, ASHP water heaters can generate about 3 to 4 units of power when consuming one unit of power, meaning that their energy efficiency is about 3 to 4 times of that of electric water heaters. Therefore, compared with electric water heaters, ASHP water heaters can reduce energy consumption by more than 70%.

Research shows that ASHPs produce about 54 kgce/household per year. An alternative option is direct electricity heating producing 170 kgce/ household annually, while a wall-hung gas boiler unit produces 185 kgce/ household annually.

Therefore, the O&M is 2,030 RMB/household for ASHP heating and 228 RMB/household for hot water, and the total O&M of 1000 households is **2.26 million RMB.**

Therefore, the total energy saving is from 1000 to 1500 tce for 100 households, which is equal to between **1500 and 2000** tons of raw coal. Assuming a raw coal price of 600 RMB/tons of raw coal, the value of energy savings is between **0.9 and 1.2 million RMB.**

As for operating costs, the situation differs in different climate zones. Shanghai Jiao Tong University, along with the Emerson Technology Company of Environmental

Optimization, has conducted research on the actual effects of EVI (Enhanced Vapor Injection) ASHPs in different climatic conditions. This study chooses a number of residential buildings in Shenyang (in the severely cold region), Beijing (in the cold region) and Liyang (in to Jiangsu province, a region with hot summers and cold winters) as research objects. The results of the research show that the operating costs of ASHPs are more than 15% less than for wall-hung gas boilers and more than 60% less than for direct electric heating in Shenyang, the research period being January to March. In the Beijing example, the operating costs of ASHP are more than 50% less than for wall-hung gas boilers, more than 70% less than for direct electric heating, and 8.8 RMB/m^2 less than for central heating, the research period being the same as Shenyang's. In summary, it is obvious that ASHP technology has significant advantages in terms of operating costs in different climatic zones.

4) SUMMARY

Compared with traditional residential heating and hot water, the key indicators of ASHPs are the following:

Table 3. Comparison between ASHPs and traditional residential heating and hot water

	INDICATORS		ASHP	ELECTRICITY	NATURAL GAS
Hot water	Initial investment	RMB	3,000-6,000	500-2,000	2,500-5,000
	O&M	RMB	228	719	239
	Energy consumption	kWh or Nm^3	438	1383	139
Heating	Initial investment	RMB	13700	3000	7000
	O&M	RMB	2030	5420	3440
	Energy consumption	kWh or Nm^3	4429	11826	1509

Based on the above indicators, it is obvious that ASHP technology has significant advantages in terms of operating costs in different climatic zones.

From the comprehensive perspective, considering the initial costs, the operating costs and the maintenance costs, ASHPs are economical. In addition, if the indoor environmental quality, residential health and municipal heating supply system are taken into account, ASHPs will be more attractive.

8.10 MEASUREMENT AND EVALUATION

Evaluation summaries are as follows:

- 1000 households with ASHPs for heating and hot water in the Yangtze River region.
- Total initial investment: 16.7-19.7 million RMB.
- Operational costs annually: 2.26 million RMB.
- Energy conservation: 1,500-2,000 tons of raw coal.
- Cost savings of energy conservation: 0.9-1.2 million RMB.

8.11 POSSIBLE COMPLICATIONS AND CHALLENGES

When promoting ASHPs, certain difficulties and obstacles may have to be faced.

There are also certain obstacles to promoting ASHP technology in the future. The first obstacle is the applicability of the technology. In the Yangtze River region, for both cooling in summer and heating in winter, the requirements regarding the compression ratio of the vapor compression refrigeration cycle are similar. Thus, this region is the most suitable area for sharing ASHP technology in both winter and summer. However, when using ASHPs for heating in winter in this region, condensation may build up in the outdoor evaporator of the heat pump. For cold areas, the heating efficiency of ASHPs will obviously decrease in winter when the environmental temperature is low, affecting the use effect. The second obstacle is the problem of the conditions for support. In order to solve the problem of heating buildings, one important precondition is that the buildings have good insulation and airtightness. However, in the case of buildings which are suitable for ASHP heating, including residential buildings in the Yangtze River region and northern rural buildings, insulation is poor. If the insulation and airtightness of buildings cannot be improved, it will be difficult to achieve the desired heating effect. The third obstacle is the problem of the business model. Unlike the central heating pattern in urban areas in the north of China, ASHP heating is household-based. In respect of the daily operation and technical maintenance of the device, there is a lack of professional technical support, affecting the use of consumers (see the HIO on ASHP in Chapter 3).

In order to promote ASHP technology better, it is suggested that several measures be taken as follows.

First of all, ASHP technology should be included in the renewable energy technologies and enjoy relevant promotional policies. Second, the range of application of ASHP technology should be defined. For hot summer/cold winter areas, ASHPs can be used for cooling in summer and heating in winter. Third, ASHPs can be used to solve the problem of winter heating in the Yangtze River region and the problem of substitution of coal-burning for northern rural residents. However, the precondition is improvements to the insulation and airtightness of buildings in order to reduce the building energy demand. Fourth, it is important to enhance technology research and development to extend the range of application of ASHP technology and to improve further the energy efficiency of the device. Fifth, it is necessary to draw up a business model and guarantee the availability of technical services.

8.12 RESPONSIBILITIES AND COORDINATION

Stakeholders of ASHP include:

- **Supply side:** real-estate developers for newly built projects or third-party and energy service companies (ESCO) for renovation and the renovation of existing buildings, which will maximize their profits.
- **Demand side:** ASHP buyers or existing residents, who will minimize their costs or be willing to pay some additional costs to obtain greater indoor quality.
- **Technical supply side:** design and consultancy entity of ASHP.
- **Government:** policy, standards, subsidies or tax reductions.
- **Financial agency:** investment and financial management, business model design.

City of Yiwu, Zhejiang, China.

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The six High Impact Opportunities (HIOs) covered in this report concern waste heat recovery in the industrial sector, passive house and air source heat pumps for the building sector, high fuel economy for trucks for cargo transport and electric vehicles for passenger transport, and energy conservation transformations of coal-fired power plants. These HIOs are expected to have huge impacts on improving energy efficiency in China by 2050. The report also presents detailed project concept notes on how to speed up implementation of two of the HIOs for the building sector through pilot projects on a commercial scale.

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