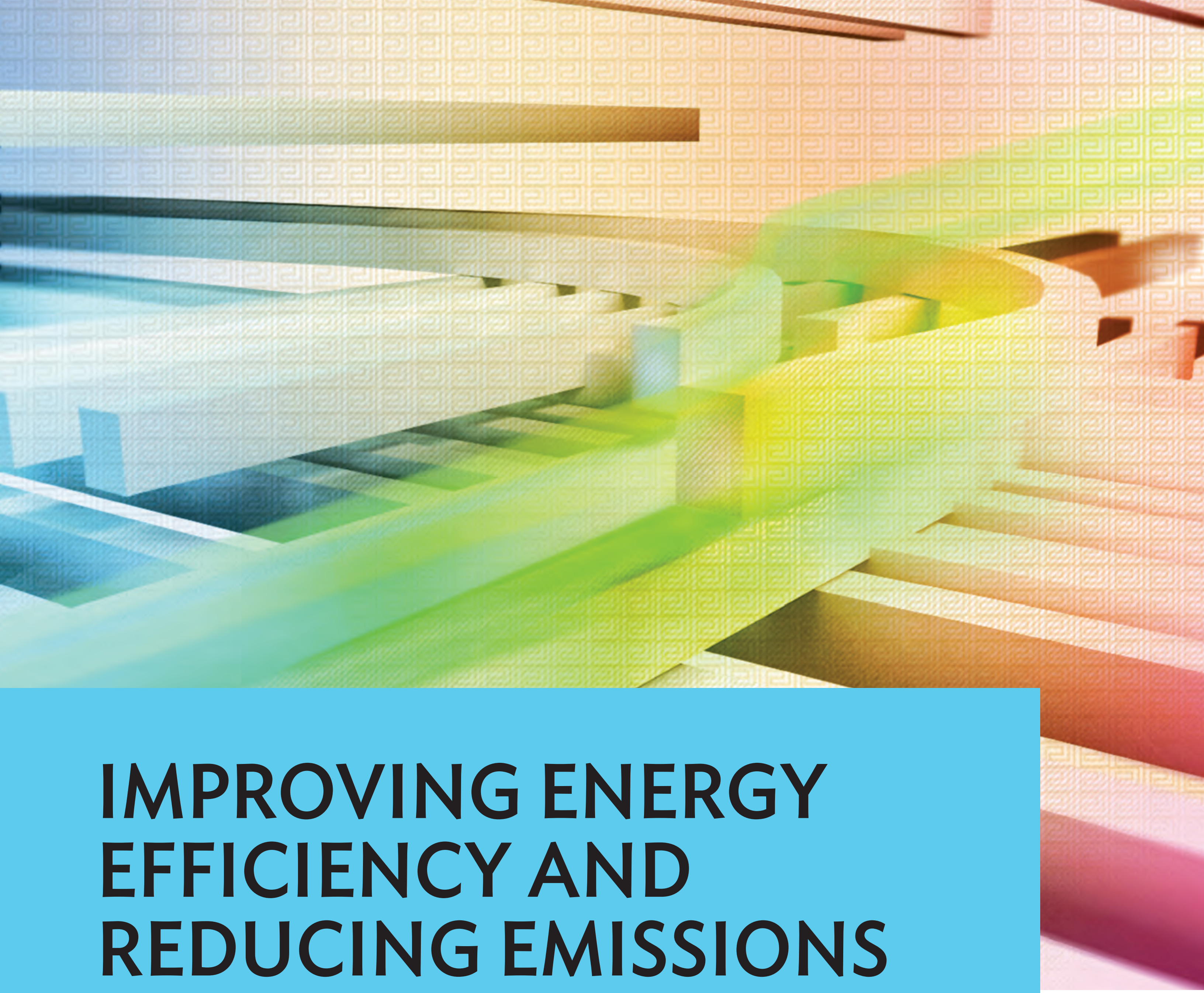

IMPROVING ENERGY EFFICIENCY AND REDUCING EMISSIONS THROUGH INTELLIGENT RAILWAY STATION BUILDINGS

ASIAN DEVELOPMENT BANK

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Foreword

One of the most important strategic objectives of all development initiatives in the People's Republic of China (PRC) is the reduction of energy consumption and carbon emission across sectors. In the PRC, for example, buildings alone consume 20.8% of the total energy produced, and a shift toward green buildings is of great importance.

This study, *Improving Energy Efficiency and Reducing Emissions through Intelligent Railway Station Buildings*, based on a technical assistance project, is a step toward achieving the goal of emission reduction and energy savings in railway station buildings. This initiative is supported by the Asian Development Bank and the China Railway Corporation. The objectives of the study are

(i) to collect and examine a number of successful, international case studies of energy-saving railway buildings (or buildings with similar characteristics), followed by an analysis of measures taken to achieve energy savings;

(ii) to outline design and operation features of domestic railway stations through available resources and field investigations;

(iii) to research, analyze, and propose feasible energy-saving solutions for domestic railway stations based on the results of the above objectives;

(iv) to propose recommendations for reduction in energy consumption and carbon emission;

(v) to propose a preliminary action plan based on market mechanisms that will enable further research and practices; and

(vi) to provide policy recommendations to the China Railway Corporation and other government agencies.

With analysis through case studies and simulation, the study provides policy recommendations to (i) address challenges posed by the lack of comfort and energy management in railway station buildings; (ii) establish classified design code or design guidelines (e.g., by climate characteristic, space function, traffic volume) to focus on energy saving in large station buildings; (iii) enhance interdiscipline and intradiscipline coordination to achieve holistic design and effective integration of design, equipment, construction, and operation; and (iv) enhance operation management of the systems.

It is our sincere hope that this report will be of interest to policy makers, practitioners, and researchers of green and intelligent buildings in the PRC and other developing member countries. As buildings consume a third of the global energy in both developed and developing countries, it is important for the railroad sector to pay sufficient attention to the use of energy in their buildings.

Ayumi Konishi
Director General
East Asia Department

Acknowledgments

This report was financed by a technical assistance project, *Improving Energy Efficiency and Reducing Emissions through Intelligent Railway Station Buildings*, funded by the Asian Development Bank. Xiaoxin Chen, senior transport specialist, led and managed the technical assistance. Tyrrell Duncan, former director, Transport and Communications Division, East Asia Department, and concurrently practice leader (transport) provided overall guidance and supervision.

Atkins Consultants (Shenzhen) Co., Ltd., Shanghai, and experts from the national consultant team, China Friendship Development International Engineering Design & Consultation Corporation, were of great help. The China Railway Corporation provided valuable assistance and institutional support.

A considerable proportion of the work required the involvement and cooperation of technology solution providers. Special thanks go to a number of internationally renowned smart building technology providers for technology descriptions and case studies.

Gloria Gerilla-Teknomo and Lin Liu peer reviewed the final report.

Abbreviations

BAS	building automation system
BMS	building management system
CRC	China Railway Corporation
EU	European Union
GDP	gross domestic product
GFA	gross floor area
HVAC	heating, ventilation, and air-conditioning
IPD	integrated project delivery
PPP	public–private partnership
PRC	People’s Republic of China

Units and Measures

CNY	yuan
km	kilometer
kW	kilowatt
kWh	kilowatt-hour
m	meter
m^2	square meter
m^2/y	square meter per year

Executive Summary

Objectives and Content

This report aims to support the national carbon emission reduction plan in railway station buildings; to learn and make use of the advanced technologies in international building management; and to ensure energy savings, safety, and comfort in railway station buildings in a cost-efficient way from the perspective of energy management, with expected energy savings of 20% through implementation of intelligent building control.

The report has (i) analyzed energy consumption and intelligent control of the railway stations in the People's Republic of China (PRC), (ii) listed energy efficiency assessment methods for buildings, (iii) determined energy-saving rates by intelligent control measures, (iv) summarized intelligent building technologies, (v) compared international and national administrative mechanisms, and (vi) provided the policy recommendations and action plan.

Background and Gap

Energy saving and carbon emission reduction of railway stations requires an effective and integrated application of intelligent technologies; the major driving forces being the following facts:

(i) With the rapid development of railway stations in the PRC, the number of stations has exceeded 5,000, and the size of the rail network will increase to 120,000 kilometers by 2015.

(ii) Buildings consume 20.8% of the total energy produced in the PRC.

(iii) The shift in the PRC's national development strategy is reflected in a series of policies such as the Twelfth Five-Year Plan of National Development and the Twelfth Five-Year Plan of Railway Development. Energy saving and carbon reduction has become a restrictive target instead of a predicted target.

(iv) Less than 50% of building automation systems (BASs) in the PRC are used for energy savings, of which less than 30% meet the performance requirements, and less than 20% can automatically control air-conditioning systems, thus there is an urgent need to efficiently use intelligent BASs.

(v) According to the European Standard EN15232, the current intelligent control level of railway station buildings in the PRC can be rated only as Class D or C, which is way behind Class B or A.

Current Energy Consumption and Deficiencies

The study of the current energy consumption in domestic railway station buildings in the PRC reveals the following:

(i) Current average energy consumption of large stations is 214 kilowatt-hour per square meter per year (kWh/m^2/y). Compared with the energy consumption of 114 kWh/m^2/y of a large public building in the PRC, railway stations have high energy-saving potential. Energy consumption of northern stations is 278 kWh/m^2/y and that of traditional stations is 307 kWh/m^2/y; this offers huge potential for saving energy.

(ii) Major deficiencies of current railway stations can be identified.

(iii) In the design stage, passive analysis and its measures are not considered seriously, BAS integration is not compatible, and there is no energy submetering system. In the procurement stage, too many suppliers and vendors present more challenges for integration, and there is a lack of comprehensive technical criteria for contractor evaluation and acceptance in tender requirements and contracts. In the construction stage, there is lack of independent, integrated testing and commissioning. In the operation stage, facility operators are not involved in acceptance procedures, and lack sufficient training to understand systems. Energy consumption is seldom monitored thus there are no baselines to compare with possible improvements. Solving the aforementioned problems will provide a stable basis for achieving energy-saving targets of railway stations in the PRC.

Energy-Saving Rates by Intelligent Measures and International Experience

The study of over 18 domestic and international cases reveals the following:

(i) Intelligent controls can help reduce energy usage by as much as 40%. If the 20:80 ratio between construction costs and operating maintenance costs is considered, the core value of intelligent controls will be even more significant. For new buildings, advanced BASs can save as much as 20% compared with manually operated facilities. For existing buildings, energy efficiency may increase significantly by 18% on average after recommissioning.

(ii) Success of intelligent control implementation comes from true understanding of control systems. Intelligent control is the interaction between building envelope, building services, and human factors, and it means the fundamental integration of all systems. It requires careful checking and verification throughout the design, installation, and commissioning stages and operation. Intelligent controls not only require hardware to be installed but also rely on accurate control strategies set up by software. An international case study shows that integrated hardware and software control systems are required as a platform to monitor and control all building equipment as well as an integrated energy management platform to monitor all energy consumption to achieve the above objectives.

(iii) Summarized are over 40 intelligent building technologies already used in commercial buildings in the PRC, which are also suitable for railway station buildings. However, the implementation of these technologies requires more detailed consideration. International experience shows that integrative design is essential for an integrated system to work rather than technologies being simply stacked together. Intelligent low-carbon railway station design and technical application should be a correct and comprehensive procedure. First, adopt passive design strategies to optimize building orientation and form according to the local climate and site conditions. Second, adopt active design strategies for highly efficient equipment to provide heating, cooling, ventilation, and lighting. Third, adopt intelligent controls for building envelope and equipment based on actual demand to sustain a safe, comfortable, and energy-efficient building environment. Finally, in terms of renewable energies, carry out technical and economic assessments to avoid possible failures and long payback periods.

Building Energy Performance Baseline

Energy consumption performance will be helpful to guide the design and operation of intelligent railway station buildings. The building energy baseline can be divided into two categories: the energy performance of the design building and the energy performance of the actual building.

(i) Regarding design building performance, newly built stations must meet the PRC's Public Building Energy Saving Standard, which means at least 50% energy savings compared with the baseline in the standard. Through dynamic software simulation, energy performance without intelligent control is about 150 kWh/m^2/y, while implementation of four key intelligent measures can enhance energy performance and reduce consumption to 127 kWh/m^2/y. Intelligent control systems can save 15.47% in energy usage. With Green Railway Station Evaluation Standard released in the PRC in 2015, it is expected that the design energy performance will be further improved.

(ii) Regarding actual building performance, the China Railway Corporation (CRC) only uses a statistical method for energy consumption management based on energy bills. There is no energy metering system to show accurate and real-time energy consumption of each station for analysis and data comparison. The huge difference in energy consumption of two real cases in the same climate zone indicates the challenges involved.

(iii) Besides the above two assessment methods, we also recommend that the CRC refer to European Standard EN15232, Energy performance of buildings—Impact of Building Automation, Control and Building Management, to guide the control design and to adopt degree-day method to guide operation and energy management.

Administrative Mechanism

For the intelligent technology integration to be effective, a better operation mechanism is required. The legal system, policies, and management play decisive roles in successful reduction in energy consumption. Unlike in developed countries, the Government of the People's Republic of China has traditionally managed the energy-saving policy in the PRC. This has gradually given way to more market influence in recent years. The Energy Saving Technology Policy issued in 2007 has put forth specific policy requirements for railway station buildings.

(i) Regarding new railway stations, the whole project process is based on traditionally uncoordinated project life cycle stages for which different departments of the CRC are responsible. During the planning stage, the station is integrated into railway line approvals and less focus is given to station assessment. During the design stage, a railway-related design institute is responsible for the station design, whereas the Science and Technology Department of the CRC is responsible for design approvals and change orders. There is no specific design review for energy savings. During the construction stage, the Project Management Center of the CRC is responsible for procurement and construction management. During the operation stage, railway bureaus or transportation companies are responsible for management, and the station operator is responsible for daily operation. The Planning and Statistical Center of the CRC is responsible for energy statistics and assessment. Such uncoordinated project phases with multiple responsible departments cause information loss on intelligent control and lack an integrative process resulting in gaps between stages. Inevitably, it is difficult to meet functional requirements and performance optimization fails.

(ii) Regarding the operation of existing stations, there are multiple responsible parties as well. Railway bureaus or transportation companies are responsible for energy fees, whereas the Planning and Statistical Center of the CRC is responsible for energy statistics and assessment. The station head and several subordinate engineers are in charge of the station, while equipment maintenance is subcontracted. Therefore, decentralized facility management without accurate and real-time energy monitoring results in sacrificing comfort for energy savings.

Conclusion

In sum, effective design and construction management for intelligent railway station systems is lacking in the PRC. To solve this problem, the whole project process and administrative mechanism need to be optimized. Once the intelligent hardware in PRC railway stations is integrated, the key is improving functional system performance. Since railway stations in the PRC are spread across different climate zones, specific measurements are essential to meet the requirements for each local environment. Safety and energy savings are basic requirements for intelligent control; therefore, mature products, recognized technologies, and brands need to be used. Suitable sites may also showcase new technologies.

Policy Recommendations

Policy recommendations cover technical and management aspects for existing as well as new railway station buildings.

For the CRC and subordinate management departments, we recommend to

(i) have a clear energy-saving plan for railway stations;

(ii) promote energy-saving showcases, education, and campaigns;

(iii) establish an intelligent railway station energy-saving standard;

(iv) develop an energy-saving incentive scheme;

(v) strengthen energy monitoring management and execute energy audits;

(vi) strengthen science and technology, and improve innovation on energy-saving technologies;

(vii) strengthen cooperation mechanisms with local government;

(viii) reform the investment and financing system by using public–private partnerships to develop new stations;

(ix) adopt third-party facility management to manage regional stations; and

(x) espouse comprehensive planning for land development, and create a new prototype of railway development.

For new railway stations, we recommend to

(i) strengthen implementation of current design standards and construction codes through enhanced commissioning, involve facilities management staff in commissioning and acceptance stages, or outsource to an independent commissioning authority;

(ii) improve the quality of energy design sections for each trade and specialty, and set up energy-saving design reviews;

(iii) improve design process by adopting low-carbon design model to achieve a Green Building Label for railway stations;

(iv) enhance integration of building automation subsystems to comply with the same standard and open protocol;

(v) improve project and design processes to enhance synergy;

(vi) adopt whole-life cycle commissioning to cover design, construction, and operation stages;

(vii) improve design and construction quality of renewable energy systems;

(viii) enhance education and incentives for facility management staff;

(ix) establish standard for operation procedure and system manuals for daily operation;

(x) carry out energy audits and recommissioning over the facility's lifetime;

(xi) set up building energy metering systems; and

(xii) adopt public–private partnership to develop new stations.

For existing railway stations, we recommend to

(i) enhance education and incentives for facility management staff;

(ii) establish standard operating procedures and system manuals for daily operation;

(iii) carry out energy audits and recommissioning over the facility's lifetime;

(iv) set up building energy metering systems;

(v) try achieving green label certification for existing buildings; and

(vi) adopt third-party facility management to manage the station.

For intelligent control measurements, we recommend to

(i) adopt correct, intelligent, low-carbon design models and processes, and prioritize passive design strategies;

(ii) establish local and remote energy metering and monitoring systems;

(iii) establish standards and classes for intelligent railway station buildings;

(iv) realize automatic heating, ventilation, and air-conditioning controls;

(v) optimize intelligent lighting control systems;

(vi) add intelligent control to building envelope; and

(vii) adopt all-in-one platforms, and open protocols for BASs.

1. Introduction

1.1 Background

1.1.1 Urgent Need for Reductions in Energy Consumption and Carbon Emissions

We see energy savings in buildings as a major strategic initiative in realizing the sustainable development of the PRC's economy

Climate change is a major threat to the global economy and causes a loss of over $1.2 trillion each year, equivalent to 1.6% of the global gross domestic product (GDP).[1] The People's Republic of China (PRC) in particular is facing severe challenges in reducing energy consumption as promised in the Kyoto Protocol, as well as at the Copenhagen Climate Change Conference in December 2009. As the biggest manufacturing country in the world, and now the largest energy consumer, the PRC is facing increasing pressure to balance economic growth with environmental protection and sustainable use of its resources as a wealthy population consumes more resources and demands a greater quality of life. Reductions in energy consumption and carbon emissions have become the most important strategic objective of the future development of the PRC. The Twelfth Five-Year Plan strives to establish sustainable economic development driven by resource conservation and increased environmental protection. Mandated targets aim to reduce energy consumption by 17% GDP by the end of the plan.[2]

A shift toward green buildings is particularly important as buildings consume a third of global energy in both developed and developing societies. Buildings consume 20.8% of the total energy produced in the PRC alone.[3] This figure will grow exponentially with the PRC's plans for rapid urbanization and improvements in living standards. We see energy savings in buildings as a major strategic initiative in realizing the sustainable development of the PRC's economy.

1.1.2 Challenges Faced by the PRC in Railway Development

In the PRC, the development of railway network began in 2003 with a plan to build over 1,000 passenger stations.[4] By the end of 2013, the rail network grew to over

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[1] University Cooperation for Atmospheric Research, *Impacts of Global Warming on the Environment, Understanding Climate Change—2007*. IPCC Working Group II Report, https://www2.ucar.edu/news/backgrounders/impacts-global-warming-natural-systems

[2] State Council of the People's Republic of China. 2011. *Twelfth Five-Year Plan*. Beijing.

[3] China Greentech Initiative. 2012. *China Greentech Report 2011*. Beijing.

[4] Consultants' surveys, 2010.

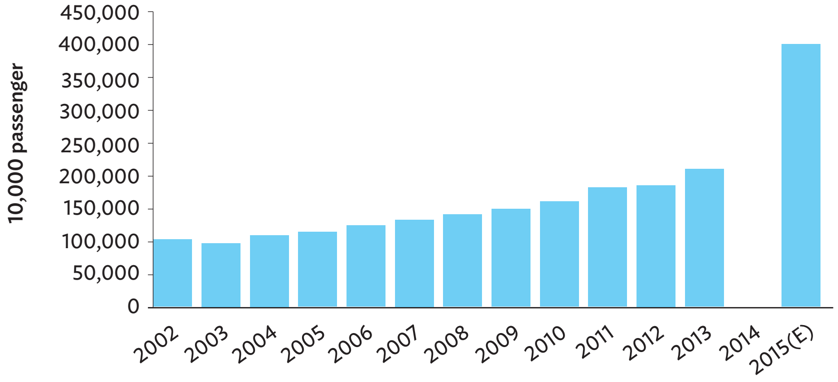
103,000 kilometers (km), an increase of 5.7% compared with that in 2012. Overall, passenger traffic in 2013 reached 2.1 billion trips, a growth of 10.8%, and the entire system consumes 17.43 million tons of standard coal annually.[5] The China Railway Corporation (CRC) plans to increase the size of its network to 120,000 km by 2015, with a capacity to transport 4 billion passengers annually (footnote 6). Figure 1 shows the annual railway passenger volume from 2002–2013 including the estimated volume for 2015.[6]

To improve service quality, many cities are constructing new stations or are retrofitting old ones. Since 2005, many stations have undergone renovations to improve system function, and increase economic returns. These stations include Beijing South, Shanghai Hongqiao, Wuhan Station, Xi'an North, Zhengzhou Station, Guangzhou South, Nanjing South, Chengdu East, Shenzhen North, and Lanzhou West. Station architecture and structure have seen a significant shift as stations evolved from single-purpose train stations to include many functions. At the end of 2010, there were 5,278 railway stations in the PRC, including 55 Super Class stations, 220 Class I stations, 396 Class II stations, and 926 Class III stations.[7] As of 2011, there were 83 large stations[8] (Gross floor area [GFA] of waiting hall is larger than 5,000 square meters [m^2]) totaling 7.26 million m^2, delivering 855 million passengers, accounting for 47.7% of total railway passenger volume.

Newly built stations (after 2003) consume 59.3% less energy than older stations

Compared with other large public buildings, railway stations have certain characteristics that have a huge impact on energy consumption. They are massive structures with high window-to-wall ratios and large floor spaces. Many new stations follow designs similar to airports. Railway stations also see high occupancy rates and are often in operation 24 hours a day. According to an energy survey conducted in large stations in 2011 (Footnote 8), energy consumption is about 214 kilowatt-hour per square meter (kWh/m^2)

Figure 1: Railway Passenger Volume



Source: National Railway Administration of the PRC. 2014. *2013 China Rail Statistical Report*. Beijing.

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[5] China Railway Corporation (CRC). 2013. *2012 China Rail Statistical Report*. Beijing.

[6] *China Rail Statistical Report*, China Railway Twelfth Five-Year Plan.

[7] National Bureau of Statistics of China. 2012. *China Rail Statistical Yearbook, 2011*. Beijing.

[8] CRC. 2012. *Energy Survey of Large Stations, 2011*. Beijing.

per year; compared with other large public buildings consuming 114 kWh/m^2 per year,[9] railway stations have high energy-saving potential (see Table 1). Newly built stations (after 2003) consume 59.3% less energy than older stations. This indicates significant opportunities for energy savings from retrofitting existing station buildings. Heating, ventilation, and air-conditioning (HVAC) systems account for 59%–67.9% of all energy consumption. Therefore, we will focus on HVAC systems in particular in this report.

With sustained and rapid development of the national economy and increases in the living standards, passengers are demanding increased comfort and greater services. This has been a particular challenge for the rail industry, especially when it comes to providing a safe, convenient, and comfortable environment in waiting halls needing to accommodate thousands of passengers at once.

Well-designed stations have stringent requirements on indoor air temperature, volume of fresh air, lighting levels, and availability of elevators, with comfortable indoor air temperature in waiting halls as top priority. Fresh air, which is an important consideration for cooling load calculation, is also a key indicator of the health and hygiene condition in the station. Indoor lighting design should provide even illumination throughout the building and be environment friendly. Elevators should be designed to balance passenger waiting times with energy use. Passenger comfort and energy-saving strategies are sometimes competing priorities that need to be carefully balanced during the design phase.

As the PRC has been building more stations, it has also been increasing the sophistication of its stations, and increasing the use of complex mechanical and electrical systems. However, the increasingly complex nature of station design makes it impossible to use a

Table 1: Comparison of Energy Use in 70 Large Stations between 2010 and 2011

Index	2010	2011	% increase
Equivalent standard coal (ton)	138,492.85	139,739.82	0.9
Electricity (1,000 kWh)	386,066.8	445,606.3	15.4
Fuel cost (CNY thousand)	515,583.9	571,309.5	10.8
Water consumption (ton)	34,878,389.00	35,576,377.00	2.0
Station floor space (m^2)	5,292,657.00	5,298,577.00	0.1
Passenger volume (thousand)	1,489,310.0	1,603,400.0	7.7
Energy consumption per passenger (kg standard coal/person)	0.093	0.087	(6.5)
Energy consumption per unit floor space (kg standard coal/m^2)	26.17	26.37	0.8
Energy density (kWh/m^2)	212.90	214.60	0.8

( ) = negative, CNY = yuan, kg = kilogram, kWh = kilowatt-hour, m^2 = square meter.

Source: Chinese Academy of Engineering. 2011. *Current Energy Consumption in Chinese Buildings and Energy Solution Analysis*. Beijing.

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[9] Chinese Academy of Engineering. 2011. *Current Energy Consumption in Chinese Buildings and Energy Solution Analysis*. Beijing.

single strategy to reduce energy consumption, such as a focus on passive design, energy-efficient equipment upgrades, or the implementation of a stand-alone automatic control system. Therefore, it is advisable to use a combination of interrelated strategies and integrated automatic control system. It is essential to build a low-carbon railway station through intelligent building controls designed in response to environmental and equipment performance requirements.

According to the central government's Twelfth Five-Year Plan of Energy Saving and Carbon Emission Reduction, large railway stations are required to optimize design and integrate automated energy management to realize gains in energy efficiency.[10] The Twelfth Five-Year Plan of Railway Development also requires the CRC to stimulate a green and low-carbon transportation plan. The government's objective is to reduce energy consumption per passenger by 5%. Railway stations in the PRC achieve significant energy savings by focusing on implementation of intelligent control measures.

1.1.3 Urgent Need for Intelligent Building Control Systems

Intelligent or smart buildings encompass a broad range of fields and providers, including those related to electrical systems, installation, computer science, and software engineering. In the PRC, architects do not focus on integrated energy management systems when designing buildings. Most design institutes consider intelligent building design as part of electrical design or separate information technology solutions. In the PRC, the design of the building, lighting, HVAC, security, energy, water systems, and control systems are put together by individual firms and outsourced contractors who do not have incentive or knowledge to integrate these different systems. In the PRC, this lack of integration presents a challenge to green buildings as a platform for integrated systems to work together to increase efficiency, and ensure the comfort and safety of tenants and occupants.

Designers do not focus on integrated energy management systems when designing buildings

Figure 2 shows the key factors affecting building energy consumption, such as building envelope, building services, human factors, and climate conditions.[11] It is crucial for the design and operation of intelligent control systems to take note of these factors through various control strategies to achieve the highest energy-saving potential.

On the premise of increasing passenger comfort, implementation of highly efficient equipment is only part of the answer. It is important that building equipment is implemented and operated properly to realize gains in energy efficiency. Intelligent building control systems such as a building management system (BMS) can play an important role in solving this problem.

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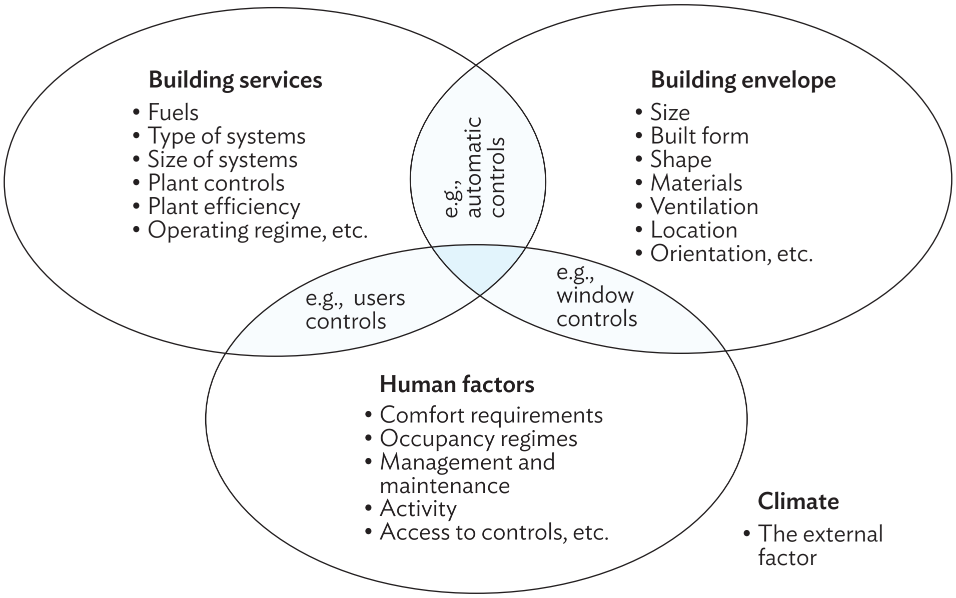
[10] State Council of the PRC. *Twelfth Five-Year Plan of Energy Saving and Carbon Emission Reduction*. Beijing.

[11] Chartered Institution of Building Services Engineers (CIBSE). 2012. *CIBSE Guide F: Energy Efficiency in Buildings*. London, United Kingdom.

Figure 2: Factors Affecting Building Energy Consumption



Source: Chartered Institution of Building Services Engineers (CIBSE). 2012. *CIBSE Guide F: Energy Efficiency in Buildings*. London, United Kingdom.

A BMS is a computer-based control system installed in buildings to control and monitor mechanical and electrical equipment, including power, lighting, HVAC, plumbing, fire, security, and parking management systems. Based on our research, proper BMS implementation can provide a secure, comfortable, and convenient working and living environment for building occupants, while reducing the need for maintenance across these many separate systems.

BMS implementation should be carried out in a way that is

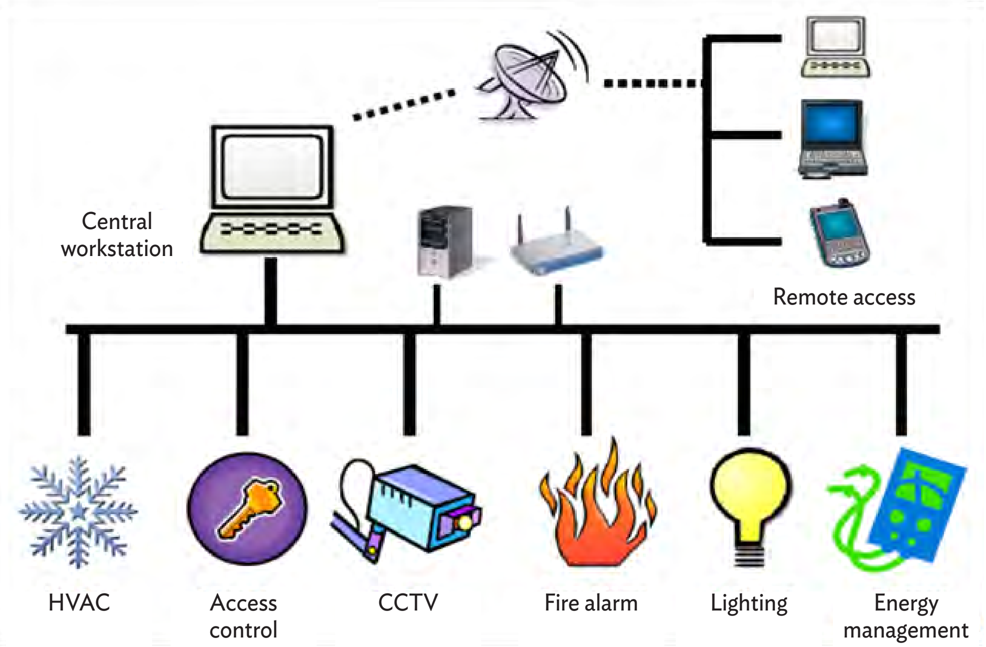
(i) economical—a reduction in energy use will reduce operation and maintenance costs in the long run;

(ii) timely—the implementation of the system should not affect the project schedule; and

(iii) user friendly—BMSs should be designed for convenient operation during construction and property management stages.

Improvements in living standards are pushing developers to offer better railway stations with shorter walking distances, comfortable indoor environments, convenient automatic ticketing systems, and other facilities not found in older stations. Increased demand for better services requires more efficient management of air-conditioning, lighting, and other building systems.

Figure 3: Diagram of Building Automation Control System



CCTV = closed-circuit television; HVAC = heating, ventilation, and air-conditioning.
Source: ADB consultants.

Experts believe that less than 50% of projects with installed energy management equipment use them to manage energy use

BMSs use sensors and status signals to monitor the operating condition of various electromechanical systems and provide feedback control signals to efficiently manage operation of equipment according to the technology, energy savings, and comfort requirements. A growing complexity in building systems is making it increasingly difficult for manual operation to address all these requirements (see Figure 3).

In railway stations, properly installed, operated, and maintained BMSs are crucial to increase passenger comfort and energy efficiency while reducing operating expenses. Through proper commissioning of BMS, energy-saving rates can reach 18% on average, with a return on investment in less than 1 year.[12]

System integration is significantly more complicated. Experts believe that less than 50% of projects with installed energy management equipment use it to manage energy use and less than 1% of installations are based on design standards (footnote 4). According to official investigations, less than 30% of projects attain performance indicators set in design requirements, that is, 70% of projects fail to meet the original design goals. The use of building automation systems is lower than 20%. In many cases, although building automation systems are installed, central air-conditioning systems are still operated

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[12] E. Mills et.al. 2004. *The Cost-Effectiveness of Commercial Buildings Commissioning —A Meta-Analysis of Energy and Non-Energy Impacts in Existing Buildings and New Construction in the United States.* http://evanmills.lbl.gov/pubs/pdf/cx-costs-benefits.pdf

manually resulting in a huge loss of energy.[13] In typical cases, a reasonable and proper control strategy could save up to 20% of air-conditioning energy consumption. According to the speech from the director of the Committee of Experts on Intelligent Building Branch of the China Construction Industry Association 2013 Annual Meeting, "currently in the PRC, the intelligent building system technology is basically clear, to ensure quality and effectiveness, we must make intelligent return to building. Return to the building is the elimination of separation for intelligent systems and building. Intelligent is relevant to the subsystem of the building, which is the integration of the various specific functional areas and is more fundamental system integration. Currently, there is a lack of evaluation criteria to measure the intelligent building performance. Return to building needs to be responsible for the full life cycle of the building, especially during the design and construction stage, and we should consider the operation and maintenance needs."

In conclusion, the PRC is undergoing rapid economic transformation and its railway development is even quicker than its GDP growth. The railway station building must be able to support the transition of passenger service to a higher standard of comfort but consume less energy. In the future, more high-speed railway stations with similar design features will be built. Given the current PRC energy consumption level, national strategy shift, and urgent needs for intelligent control, these major drivers will create new and greater requirements for the development of intelligent station buildings. Once intelligent railway station buildings are built, 70 large passenger stations are expected to save CNY200 million. In the PRC, there are more than 5,000 stations, so economic benefits are vast.

1.2 Research Objectives and Scope

The basic objectives of the study are to

(i) support the national Carbon Emission Reduction plan in railway station buildings;

(ii) learn and make use of the advanced technology in international building management; and

(iii) realize energy savings, safety, and comfort in railway station buildings in a cost-efficient way from the perspective of energy management.

Through intelligent building control implementation, energy savings of 20% can be expected.

The specific objectives are to

(i) understand international advanced smart building technology and study the applicable cases;

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[13] Tsinghua University Construction Energy Saving Institute. 2010. *Annual Report on Construction Energy Saving Development in China, 2010.*

(ii) conduct research and analysis on domestic railway station energy efficiency;

(iii) establish evaluation methods and a baseline for railway station energy consumption;

(iv) complete economic feasibility analysis on intelligent control technologies; and

(v) provide recommendations to the government based on end user investigation and policy analysis.

This study considers the following points:

(i) Differences in climate zones require different architecture design specifications, mechanical, electrical, and plumbing systems, and will result in different levels of energy consumption.

(ii) Differences in building scale result in diversified applicability and building occupancy.

(iii) Differences in station function—some are designed as passenger terminals only, some are integrated with commercial services.

There is a large variation in terms of energy-saving strategies, including building control technologies. Investing time and resources evenly across all aspects would amount to inefficiency. To concentrate limited research resources on the most important fields, we have conducted a preliminary analysis on station energy consumption. It is clear that large stations account for about half of the total passenger volume. Energy consumption in large stations is about 214 kWh/m^2/y, more than 1.3 times that of small stations (footnote 10). To achieve the biggest effect, research will focus on super large and large stations, especially high-speed rail stations.

An additional point to be considered is the number of stations in different regions. Surveys were conducted in large stations in the east and the west, and their features were analyzed. This study focuses on large passenger stations as they offer the greatest energy-saving potential.

Conclusions gleaned from the study of large station buildings can also be applied to smaller stations.

(i) Passenger stations consume more energy than freight stations.

(ii) Super Class and Class I stations consume more energy.[14]

(iii) Large transportation hubs are the preferred models for future station design.

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[14] CRC. 2012. *Classification of Railway Station, Station Building Design Code*. Beijing.

We selected two super large stations in typical climate zones as subjects for future primary research, and will consider common practices that can also be adopted by other station types.[15] The typical location of stations and their climate zones are shown in Table 2.

Table 2: Location of Major Stations across Climate Zones

Climate Zones	Station Class	Location
Very cold	Super Class	Ha'erbin, Shenyang, Qiqiha'er
	Class I	Datong, Tongliao, Baotou, Yinchuan, Xining, Jiayuguan, Urumqi
Cold	Super Class	Beijing South, Jinan, Zhengzhou, Xi'an, Lanzhou
	Class I	Shijiazhuang, Yantai, Lhasa
Summer hot, winter cold	Super Class	Shanghai Hongqiao, Wuhan, Chongqing, Chengdu
	Class I	Nanjing, Hangzhou, Xiangyang, Changsha, Guiyang
Summer hot, winter warm	Super Class	Guangzhou
	Class I	Fuzhou, Xiamen, Liuzhou, Nanning, Shenzhen
Mild	Super Class	
	Class I	Kunming

Source: ADB consultants.

Chapter 2 assesses the energy consumption in domestic stations by analyzing the current energy consumption levels of stations in the PRC. It also identifies energy-saving deficiencies and opportunities in domestic station buildings.

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[15] CRC. 2012. *Classification of Climate Zones, Building Design Code*. Beijing.

2. Energy Consumption in Domestic Stations

This chapter aims to identify deficiencies in and opportunities for energy saving by conducting an analysis of (i) developing trends in large domestic stations, (ii) energy consumption levels and ratios of large stations, (iii) design features and their impact on energy consumption, and (iv) current implementation of intelligent building measures.

2.1 Development Trends in Railway Stations

As described in Chapter 1, more energy will be consumed in station buildings due to expansion projects, higher standards of service, and a significant growth in passenger volume. A further understanding of station building development is vital to understanding how these factors will affect energy consumption. The development of stations in the People's Republic of China (PRC) can be divided into the following three stages:[16]

(i) **Side-line-type stations.** These stations were built between 1950 and 1960, for example, the Beijing Station. These stations are large, with ticketing, luggage storage, and other facilities located beside the railway tracks. Overhead passageways connect different platforms. This type of station is designed solely for the purpose of railway transportation (Figure 4).

(ii) **Mixed-use-type stations.** These facilities were commonly built during the 1990s, for example, the Shanghai Station (Figure 5), the Shenyang North Station, and the Changchun North Station. Though a majority of the station facilities are located beside the railway lines as in the side-line model, hotels, shopping malls, and other facilities are integrated into the station building. Some stations even feature high-rise hotels built on top of the station box. The overall size of these stations is large and often is the "front gate" to the city.

(iii) **Transportation hub stations.** These stations were built after 2000, for example, the Nanjing South Station, the Beijing South Station (Figure 6), the Guangzhou New Station, and the Wuhan Station. Transportation hubs are designed to transcend the requirements of railway transportation, such that they encompass different types of transport and serve as a connector between many transport options. While the buildings themselves are large, the waiting hall, ticketing areas,

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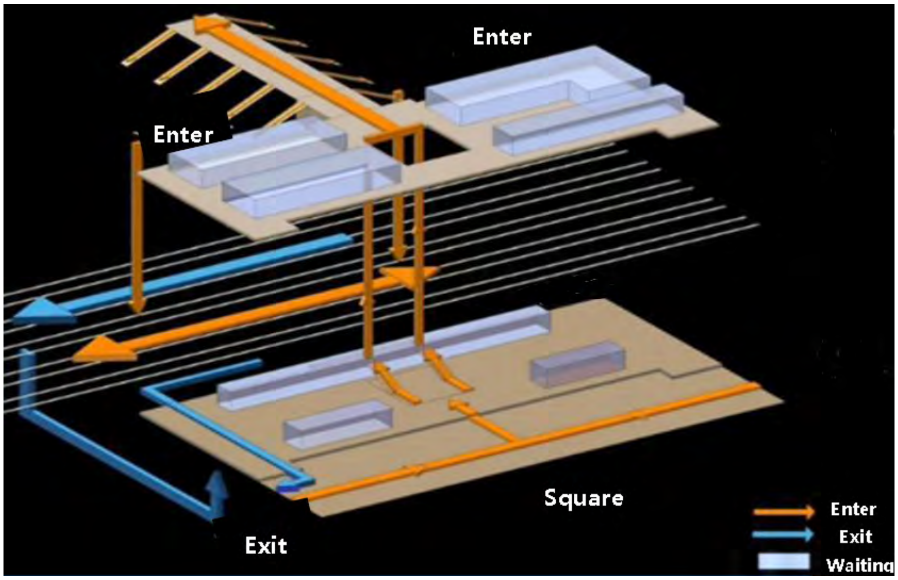
[16] Footnote 4; Z. Jian. 2009. *Contemporary Chinese Railway Station Design Theory Exploration*. China Communications Press. Beijing.

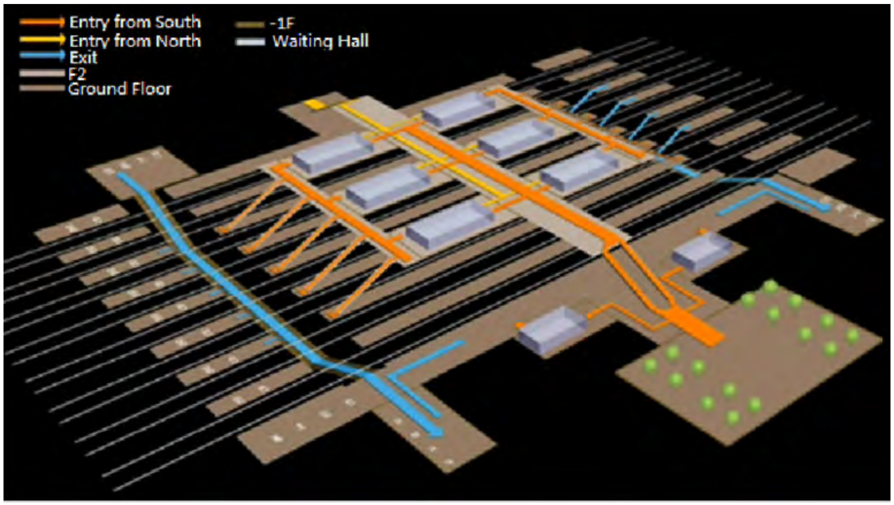
and retail space are significantly smaller as passengers tend to spend less time in the station, with most areas used for passenger transition between modes of transport. The development of transportation hubs also tends to focus more on passenger needs rather than the convenience of the transport administration.

Figure 4: Diagram of Beijing Station Passageways



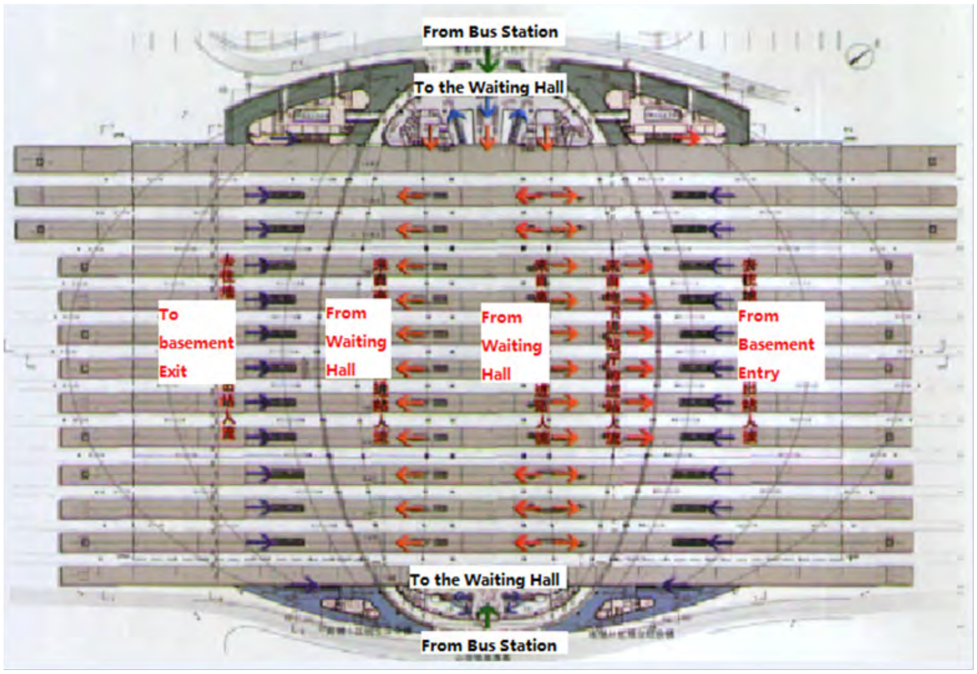
Source: Z. Jian. 2009. *Contemporary Chinese Railway Station Design Theory Exploration*. China Communications Press. Beijing.

Figure 5: Diagram of Passageway of Shanghai Station



Source: Z. Jian. 2009. *Contemporary Chinese Railway Station Design Theory Exploration*. China Communications Press. Beijing.

Figure 6: Diagram of Passageway of the Beijing South Station



Source: Z. Jian. 2009. *Contemporary Chinese Railway Station Design Theory Exploration*. China Communications Press. Beijing.

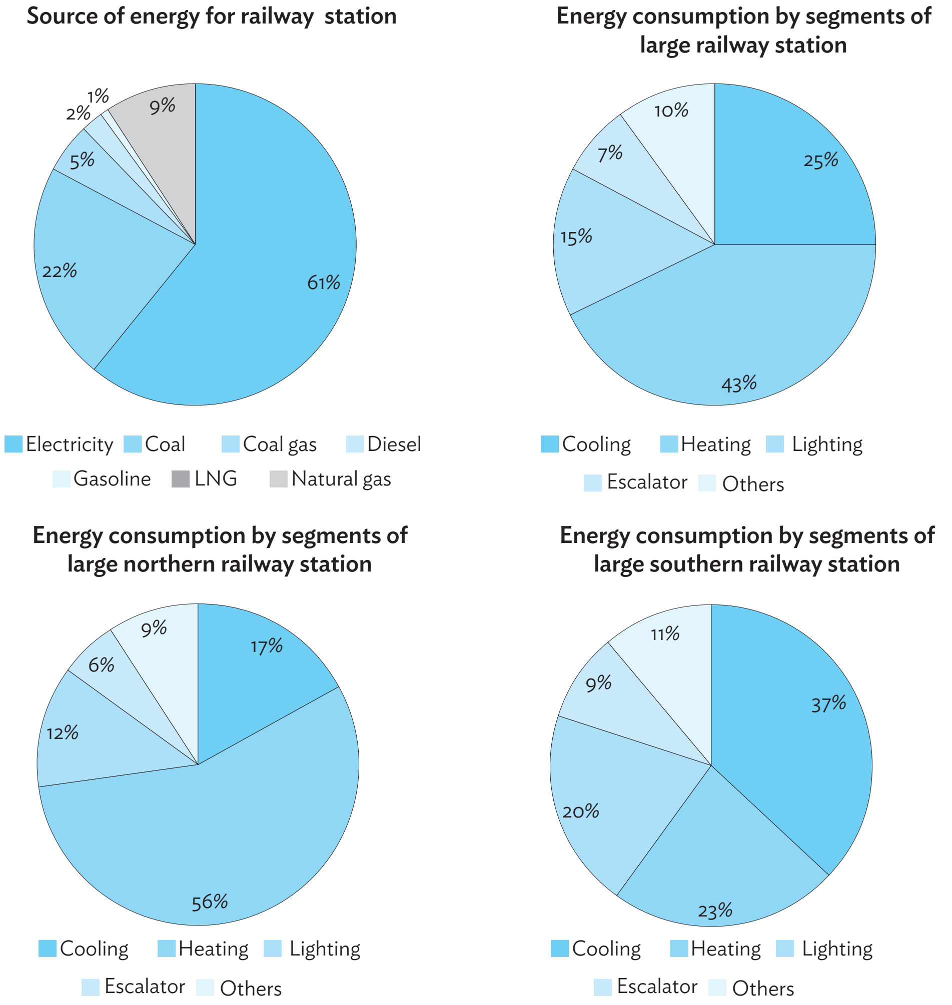
2.2 Energy Consumption of Large Railway Stations

This section summarizes the energy consumption in modern, large railway stations, mainly based on findings presented by the China Railway Corporation (footnote 8).

Consistent across all stations, air-conditioning and lighting account for the highest percentage of energy used

Railway stations rely on coal, natural gas, liquefied petroleum gas, coal gas, and petrol to provide for electricity, heat, and other energy needs. Due to variations in geography and equipment, energy sources differ between stations across the country. In large stations with waiting halls bigger than 5,000 m^2, electricity from the grid, district heating, and coal burned on-site are the main energy sources. Electricity from the grid meets 42.67% of the energy demand. Consistent across all stations, air-conditioning and heating account for the highest percentage of energy used with lighting and elevators or escalators to a lesser extent; in large railway stations, elevators contribute more to energy consumption. The breakdown of energy consumption in large railway stations is presented in the pie charts given in Figure 7; heating accounts for as much as 56% of energy use in *northern* stations because of a colder climate, while heating in *southern* stations only accounts for up to 25% of energy. Peak energy consumption always appears in the coldest and hottest months. Lighting is the second biggest energy consumer, averaging 15% of all energy consumed in large stations.

Figure 7: Energy Consumption Constitution of Large Stations


Source of energy for railway station

Energy consumption by segments of large railway station

Energy consumption by segments of large northern railway station

Energy consumption by segments of large southern railway station

LNG = liquefied natural gas.

Source: CRC. 2012. *Energy Survey of Large Stations, 2011*. Beijing.

Railway stations are categorized as large public buildings that consume large amounts of energy due to their large size and high occupant density. Figure 8 compares the average energy consumption of station buildings to typical shopping malls, which significantly exceed other public buildings in energy use.[17]

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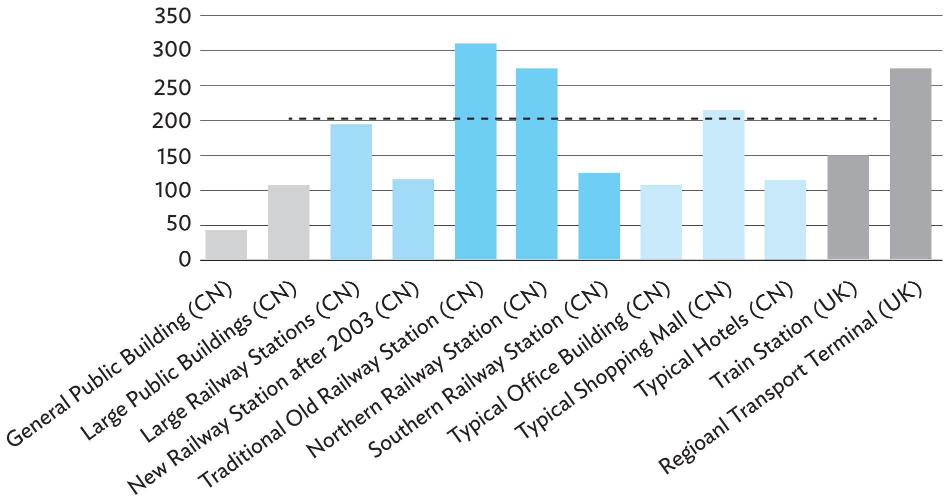
[17] Footnote 14; The Chartered Institution of Building Services Engineers (CIBSE).2008. TM46 Energy Benchmarks. United Kingdom.

Figure 8: Comparison of Energy Use by Public Building Type (kW/m^2/y)



Source: CRC. 2012. *Energy Survey of Large Stations, 2011*. Beijing.

A successful energy saving plan should be prioritized in project inception, all the way through design, construction and installation, commissioning, and operation

Energy characteristics of railway stations are explained as follows:

(i) The energy consumption rate of stations built after 2003 is about half that of traditional stations for the following reasons: (a) new stations currently account for only a third of the passenger volumes of existing traditional stations; (b) equipment in traditional stations is old and less energy efficient; (c) traditional stations purchase more heat, especially in the north; (d) new station designs feature large open spaces with abundant natural light, saving on energy; (e) integrated ticket selling, waiting, and boarding systems in new stations reduce passenger waiting times and time spent in the station allowing for smaller building footprints; and (f) stations built after 2005 are designed to higher standards with the introduction of the "Energy-Saving Design Standard for Public Buildings" building code in July 2005.

(ii) Southern stations consume about half of the energy consumed by northern stations because heating, ventilation, and air-conditioning use accounts for 60% of all energy consumed in the south, but 73% in the north.

(iii) Older buildings and stations in the north of the country consume the most energy. Reasons include (a) more heating is required in the north, (b) larger passenger volume and longer occupancy time in traditional stations, and (c) less efficient equipment in old stations.

(iv) Large station buildings consume similar levels of energy as shopping malls in the PRC. Reasons include (a) stations are designed with large open spaces requiring significantly more heating, ventilation, and air-conditioning; (b) railway stations operate longer hours than other public buildings, normally 24 hours per day; and (c) compared with other public buildings, railway stations have higher occupancy rates, thus a much higher air-conditioning and elevator load (footnote 15).

(v) Energy consumption of large railway stations in the PRC is lower than that of regional transport terminals in the United Kingdom.

2.3 Impacts of Station Design on Energy Consumption

From the investigated cases, we noticed that climate and geographic variations and demand for higher-quality built environment, including accessibility, thermal and light comfort, are all reflected in design considerations of station buildings. Many new stations are designed with high window-to-wall ratios and large open spaces requiring more elevators and increased use of central air-conditioning systems. To further explain how these design features impact energy consumption, we will analyze different aspects, taking into consideration practical use in Table 3.

Table 3: Impact of Station Design on Energy Consumption

Item	Common Design Features	Energy or Environmental Impact	Comfort Impact
Overall layout	Frequent train departures Reduced passenger waiting times Reduced walking distances Combined waiting halls	Uneven temperature requirements Frequently shifting air-conditioning load due to quick passenger turnover Increased demand for indoor fresh air systems Large open areas and corridors suffer major heat loss	Frequent changes to air quality
Architecture design	Large, cavernous indoor spaces with tall ceilings Commonly adopts steel structure Energy-saving consideration in building envelope, e.g., low-emissivity glass and roof shading. Natural lighting design	Dramatically increases air-conditioning load despite need to consider human height space only Very high window-to-wall ratio results in higher solar gain	Improves natural lighting Difficult to maintain comfort levels
HVAC equipment	Heat recovery devices in fresh air units	Heat recovery from exhaust air could save up to 60% energy	Lack of proper cleaning or filtering brings in dirty air and reduces equipment efficiency
	High COP central chiller plant	Improved equipment efficiency and performance	No impact
	Combined cooling, heating, and power generation technology (most stations do not adopt)	Adopting these practices can increase energy efficiency	No impact

continued on next page

Table 3 *continued*

Item	Common Design Features	Energy or Environmental Impact	Comfort Impact
	Stations adopt building automation for air-conditioning control; however, not concerned with energy savings and efficiency	Lack of good management strategies resulting in zero energy reductions	Monitoring mode only does not ensure consistent internal environment
Lighting equipment	Nearly all stations are equipped with energy-saving lights, including LED systems Stations adopt intelligent lighting systems Most stations enable theme control by zone, loop circuit, and time	24 hour × 365 day lighting dictates increases in energy consumption Overlap in lux levels between commercial lighting, screen lights, guidance lights, and background lighting	Strict illumination requirements for safety and security Increased need for commercial lighting
Elevator and escalator	All stations have elevators and escalators, some with many units driven by extra-large space	Increased energy consumption	No impact
Power distribution and renewable energy	Some stations adopt ground-/water-sourced heat pump Some stations adopt solar PV Most stations have installed energy meters but many are not properly used	Negligible energy reduction; some inappropriate designs and/or installations Misalignment of renewable power generation feed-in	

COP = coefficient of performance, HVAC = heating, ventilation, and air-conditioning, LED = light emitting diode, PV = photovoltaic.
Source : CRC. 2012. *Energy Survey of Large Stations, 2011*. Beijing.

In addition, trade-off between space efficiency and energy efficiency in side-line-type stations and transportation hub stations or large stations is crucial. Compact, vertical stations should be more efficient to deal with heat or cold because they have a higher volume-to-surface area ratio, but these stations will also have a higher lighting load because the lowest levels can only get limited daylight. These stations will also require additional energy for vertical transportation. In moderate climates, side-line-type stations may be more energy efficient because they can take advantage of the increased daylight opportunities without excessive heat gain or loss as a result of increased building surface area, whereas in more extreme climates, compact stations likely use less energy because heat loss or gain is a primary factor affecting energy performance.

Therefore, to achieve energy savings in station buildings, it is essential to start from design inception. Poor design decisions at the front end of a project result in higher costs to fix the issues and increased operation cost during the later stages. A successful energy-saving plan should be prioritized at project inception all the way through design, construction and installation, commissioning, and operation.

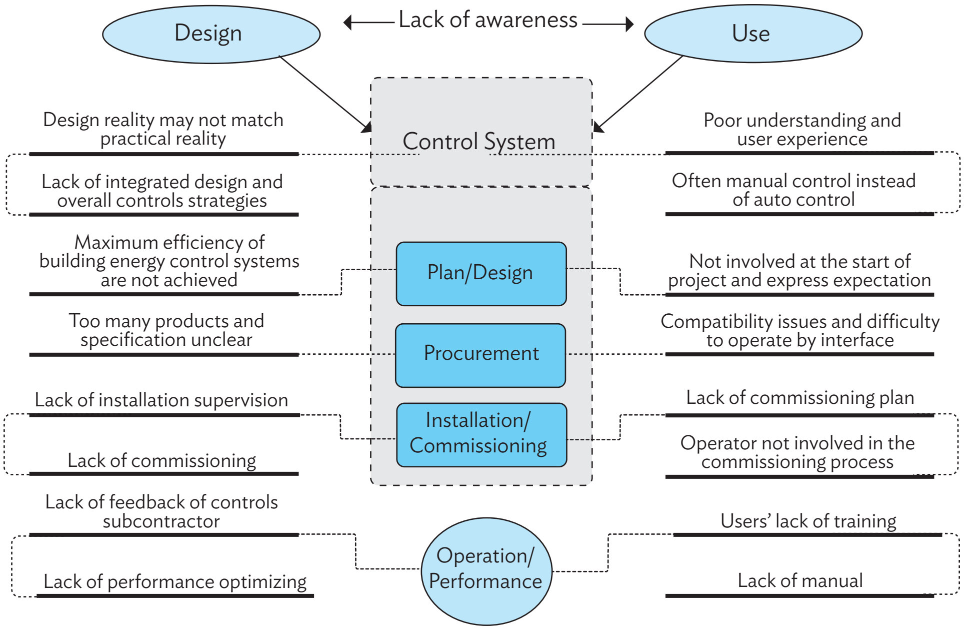
2.4 Impact of Intelligent Station Buildings on Energy Consumption

Our investigation has provided solid proof that proper management of building monitoring and evaluation equipment is critical to achieving improved building energy management. Improperly operated equipment not only fails to meet building requirements *but also consumes a lot of energy*. A building automation system (BAS) is a solution to this problem. Through proper installation and use, a BAS efficiently manages all building systems preventing mistakes created through manual operation of temperature adjustment, lighting control, and air-conditioning management, and also ensures safer and more reliable equipment operating conditions while extending the service life of the equipment.

Currently, most building control systems are only used to monitor the equipment status with very few intelligent control systems in place that are able to fully control the building environment to achieve energy savings and reduction in carbon emissions. Though BASs are adopted in many newly built railway stations as standard design practice, in reality many mechanical, electrical, and plumbing systems are operated either manually or controlled independently. The integrated management of a BAS requires further work to reap the benefits. It should be noted that weak control strategies, poorly installed control systems, and superficial commissioning will lead to *even higher* energy consumption in the building. According to our studies and field investigations, there are multiple issues as shown below regarding intelligent building control in domestic cases of implementation:

Though BASs are adopted in many newly built railway stations as standard design practice, in reality many mechanical, electrical, and plumbing systems are operated manually or controlled independently

Figure 9: Issues Arising during Domestic Intelligent Building Projects



Source: ADB consultants.

With reference to the European Standard EN15232, the intelligent building automation and control efficiency can be categorized into four different classes (Table 4):

Table 4: Building Automation and Control Efficiency

Class	Energy Efficiency
A	Corresponds to high energy performance BACS and TBM • Networked room automation with automatic demand control • Scheduled maintenance • Energy monitoring • Sustainable energy optimization
B	Corresponds to advanced BACS and some specific TBM functions • Networked room automation without automatic demand control • Energy monitoring
C	Corresponds to standard BACS • Networked building automation of primary plants • No electronic room automation, thermostatic valves for radiators • No energy monitoring
D	Corresponds to nonenergy-efficient BACS. Building with such systems shall be retrofitted. New buildings shall not be built with such systems • Without networked building automation functions • No electronic room automation • No energy monitoring

BACS = building automation control systems, TBM = technical building management systems.

Source: British Standards Institution. 2012. *Energy Performance of Buildings. Impact of Building Automation, Controls and Building Management*. BS EN 15232:2012. United Kingdom.

It can be judged that the current intelligent control level for railway stations in the PRC can measure up to only Class D or C, with a lot more to be done to achieve Class B or A.

Therefore, to effectively achieve energy savings in current stations, we need to focus on three main points:

(i) Optimize operation management by adopting intelligent building best practices. It is possible to realize a 20% savings in energy consumption through the promotion of advanced technology, specifically by reducing air-conditioning energy demand, maximizing use of natural light and ventilation, increasing the use of energy-efficient lights, and installing energy-efficient office equipment.

(ii) Use actual energy statistics to monitor the operation of stations, and gradually shift the focus of energy-saving tasks from “applying technologies” to “statistical comparison.” This will create a more systematic approach to accomplish energy savings.

(iii) Promote energy-saving education. Training should include all staff, even those not directly involved in operating mechanical equipment, to create a culture of energy-saving consciousness (i.e., reporting of inefficiencies in air-conditioning, malfunctioning air diffusers as well as malfunctioning lights, vertical circulation elements, and other energy-use-related issues). Financial incentives should be in place to encourage staff to look for and report issues, and periodic audits should be in place to check for effectiveness of staff reporting.

2.5 Deficiencies in Energy Efficiency of Current Stations in the People's Republic of China

Through the survey of the PRC's railway stations and the analysis of railway station energy consumption indicators, the main problems resulting in energy consumption higher than that of other large public buildings can be summarized as follows:

(i) In the design stage, passive energy-saving analysis and measures[18] are not considered seriously, although these are the most cost-effective measures for energy efficiency. Due to tight schedules, the design is not fully analyzed and optimized according to location, weather, and so on, especially for energy design measures.

(ii) In the design stage, BAS integration is not compatible with all components. Building control systems have been a standard requirement for newly built railway stations; however, the practical application cannot satisfy the functional requirements. The reasons for this unsuccessful application are a lack of overall consideration and a lack of effective communication or integration between design institutes, equipment suppliers, subcontractors, and end users.

(iii) Even though some energy-saving measures are considered in the design, a number of these measures cannot perform well under certain circumstances. A geothermal heat pump, for example, is considered an energy-saving measure but requires proper setup for specific and environmental conditions. New technologies need more detailed technical and economic assessment, and have higher requirements in design, construction, and operation.

(iv) In the design stage, there is a lack of consideration for energy submetering system for accurate tracking and data recording. This causes great difficulty for efficient energy management and the establishment of energy baselines.

(v) In the procurement phase, the large number of equipment suppliers and control subcontractors causes more barriers for integration, and each party is only responsible for the working content of its own contract. This is the result of price-driven procurement. Many clients pay more attention to hardware, and often neglect an investment in software and staff training.

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[18] Passive design is an approach that minimizes energy consumed by burning fuel or using power.

(vi) In the procurement phase, technical evaluation of control contractors is not comprehensive, and both tender requirements and contracts are not clear and objective enough for functional requirements, high efficiency, and energy-saving performance requirements.

(vii) In the construction phase, contractors and supervisors lay more stress on the quality of civil works, while the quality of mechanical, electrical, and plumbing systems is found wanting. Reasons are a lack of independent integrated testing and commissioning, and failure to adopt modern building management concepts.

(viii) In the construction phase, the application of related PRC national codes, especially for intelligent construction and engineering quality, is not perfect due to the tight schedule.

(ix) In the construction phase, there is a lack of ownership of or responsibility for the effectiveness of the entire BASs and associated equipment.

(x) In the operation stage, there is a lack of proper operation and maintenance manuals and operator trainings. The number of skilled engineers in facility management is low, and they are usually not involved in the commissioning and acceptance stage. Continuous energy-saving actions such as retrocommissioning and energy retrofits are not conducted, but they should be considered.

(xi) In the operation stage, there is no monitoring or recording of actual energy consumption, which could be used to reflect the real operation situation and provide a basis for analyzing and comparing the energy consumption at different times and between different locations.

These deficiencies must be tackled by policy makers in order for the PRC to successfully meet its energy-saving targets and improve service quality of its station network.

Knowing the deficiencies in the current railway station buildings in the PRC is important to be able to assess and improve on the potential energy savings of intelligent railway station buildings. Chapter 3 introduces a building assessment and simulation method used to evaluate potential energy saving and emission reduction.

3. Assessment of Potential Energy Saving and Emission Reduction through Intelligent Railway Station Buildings

The aim of this chapter is to establish a baseline for building energy consumption. We will simulate energy-saving effects using different intelligent control strategies, and recommend assessment methods.

3.1 Baseline Establishment

The building energy baseline can be divided into two categories: the energy performance of the design, and the actual energy performance of the building. In the People's Republic of China (PRC), building design performance is calculated based on design parameters according to the PRC's Public Building Energy Saving Standard. This standard uses public buildings built in the early 1980s as the baseline for comparing energy consumption. Building designs that reduce energy consumption by 50% compared with the baseline are considered standard. Simulation analysis is often used as a tool to test new designs by comparing with the baseline.

Actual energy performance is based on operating energy consumption levels. Since the PRC has been slow to adopt changes in information technology, it does not have a national database platform for building energy statistics. Instead, energy consumption is often compared with the average for consumption in similar-sized buildings. It needs to be pointed out that assumed design conditions may be different from actual operating conditions, causing a discrepancy between the original design and the actual performance.

The importance of establishing a baseline are as follows:

(i) We expect to apply some advanced energy-saving products, technologies, and system integration solutions from the international case studies to domestic projects in the future. These technologies need to be verified by economic and feasibility analyses.

(ii) In the long term, the establishment of a baseline can speed up the quantitative assessment of the energy performance for both existing and new railway stations.

The difficulties in establishing a baseline are as follows:

(i) There are numerous factors impacting energy consumption, not limited to variations in climate, building sizes, and operating conditions.

(ii) If statistical methods are adopted to perform analysis, large amounts of actual energy consumption data will be required. These data are difficult to obtain and is not the original responsibility of the China Railway Corporation (CRC).

Based on the aforementioned reasons, the annual dynamic energy simulation method will be adopted to calculate energy consumption within typical climate zones. Results can be used as a baseline to compare with different control measures. Our reasons for using this simulation method are summarized below:

(i) This method is an international and domestic common practice, for example, Design Standard for Energy Efficiency of Public Buildings.

(ii) This method gives a tolerance of 5%, which is good enough to form a precise comparison.

(iii) This method is easy to replicate across climate zones and different station sizes.

However, it still needs to pay attention to the criteria of comfort. Whether domestic or international best practice, indoor comfort quantification is still under development; therefore, this criterion have to be set in accordance with the design and operation standards in the PRC.

Though dynamic energy simulations can solve the problem to some extent, we recommend that the CRC install remote central metering systems on railway sites as soon as possible to establish a database for more accurate energy consumption comparisons.

3.2 Recommendation on Assessment Method

Appropriate assessment methods that integrate market mechanisms are important in promoting the development of energy savings for railway sites.

3.2.1 Technical and Economic Assessment

3.2.1.1 Technical Evaluation

This assessment focuses on practical energy-saving effects:

(i) Control logic of electromechanical subsystem: ensure logical control systems in different building areas, including air-conditioning, lighting, elevators, and other important electromechanical subsystems.

(ii) Comprehensive monitoring and collection of data: ensure that the energy efficiency management system properly monitors and collects building energy consumption data. Control system integration can facilitate energy efficiency management and better communication between various devices.

(iii) Integrated energy-saving effect: provide proof of energy savings without compromising basic building functions.

3.2.1.2 Economic Evaluation

This assessment focuses on the economic benefits of the technology program:

(i) Investment: technical investment costs, including the price of equipment, labor costs, construction costs, and maintenance costs.

(ii) Return: the expected return includes basic energy prices, revenue stability, and allocation.

(iii) Operations management: the complexity of the technical operations and risk management.

3.2.1.3 Applicable Evaluation

This assessment focuses on particular technical solutions and their feasibility in specific domestic stations:

(i) Building types: the size and form of the building, similar across all high-speed rail stations.

(ii) Geographic characteristics: the particular climate and comfort standards, the flow of people, and the daily building operation time.

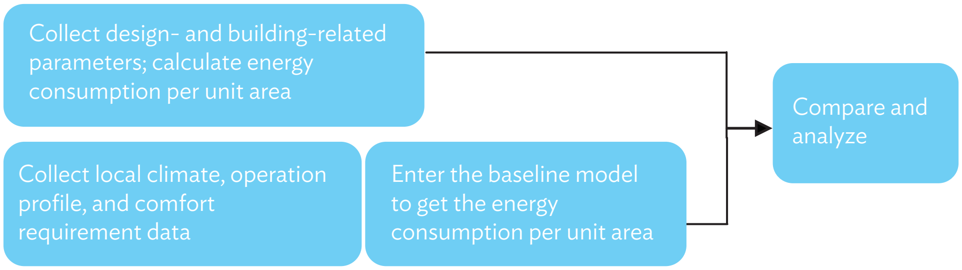
(iii) The basic energy-saving strategy: the strategies for building energy efficiency include passive building design, energy-efficient electromechanical equipment, and operation management.

In Chapter 4, we will use this method to evaluate the energy efficiency and control measures.

3.2.2 Building Energy Efficiency Assessment

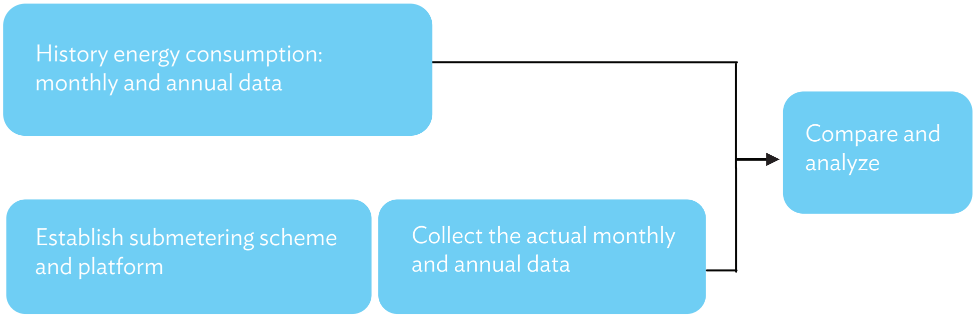
Based on the type of the building, assessment methods can be divided into method for assessing new buildings and method for assessing existing buildings:

(i) Assessment of the energy performance of new buildings: input the current design of the equipment parameters as well as the estimated real-world use data into the computer model and compare with the baseline to confirm designed energy efficiencies. The assessment process is shown below:



Source: ADB consultants.

(ii) Assessment of the energy performance of existing buildings: collect current energy consumption data and compare with each year or each month. The assessment process is shown below:



Source: ADB consultants.

Note: To truly understand the characteristics of energy consumption, the abovementioned comparative analysis methods should also include an energy breakdown of functional areas and equipment types in addition to energy consumption for the whole building. Moreover, in terms of the depth of this study, the assessment is not only for the building as a whole but also includes machine-specific, energy-saving measures, including the full fresh air operation mode during the spring and fall seasons, and cooling water temperature reset.

3.3 Railway Station Energy Assessment

A real case study is used here as a demonstration model for energy assessment. By establishing a baseline and comparing different scenarios of energy savings under intelligent measures, we can better understand the assessment process and the effectiveness of these measures.

3.3.1 Design and Operating Parameters

After detailed architectural, mechanical, and electrical design drawings, equipment parameters and operation profiles are collected, and annual energy consumption is analyzed dynamically to establish an energy consumption baseline. Other outputs, including peak curves, monthly energy consumption, and energy consumption of different equipment, can also be included.

Refer to Table 5 for a list of related parameters.

Table 5: Heating, Ventilation, and Air-Conditioning Design Parameters

Terminal equipment	Type
	Variable speed for fan (yes or no)
	Supply maximum temperature
	Supply minimum temperature
	Cooling EER
	Heating COP
Fresh air	Type
	Variable speed for fan (yes or no)
	Supply maximum temperature
	Supply minimum temperature
	Heat recovery (yes or no)
	Heat recovery type
	Heat recovery pass by (yes or no)
	Heat recovery efficiency
	Heat recovery pressure drop
Chilled water system	Capacity per chiller
	Chiller no.
	COP and IPLV
	Supply and return chilled water temperature chiller
	Primary pump data (power, efficiency, head)
	Secondary pump data (power, efficiency, head)
	VFD for secondary pump (yes or no)
	Low-zone supply and return chilled water temperature
	Middle-zone supply and return chilled water temperature
	High-zone supply and return chilled water temperature
Condenser water loop	Cooling tower type
	Number of cells for each cooling tower
	Cooling tower capacity
	Open tower control (one speed, two speed, variable speed)
	Cooling tower supply and return water temperature
	Primary pump data (power, efficiency, head)
	Secondary pump data (power, efficiency, head)
	VFD for secondary pump (yes or not)
	Low-zone supply and return condense water temperature
	Middle-zone supply and return condense water temperature
	High-zone supply and return condense water temperature

continued on next page

Table 5 *continued*

Air-conditioning hot water system	Boiler type
	Fuel type
	Boiler capacity
	Number of boilers
	Boiler thermal efficiency (%)
	Boiler supply and return water temperature
	Primary pump data (power, efficiency, head)
	Secondary pump data (power, efficiency, head)
	VFD for secondary pump (yes or not)
	Low-zone supply and return hot water temperature
	Middle-zone supply and return hot water temperature
	High-zone supply and return hot water temperature

EER = energy efficiency ratio, COP = coefficient of performance, IPLV = integrated part load value, VFD = variable frequency drive.

Source: ADB consultants.

3.3.1.1 The Settings of Comfort Index

The purpose of a building management system (BMS) is to ensure station comfort through maintenance of a range of systems, such as temperature, humidity, air quality, and lighting illumination; when setting up a BMS, the first step is to define the correct comfort requirements, and balancing comfort levels with energy consumption levels. The criteria can be classified into the following categories:

3.3.1.2 Heating, Ventilation, and Air-Conditioning System

(i) The indoor dry bulb temperature index in the station: temperatures need to be set for winter and summer months, and different station zones may use different temperatures.

(ii) The indoor relative humidity index: seasonal changes in humidity need to be determined.

(iii) The indoor air quality index in station: carbon dioxide concentration is mostly used as a measurement.

(iv) Indoor air-conditioning air speed and wind noise index: these indexes measure the quality of design and installation and are hard to achieve by simply relying on BMS.

3.3.1.3 Lighting System

(i) Station illumination requirements.

(ii) Guidance lighting, emergency lighting indexes: these may refer to Standard for Lighting Design of Buildings (GB50034-2004). These are not preset in the BMS.

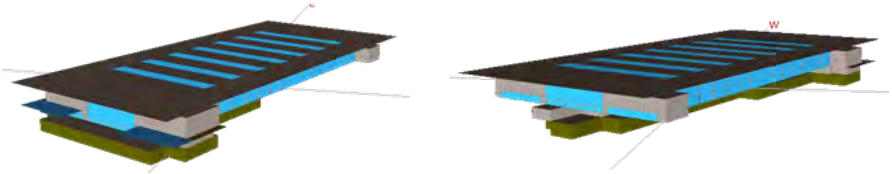
3.3.1.4 Elevator and Escalator Systems

The maximum time allowed for the passengers to wait: nowadays, large transport hubs have plenty of escalators to transport passengers. A large number of escalators will increase energy consumption, while a less number of escalators will increase passenger waiting time.

These parameters are the main energy consumption indexes for railway stations. Accuracy of these indicators will direct the BMS to undertake appropriate control strategies to meet these requirements.

3.3.2 Building Model and Basic Data

(i) Railway station model:



Source: ADB consultants.

(ii) Weather data:

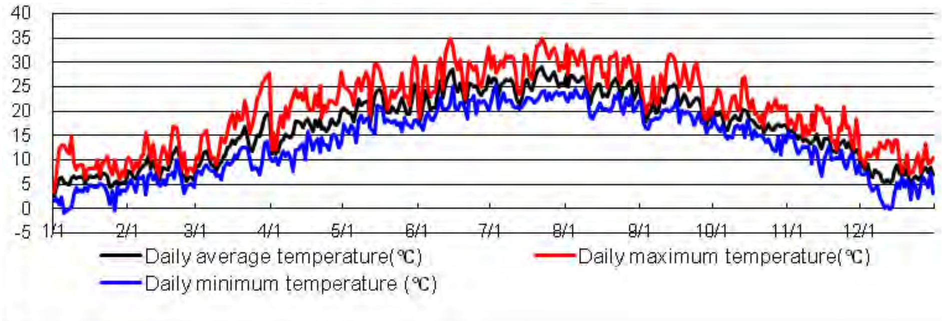
Chengdu has hot summers and cold winters; it belongs to the 3A Climate Zone according to ASHRAE 90.1 standards. The weather information for the city of Chengdu is summarized below and should be kept consistent in all simulation models.

Table 6: Climate Data

Area	Chengdu
Latitude	Northern 30.67 degree
Longitude	Eastern 104.02 degree
ASHRAE dry temperature, design temperature (99.6%)	0°C
Dry temperature, wet temperature (1%)	31°C/25°C
CDD10	2,691
HDD18	1,505

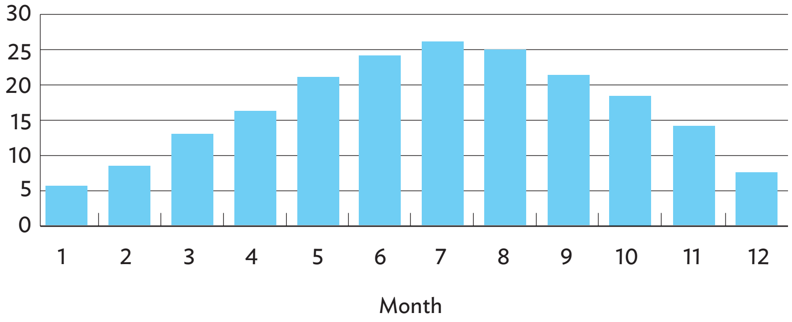
CDD10 = cooling degree day base 10°C, HDD18 = heating degree day base 18°C.
Source: ADB consultants. September 2013. *Result of the eQuest Simulation.*

Figure 10: Station B Daily Dry Bulb Temperature



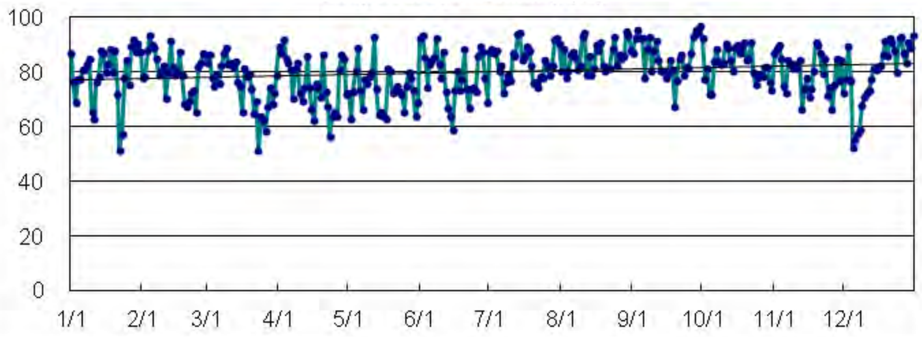
Source: ADB consultants. September 2013. *Result of the eQuest Simulation.*

Figure 11: Station B Monthly Dry Bulb Temperature



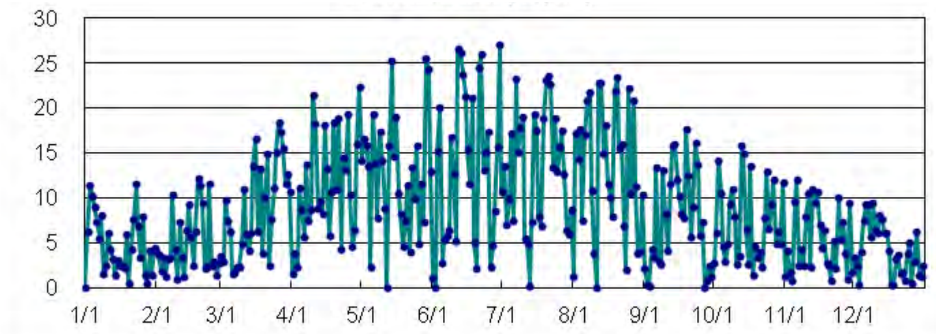
Source: ADB consultants. September 2013. *Result of the eQuest Simulation.*

Figure 12: Station B Daily Relative Humidity



Source: ADB consultants. September 2013. *Result of the eQuest Simulation.*

Figure 13: Station B Daily Radiation



m^2 = square meter, MJ = megajoule.

Source: ADB consultants. September 2013. *Result of the eQuest Simulation*.

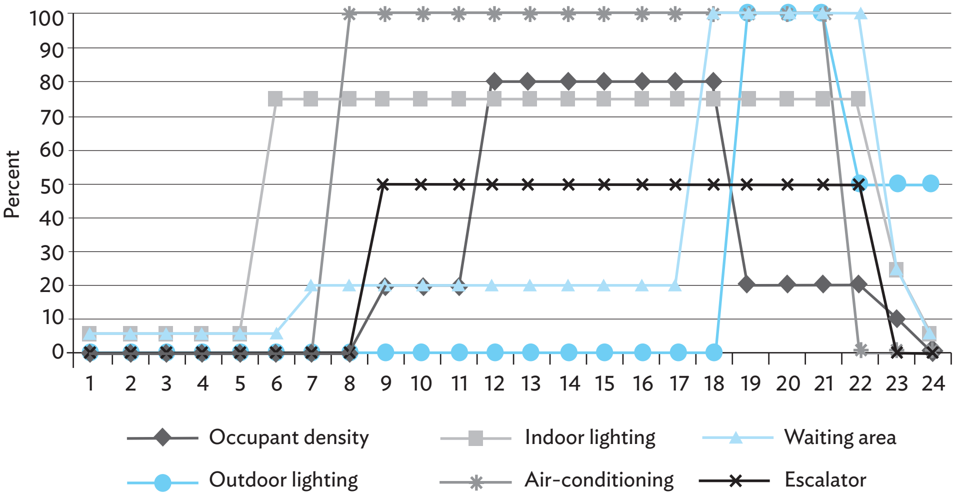
(iii) Energy billing:

In this station, air-conditioning, lighting, and other forms of energy consumption uses electricity provided by the state grid. The unit electricity price is CNY0.6195 per kilowatt-hour, and transformer capacity fee is CNY52 million monthly.

(iv) User profile:

The operation profile is shown in Figure 14; it includes occupant density and lighting and escalator timetables. The actual running time may slightly differ from these assumptions.

Figure 14: Operation Profile



Source: ADB consultants.

(v) Occupant density:

The assumed occupant density for each area is shown in Table 7.

Table 7: Occupant Density

Room Categories	Occupant Density
Tickets office	2.8 m^2/person
Service room and offices	9.3 m^2/person
Entrance hall	Seats: 520 persons
VIP room	Seats: 66 persons
Waiting area	Seats: 8,000 persons

m^2 = square meter, VIP = very important person.

Source: Ministry of Housing and Urban Rural Development. *Standard for Fire Protection Design of Building*. GB50016-2014.

(vi) Building envelope:

Due to a lack of information, the parameters for building envelope are defined according to the energy-efficient building standard.

Table 8: Building Envelope

Building Envelope		Heat Transfer Coefficient K Value (W/m^{2}K)
External wall		1.0
Roof		0.7
Floor		1.0
Window (curtain wall) 0.5<window-to-wall ratio	K value	2.5
	SC	0.4
Skylight	K value	3.0
	SC	0.4

K = kelvin, m^2 = square meter, SC = shading coefficient, W = watt.

Source: Ministry of Housing and Urban Rural Development. *Standard for Fire Protection Design of Building*. GB50016-2014.

(vii) Internal lighting:

According to the drawings, lighting power density is summarized below. This includes lighting at the external platforms and the western corridor of the railway station model. Lighting power density for the VIP room and the service center is based on assumption due to lack of credible information.

Table 9: Lighting Power Density

Area	Lighting Power Density
VIP room	7 W/m^2
Service center	10 W/m^2
Waiting area	697.3 kW
Platform	128.05 kW
Western corridor	14.08 kW

kW = kilowatt, m^2 = square meter, VIP = very important person, W = watt.

Source: Ministry of Housing and Urban Rural Development. *Standard for Lighting Design of Buildings.* GB50034-2013.

(viii) External lighting:

According to the drawings, the outdoor lighting power is 172.73 kilowatts (kW).

(ix) Equipment and plug load:

The total load of escalators is 1,211 kW, the plug load for offices and the service center is assumed as 11 watts per square meter.

(x) Heating, ventilation, and air-conditioning system:

Table 10: Heating, Ventilation, and Air-Conditioning Equipment

Monitoring and Evaluation System	Parameter for Model
Source of cooling	3× centrifugal chiller plant with a cooling capacity of 600 RT, COP: 5.396 3× ground source heat pumps; cooling capacity: 650 RT, COP: 5.51 Outlet and inlet temperature: 7°C and 12°C
Heat sink device	3× cooling towers; flow rate: 600 m^3/h, power: 16.5 kW Outlet and inlet temperature: 32°C and 37°C
Source of heat	3× ground source heat pump: heating capacity: 2,500 kW, COP: 4.71 Outlet and inlet temperature: 45°C and 40°C
Chilled water pump	Primary pump, running in constant frequency but design in variable frequency 3× water pump, flow rate: 375 m^3/h, head 39 mH_2O, power 75 kW
Cooling water pump	Primary pump, constant frequency 3× water pump, flow rate: 480 m^3/h, head 40 mH_2O, power 75 kW
GSHP water pump (ground side)	Primary pump, constant frequency 3× water pump, flow rate: 580 m^3/h, head 60 mH_2O, power 132 kW
GSHP water pump (load side)	Primary pump, running in constant frequency but design in variable frequency 3× water pump, flow rate: 400 m^3/h, head 40 mH_2O, power 75 kW

continued on next page

Table 10 *continued*

Monitoring and Evaluation System	Parameter for Model
Air-conditioning system	CAV air-conditioning system: hall, ticket office, waiting area, service room VRV system: VIP room, office, equipment room
Free cooling	N.A.
Total fresh air cooling	N.A.
Heat recovery system	Part of the office has an exhaust air heat exchanger, 60% heat recovery efficiency assumed

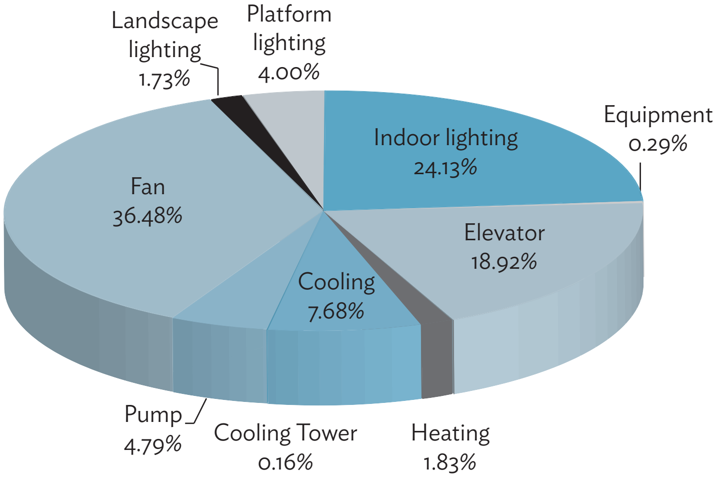
N.A.= not applicable, CAV = constant air volume, COP = coefficient of performance, GSHP = ground source heat pump, h = hour, kW = kilowatt, m^3 = cubic meter, RT = tons of refrigeration, VIP = very important person, VRV = variable refrigerant volume.

Source: Ministry of Housing and Urban Rural Development. *Design Standard for Energy Efficiency of Public Buildings*. GB50189-2005. Beijing.

3.3.3 Design Performance Assessment

Based on the previous profile, a basic model is built in which heating, ventilation, and air-conditioning operate all year round and the lighting requirement in the waiting area is the same as for other indoor areas. The baseline annual energy consumption is shown in Figure 15 and design energy performance can be derived around 150 kilowatt-hour per square meter per year (kWh/m^2/y) (not including water consumption), which means energy consumption is moderate.

Figure 15: Energy Consumption Baseline Breakdown



Source: ADB consultants. September 2013. *Result of the eQuest Simulation.*

Subsequently, the Intelligent Railway Station Building model is simulated after adding four intelligent building measures selected based on discussion with station designers and operators. All measures to be applied in the railway stations in the PRC are feasible and best fit for large space station buildings. These four measures are the following:

(i) **100% variable chiller plant.** Enables total variable frequency control over chilled and cooling water pumps as well as cooling tower fans. The pump frequency is dependent on the pressure drop within the closed loop; the speed of the cooling tower fan is dependent on the chilled water outlet temperature. According to simulation results, this measure saves 3.87% of total energy.

(ii) **Variable air volume air-conditioning system.** Enables the air-conditioning box in the entrance and the waiting areas. The minimum air volume is set at 60% of the designed value. According to simulation results, this measure saves 5.01% of the total energy.

(iii) **Heat recovery from fresh and exhaust air.** Enables full heat recovery between fresh and exhaust air in the waiting area with a heat exchange wheel. When the enthalpy difference is greater than 2.3 kilojoule per kilogram, air flows through the heat exchange wheel; otherwise, the air passes by. This measure saves 2.86% of the total energy according to simulation results.

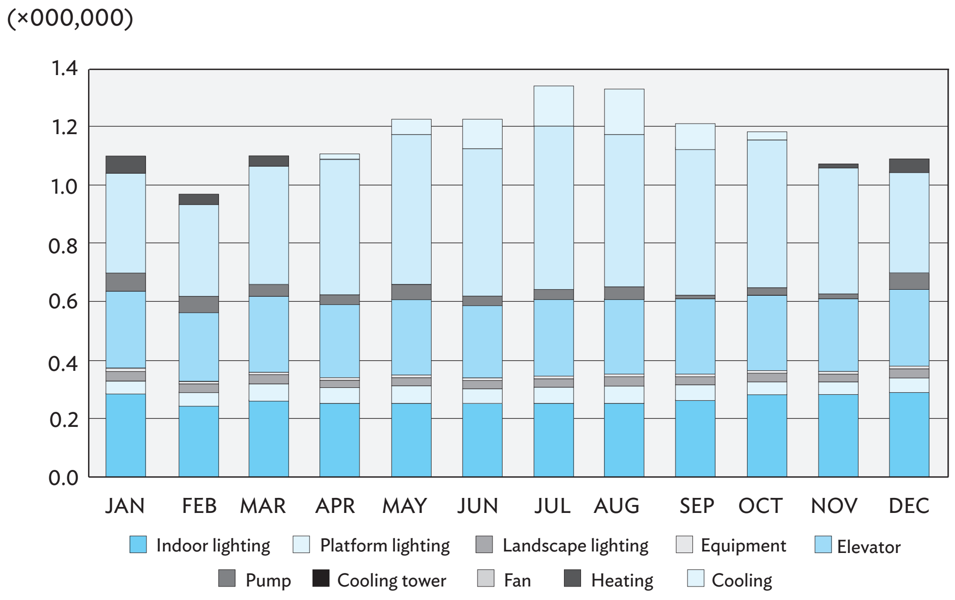
(iv) **Illumination daylighting control.** Enables illumination lighting control over lights on the sidewalk areas of the waiting area; these lights account for 40% of the total lighting for the entire waiting area. When illumination reaches 200 lux, lighting control would switch them off. This measure saves 4.82% of the total energy according to simulation results. It is noted that if a dimming system is used, the saving rate could be higher. However, dimming systems require electronic dimmable ballasts and are therefore more expensive than a switching system, especially in retrofitting existing lighting systems that do not have electronic dimmable ballasts. However, dimming systems achieve the highest savings and do not have the abrupt changes in light level characteristic of switching systems.

It is evident that that after adopting these four intelligent control measures, 15.47% of energy can be saved by using an intelligent control system

It is evident that adopting these four intelligent control measures would result in energy savings of 15.47%. The energy performance can reach 127 kWh/m^2/y.

A baseline model is constructed based on the actual design parameters of a typical high-speed railway station in the PRC. The current operation profile of the station is adjusted by rectifying improper use of the building's equipment during transition seasons. Then, a high-performance model is built by considering the four feasible intelligent control measures and their cumulative energy reduction impact. Comparison of the two simulation results shows that the intelligent building scenario can save 15.47% of the annual energy consumption. Such simulation method is easily duplicated for other real-time projects regardless of facility size or location. It is a very cost-efficient and convenient way to predict the energy performance of a building, and allows for informed decisions regarding the most appropriate intelligent building strategies. Therefore, we recommend that the CRC conduct such analysis at the design stage of their future projects.

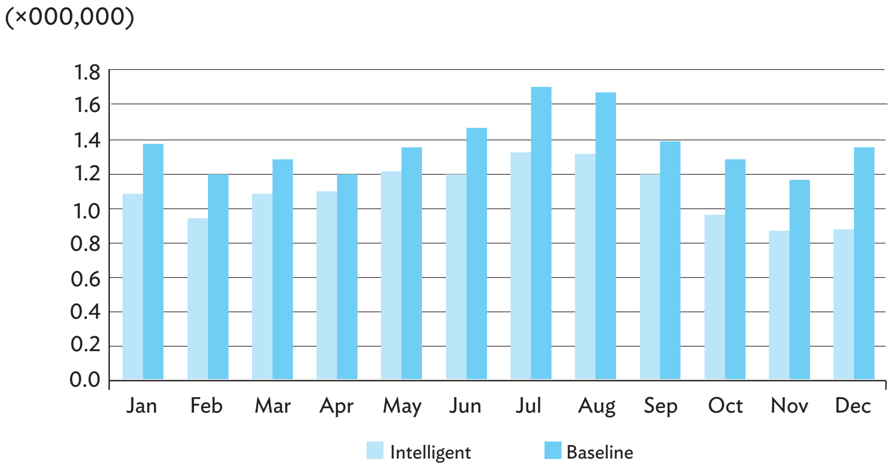
Figure 16: Four Intelligent Railway Station Building Measures toward Intelligent Energy Consumption (kWh)



kWh = kilowatt-hour, IRBS = intelligent railway station building.

Source: ADB consultants. September 2013. *Result of the eQuest Simulation*.

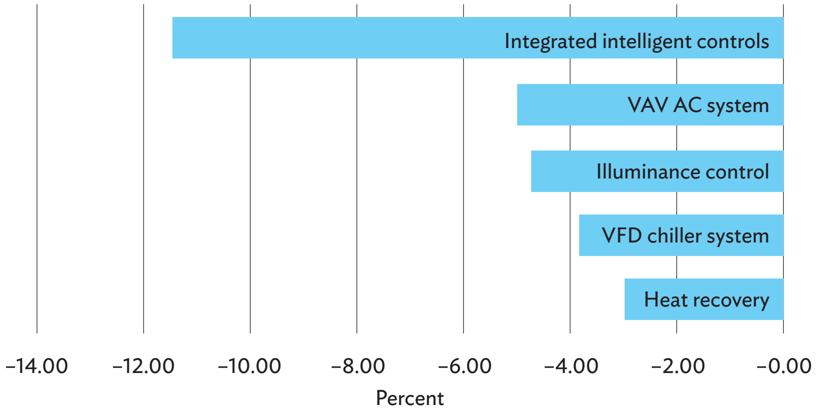
Figure 17: Comparison of Intelligent Energy Consumption with the Baseline (kWh)



kWh = kilowatt-hour.

Source: ADB consultants. September 2013. *Result of the eQuest Simulation*.

Figure 18: Intelligent Energy Saving Rate



VAV AC = variable air volume air-conditioning, VFD= variable frequency drive.
Source: ADB consultants. September 2013. *Result of the eQuest Simulation*.

3.3.4 Actual Performance Assessment

The performance of two stations, Station A and Station B, was analyzed. Information on Station A and Station B is given in Table 11. Both stations are Super Class, newly built stations, and in use for 1–2 years. Station A's size and passenger volume is greater than that of Station B.

Table 11: Basic Information of Stations A and B

Station Parameters	Station A	Station B
Climate zone	Eastern region, cold winter, hot summer	Western region, cold winter, hot summer
Type of station	Large transportation hub	Large transportation hub
Class of station	Super Class high-speed railway station	Super Class, high-speed railway station
Year built	June 2011	May 2011
Total GFA	387,000 m^2	220,000 m^2
Departure area	280,000 m^2, 60 m high	58,000 m^2, 27 m high
Ticket area		3534.5 m^2, 6 m high
Arrival area		32,000 m^2
Platform		87,000 m^2
Others (warehouse, office, etc.)	100,000 m^2	25,000 m^2
Daily train departure	92 trains, end of 2011	32 trains, July 2013
Annual passenger volume	23 million passengers, 2012	16 million passengers, 2012
Highest occupancy density	8,000 passengers	2,200 passengers

GFA = gross floor area, m = meter, m^2 = square meter.
Source: ADB consultants.

Table 12 presents the equipment in Station A and Station B. The main difference between monitoring and evaluation equipment of Station A and Station B is the heating system. Station A uses municipal steam heat while Station B uses three sets of ground source heat pumps. Otherwise, all equipment in the two stations is similar.

Table 12: Basic Information of the Facilities in Stations A and B

Station Parameters	Station A	Station B
Building envelope	Glass curtain wall plus steel structure	Glass curtain wall plus steel structure
External shading devices	No, but internal shading	No, but internal shading
Cooling and heating set temperature	Cooling 26°C, heating 20°C	Cooling 26°C, heating 18°C
Air-conditioning service area	280,000 m^2	115,000 m^2
Type of air-conditioning	Central plant (water cooled) plus area split air-conditioning	Central plant (water cooled) plus area split air-conditioning
Type of heating	Municipal steam heating	Ground source heat pump
Air-conditioning terminal equipment	Cascade air-conditioning unit, fan coil	"integrated streaming unit," ceiling mount air-conditioning unit, cascade air-conditioning unit, fan coil
Lighting area	Regular departure area, VIP departure area, ticket lobby, platform, arrival area	Regular departure area, VIP departure area, ticket lobby, platform, arrival area
Major lights	MH light, CFL light, over 20,000 lux	MH light, CFL light, over 14,000 lux
Smart lighting	Yes	Yes
Escalator and elevator	94 escalators, 36 elevators	71 escalators, 26 elevators
BAS system	Yes	Yes
Renewable energy system	Solar PV, 7 MW	3 ground source heat pumps

BAS = building automation system, CFL = compact fluorescent lamp, m^2 = square meter, MH = metal halide, MW = megawatt, VIP = very important person.

Source: ADB consultants.

From energy consumption bills of Station A and Station B, the actual building performance baseline of 2012 was determined as 347 kWh/m^2/y for Station A and 113 kWh/m^2/y for Station B. In the case of Station B, though the results were encouraging, the practices adopted in this regard were not in the best interests of the commuters. The reasons for this premise are as follows:

(i) Station B was newly built in 2011, but only half of its capacity was being used.

(ii) The station's operational behavior compromised the indoor comfort environment; in transitional seasons (April, October, November), the air-conditioning systems were off and lighting in the waiting area was switched off (manually) during the day. Such activities cannot be encouraged or considered as good energy-saving practice—maintaining a comfortable environment for commuters should always be the top priority.

(iii) The energy consumption of commercial store was not included in the station's bill.

If submetering data were available, comparisons would have been more accurate.

3.4 Summary of Assessment Methods

The assessment standard and methods that can be used for railway stations are summarized in Table 13, for reference by the CRC. After 3 years of research and development, the PRC's railway green buildings standard will be released soon. The standard will be an effective guidance and evaluation tool for railway stations in design, construction, and operation.

Table 13: Recommendation of Assessment Methods

Assessment Methods	Building Type	Description
PRC national standard	New building	Based on the Public Building Energy Efficiency Standards, calculate the relative values of energy savings as the design performance.
Simulation method	New building	Based on the dynamic energy simulation software, calculate the absolute value of energy consumption and energy saving. This method can be combined with national standard method as a simulation tool for the analysis of effectiveness of energy-saving measures.
Statistics method	Existing building	According to the survey on energy consumption on national railway stations, calculate the actual performance and set the target value as well.
Degree days method	Existing building	Through the number of degree days and hours, predict HVAC energy consumption and compare with the actual air-conditioning energy consumption as a control and analysis method.
Building automation classes	New building, existing building	According to the European Standard EN15232, building automation and the energy efficiency of buildings, determine the building automatic control classes.
Green building label	New building, existing building	Integrated green evaluation method, including China Green Building Label, LEED, BREEAM, etc.

BREEAM = Building Research Establishment Environmental Assessment Method; HVAC = heating, ventilation, and air-conditioning; LEED = Leadership in Energy and Environmental Design, PRC = People's Republic of China.

Source: ADB consultants.

In summary, the assessment tools introduced in this chapter that integrate market mechanisms are important in promoting the development of energy savings for railway sites. Three evaluation tools were introduced: (i) technical evaluation, (ii) economic evaluation, and (iii) applicable evaluation. A baseline model was constructed based on the high-speed railway station profile in the PRC. Chapter 4 uses the methods discussed in this chapter to evaluate energy efficiency and control measures and apply it to a railway station in the PRC.

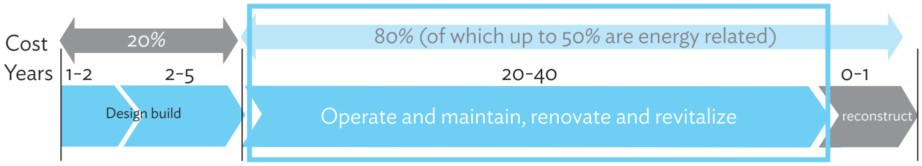
4. Intelligent Building Technologies

The aim of this chapter is to further examine the technical features, energy savings, and application scenarios of products currently available on the market. We will also analyze technology applications for stations in the People's Republic of China (PRC).

4.1 Contribution of Intelligent Building Technologies toward Energy Saving

Intelligent control is a core element of the energy-saving strategy for buildings. A properly implemented building automation system (BAS) and/or building management system ensures effective operation of the building while achieving low-carbon targets, and offers ongoing energy improvements. International studies show that intelligent controls can help reduce energy use by as much as 40%–45% if the 20:80 ratio between construction costs to operation and maintenance costs is taken into consideration,[19] the core value of intelligent controls will be even more significant (Figure 19).

Figure 19: Design and Building Cost versus Operation and Maintenance Cost



Source: L. J. Borello and K. O. Roper. 2014. *International Facility Management*, International Facility Management Association. Oxford.

In modern buildings, designers tend to introduce complex control systems that are not smart and are often too complicated to be fully utilized. Surveys of domestic buildings in the PRC indicate that most control systems only *monitor* equipment. Only a few systems are used to *monitor and control equipment*, and very rarely are these systems used to automate operations and save energy.

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[19] International Facility Management Association.

One main reason for this is that many owners do not understand the benefits of intelligent control systems in terms of energy saving. In fact, a well-designed and well-operated intelligent control system is key to comfortable, safe, energy-efficient buildings. The competitive advantages are summarized as follows:

Lower energy use in buildings not only requires good system design but also relies on accurate control strategies easily implemented by end users

(i) lower operating costs, energy consumption, and air pollution;

(ii) improved comfort for tenants who use the building;

(iii) lower energy waste;

(iv) more efficient use of equipment; and

(v) reduced maintenance, repair, and replacement costs.

Success comes from a true understanding of integrated control. A well-designed and well-operated intelligent control system is key to achieving low-carbon operation targets within holistically designed railway stations. The real power of intelligent control lies in its ability to provide useful building management information that in turn can assist in the execution of appropriate control strategies to ensure the lowest energy consumption. Lower energy use in buildings not only requires good system design but also relies on accurate control strategies easily implemented by end users.

4.2 Potential Energy Saving through Intelligent Railway Station Building

Research on the latest developments and trends in intelligent control technologies in high speed railway stations show that:

(i) Most newly built and retrofit projects in Europe, Japan, and the United States are older and were completed before 2005. Major, new high-speed railway projects are located mainly in Asia with the PRC home to the most relevant projects. Therefore, relevant international good practice on IRSB are in airports, metro stations, and other commercial buildings.

(ii) Leading solution suppliers around the world, including Schneider Electric, ABB, Siemens, Philips, Honeywell, Johnson Controls, UTC, GE, Toshiba, Yamatake, and Weldtech, had only a small number of cases in the desired market segment, due to a lower absolute number of high-speed railway stations worldwide. Due to the lack of commissioned energy-saving analysis after projects, tangible and effective statistics and studies (through intelligent control) are rare.

(iii) In building energy-saving projects, intelligent controls are often applied together with other equipment-based technologies, making it extra difficult to determine absolute contribution from control methods. Due to a lack of historical data, sub-segment measuring, and for confidential reasons, comparison of consumption before and after implementation of energy-saving measures is not comprehensive.

(iv) Most advanced technologies in intelligent building management and control systems for sub-building systems have already found a market in the PRC, mainly in commercial buildings.

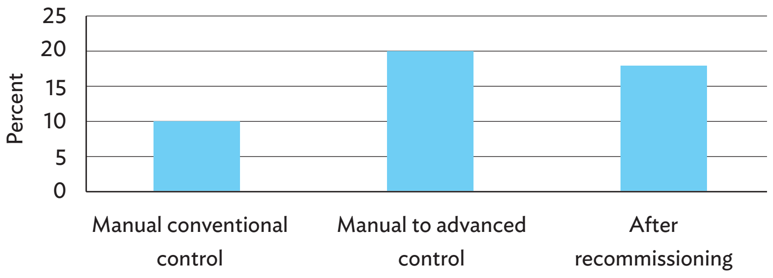
Figures 20–23 show the average energy savings from retrofitting building automation systems.

International case studies and suppliers' reports proved that well-designed systems coupled with energy-saving equipment can reduce energy use by more than 20% on average. Improving efficiency in air-conditioning will reduce energy consumption by 18% and in lighting systems by 28%.

(i) In terms of new buildings, a quantitative survey[20] conducted by Honeywell across their projects in the United States and the United Kingdom has shown that advanced building automation over heating, ventilation, and air-conditioning (HVAC) and lighting systems saves as much as 20% compared with manually operated facilities.

(ii) In terms of existing buildings, energy efficiency may increase significantly, 18% on average by recommissioning (footnote 13).

Figure 20: Energy-Saving Rate from Control and Commissioning



Source: ADB consultants based on the building control study material provided by Honeywell during research interview, May 2013.

All six international cases in the research achieved energy-saving rates of at least 20%.

Comparison of cases collected from suppliers also indicate that HVAC control and lighting control can contribute 5%–40% of energy savings. Verifying these energy-saving results will

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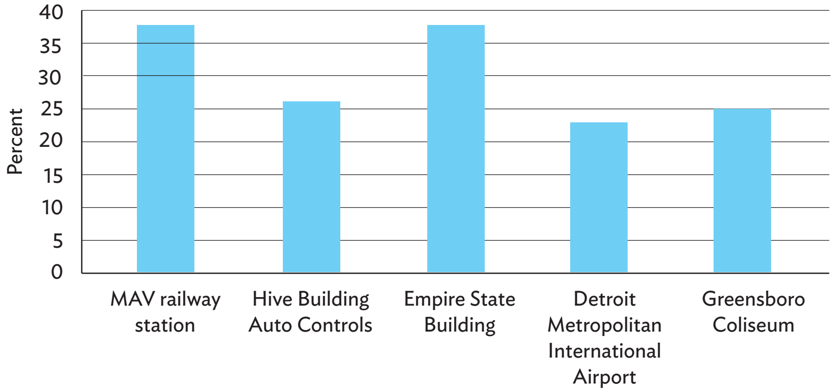
[20] Building Control Study Material provided by Honeywell during research interview.

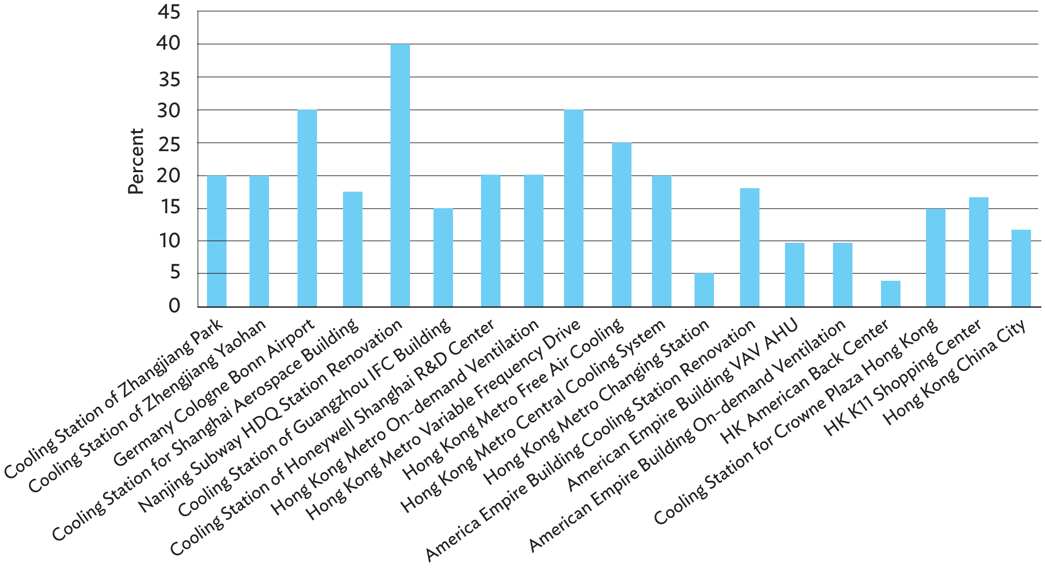
be of use in the railway stations in the PRC. In Chapter 3, we have documented a simulation based on real-time station design and characteristic as proof.[21]

Figure 21: Energy-Saving Rate of International Retrofit Cases



Source: ADB consultants based on the building control study material provided by Honeywell during research interview, May 2013.

Figure 22: Heating, Ventilation, and Air-Conditioning System Energy-Saving Rate in Selected Cases



HVAC = heating, ventilation, and air-conditioning system.

Source: ADB consultants based on supplier's presentation.

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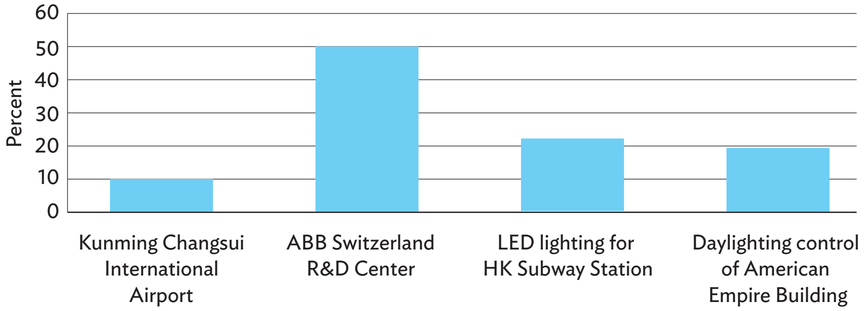
[21] Supplier's presentation on International Cases Workshop.

Figure 23: Lighting Control Energy-Saving Rate in Selected Cases



LED = light emitting diode, R&D = research and development.

Source: ADB consultants based on the building control study material provided by Honeywell during research interview, May 2013.

In studies of large stations (presented in Chapter 3), use of heating and cooling equipment accounts for 68% of total energy consumption. Lighting makes up an additional 18%, for a combined total of 86% consumption by these two systems. We found that on average 16.7% can be saved through adoption of HVAC and intelligent lighting control systems. More specifically, intelligent building technologies can be applied in the below segments where energy consumption can be greatly reduced:

(i) Air-conditioning, heating, and control systems include air-conditioning terminal equipment (air handling unit [AHU], precision air-conditioning unit [PAU], fan coil unit [FCU], variable air volume [VAV] box), entilation equipment, heating and cooling source equipment (air conditioner, boiler, refrigerator and cooling pumps, heating pumps, cooling towers, heat exchanger, and various types of electric valves).

(ii) Lighting, and lighting control system.

(iii) Hot water and water heating control system.

(iv) Electric distribution system is mainly to monitor the status of various electrical switches and metering for various circuits. Smart metering technology enables us to easily monitor, analyze, and report on energy consumption down to the individual system level. The power distribution system is independent from the building management system, and can be treated as master platform for higher level of management.

(v) Architecture design (includes building envelope).

(vi) Escalator and elevator system: mainly used to monitor and operate escalators and elevators.

(vii) Renewable energy system.

Energy savings through intelligent control strategies cannot be isolated from monitoring and evaluation equipment, system characteristics, and working principles

Energy saving through intelligent control strategies cannot be isolated from monitoring and evaluation equipment, system characteristics, and working principles. Therefore, apart from describing control strategies, we will also put effort into explaining equipment/system theories and principles.

Furthermore, the development of efficient control strategy must take operator knowledge into account. Once equipment is installed and control strategies put in place, operators need to be educated on proper system operation. Training should also include an understanding of the theories and principles behind HVAC and water system design, and implementation specific to the project. In many cases, we find that systems are not fully used because there is a lack of knowledge on operation.

4.3 Architectural Passive Features

As mentioned previously, study of energy savings in a building should not be isolated from architecture features. Table 14 describes a list of important passive design features that should be addressed in the architecture design stage, providing recommendations to designers before electrical/mechanical equipment and control systems are introduced.

Table 14: Architecture Passive Features

No.	Feature or Opportunity	Applicability	Energy and/or Economic Impact
1	Building sizing	Needs to be more accurate. Ancillary hall, concourses, or platform may be considered.	Large hall and wide concourse tends to be underused and consumes more energy.
2	Building form	Configuration for energy use needs to be optimized. The trade-off between space efficiency and energy efficiency should be understood.	In more extreme climates, compact, vertical stations should be more efficient. In moderate climates, side-line-type stations may be more energy efficient.
3	Passenger flow	Needs to be simulated more accurately.	Concourse dimension and long distances to multimodal (taxi, metro, bus) transfers tend to require more energy. Shorter walking lengths between modes use less energy. Minimize number of vertical transfers and/or reduce overall vertical distance traveled from entry to train boarding and train alighting to exit.

continued on next page

Table 14 *continued*

No.	Feature or Opportunity	Applicability	Energy and/or Economic Impact
4	Sun-shading to building exterior	Suitable for all occasions. Applies to regions south of Yellow River, including cold, hot summer and cold winter, and hot summer and warm winter climate zones.	The payback period is generally 3–5 years, and has a great improvement on thermal comfort. Movable external sun-shading is not suggested because of long payback period and high or intensive maintenance requirements.
5	Use of natural light	Widely used. Needs to avoid glare and increasing heat load in summer months. Should seek a balance between lighting and air-conditioning energy consumption.	Integrated with architecture form and space layout, usually this does not increase costs. When combined with light collectors/fiber-optic cables (very expensive), return is 20–30 years (including cables).
6	Natural ventilation	Widely used. Needs to pay attention to the in-outlet location, size, and air flow organization; can be combined with mechanical ventilation.	The energy saving is obvious with a small capital investment; return cycle can be realized within 2 years.
7	Building shape coefficient	Widely used. A particular focus on solar gain to reduce heating requirements in the north.	The current common station design and aesthetics are not conducive to energy saving. This passive design feature has the potential to save substantial energy both directly and in tandem with MEP design.
8	Window-to-wall ratio	Widely used. Considered more in the north because of greater heat loss. Needs to consider the parameters of the exterior wall and window to design.	Extent of energy savings dependent on design.
9	External wall insulation	Widely used. Insulation thickness needs to be optimized according to actual conditions.	The return cycle of optimal design based on national Design Standard for Energy Efficiency of Public Buildings is less than 3 years.
10	Double glazing window	Widely applied in all climate zones in the PRC, which could decrease the U-value and energy lost within buildings.	Almost all windows are double glazing in the PRC for many years. Design standard also regulates the way for achieving energy saving through the application of double glazing windows.

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Table 14 *continued*

No.	Feature or Opportunity	Applicability	Energy and/or Economic Impact
11	Interior space distribution	Widely used. Improves the utilization rate of space and resources.	Extent of energy savings dependent on design.
12	Building orientation	Widely used. Need to carefully consider prevailing wind and sun radiation in orienting the building.	Extent of energy savings dependent on design.
13	Roof shape/features	Suitable for all locations.	Can allow for natural ventilation, shading of building perimeter, and interior daylighting (preferably with ambient daylight)

MEP = mechanical, electrical, and plumbing; PRC = People's Republic of China.

Source: ADB consultants.

4.4 Heating, Ventilation, and Air-Conditioning System and Control

Regardless of the strategies to save energy in the HVAC system, the following aspects are considered:

(i) How to meet desired thermal requirements?

(ii) How to reduce heat or cooling demand?

(iii) What alternative energy can be used?

(iv) How to optimize system and equipment energy performance?

(v) How do the devices and/or systems communicate and operate?

Therefore, we summarize possible opportunities to save energy in a station building HVAC system (Table 15):

Table 15: Heating, Ventilation, and Air-Conditioning System and Control

No.	Opportunity	Applicability	Energy and/or Economic Impact	Note
1	Appropriate selection of chiller type	Depends on: fuel type (electricity or gas) Water cooled or air-cooled Engine type	Dependent on projects but in most cases a higher capital cost of producing operational energy reduction	Not only a choice between load capacity, but also fuel cost
2	Appropriate selection of air-conditioning water system	Suggest system designed to be as simple as possible Variable flow of primary pump, or secondary pump	Compared with fixed flow rate system, variable saves at least 20% of pump energy	
3	Highly efficient chiller	Applicable for all projects, but should consider differences between COP and IPLV, final selection based on load demand	Return on investment in about 4–5 years	
4	Highly efficient pump	Applicable for all projects. High-efficiency pump speed is variable based on demand	Will save about 20% compared with traditional pumps	Consider supply and demand and energy rates
5	Highly efficient cooling tower	Choose radiation rate greater than design settings. Extra important for maintenance	Contributes to saving energy when using chiller	Can ensure chiller performance in extreme conditions
6	Chiller plant management system	It is possible to adopt many control strategies based on refrigerating principals and air-conditioning product differences	Savings of 17%–30% compared with manual operation or current standard Building Automation	
7	Group chiller plants management—all converting systems	Dependent on project design but system using variable frequency equipment could achieve perfect control logic	Substantial energy savings	
8	Group chiller plants management—number of chillers	To add or remove number of chillers based on accurate load and performance calculations	Chillers consume substantial energy, their optimum configuration will produce significant energy savings	
9	Group chiller plants management—cooling water temperature difference	Energy savings based on refrigeration principles	Extent of energy savings dependent on design	Cannot make large changes to water temperature, may exceed humidity requirements and increase pump energy use
10	Group chiller plants management—modeling and self-learning	To establish accurate system models integrating chillers, pumps, and cooling towers; to enable self-correction, and achieve high efficiency	Extent of energy savings dependent on design	Limited suppliers, heavy reliance on specialists
11	Free cooling water and control	Most suitable in spring and fall seasons	Energy savings of 2%–5%	Depends on outside conditions

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Table 15 *continued*

No.	Opportunity	Applicability	Energy and/or Economic Impact	Note
12	Appropriate selection of heating source	Similar to air-conditioning source selection, depends on: heat pump or boiler, air-sourced or ground-sourced heat pump, gas boiler or electric boiler	Extent of energy savings dependent on design and project types	Not only a choice between load capacity but also fuel cost
13	Other air-conditioning cooling or heating source selection	Water and/or ground sourced heat pump, ice or water storage, solar thermal air-conditioning and water heating, CCHP. Need to carefully investigate feasibility, otherwise very low return on investment and difficult to maintain	Extent of energy savings dependent on design	Need to demonstrate effectiveness. Economics is also an important factor
14	Appropriate selection of air side terminals	It is better to select an “all air” system for large buildings. Some specific areas could use other types: VAV, FCU, VRV	Extent of energy savings dependent on design	
15	Variable ventilation and fresh air flow control	Suitable for stations with ventilation changes dependent on occupancy rates and fresh air supply	Saves 20% of the energy consumed by vents, also saves air-conditioning water side energy	Need to ensure indoor air quality standards are maintained
16	Heat recovery on air terminal	Heat recovery is very important in air exhaust systems, recommend all stations adopt this technology	10% energy savings in air-conditioning use	Requires automatic control
17	Lower-level ventilation and temperature control	Only supplies air to occupied spaces. This is essential for air-conditioning systems located in stations with high roofs. The temperature setting point is critical	Air-conditioning energy saving in summer above 20%	Easier to cool but more difficult to heat. Difficult to adjust supply air temperature by measuring return air
18	Displaced air supply and exhaust	To increase air ventilation during the spring and fall seasons, most prefer to use fresh outdoor air	Energy savings of 10% in the spring and fall seasons	Requires automatic control
19	Adjust temperature set point	Dependent on different regions to meet with air-conditioning design parameters	Saves about 6% air-conditioning energy for every 1°C change in temperature	Requires automatic control
20	High-efficiency vents	Select energy-saving vents and improve daily maintenance	Extent of energy savings dependent on design	Need to consider supply and demand rate
21	Material selection for pipes	To select specific materials for pipes to extend the life expectancy of materials	Minimize the possibility of installing new materials due to material aging, to achieve economic benefit	Material selections process needs to be controlled

CCHP = combined cooling, heating, and power; COP = coefficient of performance; FCU = fan coil unit; IPLV = integrated part load value; VAV = variable air volume; VRV = variable refrigerant volume.

Source: ADB consultants.

4.5 Lighting and Control

Designing of lighting systems for high-speed railway stations is a complicated process due to the following reasons:

(i) Coexistence of high and low spaces, and their interfaces

(ii) Interaction among different functional areas

(iii) Uncertainties of operation time

(iv) Uncertainties of lighting rate

This is compounded by the fact that in many cases, modern lighting design has progressed faster than technology. Table 16 shows the impact of different lighting systems.

Table 16: Lighting and Control

No.	Opportunity	Applicability	Energy/Economic Impact	Note
1	Energy-saving light source	Applicable across all regions, but differs by space types and requirements	Refer to later comments which compare with common design practices, such as (i) Office: T8 lights (ii) Station lower space: compact fluorescent light (iii) High space: metal halide light	Lights should be installed and cleaned every season to maintain luminance
2	LED	Increased lighting efficiency, but dependent on quality. Suitable for both high and low ceilings, and other functions	Capital versus operational costs balance out, but an improvement in lighting environment. Instant light	Many low-quality products on the market undermine the opportunity
	Highly efficient fluorescent light	T5 lights, high frequency electronic ballast (Hf)	Return on investment in less than 1 year	
3	Energy-efficient accessories and covers	Critical to match lighting settings with space requirements	Extent of energy savings dependent on design	
4	Intelligent lighting controls	Smart adjustment of the lighting system based on sensor feedback, can be integrated with train schedules to achieve integrated management	Usually sees economic returns of less than 1 year, but complicated control programs may take 3 years	Increased productivity
	Area theme control	Suitable for mixed spaces with varied occupant density		

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Table 16 *continued*

No.	Opportunity	Applicability	Energy/Economic Impact	Note
	Timely control	Suitable for platforms, main passenger routes		
	Occupancy control	Suitable for space such as terminals that are only used occasionally, should meet security requirements		
	Light sensor control	Link with natural lighting		
5	Illumination settings	Diversify illumination requirements in different spaces to avoid overlighting or underlighting. Requires refined design	Extent of energy savings dependent on design	

LED = light-emitting diode.
Source: ADB consultants.

4.6 Power Distribution and Energy Metering System

Although power distribution devices do not consume large amounts of energy, it is very important to maintain a safe, stable, and efficient electrical supply. When energy metering systems are installed, they provide the operator access to monitor, investigate, and study the performance of building systems and equipment. Table 17 shows the applicability and impacts of power distribution and metering systems.

Table 17: Power Distribution and Energy Metering System

No.	Opportunity	Applicability	Energy and/or Economic Impact	Note
1	High-efficiency transformer	Applicable for all projects, should be promoted, e.g., S13 level transformer	Usually sees a return on investment in 3 years	
2	Energy storage	Takes advantage of the difference between peak and off-peak electricity pricing, e.g., store energy during the night and use in the day	Usually sees a return on investment in 4–5 years	Equipment is quite expensive, and capacity is limited
3	Itemized metering	With continued reduction in costs of metering devices, itemized metering is very useful and effective	Minor increase in capital investment	Helps operators understand and investigate energy consumption trends to support proposed energy-saving measures

Source: ADB consultants.

4.7 Elevator and Escalator System

Although elevators and escalators are important items of energy-consuming equipment in transportation buildings, they are relatively easy to manage locally when compared with other building systems. A detailed approach has, therefore, not been undertaken. However, it is important during the design phase to minimize the amount of vertical transfers to reduce the energy use of vertical transportation and simplify pedestrian flow. The summary of outline findings is shown in Table 18.

Table 18: Escalator System

No.	Opportunity	Applicability	Energy/Economic Impact	Note
1	Control the number of operating escalators	Match escalator operation to occupancy rate	Energy savings of about 14%	Run escalators at full capacity to avoid energy loss
2	Variable speed escalators	Use highly efficient motors, deceleration boxes, and add variable frequency gear	Energy savings of 15%–30% possible in equipment consumption	Off or slow mode when not in use, or can be activated by human sensors

Source: ADB consultants.

4.8 Water Heating and Control

Since passengers are at station buildings only temporarily, there is little need for sanitary hot water for showering. Drinking hot water usually provided by instantaneous electric water heaters does not need automatic control. Water heating amounts to less than 1%–3% of total energy consumption.

Moreover, more attention should be paid to rainwater harvesting systems to lower the annual water consumption. In the PRC, railway stations are always large-sized buildings with large roof areas, from which plenty of rainwater can be collected, treated, and recycled for toilet flushing as well as outside landscaping.

4.9 Renewable Energy

For further reduction in carbon emission and energy conservation, renewable energy options should be taken into account after the aforementioned active and passive approaches. However, technical and economic assessments need to be carefully considered.

Table 19: Renewable Energy

No.	Feature or Opportunity	Applicability	Energy/Economic Impact
1	Solar electricity	Suitable for bright sunlight area, photovoltaic panels can be integrated into building facade and roof. However, solar electricity is not allowed feedback into the national grid.	Longer payback period, usually more than 10 years, low maintenance cost.
2	Solar water	Suitable for wider area, can be used as water pre-heating and combined with other heating methods.	Depends on the needs, large scale is more cost-effective than small scale.
3	Wind power	For higher wind speed area. However, stations are usually built in city or town center.	Calculation for local wind speed needed.
4	Combined heating, cooling, and power	Please refer to No. 13 of Table 15.	Please refer to No.13 of Table 15.

Source: ADB consultants.

4.10 Investment Justification

In a new construction scenario, the cost of creating a green and intelligent building is often not that different from the cost associated with creating a traditional building. While every building project is different and the final cost comparison can only be made based on a building's individual requirement, it should not be expected that an intelligent building will cost significantly more at the outset than a more traditional version of the same building. [22] In the PRC, the cost of BAS is based on the number of control points, normally in the range of CNY1,500–CNY2,500 per control point. As we investigated on large railway stations, the capital investment had already been made for BAS; however, their function and performance is not fully utilized. In a retrofit or an existing building project, the existing technology or system in a building can be upgraded easily and the payback is expected to be short. If saving potential is virtually achieved, the payback should be less than 5 years.

For example, according to the initial energy audit of Station A, retrofit cost of BAS is around CNY2.84 million and the saving potential is around CNY6.04 million per year. The payback period is less than 1 year.

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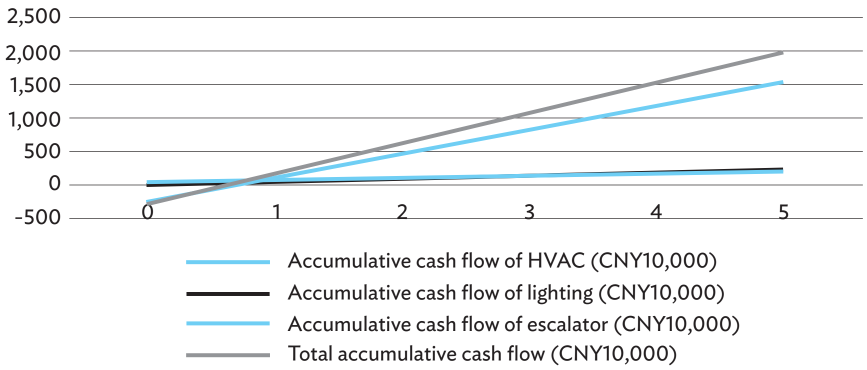
[22] Continental Automated Buildings Association. Bright Green Building—Convergence of Green and Intelligent Buildings. Webinar presentation. http://www.caba.org/brightgreen

Figure 24: Cash Flow after Retrofit



CNY = yuan, HVAC = heating, ventilation, and air-conditioning.

Source: ADB consultants.

4.11 Technical Application Suggestion

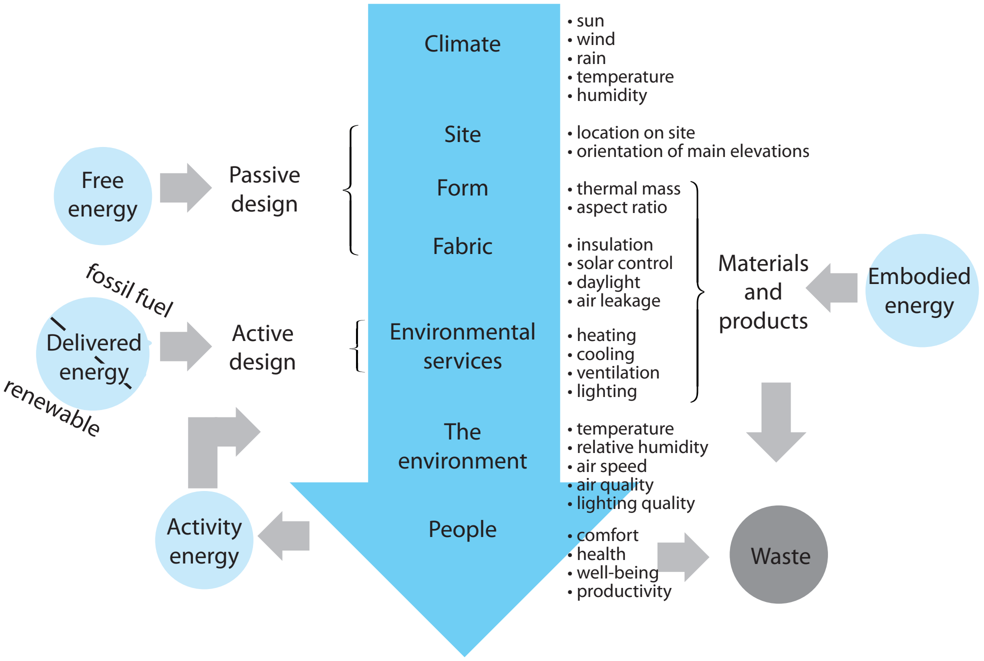
In conclusion, high-speed railway stations in the PRC have unique design features compared with other public buildings across the globe, and create their own set of challenges in achieving energy efficiency. A range of reliable, intelligent building control technologies and strategies are available and applicable for various building systems capable of providing effective energy reduction when properly designed, installed, and set up, leveraged by good passive architecture features. These potential technical solutions require more sophisticated consideration when applying to railway station buildings in the PRC.

The application of these potential technologies to the railway station buildings in the PRC should be performed as a holistic approach instead of a traditional silo model, as an integrated system instead of technology simply stacked together. It is suggested to use the low-carbon design process (shown in Figure 25) to develop the station, and to ensure that the energy emission reduction targets of the intelligent railway station buildings in the PRC are achieved.

The use of intelligent building controls support sustainability due to reduction of energy consumption, minimization or elimination of energy wastes, and reduction of costs. Figure 26 shows the different sustainability factors that are important for achieving a certain level of comfort for railway station users while at the same time saving energy and reducing emissions.

The application of building control technology in a case study of Shanghai Station showed tremendous reduction in the use of electricity and coal (Box 1). Moreover, the total investment for the retrofit was recovered in 3 years.

Figure 25: Low-Carbon Design Model



Source: Cardiff University. 2012. *Low-Carbon Design Model*. United Kingdom.

Institutional mechanisms are important to support technological integration in the building and construction sector. Chapter 5 discusses different factors needed to strengthen and operationalize the technological integration of the railway station buildings in the PRC.

Figure 26: Intelligent Control with Sustainability

Environmental sustainability	**Social sustainability**	**Economic sustainability**
• Reduce energy consumption • Eliminate energy waste • Reduce water consumption • Improve indoor air quality	• Improve comfort • Better accessibility • Enhance safety	• Lower operation cost • Reduce maintenance cost • Reduce repair and replacement cost • Extend system lifetime

Source: ADB consultant.

Box 1: Case Study—Shanghai Station Retrofit

The Shanghai Railway Station is representative of a typical older Super Class station and serves a large number of passengers. This case study demonstrates the successful implementation of intelligent building controls in a domestic station. The Shanghai Railway Station was completed in 1909. The current building was built in 1987, and went through a major renovation in 2010. Seven islands serve 13 platforms and 15 railway lines.

Annual Energy Consumption

Based on statistics from 2007 to 2009, the energy consumption in Shanghai Station was relatively stable. Electricity consumption for the Shanghai Station is 373 kilowatt-hour per square meter (kWh/m2) annually, while gas consumption is 249 cubic meter per square meter annually. Peak electricity use occurs in July and August because of air-conditioning use, while gas use peaks in January and February when heating is required. Low-use seasons occur in April, May, and November.

Equipment Status

To cool the station, the Shanghai Station uses one 2,911 kilowatts (kW) and two 2,588 kW absorption chillers together with six refrigerating pumps, two cooling towers, and six cooling pumps. There are also two 10-ton and one 6-ton steam boilers. The heating, ventilation, and air-conditioning (HVAC) system provides both cooling and heating with air. HVAC systems were operated based on weather conditions and staff reactions to temperature changes in the hall lobby. Normally, cooling starts in early May and ends in mid-October; heating starts in early December and ends in end of March. Air-conditioning equipment is the largest energy user (32%), followed by lights (14%), and other equipment (10%).

Energy-Saving Technical Measures

Before the station retrofit, existing equipment was functional and satisfied the daily requirements of the station. The station was retrofitted because statistical analysis showed that the system had a large potential for energy saving. This was due to the following reasons:

(i) Lack of control over the central plant
(ii) Lack of control over water side performance in the HVAC system
(iii) Lack of control over air side performance in the HVAC system
(iv) Low HVAC efficiency in some terminal units
(v) No energy monitoring and management system
(vi) Lack of lighting control system

The table below summarizes energy-saving measures implemented in the station after retrofits took place, and their results:

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Box 1 *continued*

No.	Technical Team	Annual Energy Saved		Investment	ROI
1	Central plant control optimization	Coal gas saved: 380,000 Nm^3	CNY1,116,000		
2	Building automation system	Electricity saved: 480,000 kWh			
3	Energy management system				
4	Lighting system optimization	Electricity saved: 1,070,000 kWh	CNY963,000		
5	Air source heat pump water heater	300,000 kWh	CNY270,000		
6	Distributed energy system		CNY2,700,000		
7	Heat and wet separation treatment		CNY2,000,000		
	Total Savings		**CNY8,049,000**	**Total Investment: CNY25,000,000**	**3.1 years**

CNY = yuan, kWh = kilowatt-hour, Nm^3 = normal cubic meter, ROI = return on investment.

Source: Johnson Controls, ADB consultants.

5. Analysis of Administrative Influence

There is a need for better operating mechanisms to support technological integration in the building construction sector. These include the following:

(i) **Economic motivation.** Linking the cost of energy consumption bills to the participants of the building process, such as investors, constructors, and operators. This will form effective incentive systems based on market demand to reduce energy consumption across entire building projects. Greater alignment is needed between the investment and customer service and needs.

(ii) **Managerial motivation.** Importance of the management of project application and audit processes need to be considered. Work needs to be done to (a) integrate project managers and stakeholders; (b) minimize barriers between project design, construction, and operation stages; and (c) improve communications between local and China Railway Corporation (CRC) in specific projects.

(iii) **Technical motivation.** Introduction of better ways to promote and educate stakeholders on equipment, products, and operation of new technologies, allowing developers to integrate energy-saving solutions with software solutions to further drive building automation. All equipment and technologies applied in railway stations is operated by people, the behavior, the habit, and the way of operating the railway station is another major factor affecting energy efficiency. Emphasis should be on the technological capacity development of railway building operators in using the new technologies and equipment.

Legal systems, public policy, and resource management play decisive factors in successful energy reduction strategies

5.1 Domestic and Foreign Legal Frameworks and Regulations

This section focuses on the institutional and legal frameworks in the People’s Republic of China (PRC), and in other countries that emphasize energy efficiency in buildings. It presents international experience in running intelligent building systems, especially the management and technical aspects of operating the systems.

5.1.1 International Energy-Saving Practices

There are a number of success stories to be found throughout the history of the international energy efficiency market. Europe and the United States have placed energy-saving strategies at the top of their national energy strategies. Japan is working to improve energy efficiency through enhanced law enforcement, and is investing majorly into developing energy-saving technologies. We will examine further how the legal system, policy implementation, and proper management practices in developed countries have led to energy management successes in the marketplace.

Legal Framework

The United Kingdom recently announced a specialized legislative document, the Climate Change Bill. The aim of this bill is to develop a clear and coherent long-term plan for emission reductions. This includes the development of a carbon emissions pricing plan, formation of a climate change committee with legal status, introduction of new emissions trading system, and the establishment of a new reporting mechanism for greenhouse gas emissions to monitor progress.

Japan has developed a number of laws: Energy Conservation Law, “Energy Conservation and Recycling Assistance Act,” Waste Disposal Act, Chemical Substance Control Law, Pollutant Release and Transfer Register (PRTR) Act, and other bills that through strict legal means control the growth of energy demand in various industries.

The United States has introduced the Energy Policy Act of 1992, Energy Independence and Security Act, Clean Water Act, Clean Air Act, Solid Waste Disposal Act, and other laws and regulations. These energy-saving and environmental regulations are designed to strictly enforce energy-saving regulations.

The European Union (EU) legislation documents related to energy savings include the Single European Act and the EC Treaty which require EU member states to work together to comply with environmental policies and guiding principles. The 2010 Energy Performance of Buildings Directive and the 2012 Energy Efficiency Directive are the EU’s main legislation when it comes to reducing the energy consumption of buildings. In addition to EU energy laws, many countries have developed corresponding energy-saving laws and regulations of their own. Recognized as one of the world’s most developed circular economies, Germany has a strong legal system to enforce environmental regulations. The Energy Saving Act and Energy Saving Ordinance are essential instruments in the German Federal Government’s energy efficiency policy. The “polluter pays” principle, the precautionary principle, and the cooperation principle are the three basic principles Germany has formulated for energy-saving laws and regulations.

Policy Enforcement

In July 2009, the United Kingdom issued two country strategy papers, the Low Carbon Transition Plan and the Renewable Energy Strategy and a series of supporting programs, including The UK Renewable Energy Strategy and British Low-Carbon Industrial Strategy to form a road map for low-carbon economic development until 2020. The government adopted a series of coercive measures to reduce or even stop exploitation of mineral resources, and prevent the functioning of businesses with high energy consumption and pollution levels. The United Kingdom also identified policies such as the "polluter pays" principle and integrated fiscal policy to encourage enterprises to save energy.

Japan has been a leader in reducing emissions in manufacturing. On the monitoring side, policies have been created requiring manufacturers to submit periodic reports of energy use. On the political side, Japan strives to establish itself as a leader in high-tech and energy-saving products.

Management Practice

Energy conservation management of foreign governments adopts an indirect management approach. To ensure the smooth implementation of the policy on energy conservation, government disseminates information to energy providers, industrial enterprises and intermediary organizations, and other entities which espouse similar principles. Nongovernment organizations such as those promoting energy technologies have also played a huge role in the promotion of energy conservation.

The Department of Energy and Climate Change is responsible for the development of energy policies and regulations, and the management of government funds for energy investments. The government is not expected to directly manage energy conservation projects.

France established an independent Environment and Energy Management Agency, which is responsible for the management of national energy standards and environmental pollution control efforts. The agency requires key energy companies to make voluntary energy assurances, and promotes energy-saving measures through intermediate organizations and enterprises.

Japan adopts a "four-level management" model in energy-saving oversight: the Prime Minister—Ministry of Economy, Trade and Industry—Agency for Natural Resources and Energy—Regional Bureaus of Economy, Trade and Industry. Headed by the prime minister, the national lead agency is responsible for the national energy efficiency policy formulation.

In the United States, state governments are responsible for checking business adherence to policy. Issues are dealt with in accordance with local and federal laws. The United States uses legal and economic means to fully mobilize the government, and business to achieve energy-saving targets.

Legal systems, public policy, and resource management play decisive factors in successful energy reduction strategies.

5.1.2 Domestic Regulations on Energy Saving in Buildings and Railway

The PRC has put extensive efforts into drafting regulation to support environmental protection. A series of laws have been established, including the Energy Saving Provisional Regulations in 1986, the China Energy Technology Policy in 1996, and the Energy Saving Law in 1998. The government, regardless of macro policies, directly controls the energy policy formulation and implementation processes in the PRC.

In the PRC, the supreme ruling body, the National People's Congress, is responsible for formulating energy strategies. The State Council and its permanent institutions develop specific implementation details. The Ministry of Environmental Protection primarily manages this. This body introduces core policies and policy implementation rules in cooperation with the National Development and Reform Commission, Ministry of Communications, Ministry of Construction, Ministry of Finance, and other departments.

The government has traditionally directly managed the PRC's energy efficiency policy. This has been gradually shifting to allow for more market influence in recent years.

To improve the management of energy efficiency in railway-related projects, the CRC carried out the Design Specification of Energy Saving in Railway Engineering Projects, and then effected the first amendment in 2001. To improve the statistical analysis of energy saving, the CRC carried out the Railway Enterprises Energy Consumption and Saving Statistics Method in 1995, and then effected the amendment in 2007. Under the requirement of energy-saving regulation and a further requirement for energy saving, the CRC started to make the Railway Energy-Saving Technology Policy in 1999, and modified it in 2007. The intention was to build up a solid norm and regulation system, and catch the related technique parameters, and then guide the development.

The following are the specific requirements from a feasibility study report on energy measurement, control, monitoring, and management of energy science and technology policy.[23]

(i) Improve energy metering and statistics by tracking energy consumption, and by energy utilization analysis.

(ii) Promote the use of intelligent measurement instruments. Major energy-consuming processes, equipment, and systems should be controlled automatically.

(iii) Following national energy monitoring standards, carry out integrated energy monitoring for key equipment.

(iv) If equipment fails to meet national standards, it should be taken out of operation.

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[23] Chinese Academy of Engineering. 2009. *Current Energy Consumption in Chinese Buildings and Energy Solution Analysis.* Beijing.

(v) Establish and improve railway service and the use of automated technology. Promote the growth of energy-saving technology consulting firms, technology services, energy information exchanges, and training in systems management.

5.2 Domestic and Foreign Practices of Economic Policies and Incentives

Economic policy is an effective means to promote energy-saving fiscal policy and financial policies.

a. **Fiscal policies (subsidies and taxes)**

Leveraging prices and taxes is one of the most effective ways to conserve energy and develop new energy sources. Finland was the first to establish a carbon tax. Presently, Denmark, Finland, Sweden, and other countries that have implemented carbon tax policies have achieved their emission targets.

Although the PRC is yet to levy environmental taxes as a separate tax, it has developed laws and regulations to encourage enterprises to accelerate the energy-saving market. The PRC is currently studying environmental tax and carbon tax levy schemes.

b. **Financial policies (green credit, green insurance, and green securities policy)**

The PRC's green finance is reliant on the government to manage and guide financial institutions and enterprises. The government has issued many policies in this area including (footnote 3):

(i) In July 2007, the Opinions on Implementing Environmental Protection Policies and Rules and Preventing Credit Risk.

(ii) In the same year, the China Banking Regulatory Commission (CBRC) issued the "Notice on Prevention and Control of High Energy Consumption and High Pollution Industry Credit Risk" and "Emission Reduction Credit Guidance."

(iii) In February 2008, the China Environmental Protection Department and China Insurance Regulatory Commission jointly issued Guidance on Environmental Pollution Liability Insurance to formalize the establishment of environmental pollution liability insurance.

(iv) On 25 February 2008, the China Environmental Protection Department issued Guidance on the Strengthening of Environmental Supervision of Listed Companies. This document outlines policy for companies to further improve and strengthen their environmental responsibilities.

c. **Policies related to railway stations**

Currently, there is no major economic policy to support railway station energy savings and management based on market mechanisms. The introduction of new equipment and systems used in the ministries is for demonstration purposes and local governments investing funds in station upgrades are for economic reasons. Unfortunately, due to the current market realities for green buildings in the PRC, there are few successful projects. There is one exception where the Chengdu government has given certain energy subsidies to the Chengdu East Railway Station (footnote 4).

Currently, the Ministry of Construction is investing a lot of effort to promote green buildings, and it promulgated the green building rating standards (GB/T50378-2006) in 2006. Recently, the State Department of Housing and Urban Construction announced the approval of the green building rating standards (GB/T50378-2014), which will take effect from 1 January 2015. The new standard has wider scope than the previous version, the staged criteria are clearer, and the methodology is more reasonable. Also, the evaluation index system gets more perfected, and the overall system is very innovative. It is reported that a green standard of railway station has been drafted by the CRC, and will be enacted soon.

5.3 Administrative Organization

5.3.1 PRC Railway Corporation

According to the People's Republic of China State-Owned Industrial Enterprises Law, set up by the central management of state-owned enterprises, the CRC was approved by the State Council with a registered capital of CNY1.036 trillion. In the Twelfth Session of the National People's Congress meeting, the Institutional Reform of the State Council and the Functional Transformation Plan was agreed upon. According to the reform, the CRC and the railway department have been separated. The CRC was officially established on 14 March 2013. Although the CRC mainly focuses on passenger and freight transportation services, its operation is far more diversified and includes the following responsibilities:

(i) Operating the train dispatching command system

(ii) Managing the national passenger and freight transportation system

(iii) Undertaking national nonprofit rail transportation projects

(iv) Ensuring the operation of special rail transportation programs, such as disaster relief and other special rail transportation programs regarding national security and social welfare

(v) Investing and financing plans of national railway system construction

(vi) Monitoring preconstruction work and project management

(vii) Ensuring transportation security and safety of the railway network

The CRC authorities have set up 20 internal departments, 18 railway bureaus, 3 professional transport companies, and several other enterprises. The CRC has more than 204 million workers, a total of CNY4.66 trillion in assets, and is responsible for the operation of 97,840 kilometers of railway lines.

The CRC's mission includes the sensible development of the railway system in the PRC, the establishment of comprehensive and normative nonprofit rail network, enhancement of subsidy regulations for rail transportation, implementation of a modern cooperation system, and improvement of the marketing competitiveness in other sectors. The State Council set up a China Railway Reform Leading Group on the same day the establishment of the CRC was announced. The CRC will continue to promote the railway reform under the guidance of the aforementioned group.

The former Ministry of Railway will become the basis of the newly formed CRC. Under it will be the former Ministry of Transport with its departments for infrastructure, equipment, operations, and scheduling. The core departments of the PRC's railway network include the Infrastructure Department, which is mainly responsible for mechanical and electric services, communication signals, railway maintenance, and so on; the Equipment Department, responsible for vehicle inspections and acceptance; the Operations Department, responsible for developing transportation plans; and the Scheduling Department, responsible for railway scheduling.

The PRC's railway industry is undergoing a top–down reform. Vertically, the CRC needs to reestablish a new type of relationship with the local railway bureaus (in the future possibly could be renamed to Local Railway Group Company), which redefines the balance between planning and marketing mechanisms. This means a decentralization of rights for personnel, finance, procurement, and other entities. The local railway bureau may also need to decentralize and provide sufficient rights to individual stations to promote market enthusiasm. From a lateral perspective, the CRC needs to adjust relationships not only with the Ministry of Transport, the National Development and Reform Commission, and other ministries but also within other provinces.

5.3.2 The Analysis of Energy Saving and Emission Reduction of the Railway Industry

The railway industry's management structure is summarized below:

(i) The CRC (audited and authorized by the National Development and Reform Commission) mainly carries out the project work. The requirements in the project proposals and feasibility studies reported in project designs are based on requirements from construction companies who are also subsidiaries of the CRC.

(ii) The CRC undertakes preliminary design work. Stations are owned by the railway administration or other transportation companies. Project design is commissioned by the professional design institutes, and final designs are then reviewed by the Science and Technology Department of the CRC.

(iii) Construction of a building is secured by transportation companies who then contract general contractors for equipment procurement, installation, and commissioning of building systems. The Project Management Center of the CRC is responsible for the entire railway network management.

(iv) The railway bureau undertakes the operation of the station. Individual management organizations control regular and high-speed railway lines.

(v) The requirements for energy-saving technologies are drafted by the Science and Technology Department of the CRC paired with research organized by railway bureaus and transport companies.

Compared with building development and procurement in other sectors, construction of PRC's station network and associated rail facilities is managed using a vertical organizational structure under an umbrella of macroeconomic policy; integration and communication between the respective parties involved in the building procurement process is negatively affected by this arrangement and informed decision making suffers as a result. Table 20 shows the relevant agencies involved in the different stages of the railway building construction process.

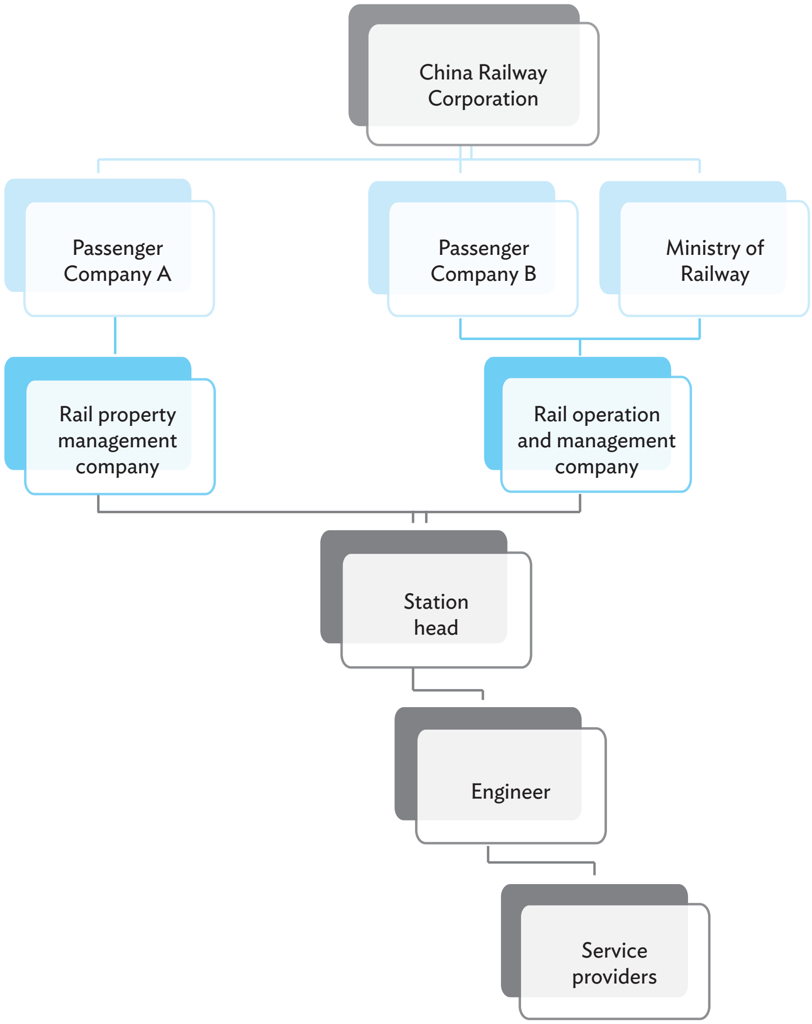
This correlation is further complicated as a major part of the normal-speed railway stations is operated by individual railway bureaus while high-speed railway stations are mostly managed by the railway line companies under an asset management regime with administration delegated by the railway bureau.

Table 20: Correlation between Project Stakeholders and Railway Stations at Different Stages of the Construction Process

Relevant Parties	Project Approval	Design	Construction 1	Construction 2	Operation	Investment
CRC	Relevant	Relevant	Relevant	Relevant	Relevant	Relevant
Passenger company		Relevant	Relevant	Relevant	Relevant	
Railway bureau					Relevant	
Station					Relevant	
Local government	Relevant					Relevant

CRC = China Railway Corporation.
Source: ADB consultants.

Figure 27: Railway Station Engineering-Related Party Structure



Source: ADB consultants.

The institutional structure design reveals that the PRC's railway station management has Chinese characteristics, which involves mainly vertical industry management (Figure 27). This makes the centrally managed national railway a game of chess with no market-based mechanisms. Each stakeholder's roles and responsibilities in the management of the entire construction process are not very clear. The main findings are listed below:

a. **The industrial management in the CRC**

(i) Development and Planning Department of CRC: preparing project proposals and research, quotation reports of medium-sized and large projects; managing programs under industrial environmental protection, energy saving, and foreign lending.

(ii) Construction Management Department of CRC: setting the building rules and regulations, technical construction work standards, construction cost and design standards, drawings, and bidding supervision.

(iii) Science and Technology Department of CRC: railway technology management procedures; the development of the outline planning, statistics, and analysis; the introduction of technology planning, scientific research, and technical supervision.

(iv) Transport Bureau (Transport Command Center) of CRC: development planning on fixed and mobile transportation equipment; greening and land management; in charge of joint venture railway corporations; local railway transport management on behalf of the CRC.

b. **The project approval stage**

The approval of a railway station project is not an independent process and should be included in the approval for the whole railway line construction. Currently, important projects have to pass the environmental, transportation, and energy consumption evaluations, but regulations for site selection are not very strict. The approvals are issued by the Planning and Statistics Department, and site selection is conducted in coordination with the local government.

c. **Design stage**

In this stage, technical solutions for energy saving are identified and electric heating systems are defined; however, lighting requires a special review process. There is no specific review for station designs. Technology to be used is the responsibility of a special unit in the CRC.

(i) Railway-related design institutes: commit to design of *station buildings*

- Adjunct Design Institute: Third Design Institute of CRC
- China Railway Construction Adjunct Institute: First, Fourth, and Fifth Design Institutes of CRC
- China Railway Consulting Firm Adjunct Design Institute: Second Design Institute of the CRC and the China Railway Consulting Firm
- Nonrail system design companies and design institutes: domestic and foreign design institutes jointly undertake most station interior and exterior design projects

(ii) Science and Technology Department of CRC: design approval, design changes, and budget proposal

d. **Construction stage**

Procurement of building systems is mostly determined at this stage. Technical specifications are provided in document design, and designers will participate in the evaluation.

(i) Railway-related construction companies: Committed to contract the construction

- Subsidiary of China Railway Engineering Corporation
- Subsidiary of China Railway Construction Corporation
- Subsidiary of China Communications Construction Group
- Subsidiary Railway Company of China Water
- Railway Corporation under China Construction Group

(ii) Project Management Center of CRC: organizing payment, project management of major issues during the construction process

(iii) Science and Technology Department of CRC: design changes and budget proposal

e. **Operation and evaluation stage**

The station's management is not responsible for the management of electricity use. Railway bureaus are responsible for power supply, and also act as the upper management for the station. Property companies often manage passenger railway lines whereas transportation companies are the actual station owners. Station owners are concerned about line operation profits and losses. The station itself is more concerned with meeting energy indicators and incentives:

(i) Individual station operator: responsible for daily operation of the station; energy consumption bills are paid by individual railway bureaus or companies, or by the CRC.

(ii) Individual railway bureaus or companies: responsible for retrofit, budget proposal, management of major issues during operation for both stations and lines.

(iii) Statistical Center of CRC: responsible for statistical and energy assessment index of all railway bureaus or companies.

To understand what all of the above means in terms of energy saving, primary responsibilities for all levels is summarized in Table 21 as follows:

Table 21: Management Hierarchy

Organization	Authority	Duty
China Railway Corporation	Planning Department, the Transport Bureau, Evaluation Center, Engineering Management Center, Statistics Center	Standardization system (technical standards and policies), evaluation system and indicators, statistical systems, information dissemination, establishment of service system
Transportation companies	Discipline head	Monitor key indicators, incentive mechanism design, technology research, and promotion of energy saving
Railway bureaus	Planning agency, transport department, railway department chief	Station management, supervision and inspection, evaluation, power supply, etc.
Railway stations	Station head, lead discipline engineer, subcontractors	Acceptance, personnel training, quantitative statistics, equipment maintenance and update, etc.

Source: ADB consultants.

5.3.3 Current Situation of CRC Energy Saving

The following information was gathered through research and investigation within the CRC, related departments, and station operation:

a. **Operation and electricity**

The CRC issues a unified assessment index of energy consumption to the railway bureaus and the operator of normal-speed railways. The railway bureaus then issue these to all stations. Electricity expenses are deducted from the railway bureau or the transportation company's operating income.

The high-speed rail system has set up a consortium of transportation companies responsible for the entire high-speed network supply chain from design and construction through to operation. The railway bureau commissioned by the station collects a management fee, the equivalent of a real estate property fee. The fee amount is determined by the CRC. In other high-speed rail cases, the railway bureau is responsible for operations and pays a "usage fee" to another group of transportation companies acting as facility managers. The fee amount is linked to the number of train journeys. Electricity consumption costs are deducted from the railway bureau's operational income.

b. **Energy index**

Energy indexes for high-speed railway stations are issued by the CRC and monitored and supervised by the railway bureau. Electricity fees for high-use lines are completely reimbursed by the transportation companies. Electricity fees for other lines are deducted from the operating income of the railway bureau.

Current national building energy efficiency requirements are set to meet the industry’s energy efficiency index. There are no economic incentives or penalties for the railway system to meet national indexes.

c. **Key performance indicators**

There is no motivation in the railway industry to save energy because the railway bureau directly reimburses electricity fees based on budgets and not actual consumption. It is undesirable to simply reduce electricity budgets as lower energy use will translate into loss of station comfort, for example, reduced lighting duration and intensity or elevator outages.

d. **Current situation of station management structure**

The station chief is fully responsible for station management. Station chiefs have electrical and/or heating, ventilation, and air-conditioning system engineering support. The management and maintenance of major equipment and systems are mostly subcontracted to external service providers. Station managers are responsible for the management of air-conditioning systems. Some electricity consumption monitoring systems (lighting, steam, etc.) has to be managed by the railway administration, and some by the users (lease holders, warehouses, etc.). There are too many monitoring systems, but they lack integration. Monitoring system selection operators are not involved in early planning stages, which lead to more work in the later stages. Facility management personnel predominantly work in isolation applying manual adjustment and control, resulting in operational errors that directly conflict with optimum system performance and actually increase the electricity consumption.

5.4 International Management Experience

The PRC’s operation mechanism accentuates “supervision” whereas international business practice puts more emphasis on “guidance.” The transition from supervision to guidance is a process of shifting from a passive to a more active role. New methodologies for project management and operation need to be established and an energy-saving standard agreed upon.

Mechanisms within the surveyed foreign railway systems are comprehensive and highly integrated, and that hierarchical structures ease the operation. Foreign technique and favorable policies facilitate reaching targets. The commissioning process and integration in railway systems need to be enhanced in the PRC.

As mentioned in previous chapters, project purchasing in the PRC lacks integration due to traditional management structures within the railway industry. The overall decision-making process is constrained by vertical and administrative organizational structures which lead to nonfunctional relationships among different departments. The limited cooperation between related entities throughout the project stages is a reason for failed objectives; new stations are equipped with advanced technology but expected energy-saving targets cannot be reached. Often, energy performance deteriorates even more during operation. According to a report, 30% of all projects require extensive rework, 40% are wasting resources, and more than 40% are behind schedule in the construction stage.

Integrated project delivery (IPD) is important in achieving good results in successful project completion. Based on international experience, the most important factors enhancing building performance are as follows:

(i) IPD and integrative design

(ii) Smart control and full commissioning scope

5.4.1 Integrated Project Delivery and Integrated Design

IPD and integrative design are the best project management practices to be learned from European countries and the United States. The American Institute of Architects defines IPD as “a project delivery approach that integrates people, systems, business structures and practices into a process that collaboratively harnesses the talents and insights of all participants to reduce waste and optimize efficiency through all phases of design, fabrication and construction.” Table 22 shows the different stages and outcomes in project management delivery.

These essential principles include mutual respect, mutual benefit, early goal definition, enhanced communication, open standard with appropriate technology, and leadership.

Table 22: Integration of the Different Stages of Project Management Delivery

Procedure	Main Job	Outcomes
Conceptual design	Decide on what to build and who is going to take the responsibility	Determined implementation of objectives, detailed cost organization, preliminary schedule, and communications
Norm design	Make conceptual design and select main options and interfaces	Clarified the work scope, relationships and agreements, and the costs for completion
Detailed design	Finalize key design and interface; follow up closely with involved parties throughout the later stages of the project	Completion of system design; coordination between all involved parties with focus on cost and schedule
Executive document	Focus shifts from design to implementation	Agreed and confirmed system design and blueprint, build working model

continued on next page

Table 22 *continued*

Procedure	Main Job	Outcomes
Institutional review	Review the design with the help of BIM and other available technologies	Pass the review and receive all required licenses and certificates
Procurement subcontracting	Establish contact with subcontractors and suppliers as early as possible to ease project process	Signed contracts with material and equipment suppliers to ensure on-time delivery dof services
Construction	Since the design has been completed in the previous stage, focus on quality and cost control	BIM enables better implementation by clearly showing the design and intent; improved quality control and waste reduction
Ending	Deliver finalized 3D design to the client and complete related tasks	Integrated project delivery is completed and eases future management and operation

3D = three-dimensional, BIM = building information modeling.
Source: ADB consultants.

Figures 28 and 29 represent the flow of traditional project delivery and integrated project management processes. By comparing these two, specific differences can be seen in cooperation and early intervention:

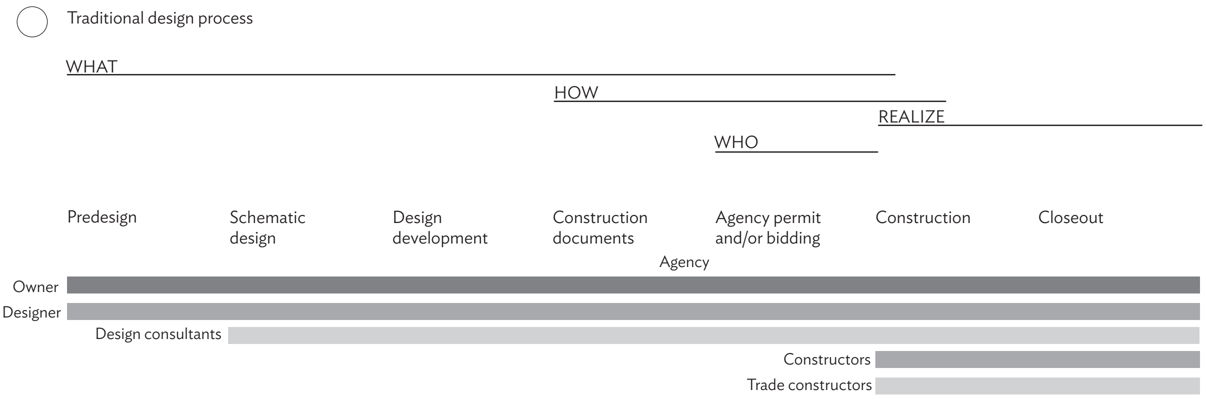
(i) **Cooperation.** In addition to the client, designer, and design consultant, professional parties such as consultants, contractors, and system integrators are involved in the integrated process.

(ii) **Early intervention.** All involved parties engage in early discussion to develop the conceptual design. This means the design consultant is involved even before the detailed design stage begins and implementation work starts during the late conceptual design rather than during the construction stage. The design of intelligent automation systems will also commence during the conceptual design stage whereas previously it used to start in the bidding stage.

IPD is a multifunctional process that combines formerly separated project stages, encourages active participation of all involved parties for technical and managerial decisions, and even considers passengers' experiences. IPD is a systematical solution to achieve the set emission reduction targets.

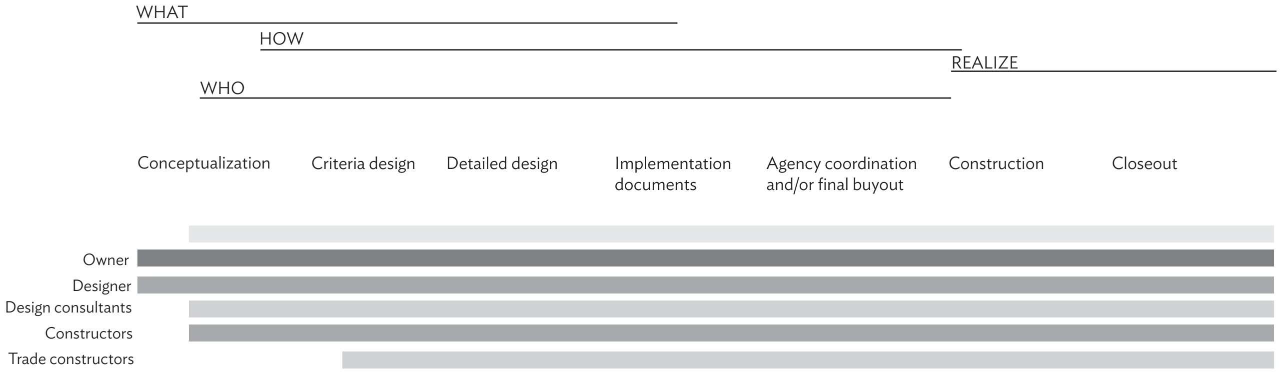
Figure 30 reflects the concept of an integrated design. Integrated design can be divided into "predesign" and "design and construction." The predesign stage includes three steps: conceptualization, preparation, and evaluation of the design. The design and construction stage is divided into four steps: schematic design, design development, construction documents, and bidding and construction. The design and construction stage focuses on

Figure 28: Diagram of Traditional Processes



Source: ADB consultants.

Figure 29: Diagram of Integrated Process

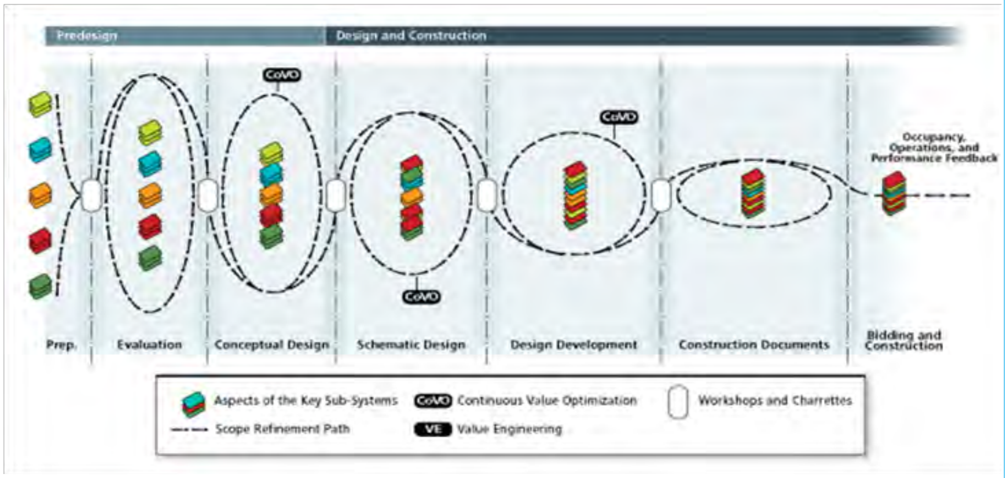


Source: ADB consultants.

the key performance of each subsystem through each step; the initial performance of each subsystem is completely independent, and experts will continuously improve and adjust the design throughout the process. This includes the development of technical specifications that are required to provide a precise interface definition with regard to the eventual integration and compatibility of various systems.

Integrated design is similar to IPD; however, it is more focused on the design process. As the best and most sustainable design practice in Europe and the United States, integrated design can avoid waste and eliminate prospective problems in advance through forward-looking design work.

Figure 30: Aspects in Integrated Process



Source: S. Mallory-Hill et al. 2012. *Enhancing Building Performance*. Blackwell Publishing, Ltd. UK.

5.4.2 Taking Control and Commissioning

Intelligent controls and whole process commissioning are the lessons to be learned from the construction of low-carbon buildings in Europe and the United States: “Intelligent control system ensures that the targets for energy conservation and carbon reduction set during the design are achieved in operation.”

To fully utilize the potential of a building’s automation system, attention needs to be paid during its design, installation, commissioning, and operation.

Case studies show that intelligent control systems have the largest share in annual energy savings (Table 23). However, the effectiveness of a control system relies on the training of its operators. Training means additional investment, but it is an essential requirement for achieving the maximum benefit of the control system.

Table 23: Impacts of Energy-Saving Measures

Strategies	Investment (k€)	Energy Saving (MWh/yr)	Emission Reduction CO_2 (ton)
1. Achieve intelligent AHU control	46	873	140
2. Optimize HVAC systems based on occupancy in real time	6	115	21
3. Optimization of temperature set point	21	402	64
4. Improve the boiler control, reduce heat loss	4.5	96	22
5. Optimize lighting control	8	133	11

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Table 23 *continued*

Strategies	Investment (k€)	Energy Saving (MWh/yr)	Emission Reduction CO_2 (ton)
6. Advanced zone control: **Indoor lighting, shading, air-conditioning regionalization, and integrated intelligent control**			
7. Green training and communication	6	84	

AHU = air handling unit, HVAC = heating, ventilation, and air-conditioning, k€ = thousands of Euro, MWh/yr = megawatt-hour per year.

Source: ADB consultants.

(i) **Planning and designing good controls.** A client's requirements for a good control system include high energy efficiency while maintaining comfort. The designers' specifications should set out the key energy features for contractors to understand what the control system needs to do.

Contractual routes and procurement can determine the performance of a control system as much as the specifications and the design of the system. The preferred maintenance regimes need to be determined at the beginning of the project, and an adequate user interface allows the operator to review the overall performance of the building.

(ii) **Installation and commissioning.** A poorly installed or commissioned control system can cause a potentially low-carbon building to consume more energy than it should. Commissioning is an internationally recognized best practice ensuring equipment and controls work effectively. This may include meters to monitor the installation, end user contribution, commissioning control systems, and seasonal commissioning.

(iii) **Operation and recommissioning.** The operators' capability to run the system is just as important as the intelligent control system itself. Successful cases in Europe prove that designers, contractors, and operators should all be involved in the commissioning stage to ensure overall quality and continuous performance optimization. Formal training handbooks and operation manuals shall be distributed to all parties. All employees should be required to complete a series of courses at the start of employment regarding the intelligent control system, tailored to their specific roles and/or tasks at the station. Employees most directly involved in operating the intelligent control systems should also be required to complete continuing education to maintain and upgrade their skills.

The intelligent control system and associated equipment that was originally commissioned during construction should be recommissioned annually or biannually to calibrate and optimize the equipment and its control system. Box 2 presents a case of a building in France using intelligent control systems.

Box 2: HIVE Tower Case (France)

The HIVE office is home to the headquarters of Schneider Electric in Paris, France, designed by the renowned designer Jean Michel Wilmotte. The main building consists of six layers, with a construction area of 35,000 square meters. It was put into use in January 2009, and currently accommodates 1,850 Schneider Electric employees with 100,000 visitors a year. Intelligent energy management was applied to the entire building process from planning and design phases, through construction, occupancy, operation, and maintenance. This has reduced energy consumption by three-quarters compared with similar buildings. This office has become an excellent representation of the green building standards and has been awarded the international certification of ISO50001 energy management systems, ISO14001 environment system certification, La Haute Qualite Environnementale (High Quality Environmental standard) green building certification, and Building Research Establishment Environmental Assessment Method green building certification.

Schneider Electric

Schneider Electric adopts EcoStruxure software in high-performance construction management where a uniform system is used to manage various elements of construction. Energy efficiency is achieved using the Struxureware building (construction) control software. Energy management systems can provide a complete power management solution for sustainable planning, energy operations, business operations, asset management, reliable power, and optimization and security systems. Technical and management personnel can control the energy costs, reduce outage time, and optimize equipment operation based on information provided by the software. Staff can monitor system operational conditions and analyze the power quality and supply reliability to improve response rates to system downtime and failure. The integrated building management system of the HIVE office is based on Schneider Electric’s EcoStruxure software and controls the following:

(i) Lighting systems

(ii) Window shutters

(iii) Access system

(iv) Closed-circuit television

(v) Heating, ventilation, and air-conditioning

(vi) Energy management system

Source: ADB Consultants based on information from Schneider Electric.

(iv) **International experience shows the importance of the whole commissioning process as quality control.** Commissioning is a systematic process of debugging and performance verification of building systems to fulfill both the design requirements and the needs of the owners. Actual performance can be verified by adding functional tests of system operation as a requirement in the design, construction, and acceptance phases (Figure 31).

The commissioning process includes the following:

Figure 31: The Commissioning Process

Predesign	• Review of owner's requirements and basis of design
Design	• Develop commissioning plan • Conduct design reviews • Incorporate commissioning requirements into construction bidding and contract documents
Construction	• Review of contractor submittals • Verify installation through prefunctional tests • Perform functional tests
Operation	• Develop system manual • Verify operation and maintenance training • Seasonal commissioning

Source: ADB consultants.

5.4.3 Public–Private Partnership

A public–private partnership (PPP) is a government service that is funded and operated through a partnership between the government and one or more private sector companies. PPP involves a contract between a public sector authority and a private party, in which the private party provides a public service or supports a project, assuming substantial financial, technical, and operational risk in the project. Therefore, PPP can provide an opportunity to improve service delivery, improve cost-effectiveness, increase investment, and make better use of assets in the PRC railway stations.

As railway stations evolve to serve a more diverse range of customer needs, there is increasingly a role for private developers and/or property managers to contribute to the design, construction, and operations of these facilities through PPPs.

In new railway stations, private developers have become adept at creating successful shopping malls and other large-scale, urban, mixed-use complexes by balancing the goals of accommodating customers' desire for comfort and amenities with the need for efficient operations. Furthermore, commercial buildings in the PRC have become a market for the “most advanced technologies in intelligent building management and control systems,” and the experience gained from commercial building control systems can be applied in new ways to stations.

Although the developers’ motivation is generally driven by generating revenue, energy savings are inherently a downstream benefit as malls and other commercial properties look to optimize the resources used to create a comfortable environment for customers. Although stations have different customer needs compared with malls, the premise of addressing customer needs is the same.

Furthermore, we are seeing an evolution of transit facilities around the world, particularly airports, as becoming not only excellent transit facilities but also successful hubs of retail, food and beverage, conferencing facilities, and other services. These new transportation hubs offer a glimpse of future trends that may influence the transportation hub station typology and suggest that mall developers’ understanding may become increasingly valuable to railway station operators.

For an existing railway station, it is recommended that a single, third-party facility manager is hired to manage the station, with a portion of the facility manager’s compensation determined based on the percentage of energy saved. Passenger comfort thresholds need to be defined so that the facility manager does not compromise the station environment.

At a symposium held at the China Railway Corporation in Beijing on 22 August 2014, Li Keqiang, the Premier of the PRC mentioned that, “China railway development cannot rely on government investment solely, railway investment and financing system reform is the key to attract social capital.”

Chapter 6 focuses on suggestions regarding management and policies, and proposes an action plan for the relevant agencies to be able to optimize and implement energy reduction policies for railway station buildings in the PRC.

6. Recommendations for Energy Efficiency and Action Plan

Improving the energy efficiency of railway station buildings is a systematic process and requires efforts regarding government policies, design, construction, operation, and maintenance. With participation from government officials to construction workers and even end users, the range of involved parties has to be wider than in the past. With a solid action plan and experience from international best practice, the management methodology, policies, and institutional responsibility need to be updated and modified to realize sustainable development. Furthermore, responsibility toward our environment needs to be remembered while balancing the interests of multiple parties with reasonable calculations and benefit analyses.

While previous chapters were concerned with technical matters and suggestions, Chapter 6 focuses on suggestions regarding management and policies and serves as a reference for decision makers.

6.1 Policy Recommendation

As the highest authority, the China Railway Corporation (CRC) is able to decide on policies for the entire railway system and can, therefore, lead and guide the modification of policies for the establishment of standards and databases for an evaluation and certification system, operation management, and operator training. Based on international best practice, an integrated design process should be the norm for managing the railway system.

1. **China Railway Corporation**

Engage in a comprehensive business model assessment to best align the implementation of sustainable strategies focused on environmental benefits with broader economic and social goals.

a. Strengthen government leadership and demonstration.

The CRC needs to play an exemplary role and take the lead in promoting key and important engineering projects to showcase the implementation of highly efficient systems and energy efficiency standards into railway stations. At the same time, the whole process—from material access, planning, and design to construction—needs to be strictly supervised and controlled.

b. Strengthen green building certification.

   The CRC needs to strengthen institutional system in terms of energy-related building certification. Railway authorities shall supplement and modify existing laws and regulations regarding current energy certification and accelerate the pace of work in establishing and improving building energy certification standards and promote implementation in new and old station buildings. As of today, a specific green building energy certification system for railway stations does not exist anywhere in the world. It is suggested that the CRC treat the Leadership in Energy and Environmental Design certification and the Green Building Label of the People's Republic of China (PRC), Green, as a platform to promote green building certification as a short-term target; that is, in 5 years as a middle term, a green railway certification system should be established in the PRC so as to promote and implement the certification in all stations.

c. Strengthen policy support for building energy certification.

   While the publication of the new green station standard is due, the CRC shall emphasize more on a supervision system and actively set up certification institutions, encourage the installation and usage of advanced energy-saving equipment and ban unqualified and highly energy-consuming products from the market, and encourage members from all sectors of the building industry to participate in the certification process which would in turn strengthen the relationship between certification institutions, material and equipment suppliers, developers, and end users.

d. Enhance technology and promote innovation capability for energy-saving technologies.

   The CRC needs to encourage research and development of energy-saving and emission-reducing technologies, and support research institutions, universities, and companies to develop products suitable for railway stations and accelerate industrialization. Also, the CRC needs to coordinate between vendors and system integrators to improve equipment compatibility.

e. Guide research and development for special equipment applicable to railway stations.

f. Strengthen cultivation of the energy service market.

g. Strengthen technical cooperation with local governments.

h. Introduce green certification.

i. Reform the investment and financing system by public–private partnership to develop new stations and to create a new prototype of railway development mode. Investment and financing system reform is key to attracting social capital. Public–private partnership can provide an opportunity to improve service delivery, improve cost-effectiveness, increase investment, and make better use of the assets in the railway stations in the PRC.

j. Ensure overall planning for land development and create a new prototype of railway development mode. Railway development should be planned to align with regional development to promote urbanization. Overall planning is not only to improve land utilization but also to support local economic, social, and environmental development. More advanced technology, such as neighborhood passive strategy and regional energy center, can be applied.

2. **Owner**

a. Strengthen the supervision management on energy saving and emission reduction.

b. Manage energy-saving technologies through appropriate research spending, ongoing research, and applied practices. Technology research should focus on the feasibility of energy conservation and economic benefits.

c. Identify energy-saving targets and incentives for design and construction.

d. Prioritize energy saving during operation and focus on recommissioning and continuous improvement.

e. Emphasize the metering scheme for energy monitoring and management.

f. Plan renovation demonstration projects based on energy efficiency with accompanying economic benefits.

3. **Design**

Sustainable design is a process stretching across all project phases and contains surveys and feasibility studies, reviews during the conceptual and detailed design stages, and inspection of construction and handover. As the national railway system is a collection of various projects, integrated and sustainable design is crucial for overall energy saving. This process also involves peer reviews for energy-related design features, performance-level ratings for various energy-consuming processes, and energy conservation measures.

a. Energy-saving features should be taken as key elements for railway station planning and design. To enhance the overall energy-saving level, technical standards, construction processes, and selection of equipment need to be improved.

b. Adopt passive design strategies to optimize building orientation and form according to local climate and site conditions.

c. Continue to carry out large-scale passenger station research on energy-saving technologies to reduce the amount of energy loss and improve energy efficiency.

d. A green building model to optimize the design and to balance comfort and energy saving.

e. Increase the quality of energy assessment report, design specification, and brief for energy-saving features; enhance energy efficiency analysis; and optimize energy-saving technology measures at various stages of the project design.

f. Establish energy audit, including energy consumption, process consumption, and equipment efficiency level, and provide energy-saving technical and management measurements.

g. Adopt whole-life cycle commissioning process to guide energy reduction from the design stage onward.

h. Increase the use of renewable energies in the design and improve the reliability and stability of operation of renewable energy systems to further promote carbon emission reduction.

i. Promote technology and knowledge exchange.

4. **Construction**

a. Enhance quality control on the contractor's submittals to ensure compatibility.

b. Standardize equipment selection.

c. Involve operation units in the procurement process.

d. Enhance the commissioning process executed by third-party consultants.

e. Enhance the acceptance process.

f. Introduce energy performance contracting as a financing vehicle for installing energy-saving systems.

g. Introduce an incentive mechanism for contractors regarding the effective installation and operations of intelligent control systems (typically paid 1 year after building completion, provided that a prescribed energy-saving threshold is met).

h. Consider project delivery methods such as design–build–operate–maintain or build–operate–transfer to improve the effectiveness of implementing green strategies with tangible, long-term energy savings.

5. **Operation**

a. Set energy-saving targets and enhance energy consumption monitoring.

b. Introduce incentive mechanism for energy saving.

c. Improve system training for operators.

d. Implement annual energy audits.

e. Execute recommissioning for existing stations every 3–5 years.

f. Obtain green building certification for existing buildings.

g. Adopt third-party facility or property management to manage the regional station. There is an evolution of transit facilities around the world toward becoming not only excellent transit facilities but also successful hubs of commercial services. Third-party management has experienced success in commercial buildings by balancing the goals of accommodating customers' desire for comfort and amenities with the need for efficient operations.

h. Engage the public in understanding and appreciating the energy savings of the station as a means of fostering broader awareness and stewardship of sustainable objectives.

6.2 Recommendation on Action Plan

Reaching the goal of energy efficient railway buildings needs concrete plans and timelines. This section details the factors and steps for implementing the recommendations for reducing energy consumption and emissions in railway stations.

6.2.1 The Factors Involved in the Implementation Plan

Items to be considered in the implementation are categorized from A to E. Category A is for management, category B for management of industrial technology, category C for energy-saving concepts and direction, category D for operation, and category E for investments (Table 24).

Table 24: Factors Involved in the Implementation Plan

Category A	(i) Clear lines of responsibility; clarify boundaries between the state-owned company and the local company. (ii) Strengthen the cooperation between all partners in the railway station development (local planning bureaus, LDI, local and foreign design consultants, suppliers, contractors, property developers and managers, and building operators). (iii) Build up an energy management structure for railway stations, which may include (a) Establishment of a database and evaluation system; (b) Introduction of the green station certification system; and (c) Establishment of a monitoring and supervision system. (iv) Introduce an incentive mechanism for railway station buildings.

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Table 24 *continued*

Category B	(i) Establish technical standards for energy conservation and retrofit projects with focus on large-scale buildings, environmental protection, and MEP and HVAC systems. (ii) Strengthen and unify the industry's management. Discuss different design and technical strategies for railway stations of different sizes and in different climate zones. (iii) Focus on compatibility between system components, starting from the beginning of the design. (iv) Strengthen inspection and discussion on the development and application of new energy-conserving technologies and strategies for newly constructed railway stations to minimize risks during the design, procurement, construction, and commissioning stage.
Category C	(i) Focus on intelligent controls for existing stations and equipment. (ii) Increase awareness of the importance of commissioning.
Category D	(i) Improve training mechanisms for system operation and maintenance.
Category E	(i) Investigate the possibility of private investments for energy-saving services. (ii) Investigate the possibility of public–private partnerships in commercial real estate in stations, structured for the purpose of improving building efficiency and reducing energy use in operations.

HVAC = heating, ventilation, and air-conditioning; LDI = local design institutes; MEP = mechanical, electrical, and plumbing.
Source: ADB consultants.

6.2.2 Main Aspects of the Implementation Plan

The overall implementation of the program will concern the CRC, the Passenger Rail Transportation Company, the railway bureau, and the railway station in aspects of policies, management, and technologies. The program will also differentiate between newly constructed and existing railway station buildings and the respective responsible entity which is either the old railway bureau or the CRC after the reform.

This study gives much advice on the construction and operation of railway station buildings, which, combined with research results and experience, shall serve as a guideline and help the project team to achieve a comfortable railway station environment, a high-level of safety, and improved energy efficiency.

The given recommendations are divided into five categories:

(i) Recommendation on organizational measures

(ii) Proposals for demonstration and/or showcase projects

(iii) Establishment of the proposed standard

(iv) Advice on process optimization

(v) Advice on operational optimization

6.2.3 Five-Year Action Plan (2014–2019)

Table 25: Action Plan

Category	Items	Description	Responsible Department	Implementation Period
Organization restructure	Organize intelligent railway working groups for energy efficiency and low-carbon emissions	Organize personnel in investment, transportation facility planning and design, construction, operational branches according to working group recommendations; coordinate and promote their findings; apply to areas such as (i) selection of demonstration projects, (ii) existing design standards, (iii) technical appraisal updates	CRC	Short term 2014
		Branch set up and organization restructure	CRC	Medium term 2016–2017
Demonstration project	Identify the demonstration site	Combined with CRC plan and research results to select the most appropriate site	CRC	Short term 2015
	Select an existing railway station for intelligent retrofit demonstration and carry out international green certification	Implement intelligent retrofit. The actual implementation of the project according to the research results and the agreed scope for demonstration purposes In the absence of a rail-specific green certification, adopt international standard of LEED EB OM (no CGBL equivalent for existing buildings) for international certification of existing buildings to achieve sustainable operation and management	CRC Consultants	Short term 2015
	Green certification to new buildings in new passenger stations	Adopt international green building standard LEED NC, and PRC Green Railway Station Label standards. Target to achieve LEED Silver and China Two Star	CRC Consultants	Short term 2015
	Promote management and technologies	Promotion campaign to other stations	CRC	Medium term 2016–2019

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Table 25 *continued*

Category	**Items**	**Description**	**Responsible Department**	**Implementation Period**
Standards establishment	Green certification implementation	Release Green Railway Station Standard and promotion	CRC	Short term 2015
	Intelligent railway passenger station standardization work	Create unified intelligent requirements, standards, and specifications for railway stations applicable to all stages of development	CRC	Medium term 2015–2016
	The establishment and assessment of national railway passenger station energy consumption baseline	Gradually establish a new national scale of railway station energy consumption baseline according to different climatic zones; use assessment methods to apply effective technical, economic analyses on energy-saving measures for specific climate zones, as reference best practice guidelines for designers and operations.	CRC	Medium term 2015–2017
	Establish energy metering and management standard, and set up local and central platform	Energy metering and monitoring system is the prerequisite for baseline database	CRC	Short, medium term 2015–2017
	Continuously updated energy consumption baseline	Update the corresponding content as more data become available from further railway passenger station projects	CRC	Long term 2018–2019
Process optimization	Improve processes of design, construction, and operations	Strengthen implementation of current design standards and construction codes	CRC	Short term 2015
	Demonstrate Intelligent railway passenger station through commissioning process	Draft testing and commissioning standards and protocols specific to passenger stations incorporating intelligent systems and chosen technologies. Introduce as best practice document and mandatory guidelines during project implementation. Approved deliverables to be regularly updated to capture benefits of advancement in technology	CRC	Short term 2015

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Table 25 *continued*

Category	Items	Description	Responsible Department	Implementation Period
	Strengthen cooperation mechanism with local government	Establish mechanisms for cooperation and to strengthen cooperation with local governments	CRC	Short term 2015–2016
	Improve processes of design, construction, and operations	Promote market intelligence hubs for product technology continuous feedback and update. Instigate peer reviews of designs by operations personnel. Introduce technical evaluation criteria for procurement activities moving away from capital cost-driven systems. Set up audit and governance process to ensure transparency and management overview. Ensure that construction and handover stages include verification of design and installation by operations personnel and responsibility to collect energy performance data after handover. Establish checklist and approval at various stages in projects' development process with energy efficiency and consumption data at their core	CRC	Medium, long term 2016–2019
	Performance indicators and the rewards or incentive schemes	Establish performance indicators to measure and benchmark parties integral to project development process from inception to operation. Set up rewards or incentive schemes for those who demonstrate improvements in energy efficiency and reductions in energy consumption without sacrificing passenger comfort measurable at various stage gates of project development. Operational phase data being the ultimate and the major benchmark in assessing effectiveness	CRC	Long term 2016–2019

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Table 25 *continued*

Category	Items	Description	Responsible Department	Implementation Period
Operational improvement	Railway station–specific operations manual and roll out of training regime	Establish operation manuals reflecting integrated solution by adopting preferred designs aligned with chosen technologies and best practice FM; roll out a program of FM training to appropriately qualified personnel with energy-saving goals and efficiency as the fundamentals	CRC	Short term 2015–2016
	Set up submetering system	Help to find problems and rectify	CRC	Short term 2015–2016
	Recommissioning all the existing railway station buildings	Activate the installed hardware with intelligent control system	CRC	Long term 2016–2019

CGBL = Chinese Green Building Label, CRC = China Railway Corporation, FM = facilities management, LEED= Leadership in Energy and Environmental Design, LEED EB OM = LEED for Existing Buildings: Operations and Maintenance, LEED NC = LEED for New Construction.

Source: ADB consultants.

Improving Energy Efficiency and Reducing Emissions through Intelligent Railway Station Buildings

Buildings in the People's Republic of China (PRC) consume 21% of the total energy produced in the country. This study analyzes and proposes feasible energy-saving and emission-reducing solutions for domestic railway stations in the PRC. The use of intelligent building controls support reduction of energy consumption, minimization or elimination of energy wastes, and cost savings. Strong institutional mechanisms and railway building management methods and policies also promote technological innovation. Moreover, these are necessary to balance the interests of multiple parties to be able to achieve energy efficiency in railway station buildings in the PRC.

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