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China's R&D for Energy Efficient Buildings: Insights for U.S. Cooperation with China

S Yu
M Evans

April 2010

Pacific Northwest
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Executive Summary

China started its national research and development (R&D) programs more than two decades ago and recently added energy efficiency and building energy research into its national programs. Currently, several R&D activities in China are planned by the national government and conducted by universities, research institutes, and national laboratories. Studying the R&D programs in China and comparing it to U.S. Department of Energy (DOE) priorities and efforts will help facilitate collaboration, and where such collaboration takes place, accelerate results in both countries.

This report includes an evaluation of China's current activities and future direction in building energy efficiency R&D and its relevance to DOE's R&D activities under the Building Technologies Program in the Office of Energy Efficiency and Renewable Energy. The researchers reviewed the major R&D programs in China including the so-called 973 Program, the 863 Program, and the Key Technology R&D Program[1] as well as the research activities of major research institutes. The report also reviewed several relevant documents of the Chinese government, websites (including the International Energy Agency and national and local governments in China), newsletters, and financial information listed in the program documents and websites.

The evaluation found that the R&D programs and activities in China paralleled those in the United States in most areas. Examples are residential integration, commercial integration, solar energy, analysis tools, and HVAC research. In other areas, such as building envelope and solid state lighting, the R&D programs in the two countries are based on the country's own circumstances but have some common areas of investigation.

Based on the results, there are many opportunities to cooperate with China on energy-efficient building technologies while taking into consideration cultural, economic, and other differences between the two countries. Capturing Chinese intellectual property is highly emphasized across all R&D programs; however, there are many areas of research that would be mutually beneficial. For example, research on technology integration, deployment, and program or policy issues seem to be of particular interest to both countries and typically have few intellectual property issues. Integrating energy efficiency policy into existing programs in China can significantly increase the impact of existing efforts to promote energy efficiency and allow DOE much more influence by linking to an existing network of people working in the field.

[1] The official translation in China is "the Key Technologies R&D Program." For the readiness of English, the report used "the Key Technology R&D Program" instead.

Acronyms and Abbreviations

BIPV	Building Integrated Photovoltaics
BTP	Building Technology Program
CABR	China Academy of Building Research
CAG	China Architecture Design & Research Group
CBMA	China Building Materials Academy
COP	Coefficient of Performance
DOE	U.S. Department of Energy
GaN	Gallium nitride
HVAC	Heating, Ventilation and Air Conditioning
LED	Light Emitting Diode
MOCVD	Metal Organic Chemical Vapor Deposition
MYPP	Multi-Year Project Plans
NDRC	National Development and Reform Commission
OLED	Organic Light Emitting Diode
PCM	Phase Change Material
SSL	Solid State Lighting

Contents

Figures

Tables

1.0 China's National Strategies in Building Technology R&D

1.1 Overview of Building Energy Consumption in China

By 2006, existing buildings in China covered 39.5 billion square meters (Building Energy Research Center, Tsinghua University 2009) of floor space and consumed 563 million metric tonnes of coal equivalent (tce), which accounted for 23.1% of total energy consumption in that year (Building Energy Research Center, Tsinghua University 2009). The building share is expected to exceed 30% by 2010 (Liang et al. 2007).

Table 1.1 and Figure 1.1. show building energy consumption by category and proportion in different types of buildings. Though rural areas have more floor space, energy consumption is comparatively low. In contrast, large-scale commercial buildings and heating systems consume more energy.

Table 1.1. Building Energy Consumption Categories in China (Cai et al. 2009)

Items		Building area (billion M^2.)	BEC (per year)	BEC (kWh/m^2)
Rural areas (exclusive of non-product energy consumption)		24	30 million tons of s.c/a (equal to 89 billion kWh) 90 billion kWh/a	7.5 kWh/m^2
Northern cities for heating		6.5	130 million tons of s.c/a (equal to 370 billion kWh)	57 kWh/m^2
Cities excluded heating	Residential	10	200 billion kWh	10–30 kWh/m^2
	Common public buildings	5.5	160 billion kWh	20–60 kWh/m^2
	Large-scale public buildings	0.5	100 billion kWh	70–300 kWh/m^2
	Subtotal	16	460 billion kWh	29 kWh/m^2
Total		40	160 million tons of s.c/a (equal to 550 billion kWh)	25 kWh/m^2 (equal to 9 kg of s.c/a)

Note: standard coal is converted into electricity according to power generation efficiency, 1 kWh = 350 g standard coal.

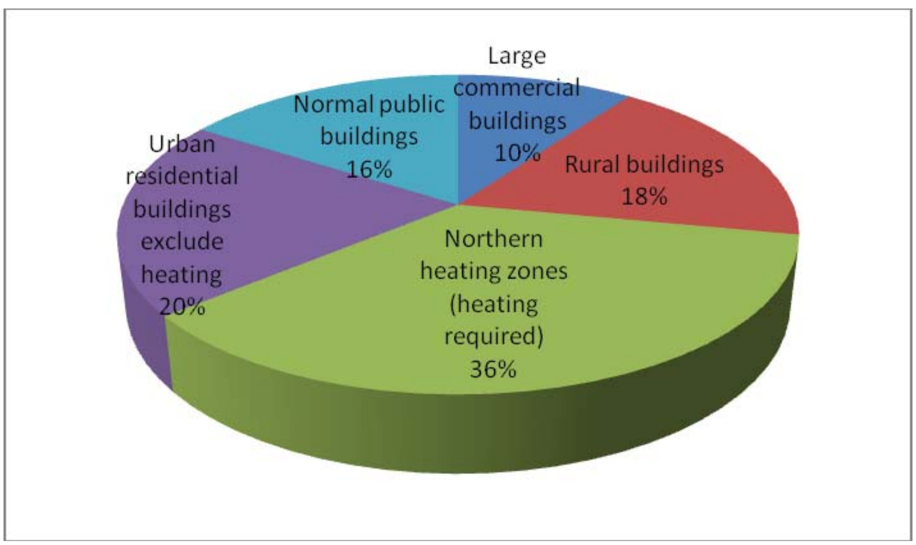

Figure 1.1. Building Energy Consumption of Different Building Types in China (Cai et al. 2009)

Chinese building energy consumption varies by building type and function, which can be summarized as follows (Building Energy Research Center, Tsinghua University 2009):

1. Differences in energy consumption across climate zones. Space heating is most heavily used in North China; if taking winter heating out of consideration, there is no great difference in energy consumption in buildings of the same category.
2. Differences in urban and rural residential buildings. The energy sources in urban and rural areas are different: coal, electricity, and natural gas are the primary energy sources used in urban areas, while biomass such as wood is widely used in rural areas. Also, household expenditures differ, and the use of home appliances contributes to the difference in energy consumption.
3. Differences in per-occupant energy consumption in commercial buildings. Except for heating consumption, the energy consumption in commercial buildings is not associated with climate zones but is positively correlated to the scale of buildings.

1.2 Short-Term and Long-Term Goals

In the *Medium and Long Term Energy Conservation Plan (2006-2020)* released by the National Development and Reform Commission (NDRC), energy conservation in residential and commercial buildings is one of three focus areas. The goal is to implement a building energy code that would result in building designs that use 50% less energy compared to benchmark buildings from the early 1980s. In megacities[2] such as Beijing and Tianjin, the standard should be raised to 65% during the 11th Five-Year Plan (2006-2010) (NDRC 2004).

Later, China set its goal for building energy efficiency in the *Notice of Ministry of Construction: Development of Energy Efficient Residential and Commercial Buildings*. The national target is that by 2020, the energy efficiency of construction and operation in residential and commercial buildings would reach that of moderately developed countries in the mid-2000s. Specifically, it is to reduce energy consumption in new buildings by 50% by 2010, and a 65% energy savings standard would be implemented in megacities, coastal areas, and North China new buildings by 2020 (Ministry of Construction 2005).

Based on this, the 11th Five-Year Plan set the following targets: by the end of 2010, decrease energy consumption in new buildings by 50%, lower space heating energy consumption in new buildings by 60%-65%, decrease power consumption in residential and small-and-medium commercial buildings by 40%, and decrease power consumption in large commercial buildings by 60% (Ministry of Science and Technology 2006).

1.3 History of China Technology R&D Program

China's national R&D efforts started more than two decades ago. Beginning in the 1980s, China formulated a series of programs for science and technology R&D. The Key Technology R&D Program, the 863 Program, and the 973 Program have formed the main body of national R&D plan while the Torch Program, the Technology Innovation Program, and the National Product Program have played an important role in building market mechanism and conducting commercialization.

[2] In China, a megacity is a city with a population of over 1 million.

Launched in 1983, the National Key Technology R&D Program was the first of such efforts. The program was created to research, develop, and commercialize key technologies for the nation and frequently bid together with demonstration projects to show and promote technologies. The program is closely associated with the nation's Five-Year Plan. Energy development and energy efficiency have been among the research priorities from the beginning of the program, since the 6^{th} Five-Year Plan.

In 1986, the 863 Program or National High-Tech R&D Program was founded. The program objective is to stimulate the development of advanced technologies in a wide range of fields, among which energy technology was added in 2001 (Osnons 2009). The general direction of research is decided by scientists after discussion, and specific projects are decided by a committee of experts. A distinctive feature of the program is that its results can quickly be used in industry (China.org.cn n.d.).

A complementary program, the 973 Program, was initiated in 1997 and implemented in 1998; it encourages fundamental/basic science research regarding cutting-edge sciences in multi-discipline areas such as biology, physics, energy, materials, etc. The program is to provide a theoretical basis and scientific foundation to solve problems.

Accompanying these research programs are also national programs that are market-oriented and target commercialization. Launched in August 1988, the Torch Program is China's most important program of high-tech industries. As a guiding program of China, it includes developing high-tech products, building industrial development zones, and exploring management and operation mechanisms. The program mainly includes projects in new technological fields such as new material, biotechnology, electronic information, integrative mechanical-electrical technology, and advanced energy-saving technology.

The Technology Innovation Program launched in 2005 and the National Product Program launched in 1998 reinforced the industry-led innovation efforts. Among all R&D and commercialization programs, energy and energy efficiency technologies and products are listed as research priorities.

1.4 National Programs of Building-Related R&D

In the 2007 White Paper *Energy Status and Policies in China*, China listed energy efficiency R&D as one of its priorities, among which building energy R&D was emphasized. The focus areas in building R&D include energy efficiency technologies and appliances, renewable energy and building integration, and building materials (State Council 2007).

Also, building energy conservation and green building is one of the focus areas in *China's National Mid/Long-term Science and Technology Development Plan (2006-2020)* (State Council 2006). In this area, China will focus on the development of green building design and technologies, building energy-saving technologies and appliances, renewable energy devices and building integration, exquisite architecture and green building technologies and appliances, energy-saving materials and green materials, high-efficient energy transfer and storage materials, and building energy codes.

The 11th Five-Year Plan underway lists the following R&D priorities (Ministry of Science and Technology 2006): building energy optimization design and integrated system; large commercial buildings energy-savings technology; renewable energy utilization, such solar energy; and a set of building energy-saving devices. There is a series of supporting programs on building R&D in the 11th Five-Year Plan[3]:

- Key technologies for building energy efficiency
- Environmentally friendly building materials and products
- Renewable energy and building integration
- New energy and energy-efficient technologies in rural areas
- Key technologies of residential buildings in towns and villages
- National project of solid state lighting.

In the coming 12th Five-Year Plan (2011-2015), there are a few focus areas related to energy efficiency building technology (Ministry of Science and Technology 2009):

Green building and building energy efficiency

- green building integrated technology
- energy-saving building technologies and devices
- application of renewable energy/resources
- building energy codes; green building evaluating and monitoring system
- energy-efficient retrofits of existing buildings and old city-town residential areas

Building materials and related technologies and devices

- energy-saving, humidity adjustment, self-cleaning and fire-proof building materials
- a set of technologies and devices for green buildings
- utilization and product development of construction waste
- steel-structure building technology

1.5 Main Building Energy Research Institutes in China

A variety of research institutes in China are working on building energy R&D. Below is a brief list of these institutions:[4]

- China Academy of Building Research (CABR)
- China Architecture Design & Research Group (CAG)
- China Building Materials Academy (CBMA)
- China National Engineering Research Center for Human Settlements

[3] The R&D programs mentioned here and all R&D activities in the following text are conducted during 2006-2010; the prototype and demonstration projects will continue for another two to three years. Some tasks and activities may be completed when this report is published. The R&D plans and activities for 2011and beyond are still underway.
[4] For detailed information on these institutes, please refer to Appendix A. Building-Related Research Institutes in China.

- Shanghai Research Institute of Building Science
- Tsinghua University
- Tongji University
- Shanghai Jiaotong University
- Harbin Institute of Technology
- University of Science and Technology of China
- Research and Development Center for Semiconductor Lighting, China Academy of Science
- Kingsung-Tsinghua Solid State Lighting (SSL) technology and application R&D center[5].

1.6 Funding

The national R&D programs are funded by the central government but the research institutes and industries responsible for the programs should be able to raise money to at least match the government funding. Generally, more funds are raised by the research institutes/industries than are invested by the central government. Meanwhile, many similar R&D activities and programs are supported and funded by local governments at the city or province level. In addition to these governmental R&D programs, industries and research institutes have many self-funded programs.

1.7 Commercialization

While commercialization programs for R&D are not so consistent or comprehensive in China, a few ways that commercialization typically occurs are:

- National/local demonstration projects associated with R&D programs
- A combination of research institutes and companies. Some research institutes were converted to research companies, other institutes started their own enterprise affiliated with research institutes/universities.
- Collaboration between research institutes and industry (joint-stock system).
- Technology transfer from research institutes to industries (by purchase).
- Business incubator and technology parks.
- National/local productivity center (government-owned).

[5] For other light emitting diode (LED) and organic light emitting diode (OLED) research institutes, please refer to Section 2.3 Solid State Lighting of this report.

2.0 Current Programs and Activities in Building R&D[6]

2.1 Residential Integration

2.1.1 Background

The amount of floor space in new residential buildings in China has increased rapidly in past decades. From 1990 to 2000, floor space per person increased from 9.9 m^2 to 19.8 m^2 in urban areas and from 17.8 m^2 to 24.8 m^2 in rural areas. It is predicted that in 2030, per capita floor space in urban areas will reach 30 m^2 and will reach 34.8 m^2 per capita in rural areas (Zhou et al. 2008). As opposed to other countries, in China the number of apartment houses slightly surpasses that of single-family homes (Figure 2.1).

Most energy consumption is from space heating and water heating, which account for 59% of residential energy consumption. Four major appliances–air conditioner, refrigerator, clothes washer, and TV–use about 21% of household energy followed by lighting (9%) and cooking (7%) (Figure 2.2).

Current residential building R&D in China is focused on building retrofits; heating, ventilation and air conditioning (HVAC) technologies across climate zones; and building integration.

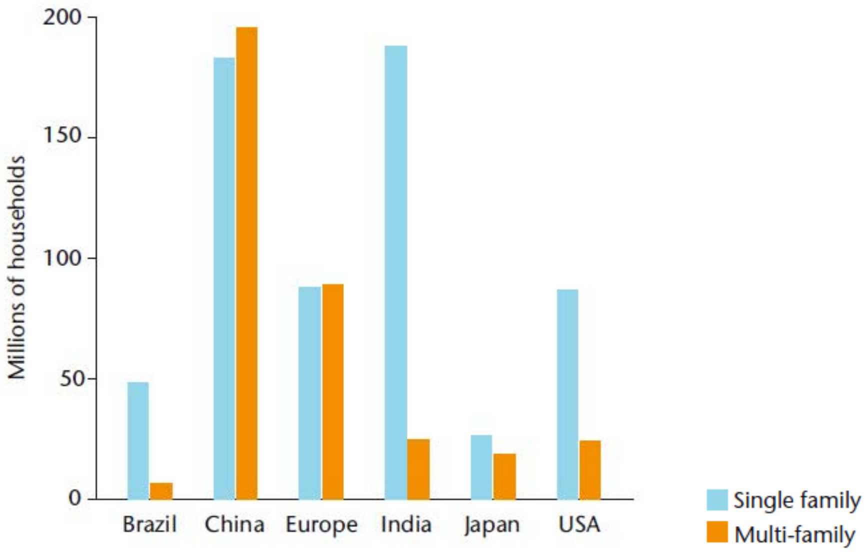

Figure 2.1. House Types in Different Countries (World Business Council for Sustainable Development 2009)

[6]The Chinese programs and activities are categorized and reorganized as DOE categorizes its Building Technology Program to more easily highlight possible area of synergy.

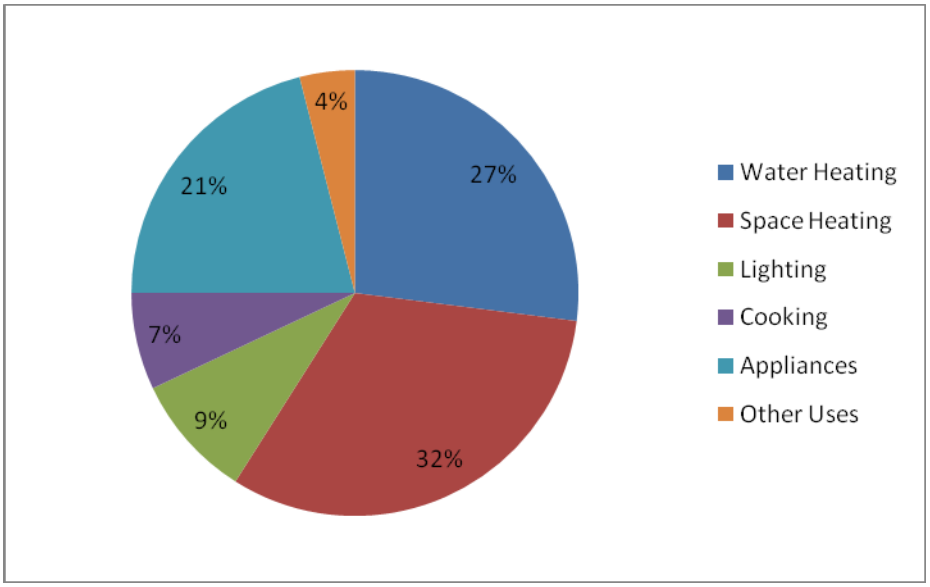

Figure 2.2. Residential Energy Consumption by End-Use (2000) (Zhou et al. 2008)

2.1.2 Energy Efficient Building Retrofits

Principal Investigator: Shanghai Research Institute of Building Science

Funding: Central government budgeted 10.5 million yuan ($1.5 million[7]) for the program, while the respective institutions would match at least 21 million yuan ($3 million).

Target:

1. Develop methods for energy consumption surveys, examination, and evaluation of existing residential buildings; develop methods for feasibility studies on residential building retrofits.
2. Develop wall, roof, and window products for cold and severe cold regions in North China and "hot summer/cold winter" regions in Middle China.
3. Develop products and methods to improve insulation of single-layer glass curtain wall.
4. Submit raw data on heating retrofits in one to two cities.

Tasks:

1. Conduct feasibility studies of retrofits in residential buildings with space heating.

   Develop methods to survey, examine, and evaluate energy consumption in these buildings; develop a comprehensive evaluation system to study the feasibility of retrofits; conduct energy consumption survey, examination, and evaluation using methods developed above and obtain raw data of one to two cities.

[7] Current value in US dollars, calculated with currency exchange rate USD:CNY=1:7. All subsequent amounts are calculated and listed the same way.

2. Building envelope: Develop prefabricated exterior wall with integrated components of heat-preservation and decoration and develop related construction technologies; develop at least two sets of easily implemented envelope products and technologies.
3. Roof: Develop a set of devices and technologies for sloped roof modification (flat-to-slope roof); in North China, further develop upside-down roof (reverse insulation and waterproof layers: insulation layer outside and waterproof layer inside) to improve heat preservation; in Middle and South China, further develop planted roof and water storage roof to improve heat insulation.
4. Exterior windows: Develop "whole-window" replacement technologies and installation techniques; develop technologies to add one window layer (to single-glazed windows); develop shading products for windows and related installation methods. The products and technologies should be applicable to various types of existing residential and commercial buildings.

Source: Ministry of Science and Technology 2007c.

2.1.3 Indoor Thermal and Humidity Control of Residential Buildings in Yangtze River Regions

Principal Investigator: College of Mechanical Engineering, Tongji University.

Funding: Central government budgeted 10.5 million yuan ($1.5 million) for the program, while the respective institutions would match at least 21 million yuan ($3 million).

Target:

1. Develop integrated control of heating, cooling, ventilation and dehumidification.
2. Propose new strategies for indoor thermal and humidity control in Yangtze River regions; integrate building envelope requirements of active environmental control with that of passive environmental control; integrate end-use devices of space cooling and space heating.
3. Finish 200,000 m^2 of demonstration projects in new buildings; buildings should consume power less than 24 kWh/m^2 for HVAC.

Tasks:

1. Identify strategies for thermal and humidity control in Yangtze River regions.

   Through investigation, examination, and simulation analysis, propose principles and strategies for environmental control of residential buildings in this area. This will include natural ventilation, shading, indoor temperature adjustment according to thermal and moisture features of the building, features of different parts of the envelope, and optimal analysis. Propose building envelope for both active and passive environmental control; identify the time period and criteria for active heating, cooling, and dehumidification.

2. Develop integrated end-use devices for thermal and humidity adjustment.

   Develop radiant natural ventilating devices that can also dehumidify (to replace heat radiating devices in winter and wind coil in summer); be able to adjust heat and cold, thermal, and humidity at the same time; use $30^{o}C$ water for heating and $15^{o}C$ water for cooling; and achieve independent control of thermal and humidity.

3. Develop small dehumidification devices for household use.

   Develop small dehumidification devices driven by power and exhaust heat; dehumidify capacity: 1-3kg/h. When the device is electric-driven, Coefficient of Performance (COP) should be greater than 4.

4. Develop household-level environmental control facilities.

   Develop household control air-source heat pump using 35°C water for heating and 15°C water for cooling, and dehumidifying at the same time generating no less than 9g/kg dry air/air. Develop the integration of heating, cooling, dehumidification, and ventilation; COP for both winter and summer is greater than 4.

Source: Ministry of Science and Technology 2007c.

2.1.4 Residential Buildings in Towns and Villages (Similar to Single-family Homes)

Principal Investigator: China Architecture Design & Research Group (CAG)

Funding: Central government budgeted 10.3 million yuan ($1.47 million) for the program, while the respective institutions would match at least 15.45 million yuan ($2.21 million).

Target: Improve energy efficiency by 50%; use renewable energy by 10-20%; the heat efficiency of gas stoves should be greater than 57%, CO emission should be lower than 500 ppm.

Tasks:

1. Low-cost technologies.

   Study low-cost energy-saving technologies including passive solar energy use, heating and natural ventilation, biomass heating, etc. Develop building integration technologies and prototype.

2. Building materials.

   Develop new energy-saving masonry blocks including related products, construction system and construction techniques; develop new energy-saving, lightweight, and high-performance walls and roofs.

3. Building envelope.

   Study key technologies in building envelope including envelope structure using local resources, thermal insulating walls, etc. Develop low-cost heat-storage materials; develop thermal insulating roof system and materials including roof system for different climate zones and foamed concrete insulating roof.

4. Renewable energy and thermal environment.

   Develop solar heating system, solar energy storage and utilization, and solar energy integrated building technologies. Develop wind energy storage and utilization technologies and small wind utilization appliances. Develop high-efficiency, low-cost small water-source heat pump and surface geothermal/ground-source heat pump. Develop analysis tools for solar energy integrated design, energy consumption, and thermal environment analysis.

5. Design.

   Develop energy-saving design standard including shapes, structure and layout, insulation characteristics of the envelope, etc.

Source: Ministry of Science and Technology 2007e.

2.2 Commercial Integration

2.2.1 Background

Until 2008, floor space of commercial buildings in China was 5.3 billion m^2, accounting for 36% of the total (Building Energy Research Center, Tsinghua University 2009). Large commercial buildings are the biggest challenge for China in achieving commercial building energy efficiency. Large commercial buildings are defined as those with more than 20,000 m^2 gross floor area (Cai et al. 2009). According to a survey by Jiang and Yang (2006), building energy consumption of large commercial buildings in China reached 100 billion kWh per year, accounting for more than 20% of the total national building energy consumption by 2004, while the total area of these buildings was about 500 million m^2, which constituted less than 4% of the national urban building area (Jiang and Yang 2006).

2.2.2 Space Conditioning System for Large Commercial Buildings

Principal Investigator(s): CAG, Hefei General Machinery Research Institute

Funding: The total budget of the project is 32.4 million yuan ($4.63 million), while 8.4 million yuan ($1.2 million) is from central government.

Target:

1. Propose new energy-saving space conditioning system including design methods and standard; develop new cooling water recycle system to lower power consumption of the water pump by more than 40%.
2. Develop liquid desiccant air-conditioning system, heat driven COP of more than 1, COP of electric driven > 5; develop and commercialize thermal/humidity-independent control end-use devices; lower HVAC energy consumption by more than 40% in Northeast, North, South, and Southwest China.

Tasks:

1. Energy Optimization.

   Analyze optimal parameters of different air-conditioning systems regarding cold/heat source, energy system, energy consumptions of cooling water and cooling tower, adjustability of system, and changing system efficiency on loads; propose parameters and designs of air-conditioning systems in different types of buildings.

2. Parameter, control, and design of temperature-humidity independent control system.

   Compare to the current central air-conditioning system and lower the energy consumption by 50%.

3. Energy saving in the air-conditioning water system.

   Study new cooling water circulating system; develop key technologies to improve the efficiency of water pump; lower power consumption of water pump of the cooling water circulating system by 60%.

4. Liquid desiccant air-conditioning system.

   Develop hot water-driven and electric heat pump-driven liquid desiccant air-conditioning system; develop functions such as heat recovery from exhaust air and air dehumidification and humidification. Energy efficiency ratio of heat driven set is not less than 1 and that of power driven set is not less than 5.5.

5. 16-18^{o}C cold source dry heat-sensible end-use devices.

   Develop different types of radiant terminals; develop dry fan-coil.

6. Cooling water facilities with out-flowing water temperature 16-18^{o}C.

   When cooling water temperature is 30^{o}C, COP of products with 1-4 MW capacity is greater than 7, and COP of products with 100 kW-1 MW capacity is greater than 6.5.

Source: Ministry of Science and Technology 2007c.

2.2.3 Energy Management and Energy-Saving Diagnostic Techniques for Large Commercial Buildings

Principal Investigator: Yi Jiang, Tsinghua University.

Funding: Central government budgeted 7.5 million yuan ($1.07 million) for the program, while the respective institutions would match at least 15 million yuan ($2.14 million).

Target:

1. Develop energy-saving control algorithm and logic; test in six different types of large commercial buildings and save energy by 30%.
2. Complete design methods and standards of energy-saving control system; develop auxiliary design tools and standard control algorithm.
3. Build a long-distance online energy consumption calculation and analysis management system in more than ten public buildings; the system includes energy-saving statistic database, analysis tools, user interface, and diagnostic tools.
4. Complete decision making tools including indicators and parameters, save energy by 30%. Publish diagnostic techniques and case studies.

Current Activities:

1. Space conditioning system energy-saving control.

   Include cold/heat source and water system control and space conditioning and wind-coil terminal control. Develop energy-saving control algorithm and logic and apply in six different types of large commercial buildings. Achieve energy-saving automated control and adjustment, and save energy by more than 30% compared to the current manual control.

2. Design, analysis, implementation, and standards of systematic controls for mechanical and electrical appliances.

   Develop auxiliary analysis tools for mechanical and electrical system energy-saving control design. Based on functions and composition of the mechanical and electrical system, automatically formulate self-control system sensor, implementation devices requirements, and necessary control algorithm.

3. Energy consumption management system

   Monitor, analyze, count, and manage a variety of energy consumption systems; conduct real-time energy consumption analysis and diagnosis. Achieve long-distance online energy management and consumption analysis of multiple commercial buildings in cities/regions. Apply the system in at least ten buildings in at least one region. Based on field performance, establish energy consumption submetering calculation and long-distance online real-time analysis management standards.

4. Decision making tools (diagnostic tools).

   Propose energy-saving, decision making standardized methods and steps; analysis indicators and parameters. Define indicators and parameters for different regions and building types. Apply diagnostic tools in more than 30 commercial buildings across a variety of regions and building types and in general situations, save energy of more than 20% through improving operation management and changing key appliances. Publish commercial building energy-saving diagnoses methods (decision making tools), steps, index, and case studies.

Source: Ministry of Science and Technology 2007c.

2.2.4 Energy-Saving Building Retrofits

1. Large-scale glass window curtain wall.

   Develop a solution for low heat-efficient, single-layer glass curtain walls, which were widely used in old commercial buildings, and also study a solution for the safety concerns of hidden framing glass curtain walls in these buildings; develop the membrane products and attachment technologies; develop inner/outer shading products and technologies to improve insulation.

Source: Ministry of Science and Technology 2007c.

2.3 Solid State Lighting

2.3.1 Background

The China National SSL Program began in June 2004, when the Ministry of Science and Technology pulled together the activities of a number of different regional development groups. To address the R&D needs for SSL, China has budgeted 350 million Yuan ($50 million) during the 11th Five Year Plan. More than 15 research institutions and university research laboratories will participate, as will more than 2500 companies involved in producing light emitting diode (LED) wafers, chips, packaging, and applications. Protection of intellectual property is a significant concern and a major element of the SSL program. Chinese companies are encouraged to file patents and to look for areas of SSL that have not yet been addressed by foreign companies, primarily in the "downstream" areas of packaging and applications (Steele 2006).

Based on the SSL program and relevant projects, China developed its capacity in R&D and is gradually building a complete production chain. It has an advantage in the lower-end integrated application. In 2008, the total value of production in the SSL industry was 70 billion yuan including 1.9 billion from chip production, 18.5 billion from packaging, and 45 billion from application products (NDRC et al. 2009).

2.3.2 Current Projects

Aligning with the China National SSL Program, China initiated a series of projects in SSL R&D and commercialization:

- Green Lighting Project
- 10,000 lights in ten cities
- Ten key energy-saving projects
- Demonstration projects of high-tech industries
- Industrial technology improvement and structure adjustment
- Advanced Technology Development Plan (the 863 Program): New Materials

Since 2005, seven industrial bases were built for technology transformation and commercialization (Table 2.1).

- 2005: Dalian, Xiamen, Shanghai, Nanchang, Shenzhen
- 2007: Shijiazhuang
- 2008: Yangzhou

Table 2.1 SSL Industrial Bases in China

Location	Upper-end Industries	Strength
Dalian	Dalian Luminglight	International technical team; high-performance products
Xiamen	San'an Optoelectronics	Complete production chain; large-scale middle and upper reach industries
Shanghai	Epilight Technology; Rainbow Optoelectronics	Technology and business workforce; good market environment; upmarket applications
Nanchang	Jingneng Optoelectronics	LED chips for general illumination
Shenzhen	Century Epitech	Large market for application; industries concentrated; good market environment
Shijiazhuang	Huineng Electronics	R&D and commercialization
Yangzhou	Xiahua optoelectronics	Complete production chain

2.3.3 Recent Progress (Through the End of 2008)

The following activities reflect recent progress in Solid State Lighting (SSL) activities.

- **Materials and Devices:** 280-nm UV LED device operating at 20mA; Gallium nitride (GaN) epitaxial layer growth –decreased X ray diffraction's full width at half maximums from 780 arcsecond to 559 arcsecond; large-scale nano and membrane photon lattice LED, 20-mA room-temperature continuous driven small chip output power improved from 4.3 mW to 8mW; completed phosphorescence multi-layers white-light OLEDs luminous efficacy has reached 45 lm/W; developed six-chip and seven-chip metal organic chemical vapor deposition (MOCVD) demonstration machines, which are under technical validation.

- **Key commercialized technologies:** Domestic-made chips account for around 50% of market share and are increasingly replacing imported chips. Power-type white-light LED packaging technology is close to the level of top international performers, And China has become an international LED packaging base. With graphic substrate technology and improved epitaxial layer structure, the power-type chip has reached 75 lm/W after packaging in an industrialized assembly. A power-type silicon-substrate LED chip reached 60 lm/W after packaging.
- **130 lm/W white-light SSL in industrial use:** Graphic substrate and epitaxy technology innovated by the R&D Center for Semiconductor Lighting, Chinese Academy of Sciences has been applied in industrial production.

Source: China Illuminating Engineering Society 2009.

2.3.4 Short/Mid-term Goals (2010 and 2015)

Below lists briefly the goals of LED industry in 2010 and 2015.

- In 2010, LED luminous efficacy will reach 100 lm/W in industry, and white-light luminous efficacy will reach 130lm/W in the laboratory.
- By 2015, LEDs will reach 150 lm/W and achieve a 40% share of China's incandescent lighting market. Such savings would be 100 billion degrees of electricity per year, more than the output of the massive Three Gorges hydroelectric project.

Source: China Illuminating Engineering Society 2009.

2.3.5 Future Direction in R&D

- **Technology and appliance**. Support R&D for key facilities and materials including MOCVD facilities, new substrate, and ultra-pure metal organic sources. Conduct fundamental R&D on GaN materials and OLED materials and devices. Support basic theoretical research for semiconductor lighting applications including photometry, colorimetry, and metrology. Tackle key technologies in market transformation including high-power chips and devices, driver circuits and standardized modules, system integration and application technologies, etc.
- **Products.** Develop and promote high-efficiency, cost-effective SSL products to replace incandescent lights and halogen tungsten lights. Develop and promote high-performance, long-lifetime SSL products to use in parking lots, tunnels, and roads. Develop products with huge market potential such as large-scale LCD backlight source and vehicle lighting.
- **Services.** Improve the SSL product examination system. Build public information services, cross-discipline designs, and an education system. Encourage energy-saving diagnosis, consulting, product promotion, and training services. Promote new energy-efficiency service mechanisms such as an energy management company and demand side management.

- Focus on high-efficiency, long-lifetime SSL products; further develop the high-power white-light LED luminescent technology; enhance heat radiation of high-power LED light source and lower the luminous decay.
- **OLED.** Lower production costs, increase lifespan, and develop a larger screen. Intensify the research cooperation between academia and industry to establish a complete production chain in OLED industries. Accelerate the market transformation from research to industry.

Source: NDRC et al. 2009.

2.4 Heating, Ventilation and Air Conditioning (HVAC) and Water Heating

It has been estimated that HVAC accounted for some 65% of the energy consumption in the building sector (Yao et al. 2005).

2.4.1 Air-Source Heat Pump

Principal Investigator: Beijing General Human-Environment Technology Corporate

Funding: Central government budgeted 7.5 million yuan ($1.07 million) for the program, while the respective institutions would match at least 22.5 million yuan ($3.21 million).

Target:

1. Develop a air heat pump with a capacity of 5-300 kW. When heating at 15^{o}C outdoor temperature and 35^{o} C ventilating air, the COP of a 5-kW heat pump is not less than 2.75, and at 15^{o} C outdoor temperature and 40^{o} C ventilating air, the COP of a 300-kW heat pump is not less than 2.48. When cooling, the performance should be greater than the Class III energy-efficiency products.
2. Commercialize the products.

Tasks:

1. Decrease frosting in air-to-air heat-exchangers.

   Change the configuration and material of heat-exchangers; apply new surface materials to reduce frosting and decrease frost's impact on the heat-exchangers.
2. Intelligent and high-performance defrost technologies and defrost control.

   These technologies include the detection of frost status, defrost technologies, and high-performance defrost procedures.
3. Enhance energy efficiency for systems that have a huge temperature gap between cold and heat terminals.

   Develop heat pumps with high-performance in temperature ranges of -10-10^{o}C and 30-40^{o}C.

Source: Ministry of Science and Technology 2007c.

2.4.2 Water and Ground Source Heat Pump

Principal Investigator: CABR

Funding: Central government budgeted 9.5 million yuan ($1.36 million) for the program, while the respective institutions would match at least 28.5 million yuan ($4.07 million).

Target:

1. Develop application criteria and technology guidance for a groundwater and soil heat pump.
2. Develop a soil heat pump engineering analysis package and optimal design methods of water and geothermal heat pump.
3. Develop a high-efficiency water source and ground source heat pump. For water-wind heat pump, when cooling capacity of less than 100 kW, heating COP reaches 3.9 (groundwater) or COP reaches 3.4 (ground loop design), and cooling COP reaches 5.0 (groundwater) or 4.9 (ground loop design). For water-water heat pump, when cooling capacity is more than or equal to 150kW, heating COP reaches 4.6 (groundwater) or 4.0 (ground loop design), and cooling COP reaches 5.9 (groundwater) or 5.7 (ground loop design).

Tasks:

1. Adaptability of water and geothermal heat pumps.
2. Application of soil-source heat pumps.
3. Groundwater and surface water heat pumps.

   Study the optimal energy design of ground/surface water heat pump systems; study the heat transfer model of closed-surface water heat exchangers; develop engineering analysis software for closed-surface water heat pumps; develop ground/surface water heat pump demonstration projects.
4. Wastewater and sea water heat pumps.
5. High-performance water-source heat pump generators.

   Develop high-performance water source heat pumps including a 100-kW/lower water-wind heat pumps and 150-kW/higher water-water heat pumps.
6. Systematic plan for the use of water and geothermal heat pumps.

   Develop a database for designing water and geothermal heat pumps including groundwater, soil, wastewater, seawater and surface water; propose a systematic plan for the use of water and geothermal heat pumps.

Source: Ministry of Science and Technology 2007c.

2.4.3 Space Heating

Principal Investigator: Harbin Institute of Technology

Funding: Central government budgeted 12 million yuan ($1.71 million) for the program, while the respective institutions would match at least 24 million yuan ($3.43 million).

Target:

In a residential community of not less than 300,000 m^2, test approaches to make space heating energy consumption lower than 7 m^3 natural gas/m^2 or 10 kg coal equivalent/m^2. Heat consumption is lower than 0.3GJ/m^2.

Tasks:

1. Household heat calculation and control.

   Develop products that can calculate, control, and adjust heat supply in each household; widely apply these products in residential buildings with a heating system.

2. Low-temperature heat supply end-use devices.

   Develop new heat supply end-use devices; i.e., floor radiant heating, fan-coil heating, or high-performance radiator. The goal is to install end-use devices to 4W/^{o}C per construction unit and the size of new device should not be larger than the current radiator; the cost will be 50-70 yuan per m^2.

3. Adjustable temperatures for independent buildings.

Source: Ministry of Science and Technology 2007c.

2.4.4 High-Efficiency Application of Low-Grade Energy

Principal Investigator: Hefei General Refrigerating Equipment Company

Funding: Central government budgeted 6.5 million yuan ($0.93 million) for the program, while the respective institutions will match at least 13 million yuan ($1.86 million).

Target:

1. Develop air-source heat pump for water heating in households with heating COP greater than 4 and capacity from 80 to 200 L.
2. Develop indirect evaporative air conditioning system and lower the power consumption by 30%.

Tasks:

1. CO_2 air-source heat pump water heating set.

   Develop hot water preparation devices for household use and combine them with an air conditioning system. Develop products with capacity of 80-200 L and extract heat from indoor/outdoor air to prepare hot water of 50-60^{o}C; COP of heat preparation is not less than 4.

2. Low-turbidity wastewater heat recovery and hot water preparation for residential buildings.

   Develop a drainage system classifying water quality and develop low-turbidity wastewater heat recovery facilities; develop a water-water heat pump hot water machine by using low-turbidity wastewater; COP of exhaust heat recycle is not less than 6.

3. Indirect evaporative cooling.

   Develop indirect evaporative cooling set for dry areas in Northwest China; use dry air of dew point temperature 13^o C to generate cold air of wet-bulb temperature less than 17^o C and to generate cold water less than 17^o C; COP more than10.

4. Direct/indirect evaporative air conditioning system.

   Study features of an air conditioning system that is suitable for using evaporative cooling technology and develop the temperature/humidity control system.

Source: Ministry of Science and Technology 2007c.

2.4.5 Indoor Thermal and Humidity Loads Adjustment System for New Buildings

Principal Investigators: Tsinghua University

Funding: Central government budgeted 2 million yuan ($0.29 million) for the program, while the respective institutions will match at least 2 million yuan ($0.29 million).

Tasks:

To lower the indoor thermal and humidity loads, develop new indoor thermal and humidity environment adjustment products integrated with indoor materials and components. Develop materials and components with energy-storage and humidity-adjustment capacities, phase change heating/cooling terminal devices with energy-storage and humidity-adjustment capacities, novel energy-storage and humidity-adjustment technologies, and optimization and technical-and-economic analysis of thermal/humidity adjustment.

The materials and components should be environmentally friendly and meet both the requirements of the thermal/humidity environment and that of lifespan, structure, fireproofing, and hygiene. The phase change temperature of phase change materials should reach the indoor temperature design, improve thermal-storage capacity by more than 50% compared to concrete, and cost less than 150 yuan/m^2 in new buildings. When indoor temperature and humidity is 30-70%, humidity adjustment materials are more than 450kg/m^3 with a cost of less than 45yuan/kg.

Source: Ministry of Science and Technology 2007c.

2.5 Building Envelopes and Windows

2.5.1 Envelopes and Windows in New Buildings

Principal Investigator: CABR

Funding: Central government budgeted 11.5 million yuan ($1.64 million) for the program, while the respective institutions would match at least 23 million yuan ($3.29 million).

Target:

1. Develop energy-saving walls, roofs, and floors fitting different climate zones; develop related heat engineering calculation and evaluation software.
2. Complete insulation design toolkit across climate zones.
3. Develop an adjustable transparent building envelope and shading devices and commercialize the products.
4. Develop room ventilation devices and commercialize.
5. Finish eight prototypes.

Tasks:

1. Opaque building envelope in cold and severe cold regions.

   Improve the use of external insulating composite wall and roof with different heat-preserving materials and structures. Develop new sandwich heat-preserving walls; study the prefabricated heat-preserving walls. Establish systematic theories and tools for the building envelope design in cold and severe cold regions, and develop relevant analysis tools. Make a manual/toolkit for building envelope heat-preservation design.

2. Opaque building envelope in “hot summer/cold winter” and “hot summer/warm winter” regions.

   Develop a composite wall and roof for heat preservation and insulation; develop a wall material that will reach the requirement of heat preservation and insulation; study various internal wall heat preservation and insulation technologies; formulate systematic theories and tools for the building envelope design in “hot summer/cold winter” and “hot summer/warm winter” regions and develop relevant analysis tools; make a manual/toolkit for building envelope heat insulation design.

3. Transparent building envelope energy-saving technologies and products.

   Develop a high-performance glass curtain wall with a low heat-transmission coefficient, low-temperature radiation and solar radiation; study high-R frames of windows and curtain walls; develop exterior shading products and technologies for windows and transparent curtain walls across climate zones; develop new types of double-skin exterior windows and glass curtain walls; develop light-through and shading devices that will change physical properties as exterior climate changes; develop software tools to calculate shading in buildings and calculate and evaluate heat efficiency of the double-skin ventilating window curtain wall.

4. New ventilating facilities.

   Develop ventilating facilities for the exterior wall, roof, and exterior window; the new ventilating facilities should also include features such as sound insulation, air filtration, and recycling heating from exhaust air.

Source: Ministry of Science and Technology 2007c.

2.5.2 Heat Reflective Wall Coatings

Principal investigator: CBMA

Target:

Reflectivity in infrared area greater than/equal to 85%, hemispherical emissivity greater than/equal to 85%; change amplitude of emissivity-reversible materials greater than 0.6; insulation coatings should help to raise temperature in winter by 8-10^{o} C and lower temperature in summer by 5-8^{o} C.

Tasks:

Screen and optimize fluorine-modified silicone-acrylate emulsions, develop phase change materials whose emissivity will change with temperature, study the compatibility of coatings and features of reflective insulation, test emissivity and its change with temperatures, and develop heat reflective insulation coatings.

Source: Ministry of Science and Technology 2007d.

2.5.3 Windows in Typical Regions

Principal investigator: CABR

Funding: Central government budgeted 4.2 million yuan ($0.6 million) for the program, while the respective institutions would match at least 8.4 million yuan ($1.2 million).

Target:

1. In “hot summer/warm winter” regions, shading coefficient of less than 0.2, K less than/equal to 2.5w/(m^2*k); in “hot summer/cold winter” regions K less than/equal to 2.0w/(m^2*k); in “cold and severe cold” regions K less than/equal to 1.8w/(m^2*k)
2. Establish standards of materials and products and develop methods of examination and evaluation for windows across three different climate zones mentioned above.

Tasks:

1. Windows for “hot summer/cold winter” regions.

   Study shading technologies including exterior shading, interior shading, and middle shading and physical properties such as waterproofing and wind-pressure resistance; increase durability of exterior windows; develop the standard and code for exterior windows and test technologies; complete an application system of windows including materials, design, fabrication, installation, and acceptance.

2. Windows for “hot summer/warm winter” regions.

   Study shading and insulation technologies; insulation technologies include the selection of structural, face, and airtight materials, and shading technologies include exterior shading, interior shading, middle shading and adjustable shading, and physical properties such as airproofing, waterproofing, and wind-pressure resistance. Increase durability of exterior windows. Develop the standard and code for exterior windows and test technologies; complete an application system of windows including materials, design, fabrication, installation, and acceptance.

3. Windows for “cold and severe cold” regions.

   Study insulation technologies including the selection of structural, face, and airtight materials; study the impact of airproofing on windows’ energy savings and function and energy efficiency requirements of the structure where installed, and technologies and physical properties (airproofing, waterproofing, and wind-pressure resistance, etc.); improve durability of exterior windows; develop the standard and code for exterior windows and test technologies; complete an application system of windows including materials, design, fabrication, installation, and acceptance.

Source: Ministry of Science and Technology 2007d.

2.6 Analysis Tools

Target Markets: Architects, engineers, energy consultants, researchers, and planners

Current tools developed: Designer Simulation Toolkit **(**DeST) by Tsinghua University; PKPM based on DOE-2 by the Institute of Building Engineering Software.

Principal Investigators: Tsinghua University

Funding: Central government budgeted 9 million yuan ($1.29 million) for the program, while the respective institutions would match at least $18 million yuan ($2.57 million).

Target:

1. Develop a range of simulation tools to conduct tasks such as analyzing the microclimate of building groups, the thermal environment and energy consumption of individual buildings, natural ventilation, daylighting simulation analysis, HVAC and heat/cold source, and city energy planning. This also involves study the interoperability of these tools.
2. Propose optimal design of building groups, individual buildings, and HVAC and heat/cold source; establish evaluation system of optimal design and build evaluation standards; apply the system in eight to ten architecture design and research institutes (capacity building and workforce).

Tasks

1. Simulation analysis of a group of buildings for energy optimization design.

   Develop software to simulate the microclimate of a group of buildings; the simulation analysis is for design and planning use.

   Target planners, architects, and consulting engineers, develop simulation analysis tools on regional heat islands and the microclimate of a group of buildings; the tools should be able to make hour-by-hour predictions of microclimate distribution and its impact on building energy consumption on a particular day and for different ground surfaces, different landscaping, and different shapes and arrangement of buildings. (The microclimate includes air temperature, humidity, wind speed, solar radiation, temperature of the building envelope and ground surface, average radiant temperature, heat island strength, and thermal comfort, etc.)

   Standardize the use of microclimate simulation analysis based on different purposes and different stages in design and planning including defining parameters, selecting a turbulence model, generating mesh generation, simulating area control, etc.
2. Simulation analysis of energy saving for individual buildings and optimization of thermal environment.

Target architects and engineers, develop a software package to simulate the thermal environment and energy consumption in different design stages; enable direct and fast multi-directional data flow/exchange between computer-aided design (CAD) and the simulation software.

The analysis package should be able to:

1. Simulate annual heating and air-conditioning loads and simulate energy consumption of lighting, HVAC, and cold/heat-source systems for individual buildings.
2. Analyze solar gain and daylighting and simulate the impact of different daylighting control plans on energy consumption for individual buildings.
3. Simulate the impact of various transparent interior/exterior envelopes to building energy consumption and thermal environment.
4. Simulate the impact of passive energy-saving designs (such as tunnel wind ventilation, passive solar-energy house, natural/heat-pressure ventilation) on energy consumption and thermal environment.
5. Simulate auxiliary energy-saving designs for special spaces (such as tall halls, stadiums, airports, museums, exhibition rooms, etc.).

All modules mentioned above could be used alone or integrated with other thermal simulation tools.

3. Simulation of HVAC and energy-supply system.

   Target HVAC engineers develop a dynamic modeling package to simulate HVAC and energy-supply systems that will fit the requirements of different design stages (air management, device selection, heat/cold source, network design, self-control system, etc.). Develop simulation analysis of urban energy planning including simulation of new heating network and combined heat/power/cold supply systems, etc.

4. Integration of different simulation software packages (interoperability).

   Establish a standard platform to integrate existing tools, database, input/output, and simulation tools mentioned above; enable multi-directional data exchange, integrated use and display.

   Study database standardization, data exchange, and data display.

5. Evaluation system for energy saving and optimization.

   Target architects and engineers, conduct simulation analysis of energy consumption of different building designs in different climate zones; the analysis should also include impacts to energy consumption of the following aspects: building features (shape coefficient, orientation/exposure, window-wall ratio, etc.), envelope selection (door, window, wall, roof, floor, shading/reflection, etc.), cold/heat source system and efficiency, HVAC efficiency, inner disturbance heat source, ventilating, and operation scheme.

   Study the feasibility and effect of using renewable energy (such as tunnel wind, natural ventilation, passive solar energy, natural light, etc.); study principles of optimal design for different types of buildings, regions, planning, evaluation and retrofits purpose; study feasibilities of different optimization measures based on life-cycle cost analysis.

Source: Ministry of Science and Technology 2007c.

2.7 Solar Energy and Integrated Renewable Energy

2.7.1 Renewable Energy and Building Integration Technologies

2.7.1.1 Technical and Economic Analysis of Renewable Energy and Building Integration Technologies

Principal Investigator: CABR

Funding: Central government budgeted 2 million yuan ($0.29 million) for the program, while the respective institutions will match at least 2 million yuan ($0.29 million).

Tasks:

Propose technical and economic analysis and index system for adaptability to renewable energy and building integration in different climate zones, different resource zones, and different types of buildings, and develop relevant evaluation software. Develop renewable energy and building integration plans, energy analysis, and optimal design of renewable energy and building integration.

Incremental investment for renewable energy use is no more than 40% and adding investment periods are less than/equal to 8 years.

Source: Ministry of Science and Technology 2007b.

2.7.1.2 Solar HVAC Systems and Building Interfaces

Principal Investigators: Shanghai Jiaotong University

Funding: Central government budgeted 6 million yuan ($0.86 million) for the program, while the respective institutions will match at least 9 million yuan ($1.29 million).

Target: Solar energy in the building composite energy system greater than/equal to 60%; solar space conditioning heating systems with COP greater than/equal to 0.4; solar heat pump heating systems with COP greater than/equal to 5; solar and heat pump combined energy systems with COP greater than/equal to 5. Develop analysis tools/software for a composite energy system.

Tasks: Develop a building composite energy system mainly relying on solar energy; develop a solar cooling dehumidification system; develop a solar and heat pump combined heating and cooling system, develop a related building interface.

Source: Ministry of Science and Technology 2007b.

2.7.1.3 Modular Solar Thermal Collector

Principal Investigators: University of Science and Technology of China

Funding: Central government budgeted 2 million yuan ($0.29 million) for the program, while the respective institutions will match at least 4 million yuan ($0.57 million).

Tasks:

Modular solar energy collectors integrated with the building envelope and both have the same lifespan; modular solar energy collectors and building interface; solar energy collector component.

Source: Ministry of Science and Technology 2007b.

2.7.1.4 Demonstration Projects of Renewable Energy and Building Integration

Principal Investigators: Center of Science and Technology of Construction, Ministry of Construction

Funding: Central government budgeted 33 million yuan ($4.71 million) for the program, of which 8 million yuan would be used for developing a standard, promotion, project management and operation testing, while the responsible organization would match at least $8 million yuan; 25 million yuan would be used for demonstration projects, while the responsible institutions will match at least 50 million yuan.

Tasks:

Demonstrate integrated building construction, acceptance, management and testing; monitor and control building energy system operation/performance; promote integrated building technologies.

Build the projects in different climate zones with individual buildings of approximately 300-5,000 m^2; the total for all demonstration projects is more than 30,000 m^2. The design of the buildings should surpass the existing energy-saving design standard and renewable energy should account for 60% and 70% of energy use in residential and commercial buildings, respectively. The incremental investment should be less than 40% of the total investment.

Develop design, construction, and acceptance standard or code for renewable energy-integrated buildings.

Source: Ministry of Science and Technology 2007b.

2.7.1.5 Large-Scale Application of Solar Energy

Principal Investigator: CABR

Funding: Central government budgeted 9.5 million yuan ($1.36 million) for the program, while the respective institutions will match at least 19 million yuan ($2.71 million).

Target:

1. Build one demonstration project/prototype for a combined solar heating, cooling, and water heating system for year-round use with a solar fraction greater than 30%.
2. When the working temperature is 45^oC, the environment temperature is 0^oC, and solar irradiance is 600W/m^2, the instantaneous efficiency of the solar thermal collector should be greater than 40%.

3. Develop solar heating system optimal design software and system operation benefit analysis software. Provide optimal design parameters for different regions, types of buildings, system functions, and methods of energy storage.
4. Build two to three solar heating demonstration projects including at least one project of passive solar design and one of seasonal thermal storage to ensure the year-round solar fraction is greater than 30%.

Tasks:

1. Solar thermal utilization in buildings.

   Develop a medium/high solar thermal collector that fits different climate zones, types of buildings, and meets the requirement of solar heating/cooling and tackles the key technologies in structure optimization, materials, skills, and manufacturing. Study solar heating and building integration focusing on key technologies to install a solar thermal collector at a balcony and wall.

2. Large-scale application of large and medium-sized solar (space and water) heating optimization technologies and software development

   Study key technologies for a medium/large-scale solar (space and water) heating system proposing a solar heating system from different climate zones and types of buildings and defining the optimal design parameters including solar fraction, flow in the thermal collector system, water supply temperature, capacity of thermal storage tank, etc.

   Study key technologies for short-term and seasonal energy storage of the solar heating system including numerical value analysis of a solar-assisted, ground source heat pump and ground reservoir thermal storage and exchange system (for cold and severe cold regions), optimal design of short-term and seasonal energy storage system, application of solar energy storage system, and demonstration projects for a solar heating system.

   Develop solar heating system optimal design software providing optimal design parameters, benefit analysis, and design of a medium/large-scale-solar heating system.

3. Combined solar heating, cooling, and water heating “triple-play” systems

   Develop technologies and software for solar air conditioning optimal design including operation mode and energy storage methods of solar air conditioning; develop software for the optimal design of a solar air conditioning system including design of a solar thermal collector system, configuration of thermal/ice storage tank, and benefit analysis, etc.

   Develop and test demonstration projects for the “triple play” system including project design and construction of the year-round use of the “triple play” system, system operation and testing, monitoring system performance, and benefit analysis.

4. Combined use of solar energy and other types of energy in buildings.

   Develop technologies for optimal building design and intelligent control of combined solar thermal, solar electric, and other energy including optimum distribution/configuration of a solar thermal system and normal auxiliary energy, optimal design of building integrated photovoltaics (BIPV), and intelligent control of solar energy buildings.

Develop an assessment method and standard for solar energy buildings, propose individual indicators, standard, weight, and comprehensive assessment method, and build comprehensive assessment systems of combined solar energy buildings.

5. Passive solar design.

   Study the building envelope for passive solar design, propose window-to-wall ratio and indicators of wall/door thermal properties across climate zones and solar energy types, and optimal model of passive solar thermal collector according to building types and functions.

   Optimize the design parameters of passive solar collectors, develop optimal designs for natural ventilation and building cooling systems, develop cooling and ventilation systems using ground-source heat pumps, and develop a passive solar heating/cooling demonstration project.

Source: Ministry of Science and Technology 2007c.

2.8 Others

2.8.1 Energy Consumption Analysis and Technical/Economic Assessment of Energy-Efficient Technologies

1. Energy consumption statistic model and methods.
2. Technical assessment.
3. Study the energy demand of different types of buildings in different climate zones and connect the demand with energy-efficient technologies. Define and evaluate technology options, economic costs, environmental impacts, and performance and effects.
4. Labels and management.
5. Incentives.
6. Investment.
7. Services and supervision.

Source: Ministry of Science and Technology 2007c.

2.8.2 Building Energy Code and Technical Support Document

1. Building energy code system and standard.
2. Residential building energy code.
3. Commercial building energy code.

   Develop and revise the commercial building design standard including survey of commercial building energy consumption across climate zones, heating and/or space conditioning system, lighting, building envelope and miscellaneous appliances; study and analysis of factors relating to different climate zones to impact commercial building energy consumption and indoor humidity and thermal environment; propose coverage of the commercial building design standard and key control indicator and defining limits of the design standard; propose principles of special commercial building energy saving design.

4. Examination and acceptance standard.
5. Existing residential building retrofit standard.
6. Existing commercial building retrofit standard.

   Develop fundamental research of commercial building retrofits including methods for conducting feasibility studies of commercial building retrofits across climate zones, identify the priorities of different types of building retrofits, and identify the key control indicators for commercial building retrofits. Develop or revise commercial building retrofit standards.

Source: Ministry of Science and Technology 2007c.

3.0 Mapping China's Activities in Building R&D to DOE Building Technology Program Multi-Year Project Plans

In an effort to assess areas of potential collaboration with China, this section provides a series of "maps" drawing linkages between China's R&D activities and tasks specified in the Building Technology Program (BTP)'s Multi-Year Project Plans (MYPPs). The maps describe synergies between the research programs in China and the United States, and as such, they may help identify areas for possible future collaboration.

Since the original Chinese organization of the programs was quite different from BTP's MYPP, it is presented in a way to clarify potential synergies. Tasks mapped here do not include all in MYPPs, but only those where there are synergies. In addition, Appendix C provides a matrix with a visual summary of the relevant areas of intersection.

3.1 Residential Integration

United States	China
New Homes Approach and Activities	
Stage 1 – Zero energy home technology pathways	The 12th Five-Year Plan underway includes funding for building roadmap and technology scoping studies for the next five years, 2011-2015. The plan should include strategies and tasks to achieve the target energy savings in each climate region, in urban and rural areas, and in single-family and multi-family homes. Specific R&D tasks will likely derive from this work.
Stage 2 – System performance evaluations.	Most core technology R&D programs in national R&D programs would be followed by prototype or demonstration projects to determine the reliability and cost-effectiveness of the solutions. Specifically, in residential buildings in towns and villages (similar to single-family homes), the task is to study low-cost energy-saving technologies including passive solar energy use, heating and natural ventilation, biomass heating, etc., and to develop building integration technologies and prototypes. Ten prototypes in ten climate regions will be built at the end of the project.
Stage 3 – Prototype house evaluations	Not sure
Stage 4 – Initial community-scale evaluations	Not directly associated with R&D programs, the idea of scaling up low-energy residential buildings was incorporated into other national deployment programs. Some technologies developed during the10th Five-Year Plan were scaled up during the 11th Five-Year Plan.
Stage 5 – Final evaluations in occupied homes	Not sure
Existing Homes Activities	
Existing Homes Technical Pathways	Similar to new homes technical pathways, the 12th Five-Year Plan underway includes funding for building roadmap and technology scoping studies for the next five years, 2011-2015.
Market Conditioning and Transformation Analysis	There are several national programs on existing building retrofits to deploy and test technologies. These deployment programs are based on analysis of effective activities and strategies to achieve widespread market acceptance of energy-efficient retrofits. Currently, there are large-scale energy-efficient retrofit programs in buildings with space heating in North China.

United States	China
Attic and Roof Strategies	Develop a set of devices and technologies for sloped-roof modification (flat-to-slope roof); in North China, further develop upside-down roof (reverse insulation and waterproof layers: insulation layer outside and waterproof layer inside) to improve heat preservation; in Middle and South China, further develop planted roofs and water storage roofs to improve heat insulation.
Not covered	Existing Building Retrofits: Building Envelope Develop prefabricated exterior wall with integrated components of heat-preservation and decoration and related construction technologies; develop at least two sets of easily-implemented products and technologies. Exterior Windows Develop "whole-window" change technologies and installing techniques; develop technologies to add one window-layer (to single-glazed windows); develop shading products for windows and related installing methods. The products and technologies should be applicable to various types of existing residential and commercial buildings.
Residential Space Conditioning System Integration	
Development of space conditioning retrofit strategies for deep energy retrofits in support of the existing buildings research program,	Conduct feasibility studies of retrofits of residential buildings with space heating: Develop methods to survey, examine and evaluate energy consumption in these buildings; develop a comprehensive evaluation system to study the feasibility of retrofits; conduct energy consumption survey, examination and evaluation using methods developed above and obtain raw data of one to two cities.
Development of climate-specific guidelines for estimating and implementing whole-house dehumidification needs for efficient homes, including Builders Challenge and Building America 50%+ homes.	Identify strategies for thermal and humidity control in the Yangtze River regions: Through investigation, examination, and simulation analysis, propose principles and strategies for environmental control of residential buildings in this area. This will include natural ventilation, shading, indoor temperature adjustment according to the thermal and moisture features of the building, features of different parts of the envelope, and optimal analysis. Propose building envelope fits for both active and passive environmental control; define the time period and criteria for active heating, cooling, and dehumidification.

Source: DOE 2008a 2008b 2009e; Ministry of Science and Technology 2007b 2007c 2007e 2009.

3.2 Commercial Integration

United States	China

United States	China
Advanced Energy Design Guides and Technical Support Documents	Commercial building energy code[8] Develop and revise the commercial building design standard including survey of commercial building energy consumption across climate zones, heating and/or space conditioning system, lighting, building envelope and miscellaneous appliances; study and analysis of factors relating to different climate zones to impact commercial building energy consumption and indoor humidity and thermal environment; propose the coverage of commercial building design standard and key control indicator and defining limits of the design standard; propose principles of special commercial building energy saving design. Existing commercial building retrofits standard Develop the fundamental research of commercial building retrofits including methods of feasibility studies for commercial building retrofits across climate zones, identify the priorities of different types of building retrofits, and identify the key control indicators for commercial building retrofits. Develop or revise commercial building retrofits standards.
Decision Tool for Evaluating Technology Package Selections	Design, analysis, implementation, and standards of systematic controls for mechanical and electrical appliances: develop auxiliary analysis tools for mechanical and electrical system energy-saving control design. Based on the functions and composition of the mechanical and electrical system, automatically formulate a self-control system sensor, implementation devices requirements, and necessary control algorithm. Decision making tools: propose energy-saving decision making standardized methods and steps, analysis indicators, and parameters. Define indicators and parameters for different regions and building types. Apply diagnostic tools in more than 30 commercial buildings across a variety of regions and building types and in general situations, energy savings of more than 20% through improving operation management and changing key appliances
Directed R&D	The 12th Five-Year Plan underway includes funding for building roadmap and technology scoping studies for the next five years, 2011-2015. The primary institutions responsible for that are CABR, CBMA, China Academy of Urban Planning and Design, China National Engineering Research Center for Human Settlements, Tsinghua University, Tongji University, Southeast University, Shanghai CABR, Shenyang CABR, China Metallurgical Group Corporation-Building Design Research Institute, etc. Specific R&D tasks will likely derive from this work.

Source: DOE 2008a 2009c; Ministry of Science and Technology 2007c 2009.

3.3 Solid State Lighting

United States	China
LED Priority Core Technology and Product Development Tasks	
A6.3[9] system reliability methods	Study design of LED functional luminaries, build accurate optical model to achieve the best-performance light efficacy.

[8] In China, the documents associated with the building energy code are becoming increasingly detailed and, while they are not targeted at the most advanced buildings, they do provide useful and detailed information on building design and construction.
[9] The U.S. side will mention specific clauses in DOE’s “Multi-Year Program Plan FY’09-FY’15: Solid-State Lighting Research and Development.” (Internal working document).

B1.3 Phosphors	Study the compatibility of phosphors and chip wavelength
B3.4 emitter thermal control	Study LED luminaries' thermal emission, improve light efficacy and lifetime. Optimize luminaires' light distribution, thermal emission and structure, improve light efficacy and lifetime.
B4.2 epitaxial growth	Develop growth materials such as GaN materials
B6.2 luminaire thermal management techniques	R&D on system integration techniques and application.
B6.3 optimizing system reliability	LED functional lighting scale-up production and product examination system to determine failure. Improve SSL product examination system to the international level.
Other Identified LED Core Technology and Product Development Tasks	
A1.1 Alternative substrates	Develop novel substrates
A4.4 manufacturing simulation	Develop cost control methods to accelerate commercialization process.
A7.4 driver electronics	Tackle key technologies, such as driver electronics or driver circuit.
B7.3 smart controls	High-reliability, high-efficiency LED combined driver and intelligent control, integrated light electromagnetic compatibility design.
OLED Priority Core Technology and Product Development Tasks	
C1.1 novel device architectures	Develop novel OLED materials and devices
C1.2 novel materials	
D6.2 large-area OLED	Develop large-area OLED panels

Source: DOE 2008a 2009f; NDRC et al. 2009; Office of New Material Technologies, the 863 Program 2009.

3.4 HVAC and Water Heating

United States	China
HVAC	
Residential HVAC	
Advanced HVAC/Water Heating Implementation in BEopt Analysis	Groundwater and surface water heat pump Study the energy optimal design of the ground/surface water heat pump system; study the heat transfer model of closed-surface water heat exchanger; develop engineering analysis software for closed surface water heat pump; develop ground/surface water heat pump demonstration project.
Retrofit Energy Efficiency Opportunities and Barriers for HVAC and Water Heating	Feasibility studies of retrofits of residential buildings with space heating Develop methods to survey, examine ,and evaluate energy consumption in these buildings; develop a comprehensive evaluation system to study the feasibility of retrofits; conduct energy consumption investigation, examination and evaluation using methods developed above and obtain the raw data of one to two cities.
Commercial HVAC	

United States	China
Solar-Assisted Heat Pump Systems	Solar HVAC system and building interface Target: Solar energy in the building composite energy system >= 60%; Solar space conditioning heating COP >=0.4; solar heat pump heating system COP >=5; solar and heat pump combined energy system COP >=5. Develop analysis tools/software for composite energy system. Tasks: Develop building composite energy system mainly relying on solar energy; develop solar cooling dehumidification system; develop solar and heat pump combined heating and cooling system, develop related building interface.
Water Heating	
Heat Pump Water Heater	CO_2 air-source heat pump water heating set Develop the hot water preparation devices for household uses and combine them with air conditioning system. Develop the products of 80-200L, and extract heat from indoor/outdoor air to prepare hot water of 50-60^{o}C; COP of heat preparation is not less than 4.
Appliances	
Improved User Interface of Residential Thermostats	Household heat calculation and control Develop products that can calculate, control and adjust heat supply in each household; widely apply these products in the residential buildings with heating system.

Source: DOE 2008a 2009d; Ministry of Science and Technology 2007b 2007c.

3.5 Building Envelopes and Windows

United States	China
ENVELOPE	
Advanced Attic and Roofing Systems	
Task 1. Integration of phase change materials (PCM), Cool Colors, ASV, Radiant Barrier and Advanced Lightweight Insulations	There is wide interest from industries and research institutes on cool roofs and PCM, but no such national R&D program has been revealed yet.
Task 2. Regionally Optimize Above-Sheathing Ventilation	New ventilating facilities Develop ventilating facilities for exterior wall, roof, and exterior window; the new ventilating facilities should also include features like sound insulation, air filtration, and recycling heating from exhaust air.
Task 3. Best Practice for Integration of PCM in Roof and Attic Assembly	There are a variety of studies on PCMs under new materials R&D programs, but no such national R&D program has been revealed on PCM in roof and attic. There were national R&D programs on PCM in floor and walls.
Task 4. Demonstration of Dynamically Active Roof and Attic	Together with other building envelope techniques developed under the program, there would be eight cases for whole-house demonstration.
Task 5. Accelerating Rating for Cool Roofs	Though not listed in the national R&D plan, there is a strong interest in cool roof rating in China. The China Building Material Test and Certificate Center has a testing laboratory of cool roofs.
Advanced Wall Systems	
Task 1. Whole-House Demonstration of Advanced Wall System	Together with other building envelope techniques developed under the program, there would be eight case studies for whole-house demonstration.

United States	China
Task 2. New Generation of Dynamically-Acting Composite Non-Wood Structural Sheathings	Opaque building envelope in cold and severe cold regions Improve the uses of external insulating composite wall and roof with different heat-preserving materials and structures. Develop new sandwich heat-preserving walls; study the prefabricated heat-preserving walls.
Materials	
Task 1. Fibrous Insulation Manufactured to Contain PCMs	There are a variety of studies on PCMs under New Materials R&D programs, and no specific information revealed on PCMs' application in buildings.
Task 2. Reduction in Envelope Durability Problems	The "environmentally friendly building materials and products" mentions that the program will improve the performance and durability of walls and windows.
Task 3. Changeable Roof Reflectivity	Heat reflective wall coatings Target: Reflectivity in infrared area >= 85%, hemispherical emissivity >= 85%; change amplitude of emissivity-reversible materials > 0.6; insulation coatings should help to raise temperature in winter by 8-10oC and lower temperature in summer by 5-8oC. Tasks: Screen and optimize fluorine-modified silicone-acrylate emulsion, develop phase change materials whose emissivity will change with temperature, study the compatibility of coatings and features of reflective insulation, test emissivity and its change with temperatures, and develop heat reflective insulation coatings.
Enabling Technologies	
Task 3. National/International Standards.	China is working on standards for various energy saving products. There is a strong interest from industry on product standards.
Task 4. Facilitate Private Industrial Research.	Under the "National Technology Innovation Program Plan," facilitating private industrial research is named as priority for all kinds of R&D programs.
WINDOWS	
Highly Insulating (High-R) Windows	
High-R Glazing Systems	China has been working on vacuum glazing over the past decade and active efforts are from industry. Beijing Synergy Vacuum Glazing company is one of the pioneers in this area. The heat-strengthened vacuum glazing they developed recently has a low-E and high-R value and better resistance to environmental conditions. Also, there has been strong interest from industry on triple-glazed windows.
High-R Frame Designs and Materials	Transparent building envelope energy-saving technologies and products Study high-R frames of windows and curtain walls
Field Demonstration of Systems Benefits of High-R Window Technologies	Not sure

United States	China
Daylighting and Advanced Façades	Transparent building envelope energy-saving technologies and products Develop high-performance glass curtain wall with low heat-transmission coefficient, low-temperature radiation and solar radiation; develop light-through and shading devices that will change physical properties with the atmosphere; develop new types of double-skin exterior windows and glass curtain walls; develop exterior shading products and technologies for windows and transparent curtain walls across climate zones.
Enabling Technologies	
Task 1. Software Tools Development	Transparent building envelope energy-saving technologies and products. Develop software tools to calculate shading in buildings and to calculate and evaluate heat efficiency of double-skin ventilating window curtain wall. Develop related heat engineering calculation and evaluation software for energy efficient roofs, walls, floors across climate zones.
Task 2. National/International Standards	China is working on standards for various energy saving products. There is a strong interest from industry on product standards.

Source: DOE 2008a 2009b; Ministry of Science and Technology 2007c 2007d 2007f.

3.6 Analysis Tools

United States	China
Extend the Capabilities:	
Support development, analysis, and compliance with building energy standards (ASHRAE 90.1, 189.1, California Title 24)	N/A
Support BT RD&D (elements that currently employ building simulation tools that use EnergyPlus for research and analysis)	Simulation analysis of energy saving for individual buildings and optimization of thermal environment
Coverage of state-of-the-art building energy efficiency and renewable energy and other zero energy building technologies that analysis tools can evaluate	Simulation of HVAC and energy-supply system Target HVAC engineers, develop a dynamic modeling package to simulate HVAC and energy-supply systems that will fit the requirements of different design stages (air management, device selection, heat/cold source, network design, self-control system, etc.). Develop simulation analysis of urban energy planning including simulation of new heating network and combined heat/power/cold supply systems, etc.

United States	China
Deploy Analysis Tools:	
Interoperability with other building design tools	Integration of different simulation software packages (interoperability). Establish a standard platform to integrate existing tools, database, input/output, and simulation tools mentioned above; enable multi-directional data exchange, integrated use and display. Study database standardization, data exchange, and data display.
Extend EnergyPlus to other broader-based engineering design tools	Integration of different simulation software (interoperability) Establish a standard platform to integrate existing tools, database, input/output, and simulation tools mentioned above; enable multi-directional data exchange, integrated use and display[10]. Study database standardization, data exchange, and data display.
Not covered	Building group and microclimate

Source: DOE 2008a 2009a; Ministry of Science and Technology 2007c.

[10] This has been complete in China's analysis tool-PKPM.

3.7 Solar Energy

United States	China
Low-cost Solar Water Heaters for Zero Energy Homes	Large-scale application of large and medium-sized solar (space and water) heating optimization technologies and software development. Study key technologies for medium/large-scale solar (space and water) heating system, proposing solar heating system from different climate zones and types of buildings and defining optimal design parameters, including solar fraction, flow in thermal collector system, water supply temperature, capacity of thermal storage tank, etc. Study key technologies for short-term and seasonal energy storage of the solar heating system including numerical value analysis of solar assisted ground source heat pump and ground reservoir thermal storage and exchange system (for cold and severe cold regions), optimal design of short-term and seasonal energy storage system, application of solar energy storage system, and demonstration projects of solar heating system. Develop solar heating system optimal design software, providing optimal design parameters, benefit analysis, design of medium/large-scale solar heating system.
Combined Solar Heating, Cooling, and Water Heating Systems for ZEH	Combined solar heating, cooling, and water heating "triple-play" systems Develop technologies and software for solar air conditioning optimal design including operation mode and energy storage methods of solar air conditioning; develop software of optimal design of solar air conditioning system, including design of solar thermal collector system, configuration of thermal/ice storage tank, and benefit analysis, etc. Develop and test demonstration projects for the "triple play" system including project design and construction of the year-round use of the "triple play" system, system operation and testing, monitoring system performance, and benefit analysis.
Solar Electric/Solar Thermal Pathways to ZEH	Combined use of solar energy and other types of energy in buildings Develop technologies for optimal building design and intelligent control of combined solar thermal, solar electric and other energy, including optimum distribution/configuration of solar thermal systems and normal auxiliary energy, optimal design of building BIPV, intelligent control of solar energy buildings. Solar HVAC systems and building interfaces. Develop solar cooling dehumidification systems; develop solar and heat pump combined heating and cooling systems. Solar space conditioning heating systems with COP >=0.4; solar heat pump heating systems with COP >=5; solar and heat pump combined energy system with COP >=5.
Solar Rating and Certification Corporation Technical Support	Combined use of solar energy and other types of energy in buildings Develop assessment method and standard for solar energy buildings, propose individual indicators, standard, weight, and comprehensive assessment method, and build comprehensive assessment systems of combined solar energy buildings. Demonstration projects of renewable energy and building integration Development design, construction and acceptance standard or code for renewable energy integrated buildings.
Not covered	China mentioned passive design and solar thermal collector development; assessment software of building solar energy use.

Source: DOE 2008a 2009g; Ministry of Science and Technology 2007a 2007b 2007c..

4.0 Conclusion

The research and assessment conducted in this report suggest that the BTP research program and China's national building R&D programs have potential synergies in many areas including core technology R&D, deployment programs, and technology transfer.

Residential and commercial integration projects are defined by the countries' special circumstances as China has an emphasis on energy-efficient building retrofits and BTP's efforts are more active in new buildings. However, there are some technologies and decision making tools in which similar research is underway.

In solid state lighting, the United States has technology advantages in most areas. China's strength is on "downstream" packaging and appliances. China has also begun to build a manufacturing capacity for core technology products. Developing Chinese-owned intellectual property is greatly emphasized in China's SSL programs. In addition, there is a large market for LED products in China, a trend led by large government procurements programs. There appears to be potential for technology transfer and collaboration in SSL technologies and deployment.

The maps of technical synergies provided in Section 3 highlight potential areas of collaboration in HVAC and building envelopes as well. Industry and research institutes are actively engaged in efforts relating to building envelopes, but not all are associated with national R&D programs. As a result, such U.S.-Chinese collaboration might be with companies or laboratories.

The United States has strengths in developing analysis tools and potential in technology transfer. In China, there are efforts relating to software validation. How to localize the software package and convert it to the Chinese interface would be an issue in the collaboration. Solar energy is an active research area in both countries. Both countries are going in the same direction and at the same pace. The national R&D programs of both countries could complement each other. There is huge potential for collaborative R&D of new technologies.

Since many U.S. companies have expressed concerns about intellectual property rights in China, deployment might be an advantageous area in collaboration. The Chinese government is considering ways to improve building energy efficiency and has initiated several national programs to deploy energy-efficient building technologies across the country. With strong domestic efforts, there would be a great opportunity for international collaboration in building energy efficiency in the near future.

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Appendix A

Building-Related Research Institutes in China

Appendix A

Building-Related Research Institutes in China

Institutes	Chinese	R&D areas
Tsinghua University (Building Energy Research Center)	清华大学(建筑节能研究中心）	Analysis tools; energy management and energy efficiency diagnosis; phase change materials in solar heating and buildings installed with solar technology; large commercial building energy savings; HVAC.
China Academy of Building Research (CABR)	中国建筑科学研究院	Analysis tools; materials; HVAC (thermal environment); daylighting; building code; curtain walls, structures; solar integration; large-scale buildings. CABR is much larger than the other institutions and has several testing laboratories.
China Building Materials Academy (CBMA)	中国建筑材料科学研究院	Building materials; glass; building envelope, evaluation.
Harbin Institute of Technology	哈尔滨工业大学	Walls; windows; heat pump; space heating; insulation materials; solar energy and renewable energy.
Tongji University (Building Energy Efficiency and Energy Center)	同济大学 (建筑节能与能源中心）	Building envelope (insulation, shading, roof, solar reflection, etc.); windows (curtain wall); HVAC (natural ventilation, recycled exhaust heat, ventilation, water, independent calculation and control of household energy consumption, etc.); phase change materials.
China Architecture Design & Research Group (CAG)	中国建筑设计研究院	Optimal simulation of the building environment; heating engineering, space conditioning, appliances, sewage, new energy and renewable energy, building operations.
Shanghai Jiaotong University	上海交通大学(绿色实验室)	Renewable energy; solar energy and building integration; Micro- combined cooling, heating and power; water-source heat pump.
University of Science and Technology of China	中国科学技术大学	Heat pump; solar and renewable energy, building retrofits.
China National Engineering Research Center for Human Settlements	国家住宅与居住环境工程技术研究中心	Solar energy; residential buildings; rural buildings; evaluation.
Shanghai Research Institute of Building Science	上海建筑科学研究院	Commercial buildings diagnosis and energy efficient retrofits; energy efficiency examination and evaluation; building envelope; green building integration; renewable energy and building integration; improvement of building environment simulation and control; building intelligent system integration; building retrofits integration.
Research and Development Center for Semiconductor Lighting, China Academy of Science	中科院半导体照明研究所	LED and OLED.
Kingsung-Tsinghua SSL technology and application R&D center	勤上光电-清华半导体照明技术与应用研发中心	LED and OLED; LED technology standard.
Beijing Synergy Vacuum Glazing company	北京新立基真空玻璃技术有限公司	Vacuum glazing.

Appendix B

Recent Highlights of DOE-China Cooperation

Appendix B

Recent Highlights of U.S. Department of Energy-China Cooperation

During Secretary Chu's visit to China in July 2009, the U.S. Department of Energy and the Chinese Ministry of Urban-Rural Development signed a Memorandum of Understanding on Energy-efficient Buildings and Communities, which listed several areas of collaboration in building energy R&D. These include: 1) exchange of experts and technicians to learn from each other's experiences with efficient building technologies including: high-performance HVAC, insulation, lighting, cold storage, geothermal heat pumps, building-integrated photovoltaics, and solar thermal systems; 2) joint analysis of lessons learned from international experience with energy-efficient buildings and communities; 3) exploration of the feasibility of a joint project in China to demonstrate green buildings, building energy savings, and renewable energy technologies.

In November 2009, President Obama visited China and signed a Protocol with Chinese President Hu Jintao to formally establish a United States-China Clean Energy Research Center, under which building energy efficiency is one of the research priorities.

Appendix C

Multi-Year Project Plans-China Matrix Spreadsheet

Appendix C

Multi-Year Program Plan-China Matrix Spreadsheet[11]

11th Five-Year Plan Supporting Programs	Projects and Tasks	No(*) or unclear(?) relevant R&D in U.S.	BTP MYPPs: Residential Integration			Commercial Integration			HVAC				Building Envelope					Windows				Analysis Tools			Solar Heating and Cooling			
			New Homes Approach and Activities	Existing Homes Activites	Residential Space Conditioning System Integration	Advanced Energy Design Guides&Technical Support Documents	Decision Tool for Evaluating Technology Package Selections	Directed R&D	HVAC	Water Heating	Appliances	Miscellaneous	Advanced Attic and Roofing Systems	Advanced Wall Systems	Advanced Foundations	Materials	Enabling Technologies	Highly Insulating Windows	Second-Generation Dynamic Windows	Daylight Redirecting	Enabling Technology Research for Efficient Products	Extended Capabilities of Analysis Tools	Validate Tools	Deploy Analysis Tools	Low-cost Solar Water Heaters for Zero Energy Homes	Combined Solar Heating, Cooling, and Water Heating Systems for ZEH	Solar Electric / Solar Thermal Pathways to ZEH	Solar Rating & Certification Corporation Technical Support
Research and demonstration of key technologies for residential buildings in towns and villages (single-family homes)	**Key Technologies in Residential Building Energy Efficiency**																											
	Building envelope		■																									
	Solar integration and wind use		■																									
	Analysis tools		■																									
	Heat pump		■																									
	Appliances		■																									
	A Set of Technologies for Residential Buildings' Planning and Design																											
	Low cost energy-saving technologies for towns and villages		■																									
	Strategies, Policies and Standards for Residential Building Development																											
	Energy efficient design standard		■																									
Environmentally friendly building materials	**Functional and Environmentally Friendly Coatings**																											
	Heat reflective wall coatings															■												
	Windows in Typical Regions																											
	Windows for "hot summer cold winter" regions	?																										
	Windows for "hot summer warm winter" regions	?																										
	Windows for "cold and severe cold" regions	?																										
Renewable Energy and Building Integration Technologies	**Technical and Economic Analysis of Renewable Energy and Building Integration Technologies**	?																										
	Indoor Thermal and Humidity Loads Adjustment System for New Buildings	?																										
	Solar HVAC Systems and Building Interfaces								■																		■	
	Modular Solar Thermal Collector	?																										
	Demonstration Projects of Renewable Energy and Building Integration																											■

[11] The Chinese projects and tasks were organized as they are in the Chinese document. The interconnections of SSL tasks and activities between China and the United States are fully described in the body of this report, Section 3.3 Solid State Lighting, and are not repeated here.

In addition, residential buildings in China include both single-family homes and high-rise apartment buildings, while the latter is identified as commercial buildings in the United States. Therefore, activities relating to residential buildings in China were mapped and connected to both residential and commercial integration activities in the United States.

11th Five-Year Plan Supporting Programs	Projects and Tasks	No(*) or unclear(?) relevant R&D in U.S.	BTP MYPPs																									
			Residential Integration			Commercial Integration			HVAC				Building Envelope					Windows				Analysis Tools			Solar Heating and Cooling			
			New Homes Approach and Activities	Existing Homes Activities	Residential Space Conditioning System Integration	Advanced Energy Design Guides& Technical Support Documents	Decision Tool for Evaluating Technology Package Selections	Directed R&D	HVAC	Water Heating	Appliances	Miscellaneous	Advanced Attic and Roofing Systems	Advanced Wall Systems	Advanced Foundations	Materials	Enabling Technologies	Highly Insulating Windows	Second-Generation Dynamic Windows	Daylight Redirecting	Enabling Technology Research for Efficient Products	Extended Capabilities of Analysis Tools	Validate Tools	Deploy Analysis Tools	Low-cost Solar Water Heaters for Zero Energy Homes	Combined Solar Heating, Cooling, and Water Heating Systems for ZEH	Solar Electric / Solar Thermal Pathways to ZEH	Solar Rating & Certification Corporation Technical Support
Key technologies of building energy efficiency	**Energy Efficient Building Retrofits**																											
	Conduct feasibility studies of retrofits in residential buildings with space heating			■	■				■																			
	Building envelope	?																										
	Roof			■																								
	Exterior windows	?																										
	Large-scale glass window curtain wall																											
	Indoor Thermal and Humidity Control of Residential Buildings in Yangtze River Regions																											
	Indentify strategies for thermal and humidity control in Yangtze River regions				■																							
	Develop integrated end-use devices for thermal and humidity adjustment																											
	Develop small dehumidification devices for household use																											
	Develop household-level environment control facilities																											
	Space Conditioning System for Large Commercial Buildings																											
	Energy optimization																											
	Parameter, control, and design of temperature-humidity independent control system																											
	Energy saving in the air-conditioning water system																											
	Liquid desiccant air-conditioning system																											
	16-18° C cold source dry heat-sensible end-use devices																											
	Cooling water facilities with out-flowing water temperature 16-18° C																											
	Energy Management and Energy-Saving Diagnostic Techniques for Large Commercial Buildings																											
	Space conditioning system energy-saving control						■																					
	Design, analysis, implementation and standards of systematic control for mechanical and electrical appliances						■																					
	Energy consumption management system						■																					
	Decision making tools (Diagnostic tools)						■																					
	Analysis tools																											
	Simulation Analysis of a group of buildings for energy optimization design	*																										
	Simulation analysis of energy saving for individual buildings and optimization of thermal environment																					■		■				
	Simulation of HVAC and energy-supply system								■													■						
	Integration of different simulation software packages (interoperability)																							■				
	Evaluation system for energy saving and optimization					■																		■				
	Envelopes and Windows in New Buildings																											
	Opaque building envelope in cold and severe cold regions													■														
	Opaque building envelope in "hot summer cold winter" and "hot summer warm winter" regions																											
	Transparent building envelope energy-saving technologies and products																	■		■	■							
	New ventilating facilities												■															

11th Five-Year Plan Supporting Programs	Projects and Tasks	No(*) or unclear(?) relevant R&D in U.S.	BTP MYPPs																									
			Residential Integration			Commercial Integration			HVAC				Building Envelope					Windows				Analysis Tools			Solar Heating and Cooling			
			New Homes Approach and Activities	Existing Homes Activites	Residential Space Conditioning System Integration	Advanced Energy Design Guides& Technical Support Documents	Decision Tool for Evaluating Technology Package Selections	Directed R&D	HVAC	Water Heating	Appliances	Miscellaneous	Advanced Attic and Roofing Systems	Advanced Wall Systems	Advanced Foundations	Materials	Enabling Technologies	Highly Insulating Windows	Second-Generation Dynamic Windows	Daylight Redirecting	Enabling Technology Research for Efficient Products	Extended Capabilities of Analysis Tools	Validate Tools	Deploy Analysis Tools	Low-cost Solar Water Heaters for Zero Energy Homes	Combined Solar Heating, Cooling, and Water Heating Systems for ZEH	Solar Electric / Solar Thermal Pathways to ZEH	Solar Rating & Certification Corporation Technical Support
Key technologies of building energy efficiency	**Large-Scale Application of Solar Energy**																											
	Solar thermal utilization in buildings	?																										
	Large-scale application of large and medium-sized solar (space and water) heating optimization technologies and software development																								■			
	Combined solar heating, cooling, and water heating "triple-play" system								■																	■		■
	Combined use of solar energy and other types of energy in buildings																										■	■
	Passive solar design	*																										
	Water and Ground Source Heat Pump																											
	Adaptability of water and geothermal heat pumps																											
	Application of soil-source heat pumps																											
	Ground water and surface water heat pumps								■																			
	Waste water and sea water heat pumps																											
	High-performance water-source heat pump generators																											
	Systematic plan for the use of water and geothermal heat pumps																											
	High-Efficient Application of Low-Grade Energy																											
	CO_2 air-source heat pump water heating set									■																		
	Low-turbidity wastewater heat recovery and hot water preparation for residential buildings																											
	Indirect evaporative cooling																											
	Direct/indirect evaporative air conditioning system																											
	Air-Source Heat Pump																											
	Decrease frosting in air-to-air heat-exchangers																											
	Intelligent and high-performance defrost technologies and defrost control																											
	Enhance energy efficiency for the system having huge temperature gap between cold and heat terminals																											
	Space Heating																											
	Household heat calculation and control										■																	
	Low-temperature heat supply end-use devices																											
	Adjustable temperatures for independent buildings																											
	Energy Consumption Analysis and Technical/Economic Assessment of Energy Efficient Technologies																											
	Energy consumption statistic model and methods																											
	Technical assessment										■																	
	Labels and management																											
	Incentives																											
	Investment																											
	Services and supervision																											
	Building Energy Code and Technical Support Document																											
	Building energy code system and standard																											
	Residential building energy code																											
	Commercial building energy code					■																						
	Examination and acceptance standard																											
	Existing residential building retrofit standard																											
	Existing commercial building retrofit standard					■																						

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