Research on an energy-efficiency improvement roadmap for commercial buildings in China

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Abstract

To reduce the building sector's approximately 30 % contribution to primary energy consumption and global warming, several developed countries have formulated Building Energy Efficiency Improvement Roadmaps (BEEIRs) to guide future improvements in building energy performance. In early 2014, the Chinese Ministry of Housing and Urban-Rural Development initiated the Building Energy-Efficiency Improvement Program of research activities on which a Chinese BEEIR will be based.

This paper describes the research supporting development of China's BEEIR for commercial buildings with a focus on the series of surveys of institutions and experts conducted to obtain information on current and expected future conditions and the analysis of the survey results. We compare the proposed BEEIR targets for new and existing commercial buildings and present recommendations regarding the BEEIR's implementation.

Introduction

Climate change, environmental pollution, and energy resource challenges have elicited global consensus about the need for sustainable development, energy conservation, and carbon and pollutant emissions reductions. Worldwide, the building sector consumes about 30 % of primary energy and contributes a similar percentage to global carbon dioxide (CO_2) emissions (IEA 2010). These percentages are rising as the world economy continues to develop, and urbanization and living standards increase. Many developed countries have focused on building energy efficiency since the 1970s; their efforts have significantly reduced building-related energy consumption and CO_2 emissions. In recent years, several developed countries have developed Building Energy Efficiency Improvement Roadmaps (BEEIRs) to guide future improvements in building energy performance. Table 1 shows the efficiency targets of 11 countries' BEEIRs (A. Marszal et al. 2009, EPBD 2010, eceee 2014, Zhang et al. 2013). The leading energy-efficiency target among these plans is achievement of net-zero- or nearly-zero-energy buildings (several countries use these or other terms that reflect the same underlying concept: that a building uses no more energy than can be produced from on-site renewable sources).

BEEIRs have been developed for different types of buildings, e.g., residential, commercial, new, existing, government, and privately owned. In addition to energy-performance targets, BEEIRs include supporting measures, such as technical solutions, financing, and basic policy frameworks. BEEIRs not only help improve the energy performance of individual buildings but also help develop the building energy-efficiency industry.

Building energy efficiency has been on China's policy agenda since the 1980s, and the energy performance of residential and commercial buildings has improved significantly since that time. To define the future direction of building energy efficiency in China and send a signal to Chinese industries to develop advanced energy-efficiency technologies and materials, the Chinese Ministry of Housing and Urban-Rural Development (MOHURD)[1] in 2014 initiated the Building Energy Efficiency

1. MOHURD is the main administrative agency in charge of building energy efficiency in China.

Table 1. Building energy-efficiency targets from 11 countries.

Country	Year	Building energy-efficiency target
Ireland	2013	achieve net-zero-energy building[1]
Finland	2015	implement the passive house[2] standard
United Kingdom	2016	achieve nearly zero energy building[3] zero carbon by 2016 in new residential buildings and by 2019 in new commercial buildings
Norway	2017	implement the passive house standard
Denmark	2020	reduce building energy consumption by 75 % compared to 2006
France	2020	achieve positive-energy building[4]
Germany	2020	achieve zero-fossil-fuel-consumption building[5]
Hungary	2020	achieve zero emissions
Netherlands	2020	achieve energy-neutral building[6]
Japan	2020	achieve net-zero-energy building by 2020 in new commercial buildings and 2030 in all new buildings
United States	2030	achieve net-zero-energy building in new federal buildings

[1] *A net-zero-energy building (NZEB or ZNB) is defined differently in different countries. In general, such a building is an energy-efficient structure that consumes no more energy than can be supplied by on-site renewable technologies. Some definitions also specify that a net-zero-energy building not add to greenhouse gas emissions (sometimes called a "zero-carbon building"). If an NZEB/ZEB consumes non-renewable resources during some periods, it must reduce energy consumption (and greenhouse gas production) by an equal amount at another time so that the building causes no net increase in either category.*

[2] *A passive house is an ultra-low-energy-consuming building designed to meet a specific energy-efficiency standard. Passive house standards can apply to non-residential buildings.*

[3] *A nearly-zero-energy building (nZEB) is defined by the European Union similarly to a net-zero-energy building as described above: a nearly-zero-energy building requires a small amount of energy that can be supplied by energy from renewable sources, including those produced on-site or nearby.*

[4] *A positive-energy building produces more energy than it consumes.*

[5] *A zero-fossil-fuel-consumption building operates without the need for fossil fuel.*

[6] *An energy-neutral building produces the same amount of energy that it consumes.*

Improvement Program (BEEIP). BEEIP aims to develop a BEEIR based on scientific research. This paper focuses on the development of the BEEIR for China's commercial-building sector.

Research activities

The research described here was organized and conducted by MOHURD in support of developing a BEEIR. To ensure scientific objectivity, the activities got a number of Chinese research institutes and experts involved. Core members of the BEEIP research team were government officials with experience in energy efficiency of buildings, academics involved in cutting-edge building efficiency works, and doctoral candidates who helped perform surveys and analysis. Research participants were chosen based on their experience, knowledge, and reputation and included institutions, individual experts, government departments, and market actors. The research process was divided into three stages: preparation, which included a literature review and formulation of a framework for the subsequent activities; surveys of institutions, which entailed development and administration of questionnaires to determine the current status of energy-efficiency activities and planning; and a Delphi process entailing two rounds of surveys of an expert panel. Figure 1 is a schematic representation of the research process phases. Each phase of the research is further defined in the following subsections.

A key goal of this research program was to comprehensively forecast future energy use. Because data to support such forecasts are currently lacking, the project sought to obtain needed information using extensive surveys of both institutions and experts.

RESEARCH PREPARATION STAGE

The primary tasks during the research preparation stage were to clarify the research goals and define the research framework. The BEEIP research team carried out a comprehensive literature review and held workshops to develop the basic research framework. A few key experts were interviewed in depth to help refine the framework. The framework was confirmed during several meetings involving the research team and experts.

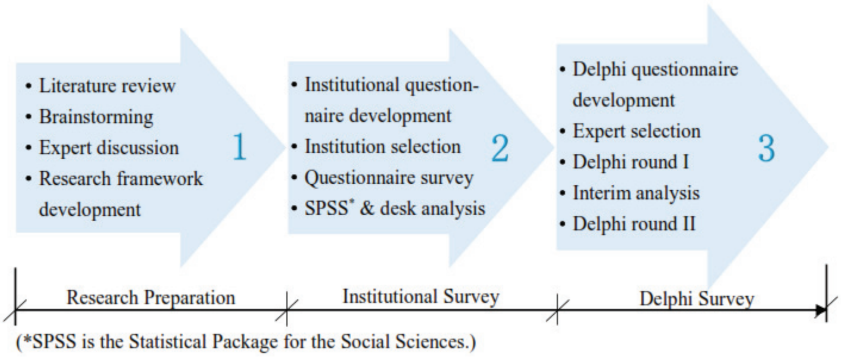

Figure 1. Stages in research supporting development of China's BEEIR.

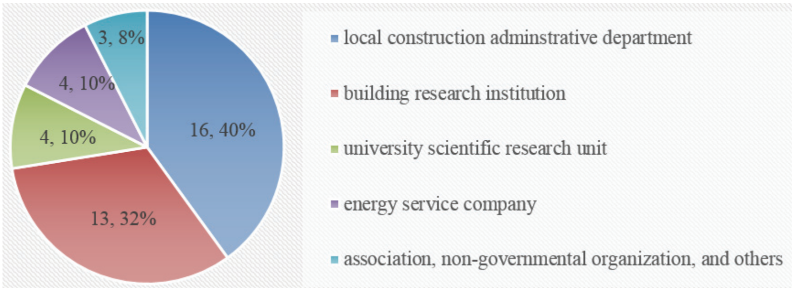

Figure 2. Institutional survey participants, by type.

INSTITUTIONAL QUESTIONNAIRE STAGE

During the institutional questionnaire stage, the research team designed and administered a semi-structured survey for collecting data and suggestions about energy efficiency in buildings. The questionnaire had two parts. The first asked for basic information about the respondent: type of entity, location, business area or research field related to building energy efficiency, etc. The second section was designed to elicit the respondent's BEEIR vision, support system for energy efficiency, and other relevant factors. For the BEEIR vision, respondents were invited to fill in their roadmaps, including time schedule and energy-efficiency targets. In regard to support systems and influential factors, respondents were invited to indicate the level of importance of specific elements, such as policy system, technology system etc. The level of importance is measured on a 5-point Likert scale,[2] where 1 is extremely unimportant, 2 unimportant, 3 neutral, 4 important, and 5 extremely important. Most questions presented pre-determined choices along with a blank where respondents could fill in additional options, comments, and suggestions. Figure 2 shows the participants in the institutional questionnaire phase of the research, by type.

The selection of institutional participants was a complicated, comprehensive process based on candidates' professionalism, experience, reputation and influence, capabilities, entity type, location (in regard to both climate and economic circumstances), and other factors. Eventually, with organization by MOHURD, 40 institutions with commercial buildings were selected. As shown in Figure 2, local construction industry administrative departments account for 40 % of the total institutional participants because these are the main entities that implement central government building energy-efficiency policies and are most familiar with local policies. Building research institutions represent approximately 32 % of the survey participants because they are the professional entities that conduct research, design, consulting, and other activities related to building energy efficiency in China.

The questionnaire was sent to the institutional participants by email, and completed questionnaires were returned two weeks later. The team analyzed the questionnaire responses using the Statistical Package for the Social Sciences (SPSS). Based on the results from the institutional questionnaire, the team developed the first round of Delphi questionnaires, described in the following subsection.

DELPHI QUESTIONNAIRE STAGE

The third stage of research used the Delphi method, which systematically develops consensus among experts regarding projected future developments and events. This judgmental forecasting procedure utilizes an anonymous, written, multi-stage survey process in which feedback regarding the group's opinion is provided after each round (Delbecq et al. 1986, Linstone et al. 1975, Rowe et al. 2001). We conducted two Delphi surveys, with one feedback report and opportunity for revision of first-round answers between the two survey rounds. This approach was designed to minimize research fatigue and ensure a high response rate and validity of data (Mitchell et al. 1991). Research has shown that survey participants' opinions usually change over time and that the most reliable study results

2. A Likert scale is a psychometric scale commonly involved in research that employs questionnaires. It is the most widely used approach to scaling responses in survey research. The format of a typical five-level Likert item, for example, could be: 1 – strongly disagree; 2 – disagree; 3 – neither agree nor disagree; 4 – agree; 5 – strongly agree.

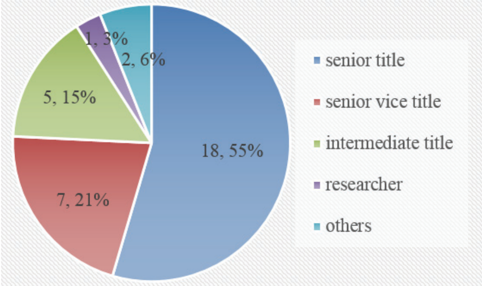

Figure 3. Delphi survey participants by job title.

are often obtained after the first iteration (Rowe et al. 1991, Woudenberg et al. 1991). Figure 3 shows the job titles of the Delphi survey participants.

The first-round Delphi questionnaire was developed based on analysis of the results of the prior research, including the institutional questionnaire results. This questionnaire focused specifically on the BEEIR roadmap, using an indicator system and suggested solutions. The level of importance of the indicators was assessed using five-point scale.

Criteria used to select the Delphi panel of experts included professionalism, experience, reputation and influence, capability, and other related factors. The number of experts on a Delphi panel can vary from 10 to 50, with the primary consideration being that the panel should be sufficiently large to allow the patterns of response to be clearly seen but not so large that complication and disagreement are likely to result among panel members (Rowe et al. 2011). The Delphi panel for this research had 33 members, most of whom were leading Chinese experts in energy efficiency of buildings, including professionals and well-respected local experts from academia/universities, the government, and industry.

The questionnaires were sent out, returned, and analyzed in the same manner as for the institutional survey. Based on an interim analysis of the Delphi panel's first rounds of feedback, the research team repeated the questionnaire design process to produce the second questionnaire, followed by the same subsequent steps as for the previous round. A separate experts' meeting was held for the final survey results. The results are described in the next section of this paper.

Results and discussion

FACTORS AFFECTING THE BEEIR

Based on information from the research preparation phase, the research team created institutional survey questions related to five overarching factors affecting the BEEIR: technology, economy, market, capacity, and policy. Figure 4 shows the degree of change in the influence of each five factor on the BEEIR in the short and long term, according to the result of the institutional survey.

The degree of each factor's importance was assessed using a scale of 1–5 points where 1 signifies the least important and 5 the most. Figure 4 shows that the mean value of the five factors is high and does not change significantly from the short term (2016–2020) to the long term (2020–2030). This indicates that all five factors remain influential through 2030. However, the priority order of the factors changes. In the short term, policies are the most influential factor, and the market is the least influential. In the long term, the result is the opposite; the market system becomes the most influential factor with a 4.38 mean value, and policies are the least important with a 3.98 mean value. The mean value of the other three factors changes, but only slightly. For example, the mean value of technology decreases from 4.13 in the short term to 4.03 in the long term. This indicates that technology is an important factor for the BEEIR through the year 2030.

The result that stands out is the shift in influence from policy support in the short term to market mechanisms in the future. In the near term, supporting policies are needed to cultivate the commercial-building energy-efficiency market in China. However, once the market is mature, the government should gradually withdraw from the market.

Figure 5 shows that all of the types of institutions participating in the survey give similar assessments of the five factors' short-term influence on the BEEIR. However, their assessments of long-term influence differ. In the long-term perspective, government departments focus more on technology and market factors, research institutions focus more on economics, and the other institutions place more emphasis on policy and capacity factors. These differing views are a result of the different roles that these entities play in the market system and their differing goals and resources. A sound commercial building energy-efficiency market should fully motivate all of these diverse entities to participate and cooperate.

THE ROADMAP

As the research progressed, the team formulated a time schedule for mid- and a long-term development of China's BEEIR during the period 2016 to 2030 (shown in Figure 6).

The initial state of the BEEIR was set in 2016, the intermediate state in 2020, and the BEEIR vision was projected to be achieved in 2030. The research team determined that 15 years was a suitable time frame, neither too short nor too long and appropriately segmented to correspond to the Five-Year Plan (FYP) intervals and government transitions. The initial state was set in 2016 to synchronize with the start of the 13th FYP and to allow for one year's preparation from the time the research was completed. The intermediate state is set in 2020, which corresponds to the start of the 14th FYP.

Tables 2 through 5 present the detailed energy-efficiency standards for new and existing commercial buildings based on the institutional and Delphi survey responses for each of the BEEIR milestone years.

Survey results for new commercial buildings

Table 2 shows the survey results regarding appropriate BEEIR efficiency levels for new commercial buildings in the target years. The final results from round 2 of the Delphi survey are as follows:

- In 2016: 1) the latest energy efficiency design standard should be implemented, which is 62 % more efficient than 1980s' building energy performance baseline; 2) government office buildings and all large (floor area $\geqslant$ 20,000 m^2) commercial buildings in all types should meet at least the Green Building (GB) one-star level.

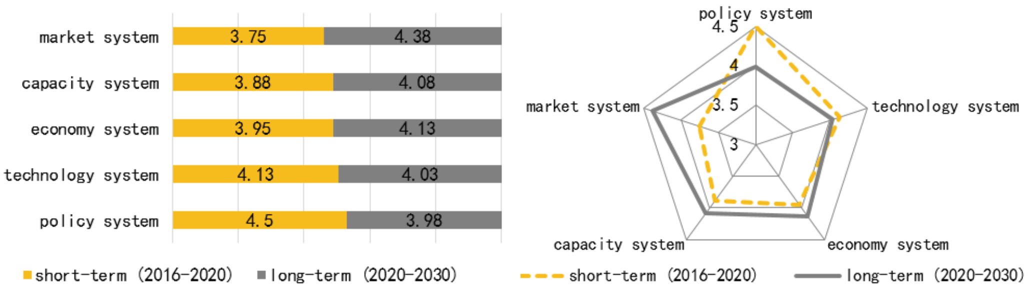

Figure 4. Short- and long-term influence of five factors on the BEEIR.

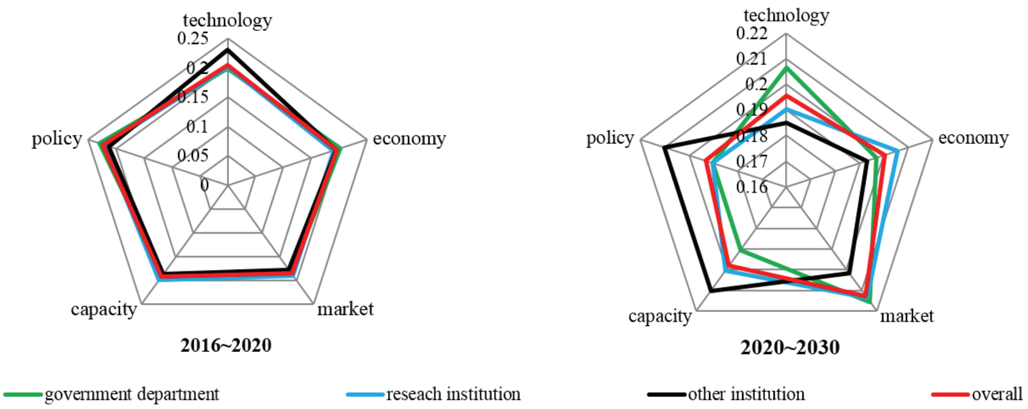

Figure 5. Weighting of factors affecting the BEEIR, as assessed by different types of institutions.

Figure 6. Three phases of China's BEEIR (2016–2030).

- In 2020: 1) all new commercial buildings should consume 20 % less energy than the 2016 baseline (about 70 % more efficient than 1980s' baseline); 2) renewable energy should supply no less than 10 % of total building energy consumption; 3) heating, ventilation, and air conditioning (HVAC) energy consumption should be 30 % less than the 2016 baseline; 4) all commercial buildings with floor area ⩾ 5,000 m² should meet current minimum GB requirements.
- In 2030: 1) all new commercial buildings should use 30 % less energy than the 2020 baseline (about 79 % more efficient than 1980s' baseline); 2) renewable energy should supply at least 20 % of total building energy consumption; 3) buildings should achieve an nZEB target of HVAC site energy consumption ⩽ 15 kilowatt hours per square meter times per year (kWh/m²•a), which is equivalent to 5.7 kilograms coal equivalent (kgce); 4) all commercial buildings with floor area ⩾ 2,000 m² should meet current minimum GB requirements.

Table 2 also shows how efficiency targets evolved over the course of the three surveys:

- The energy-efficiency improvements to be achieved by the BEEIR evolved as the questionnaire process unfolded. In the first (institutional) questionnaire, energy-efficiency improvement elements were included for the year 2016 only, and GB requirements were mentioned for the years 2016 and 2020 but not after. As a result of the responses to the Delphi questionnaires, the research team developed the milestone years of 2016, 2020, and 2030 for phased achievement of the BEEIR vision. The Delphi panel increased the design requirements of the standard in 2016 and implemented GB requirements based on building size for the years 2020 and 2030. And they set the energy-savings requirements for both 2016 and 2030 as well.
- As the process progressed, renewable-energy requirements were incorporated starting in 2020, and targets for the per-

Table 2. Survey results – efficiency levels for new commercial buildings in target years 2016–2030.

Year	BEEIR new commercial-building energy-efficiency improvement targets		
	Institutional Survey	Delphi survey round 1	Delphi survey round 2
2016	62 % energy-efficiency design standard; GB★*	65 % energy-efficiency design standard; GB★	Latest energy-efficiency design standard (GB 50189-2015, 62 % energy efficiency); GB★ in government public buildings & large (floor area ≥ 20,000 m^2) commercial buildings.
2020	GB★★*	75 % energy-efficiency design standard; GB★★	Reduce energy consumption based 20 % compared to 2016 (about 70 % more efficient than 1980s' baseline); renewable energy supplies no less than 10 % of total building energy consumption; HVAC** energy consumption decreased 30 % compared to 2016 baseline; All commercial buildings with floor area ≥ 5,000 m^2 should meet current minimum GB standards.
2030	Nearly-zero-energy building (nZEB)	HVAC energy consumption ≤ 15 kWh/m^2·a (≈ 5.7 kgce)	Reduce energy consumption 30 % compared to 2020 (about 79 % more efficient than 1980s' baseline); renewable energy supplies no less than 20 % of the total building energy consumption; achieve nZEB*** level with HVAC site energy consumption ≤ 15 kWh/m^2·a (≈ 5.7 kgce); All commercial buildings with floor area ≥ 2,000 m^2 should meet current minimum GB standard requirements.

** GB: Green Building. GB★ is the Chinese GB standard lowest (one-star) of the standard's three levels, and GB★★ is the middle level.*
*** HVAC: Heating, ventilation, and air conditioning*
**** nZEB: Nearly-zero-energy building*
Site energy consumption 15 kWh/m2·a ≈ 5.7 kgce, is converted using the 2013 electricity consumption baseline.

centage of building energy consumption to be supplied by renewable energy were established for 2020 and 2030.

- The roadmap toward full implementation of the BEEIR was improved during the course of the surveys. Concepts for progressive efficiency improvements that emerged during the process included transitioning from energy-efficiency improvements in single buildings to improvements in whole urban areas, transitioning from simply conserving energy to more proactive green and ecological strategies, and transitioning from "shallow" to "deep" green building characteristics. In addition, to the key target of a near-zero-energy building was gradually refined to target HVAC energy consumption near zero in 2030, with an advanced HVAC energy consumption level below 15 kWh/m^2•a.

Survey results for Existing commercial buildings

Table 3 shows the final BEEIR targets for existing commercial buildings:

- In 2016: a commercial-building energy-consumption quota should be established that represents a reasonable benchmark energy intensity or performance for each region in China.
- In 2020: 1) existing commercial buildings should reduce their energy consumption by 20 % compared to 2016 energy use; 2) all whole-building retrofit projects should include green-update elements and meet the current energy consumption requirements; 3) in all partial retrofit projects, the retrofitted building elements should meet regional commercial-building energy-efficiency design standards.
- In 2030: 1) existing commercial buildings should reduce their energy consumption by 50 % compared to 2016 energy use (equal to 35 % compared to the 2020 quota); 2) whole-building retrofit projects should include green-update elements and meet the current energy consumption requirements; 3) in all partial retrofit projects, the retrofitted building elements should meet regional commercial-building energy-efficiency design standards.

In Table 3, we can also see how energy-efficiency targets evolved during the three rounds of surveys:

- The BEEIR roadmap was enhanced. In the institutional questionnaire stage, no concrete energy-efficiency targets or accounting methods were identified; only elements of energy-efficiency improvements were given. Following the Delphi surveys, the roadmap was refined to include energy-consumption reductions of 20 % in 2020 and 50 % in 2030, compared to the 2016 commercial-building energy-consumption quota. In addition, climate zone and economic conditions were taken into consideration when these quotas

Table 3. Survey results – efficiency levels for existing commercial buildings in target years 2016–2030.

Year	BEEIR existing commercial-building energy-efficiency improvement targets		
	Institutional Survey*	Delphi survey round 1*	Delphi survey round 2
2016	10 % energy-efficiency improvement	20 % energy-efficiency improvement	Establish regional commercial-building energy-consumption quotas.
2020	20–30 % energy-efficiency improvement	40–50 % energy-efficiency improvement	Reduce energy consumption by 20 % compared to 2016 quota; Implement green updates in whole-building retrofits & meet current energy-consumption quota; Implement regional commercial-building energy-efficiency design standards in partial retrofits.
2030	Implement green update	70 % energy-efficiency improvement; implement green update	Reduce energy consumption by 50 % compared to 2016 quota (35 % decline compared to 2020 quota); Implement green updates in whole-building retrofits & meet current energy-consumption quota; Implement regional commercial-building energy-efficiency design standards in partial retrofits.

** For existing commercial buildings, the energy-efficiency improvement baseline for columns 2 (institutional survey) and 3 (Delphi survey round 1) is the energy performance before retrofit.*

were defined as proportions of prior energy consumption rather than as fixed values.

- The specific content of energy-efficiency improvements was elaborated over the course of the surveys. In the institutional questionnaire stage, there were no separate targets for whole-building and partial retrofits. Because partial-retrofit energy consumption is difficult to calculate, and it is difficult to meet energy-efficiency requirements through partial retrofits, the Delphi panel proposed separate targets for whole-building and partial retrofits. Whole-building retrofits are required to achieve the current energy-consumption target. Partial retrofits are required to implement the current regional new commercial-building energy-efficiency design standard. This allows for existing commercial-building retrofits to be customized to local conditions.
- Green building requirements were strengthened for existing commercial buildings over the course of the surveys. The requirement to include green updates was set for 2020 and 2030 in the institutional questionnaire; as a result of the Delphi process, the requirement was moved earlier, to 2016. This requirement is consistent with the requirement for new commercial buildings and will promote the development of green buildings.

PERFORMANCE INDICATORS

Performance indicators are important for defining and quantifying the progress toward meeting the BEEIR goals. Influenced by the Chinese GB rating, we developed an indicator system that encompasses not only energy consumption but also other green and ecological elements (the GB rating includes not only energy efficiency but also water and materials efficiency, indoor environment enhancement, and waste reduction). We organized these elements into three categories: healthy and comfortable quality of life, least resource consumption, and minimal environmental impact. They were further broken down into sub-indicators with specific values that become increasingly strict from 2020 to 2030.

The year 2020

The final series of indicators for the BEEIR intermediate state in 2020 is shown under Delphi round 2 in Table 4. This series of indicators evolved over the course of the surveys as follows:

- The original indicators became increasingly specific with each survey. For example, the initial value of the indicator "indoor temperature and humidity" on the institutional questionnaire was simply the phrase "appropriate indoor temperature and humidity". This description was elaborated during the course of the surveys, with different energy requirements for China's three major climate zones (cold and severe cold, hot summer and cold winter, hot summer and warm winter). Another important improvement was the addition of the indicator "new & renewable energy utilization". The criteria for this indicator were set as "regions that have accessible renewable energy resources should develop and use them; in these areas renewable energy should supply more than 10 % of total building energy consumption". This indicator not only provides a target for the overall goal of renewable energy use, it also provides an implementation plan and accounting methods.
- Several important indicators were added. For example, in the "least resource consumption" category, three indicators were added: building energy-efficiency level, non-tradi-

Table 4. BEEIR status indicators for 2020 (intermediate stage).

	The year 2020		Institution survey		Delphi round 1		Delphi round 2	
Field	Indicator	Value	A*	B*	A	B	A	B
Healthy and comfortable quality of life	Indoor temperature and humidity	Cold and severe cold zone: the average temperature in winter should be about 20 °C, temperature in summer not higher than 26 °C, and the relative humidity 40 %–60 %.	—	—	■	■	■	■
		Hot summer and cold winter zone: temperature in winter not lower than 18 °C, temperature in summer not higher than 26 °C.	—	—	■	■	■	■
		Hot summer and warm winter zone: temperature not higher than 26°C year round.	—	—	■	■	■	■
	Indoor acoustic environment	Window closed: ≤ 45 dB (daytime); & ≤ 35 dB nighttime).	■	■	■	■	■	■
	Indoor lighting environment	Meet standard for lighting design of buildings (GB 50034-2013)	■	■	■	■	■	■
	Indoor air quality	Meet code for indoor environmental pollution control of civil building engineering (GB 50325-2010); CO_2 concentration ≤ 1,000 PPM.	■	■	■	■	■	■
	Public facilities	Elevator, fire control, accessibility, etc.	■	■	■	■	■	■
Least resource consumption	Building energy-efficiency level	Meet year-2020 BEEIR requirements.	—	—	—	—	■	■
	Non-traditional water utilization	≥ 30 %	—	—	—	—	■	■
	Waste-heat utilization	Can be counted as alternative to conventional energy and calculated into energy savings.	—	—	—	—	■	■
	HVAC energy consumption	< 15 kWh/m^2•a	■	—	—	—	—	—
		< 60 kWh/m^2•a	—	—	■	—	■	—
	Circulating-water utilization	> 50 %	■	—	■	—	■	—
	New & renewable-energy utilization	In regions with accessible renewable-energy resources, renewable energy utilization ratio ≥ 10 % of total building energy consumption.	—	—	—	—	■	■
		In regions with accessible renewable-energy resources, renewable energy utilization ratio ≥ 12 % of the total building energy consumption.	■	—	■	—	■	—
Minimal environmental impact	Carbon-emissions baseline	Establish carbon-emissions baseline of commercial-building sector.	■	—	■	—	■	■
	Construction-waste recycling	≥ 30 %	—	—	—	—	■	■
	Harmful substances emissions		■	■	■	—	■	—

**"A" is the new-commercial-building sector; "B" is the existing-commercial-building sector.*

tional water utilization, and waste-heat utilization. These indicators increase the types of renewable energy that can be incorporated into buildings to reduce overall fossil-fuel consumption and place emphasis on use of water resources. In the second round of the Delphi survey, the indicator "construction-waste recycling" was added to the category "minimal environmental impact." This indicator constrains the emissions associated with building construction and demolition.

- Infeasible elements of the original formulation of the BEEIR were amended during the course of the surveys. For instance, on the institutional survey, the original value of the indicator "HVAC energy consumption" under the "least resource consumption" category was 15 kWh/m^2•a in 2020. The Delphi panel experts thought this level was too ambitious to achieve in 2020, both technologically and managerially. They suggested adjusting the value to 60 kWh/m^2•a in 2020, and then decreasing step by step

Table 5. BEEIR status indicators for 2030 (vision stage).

	The year 2030		Institution survey		Delphi round 1		Delphi round 2	
Field	Indicator	Value	A*	B*	A	B	A	B
Healthy and comfortable quality of life	Indoor temperature and humidity	Same as 2020 (Table 4).	—	—	■	■	■	■
	Indoor acoustic environment	Same as 2020 (Table 4).	■	■	■	■	■	■
	Indoor lighting environment	Same as 2020 (Table 4).	■	■	■	■	■	■
	Indoor air quality	In addition to contents shown in Table 4, daily average PM2.5* concentration ≤ 30 micrograms per cubic meter.	■	■	■	■	■	■
	Public facilities	Same as 2020 (Table 4).	■	■	■	■	■	■
Least resource consumption	Building energy-efficiency level	Meet BEEIR year-2030 requirements.	—	—	—	—	■	■
	Non-traditional water utilization	≥ 50 %	—	—	—	—	■	■
	Waste-heat utilization	Same as 2020 (Table 4).	—	—	—	—	■	■
	HVAC energy consumption	≈ 0	—	—	■	—	—	—
		< 15 $kWh/m^2 \cdot a$	—	—	■	—	■	—
	Circulating-water utilization	Same as 2020 (Table 4).	—	—	■	—	■	—
	New & renewable-energy utilization	In regions with accessible renewable energy resources, renewable energy utilization ratio ≥ 20 % of the total building energy consumption.	—	—	—	—	■	■
		Use more renewable energy than 2020.	■	—	—	—	—	—
		Renewable-energy utilization ratio ≥ 30 % of total building energy consumption.	—	—	■	—	■	—
Minimal environmental impact	Carbon-emissions baseline	Decrease carbon emissions baseline 20 % based on 2020.	—	—	—	—	■	■
	Construction-waste recycling	100 %	—	—	■	—	■	■
	Harmful substances emissions	≈ 0	■	—	■	—	■	—

"A" is the new-commercial-building sector; "B" is the existing-commercial-building sector; PM2.5 is 2.5-micron particulate matter.

to 15 $kWh/m^2 \bullet a$ and even 0 by 2030. Furthermore, the indicator "harmful substances emissions" under the "minimal environmental impact" category was present on the institutional survey, but Delphi survey results suggested that this indicator only relates to the construction phase of new buildings and is not applicable to existing commercial buildings, so we deleted this indicator for existing commercial buildings.

The year 2030

Table 5 shows the targets for the indicators in the year 2030. Most of the changes in these targets during the course of the surveys are similar to those described in the above analysis for the year-2020 indicators. The 2030 indicators fall into two categories: indicators that are identical to those in 2020, and those that are upgraded in relation to the 2020 values.

Indicators that are identical to those in 2020 are shown in blue shading in Table 5. Some of these indicators did not change because the most appropriate value was achieved in 2020, so there was no need to further improve. This applies, for example, to indoor temperature and humidity, indoor acoustic environment, indoor lighting environment, and public facilities. Other indicators did not change from 2020 to 2030 because it would be difficult to achieve a higher level than that defined for 2020. Waste-heat utilization and circulating-water utilization belong to this category.

The second category comprises indicators whose values increased from those in 2020, or that were not included in 2020. These indicators are shown in green shading in Table 5. An example of an additional indicator that was not included in 2020 is the daily average PM2.5 concentration of $\leqslant 30$ ug/m^3 under the category "indoor air quality" in 2030.

Conclusions and recommendations

At the end of 2014, the three BEEIP surveys described in this paper were complete, and the basic outline of a BEEIR for Chinese commercial buildings had been developed. After additional analysis, the BEEIR will be issued by the government within 2015.

The BEEIR contains three milestones: the baseline status of commercial building energy efficiency in 2016, an intermediate more efficient status in 2020, and full achievement of the BEEIR vision in 2030. Having this long-term roadmap is a big step forward for the commercial building energy-efficiency industry in China. The BEEIR's outline of the future direction for commercial building energy efficiency sends a signal to Chinese industries to improve their capacities and upgrade technologies and materials to meet the BEEIR standards.

Our research developed two indicator systems to help quantify progress under the BEEIR. Influenced by the Chinese green building concept, the indicator systems address not only energy efficiency but also water efficiency, materials efficiency, indoor environmental quality, and other related areas. By addressing taking in all of these elements, the Chinese BEEIR is more comprehensive and environmentally friendly than other countries' BEEIRs that only concentrate on energy efficiency. However, these additional elements mean that China's BEEIR will be much harder to implement than other countries' BEEIRs because many elements in addition to energy efficiency must be addressed. China's BEEIR will only be fully implemented and its goals realized with the cooperation of the government departments related to the various areas of focus.

The five factors on which the BEEIR development focused – technology, economy, market, capacity, and policy – represent the five key systems needed to support commercial-building energy-efficiency improvements. The assessment of the influence of these factors that was undertaken as part of this research indicated that all five factors are influential in both the short and long term. This indicates that China needs to comprehensively strengthen these five elements to provide robust support for the BEEIR.

Although China's BEEIR is based on a solid foundation of scientific research, it is inevitable that some improvement and adjustments will be needed in response to future conditions. However, the focus should remain on achieving high-level efficiency in buildings, based on ecological concepts.

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