Evaluation of Energy Savings of the New Chinese Commercial Building Energy Standard

Wei Feng, Ke Huang, Mark Levine and Nan Zhou, Lawrence Berkeley National Laboratory
Shicong Zhang, Lawrence Berkeley National Laboratory and China Academy of Building Research

ABSTRACT

China consumed roughly 30% primary energy in its building sector in 2010. While U.S. energy consumption is primarily by existing buildings, new construction is the main driver of China's commercial building energy use. From 1996 to 2008, the total floor space of commercial buildings increased from 2.8 billion m^2 to 7.1 billion m^2. Currently, approximately 0.5 billion m^2 of new commercial building floor space is built every year. China issued its own standards for commercial (public) buildings (GB50189) in 1993, with an initial emphasis on reducing energy consumption in hotels. After that, the standards were revised to include other commercial building types. The last update, in 2005, mandated that commercial buildings be 50% more efficient than a baseline defined by 1980s building characteristics. The new 2014 update anticipates that new commercial construction will be 65% more efficient than the previous baseline.

This paper compares the difference between the new 2014 update and the previous 2005 version. To understand the energy performance of code-compliant buildings, and to calculate savings under the new commercial standard, we modeled a few Chinese office reference buildings in representative Chinese climate regions. The Chinese reference buildings were developed using common Chinese building systems and characteristics described in the 2005 and 2014 building standards. Simulation analysis was conducted to compare the energy savings of the 2014 standard with previous versions and ASHRAE 90.1 performance. Finally, recommendations are provided for revising and improving the new standard.

Keywords

- Energy efficiency
- Commercial buildings
- Building energy standard
- Reference building
- Simulation

Introduction

Globally, 35% of all energy used in buildings occurs in the United States and China. In developed and undeveloped countries, energy use in commercial buildings is predicted to increase by 0.9% and 2.7% per year respectively, from 2007 to 2035 (EIA, 2010). China has surpassed the United States to become the world's largest energy consumer and greenhouse gas (GHG)-emitting country. China has roughly 10 billion m^2 of commercial building stock, with an annual new construction rate of 0.5 billion m^2. The Chinese government has developed comprehensive policies to address energy efficiency in commercial buildings. Upgrading the commercial building energy standard is a government policy that has received wide attention.

China issued its own standards for commercial (public) buildings, GB50189, in 1993, with an initial emphasis on reducing energy consumption in hotels. After that, the standard was revised to include other commercial building types. The last update, in 2005, mandated that commercial buildings be 50% more efficient than a baseline defined by 1980s building characteristics[1] (Ministry of Housing and Urban Rural Development [MOHURD] 2005). The current 2014 update (MOHURD 2014) mandates that new commercial construction be 65% more efficient than that baseline, or 30% more efficient than the 2005 standard. Policymakers and standards developers are emphasizing this 65% efficiency goal, but energy-savings evaluation and validation have not yet been studied for the new standard. In addition, while previous studies (Huang and Deringer 2007, Hong 2009, Evans 2010) have compared measures of Chinese and U.S. standards, few studies compared the measures' improvement as well as the performance of Chinese commercial building energy standards in contrast to ASHRAE 90.1.

To quantify the energy performance of the new Chinese commercial building standard (GB50189), the authors developed a Chinese office reference building and used it to compare implementation of measures in the 2014 standard with measures in the 2005 standard. While the absence of a building standard in the 1980s makes it difficult to evaluate whether the 2014 update will save 65% over the baseline, this analysis allows evaluation of whether the 2014 standard will be 30% more efficient than the 2005 standard. In addition, the paper compares measures and energy performance of the 2014 standard with ASHRAE 90.1-2013 to identify further opportunities for improvement in the Chinese standard.

Methodologies

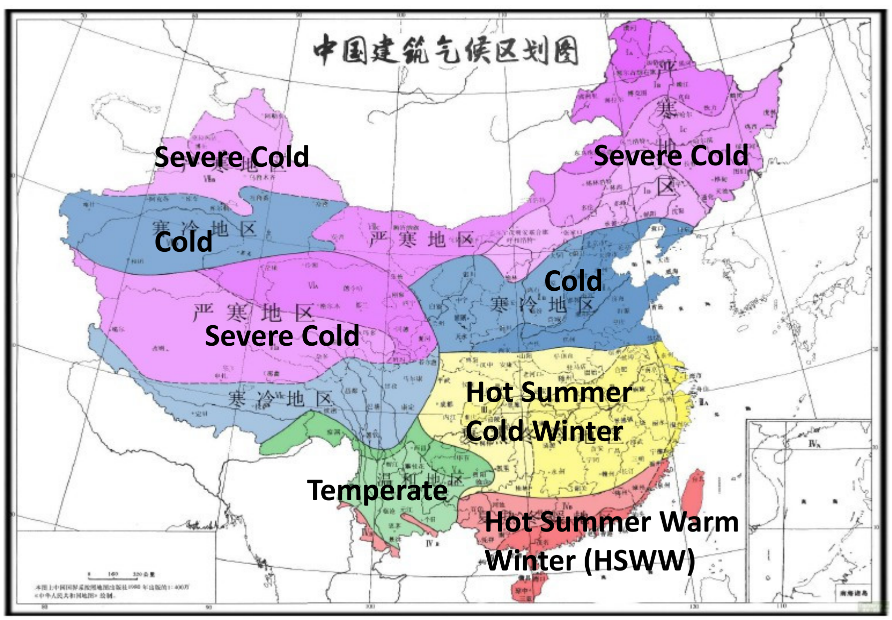

Figure 1. Chinese climate zones.

[1] The 1980s baseline assumes that buildings in China were constructed without rudimentary energy efficiency measures.

Measure Comparison

The first and foremost task required for comparing building energy standards is to understand the climate zone difference between China and the United States. As shown in Figure 1, China has five climate zones. In order to understand the difference between China and the United States, we compared Chinese climate zones with ASHRAE climate zones shown in Table 1 (Xu 2012).

We compared four main sections of the three building standards: wall and roof performance, fenestration requirements, chiller performance requirements, and lighting power density. The first two are dependent on climate zone, while the latter two are not. For climate-zone-dependent measures, we compared all Chinese climate zones with ASHRAE climate zones, but we only selected a single climate zone to demonstrate in this paper — the Chinese cold climate zone, which compares to U.S. climate zone 5.

The fenestration system comparison is showed in Table 2[2]. It is the first time China has used a Solar Heat Gain Coefficient (SHGC) in its building energy standards to replace the shading coefficient (SC), making the Chinese standards consistent with ASHRAE and international definitions. The new Chinese standard upgrades exterior window performance over the 2005 version. The Chinese standard defines exterior glazing's U value and SHGC based on a window-to-wall ratio (WWR) of from less than 20% to 100%. As such, it is difficult to compare directly with ASHRAE 90.1-2013, which has different values by framing type rather than by WWR. However, it is common in complying with ASHRAE 90.1 to prescribe exterior glazing properties under 40% and to use trade-off methods to calculate building energy performance if the WWR is higher than 40%. The developers of the Chinese standard stated that giving stringent U values and SHGC values at high WWR values does not exclude using trade-off methods; should a building fail to meet the window properties requirement, the trade-off method is still valid.

Table 3 shows the U value requirement of walls and roofs. It was found that the new Chinese standard has made a distinct improvement in building envelope thermal performance over the 2005 standard, but a significant gap still exists with ASHRAE standards in a similar climate region.

Chiller performance comparison is shown in Table 4. Compared with the 2005 standard, the new Chinese standard demonstrates significant improvement: higher Chiller minimum coefficient of performance (COP) and Integrated Part Load Value (IPLV) values for all types of chillers. However, the performance given by the new Chinese standard is still lower than values defined by ASRHAE 90.1-2013.

Requirements for lighting power density in the new Chinese standard have been improved compared with the 2005 standard, as shown in Table 5. In addition, for some building types, the maximum lighting power density values defined by the new Chinese commercial building energy are slightly lower than values defined by the Building Area Method in ASHRAE 90.1-2013.

Building Simulation

To assess the performance of the Chinese commercial building energy standards, we developed a few Chinese reference buildings (DOE 2010). The reference buildings were

[2] This paper uses SI units through all the analysis and comparison.

modeled using the measures defined by the 2005 and 2014 commercial building standards. Parameters such as a building's shape, number of floors, WWR, and HVAC system types were collected through our surveys of both existing buildings and design drawings of new construction from Chinese design institutes. Table 6 shows the characteristics of the Chinese reference office buildings, and Figure 2 shows the Chinese reference office building geometry. The Chinese office reference building has 18 floors and no basement. Each floor has four perimeter zones and one interior zone. The Chinese commercial building energy standards include suggested building operating conditions and schedules. Figure 3 shows the weekday occupancy, lighting, and plug load schedules. Cooling and heating setpoints for weekday schedules are shown in Figure 4.

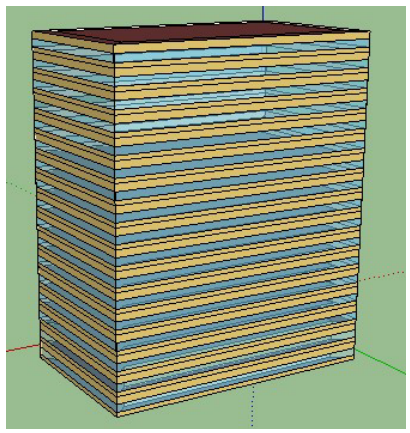

Figure 2. Chinese reference office building geometry.

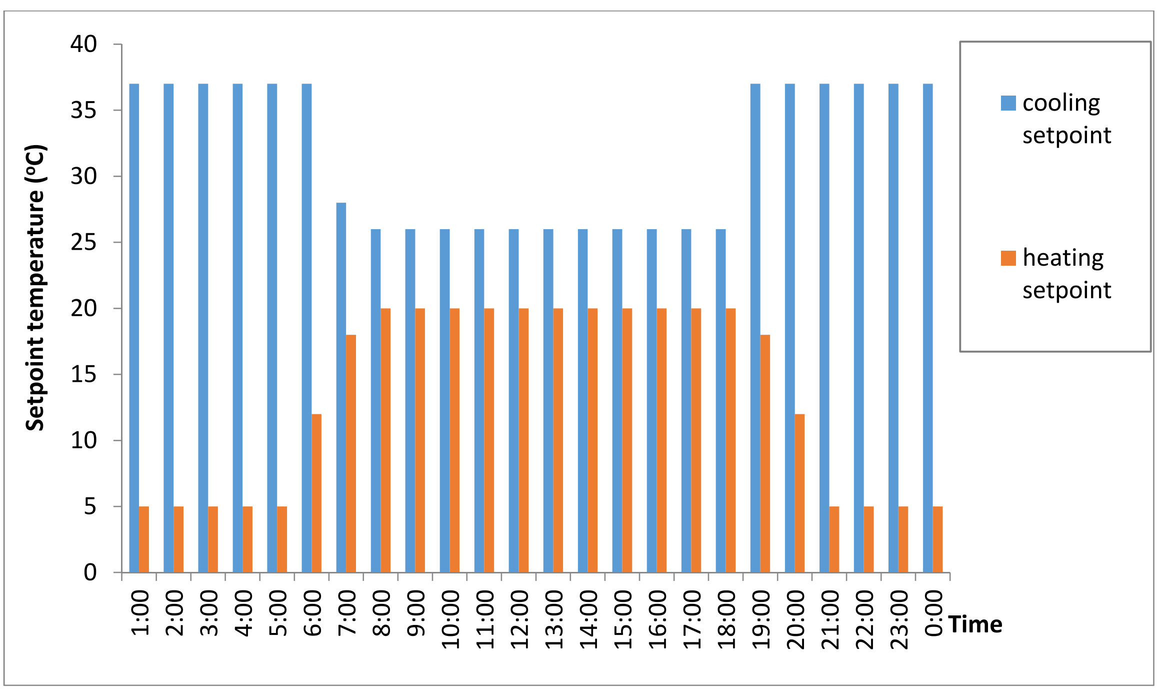

Figure 3. Cooling and heating setpoint temperatures for a typical weekday.

Buildings in China are controlled in "partial operation," in contrast with buildings in the United States, which usually are operated in a "continuous manner." Under this circumstance, the availability of heating and cooling plants in Chinese buildings is limited to certain operating periods. In Beijing, for example, a district heating system is only available from the middle of November to the middle of March the following year, a four-month period. Cooling is operated by a building's management team and usually is available only for a three-month period in summer, i.e., 6/1~8/31. The operation difference is captured in the Chinese reference building model. In addition, the cooling setpoint is higher than that of the reference buildings developed for the United States. All these features can result in lower energy consumption in Chinese commercial buildings compared with models using U.S. operating conditions. Reference office buildings were modeled in EnergyPlus in three representative Chinese cities: Beijing, Shanghai, and Guangzhou for 2005 and 2014 standards, based on the features described above.

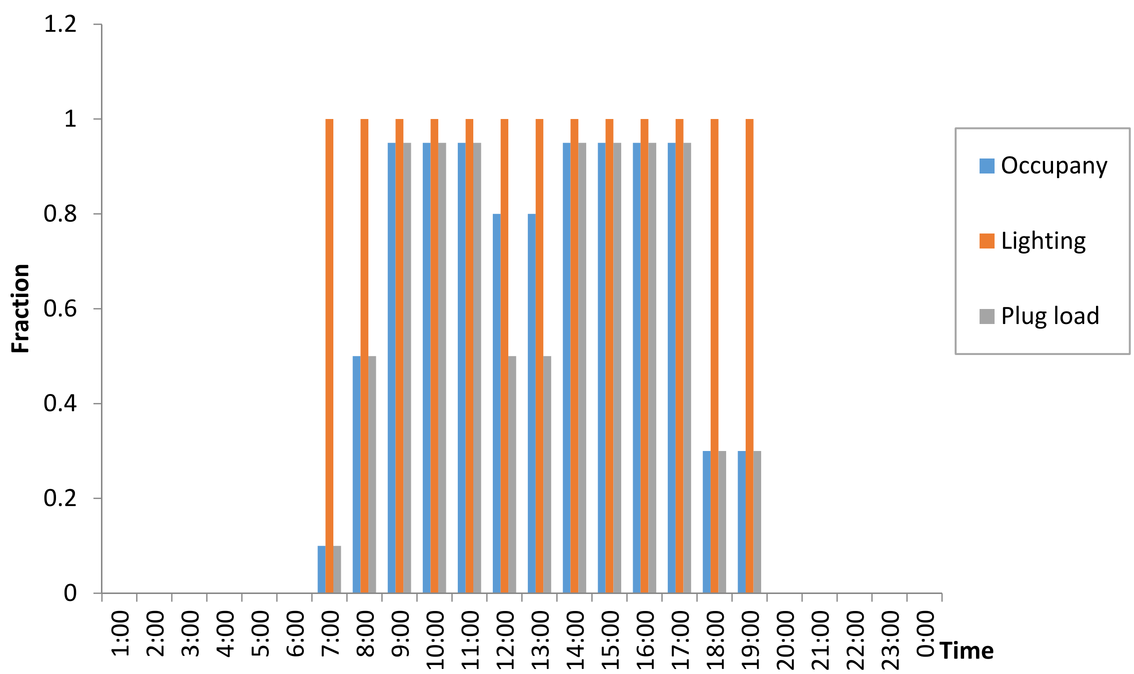

Figure 4. Occupancy, lighting and plug load schedules for a typical weekday.

Results

The simulated reference building performance is shown in Figure 5. Overall, the new standard has significantly improved energy performance compared with the 2005 version. Buildings in north China (e.g., Beijing) enjoy a 27% improvement due to energy savings from heating, cooling, lighting, plug load, etc. The performance improvement in transition (e.g., Shanghai) and warm (e.g., Guangzhou) climates are 23% and 24%, respectively.

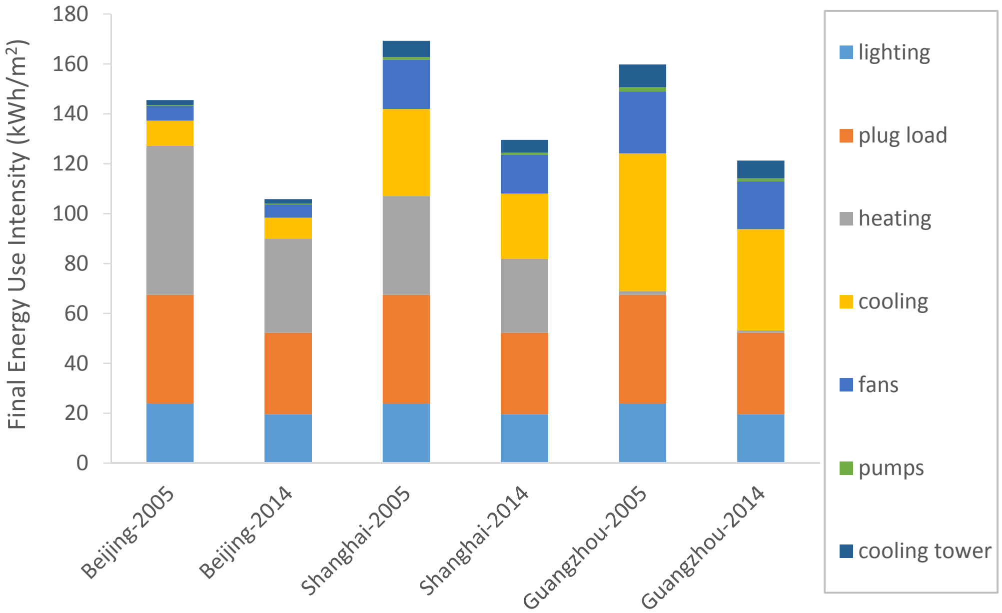

Figure 5. Energy performance of Chinese office reference buildings.

To calculate the Chinese national average values, we used weighting factors for office buildings in the north, transition, and south climate regions. On average, the new Chinese standard demonstrates an overall 25% energy savings over the 2005 version. It is slightly lower than MOHURD's 30% energy savings based on the 2005 standard. Compared to ASHRAE standard performance, calculated by using U.S. reference buildings (Tornton 2010, Liu 2012), the Chinese building standard performance is roughly 20% behind the performance of ASHRAE 90.1-2013. However, it has exceeded the performance of ASHRAE 90.1-2004. The weighted average office building performance is shown in Figure 6, compared with ASHRAE standards.

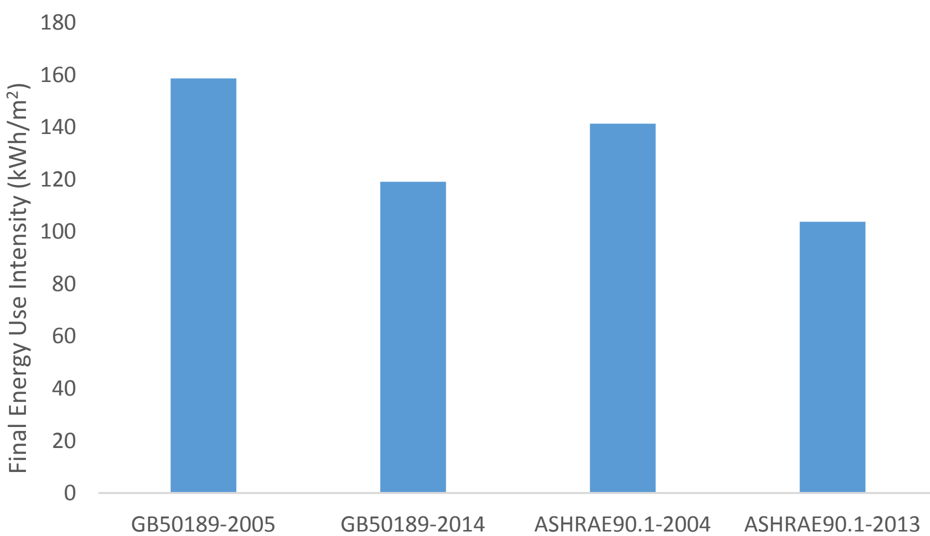

Figure 6. Office reference building energy performance comparison.

Discussion

Many factors affect the performance improvement of the new Chinese commercial building energy standard. The upgrade of building envelope measures has reduced heating energy by about 37% in North China (Beijing) office buildings. The decrease of the maximum allowable lighting power density results in an 18% lighting energy savings. The chiller performance upgrade, together with envelope performance increases, reduces cooling energy use by 26% in the warm climate region (Guangzhou).

Nonetheless, the new Chinese commercial building energy standard still exhibits a noticeable gap compared with ASHRAE 90.1-2013. Even though the performance of the simulated office reference buildings is only 20% higher than that calculated from ASHRAE standard, gaps can still be found in individual measures. In addition, the reference office buildings in China are operated using different thermal comfort criteria, and HVAC systems are only available during certain time periods. If Chinese reference buildings were operated and modeled similar to those in the United States, higher energy consumption would be expected, and thus there would be a larger gap with ASHRAE 90.1-2013.

Conclusion, Suggestion, and Future Work

This paper conducted a quantitative analysis of the new Chinese commercial building standard GB50189-2014. The measures of the new standard are compared with the previous version adopted in 2005 and the latest ASHRAE 90.1-2013. Chinese office reference buildings were developed to evaluate the energy performance of the new standard compared with the 2005 version. It was found that the new standard yields a 25% site energy savings over the previous version. Even though the savings are less than the 30% goal set by MOHURD (or 65% savings based on the 1980 standard), the new standard still demonstrates significant performance improvement.

The performance of the new Chinese commercial building standard is 20% behind ASHRAE 90.1-2013. Given that Chinese buildings are operated using different thermal comfort criteria, and cooling and heating plants are only partially available during the year, the actual energy consumption of the Chinese reference buildings would be higher if U.S. building operating conditions were used. To further improve performance under the Chinese commercial building energy standard, the following suggestions are given, based on lessons learned from the experience of ASHRAE 90.1:

- Further improve building envelope performance in severe cold, cold, and hot summer cold winter climate zones.
- Include measures to encourage shading and natural ventilation for buildings in hot summer and warm winter climate zones.
- Improve commercial buildings' air-tightness level.
- Include lighting control measures in the commercial building standard.
- Include air-side economizer requirements in the standard.
- Promote cool roof measures and encourage roof materials with high solar reflectance.
- Use appropriate measures to control chilled water temperature, supply air temperature, fan static pressure, hot water temperature, and so on.
- Encourage the installation of heat recovery devices in HVAC systems.
- Use demand-control ventilation.

This study only developed large office reference building models for different climate zones in China in representative cities such as Beijing, Shanghai, and Guangzhou. To gain a comprehensive understanding of the new standard's performance, models of more commercial building types — such as hotels, shopping malls, schools, and so on — in more cities should be developed. In addition, it is important to conduct cost-efficiency analyses for key measures in the new Chinese commercial building energy standard. Finally, in contrast to ASHRAE 90.1, which is updated every three years, the Chinese commercial building standard was implemented in 2005, and the newly proposed revision is expected to be effective by 2014, a nine-year period. Given the rapid urbanization process in China, more frequent updates are suggested for future energy standard developments.

Acknowledgement

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Table 1. Window characteristics comparison: US Climate Zone 5 and Chinese Cold Climate Zone

<table>
<tr><th rowspan="3"></th><th colspan="3">ASHRAE90.1-2013</th><th colspan="6">GB50189-2005</th><th colspan="6">GB50189-2014</th></tr>
<tr><th rowspan="2">Framing Type[3]</th><th rowspan="2">U</th><th rowspan="2">SHGC max</th><th colspan="3">S≤0.3</th><th colspan="3">0.3＜S≤0.4</th><th colspan="3">S≤0.3</th><th colspan="3">0.3＜S≤0.4</th></tr>
<tr><th>WWR</th><th>U</th><th>SHGC(E, S, W/N)[4]</th><th>WWR</th><th>U</th><th>SHGC(E, S, W/N)</th><th>WWR</th><th>U</th><th>SHGC(E, S, W/N)</th><th>WWR</th><th>U</th><th>SHGC(E, S, W/N)</th></tr>
<tr><td rowspan="8">Vertical Fenestration, 0%~40% of Wall</td><td>Nonmetal framing</td><td>1.82</td><td rowspan="8">0.4</td><td>≤0.2</td><td>3.5</td><td>-</td><td>≤0.2</td><td>3</td><td>-</td><td>≤0.2</td><td>3</td><td>-</td><td>≤0.2</td><td>2.8</td><td>-</td></tr>
<tr><td>Metal framing, fixed</td><td>2.38</td><td>0.2-0.3</td><td>3</td><td>-</td><td>0.2-0.3</td><td>2.5</td><td>-</td><td>0.2-0.3</td><td>2.7</td><td>0.52/-</td><td>0.2-0.3</td><td>2.5</td><td>0.52/-</td></tr>
<tr><td>Metal framing, operable</td><td>2.84</td><td>0.3-0.4</td><td>2.7</td><td>0.588/-</td><td>0.3-0.4</td><td>2.3</td><td>≤0.588/-</td><td>0.3-0.4</td><td>2.4</td><td>0.48/-</td><td>0.3-0.4</td><td>2.2</td><td>0.48/-</td></tr>
<tr><td rowspan="5">Metal framing, entrance door</td><td rowspan="5">4.37</td><td>0.4-0.5</td><td>2.3</td><td>0.50/-</td><td>0.5-0.5</td><td>2</td><td>≤0.50/-</td><td>0.4-0.5</td><td>2.2</td><td>0.43/-</td><td>0.4-0.5</td><td>2</td><td>0.43/-</td></tr>
<tr><td rowspan="2">0.5-0.7</td><td rowspan="2">2</td><td rowspan="2">0.42/-</td><td rowspan="2">0.5-0.7</td><td rowspan="2">1.8</td><td rowspan="2">≤0.42/-</td><td>0.5-0.6</td><td>2</td><td>0.40/-</td><td>0.5-0.6</td><td>1.8</td><td>0.40/-</td></tr>
<tr><td>0.6-0.7</td><td>2</td><td>0.35/ 0.60</td><td>0.6-0.7</td><td>1.8</td><td>0.35/ 0.60</td></tr>
<tr><td colspan="6" rowspan="2">N/A</td><td>0.7-0.8</td><td>1.8</td><td>0.35/ 0.52</td><td>0.7-0.8</td><td>1.6</td><td>0.35/ 0.52</td></tr>
<tr><td>0.8-1.0</td><td>1.5</td><td>0.30/ 0.52</td><td>0.8-1.0</td><td>1.4</td><td>0.30/ 0.52</td></tr>
<tr><td>skylight, 0%~3% of Roof</td><td colspan="2">2.84</td><td>0.4</td><td colspan="6">N/A</td><td colspan="6">N/A</td></tr>
</table>

[3] The Chinese commercial building energy standard defines exterior glazing's U value and SHGC based on the WWR value, while ASHRAE 90.1 defines U value based on different framing types.

[4] The GB50189-2005 standard used shading coefficient (SC). Here, we convert it to SHGC by multiplying a value of 0.87

Table 2. Wall and roof U value comparison: US Climate Zone 5 and Chinese Cold Climate Zone

U value (unit: $W/(K\ m^2)$)	ASHRAE90.1-2013		GB50189-2005		GB50189-2014	
			S≤0.3[5]	0.3＜S≤0.4	S≤0.3	0.3＜S≤0.4
roof	Insulation Entirely above Deck	0.184	0.55	0.45	0.45	0.4
	Metal Building	0.21				
	Attic and Other	0.119				
wall	Mass	0.513	0.6	0.5	0.5	0.45
	Metal Building	0.286				
	Steel Framed	0.315				
	Wood Framed, Other	0.291				

Table 3. Chiller performance comparison

	ASHRAE90.1-2013			GB50189-2005				GB50189-2014		
		Path A								
	CC[6] (kW)	COP	IPLV	Type	CC (kW)	COP	IPLV	CC (kW)	COP	IPLV
Water cooled	＜264	4.69	5.87	Reciprocating /Scroll	<528	3.8	N/A	≤528	4.1	4.9
	264-528	4.89	6.29							
	528-1055	5.33	6.52		528-1055	4		N/A		
	1055-2110	5.77	6.77		1055-1163					
	1163-2110				>1163	4.2				
	＞2110	6.29	7.04							
	＜264	4.69	5.87	Screw	＜528	4.1	4.47	≤528	4.7	5.45
	264-528	4.89	6.29							
	528-1055	5.33	6.52		528-1055	4.3	4.81	528-1163	5.1	5.85
	1055-1163	5.77	6.77		1055-1163					
	1163-2110				＞1163	4.6	5.13	＞1163	5.5	6.2
	＞2110	6.29	7.04							
	＜528	5.77	6.4	Centrifugal	＜528	4.4	4.49	≤1163	5.2	5.35
	528-1055				528-1055	4.7	4.88	1163-2110	5.5	5.6

[5] S is surface to volume, in unit m^2/m^3
[6] CC: cooling capacity

	1055-1163	6.29	6.77		1055-1163					
	1163-1407				＞1163	5.1	5.42	＞2110	5.8	6.1
	1407-2110		7.04							
	＞2110									
Air cooled	≤528	2.99	4.05	Reciprocating /Scroll	≤50	2.4	N/A	≤50	2.6	3.1
			4.14		＞50	2.6		＞50	2.8	3.35
	＞528		4.05	Screw	≤50			≤50		3
			4.14		＞50	2.8		＞50	3	3.2

Table 4. Maximum lighting power density comparison

Building type (unit: W/m^2)	ASHRAE90.1-2013	GB50189-2005	GB50189-2014
Office	8.8	11	9
Hotel/motel	9.4	15	7
Retail	13.6	12	10
School/University	9.4	n/a	9
Hospital	11.3	n/a	10

Table 5. Chinese reference building characteristics

	GB50189-2005	GB50189-2014
Shape	50m * 30m	
Floors	18 floors	
WWR	0.4	
HVAC system	VAV with reheat; terminal hot water radiator (only in Beijing)	
Lighting power density	11 W/m^2	9 W/m^2
Plug load power density	20 W/m^2	15 W/m^2
Occupancy density	8 m^3/person	
Chiller COP	4.7	5.2
Boiler efficiency	0.89	0.89
Air tightness	7.5 $m^3/(m^2\ hr)$	3 $m^3/(m^2\ hr)$
OA rate	30 m^3/(hr person)	
Pumps	variable speed	