Journal of Southeast University (English Edition) Vol. 26, No. 2, pp. 151 – 155 June 2010 ISSN 1003—7985

Benchmarking of energy efficiency standards for residential buildings in China

Chen Hua[1] Lee Weiling[2]

([1] Tianjin Key Laboratory of Refrigeration Technology, Tianjin University of Commerce, Tianjin 300100, China)
([2] Department of Building Services Engineering, the Hong Kong Polytechnic University, Hong Kong, China)

Abstract: In order to benchmark the energy efficiency standards for residential buildings in China, the Hong Kong building environment assessment method (HK-BEAM) is chosen as the compliance criteria for assessment. The annual energy consumption and the overall thermal transfer value (OTTV) of a baseline residential building prescribed in the Chinese codes and the HK-BEAM are evaluated and compared by the energy budget approach. The results show that in the Chinese codes, the OTTV of the residential building is lower, but the annual energy consumption and the cooling load are higher than those in the HK-BEAM. The annual energy use difference amounts to 13.4%. All the compliance criteria except the ventilation rate and the equipment power in the Chinese codes are set higher than those in the HK-BEAM. However, the compliance criteria of the ventilation rate and the equipment power, especially the ventilation rate, result in much energy consumption, which ultimately induces a high energy budget for residential buildings.

Key words: Chinese energy efficiency code; Hong Kong building environment assessment method (HK-BEAM); energy budget approach; residential buildings

In China, coupled with the rapid economic development and urbanization in the past two decades, various buildings have been rapidly established and energy consumption, especially electricity use, has sharply increased. The Chinese building sector accounted for 23% of the total energy use and increased to one-third by the end of 2009. The energy consumption in the residential sector increased by 14% from 1996 to 2001 in which air-conditioning and heating accounted for 55% of the total energy consumption. The building energy consumption data, which is nearly twice that of residential buildings in developed countries under the same climate conditions, indicate that many traditional residential buildings are not energy efficient[1]. Therefore, more measurements should be taken to reduce the energy consumed for air-conditioning and heating while maintaining comfortable indoor thermal environments in residential buildings.

In China, energy efficiency efforts began in the early 1980s. The first building energy code "Energy Conservation Standard for New Heating in Residential Buildings JGJ 26—1986" was introduced in 1986[2]. Since then, many other codes have been introduced to different climate zones in China. In July, 2003, a design standard for energy efficiency of residential buildings in hot summer and warm winter zones (JGJ 75—2003) was also issued[3]. Although the energy codes in China have been developed over two decades, no information about the effectiveness of the energy codes or whether they have been well received by the industry has been published. There are only critiques about the Chinese codes not comparable to similar codes used in developed countries, especially for the requirements concerning heat transfer coefficients and air-tightness indices of the building envelope[4].

Hong Kong is geographically located at the hot summer and warm winter zone of China and is often considered as a developed city. The energy requirements of the commercial sector accounted for 59% of the total energy consumption in 1997 and exhibited an increase of 5% over the previous years[5]. Under the energy and environmental policies in Hong Kong, the Electrical and Mechanical Services Department established the Energy Efficiency Office (EEO) in 1994 with the vision of transforming Hong Kong into a top-ranking city in the economic use of energy. Following the buildings department's codes of practice on the overall thermal transfer value (OTTV)[6] of buildings, the EEO published four codes of practice regarding the energy efficiency of building services installations, focusing on the non-domestic building sector.

So far, there is no mandatory building energy code considering the energy efficiency practice of residential buildings in Hong Kong. The Hong Kong building environment assessment method (HK-BEAM)[7], modelled on the UK Building Research Establishment's BEREEM[8], is a voluntary scheme first launched in December, 1996. In 2005, two new versions for new and existing buildings were launched for developing the framework and expanding the range of the building types. The HK-BEAM has received a good participation level since the scheme was launched. Herein, the benchmark requirements of the HK-BEAM are selected as benchmarks to be compared with the Chinese codes of residential buildings for the determination of the "relative" performance between the Hong Kong codes and the Chinese codes.

To benchmark the Chinese codes against the Hong Kong codes, a 40-floor Harmony-type residential building is chosen as the baseline building in this paper. The façade and the fenestration details are redefined according to the Hong Kong codes and the Chinese codes. HTB2[9] is used to evaluate the impacts of the thermal performance of the baseline building in conjunction with different facade and fenestration design features. Another simulation package, BECRES[10], is used to evaluate the corresponding energy use. The potential

Received 2009-11-17.

Biography: Chen Hua (1972—), female, doctor, associate professor, florahchen@yahoo.cn.

Foundation item: The Natural Science Foundation of Tianjin (No. 08JCYBJC26800).

Citation: Chen Hua, Lee Weiling. Benchmarking of Energy Efficiency Standards for Residential Buildings in China[J]. Journal of Southeast University (English Edition), 2010, 26(2): 151 – 155.

energy benefits are evaluated. Moreover, the modified OTTVCAL is applied to calculate the OTTV of the residential building.

1 Comparison of Characteristics of Baseline Residential Building

The Chinese building energy codes (BEC) and the HK-BEAM adopt the energy budget approach for evaluating the compliance of all the proposed designs, which provides flexibilities in making trade-offs among the performances of different envelope assemblies and service systems for residential buildings. A baseline building is assumed to calculate the energy cost budget before performance assessment. The characteristics of the baseline residential building in the Chinese building energy codes and the HK-BEAM are listed in Tab. 1. In Tab. 1, the envelope design features of the Chinese building energy codes are chosen as the provisions set for residential buildings in the hot summer and warm winter zones. It can be seen that the Chinese building energy codes set much higher standards than the HK-BEAM.

Tab. 1 Comparison of characteristics of baseline residential building

Characteristics	Chinese BEC		HK-BEAM	
	Parameter	Value	Parameter	Value
Indoor design conditions	Temperature/℃	26	Temperature/℃ Relative humid/%	22 50
Envelope features	Wall heat transfer coefficient/($W \cdot m^{-2} \cdot K^{-1}$)	2.0	Wall heat transfer coefficient/($W \cdot m^{-2} \cdot K^{-1}$)	3.53
	Roof heat transfer coefficient/($W \cdot m^{-2} \cdot K^{-1}$)	1.0	Roof heat transfer coefficient($W \cdot m^{-2} \cdot K^{-1}$)	1.97
	Window heat transfer coefficient/($W \cdot m^{-2} \cdot K^{-1}$)	6.0	Window heat transfer coefficient/($W \cdot m^{-2} \cdot K^{-1}$)	5.89
	Shading coefficient	0.45/0.55(north)	Shading coefficient	0.65
	Window-to-wall ratio	0.5	Window-to-wall ratio	0.65
Occupation densities	Living room/person	3	Living room/person	2
	Bedroom/person	2	Bedroom/person	2
Ventilation rate	Fresh air supply/($times \cdot h^{-1}$)	1	Infiltration/($times \cdot h^{-1}$)	0.5(AC on)/3(AC off)
	Infiltration per square meter window/m^3	7.5		
Lighting power intensities	Living room/($W \cdot m^{-2}$)	7	Living room/($W \cdot m^{-2}$)	14
	Bedroom/($W \cdot m^{-2}$)	7	Bedroom/($W \cdot m^{-2}$)	17
Equipment power intensities	Living room/($W \cdot m^{-2}$)	30	Living room/($W \cdot room^{-1}$)	142
	Bedroom/($W \cdot m^{-2}$)	0	Bedroom/($W \cdot room^{-1}$)	45
AC features	COP	2.7	COP	2.4(≤2.24 kW)/ 2.5(>2.24 kW)
	Daily operation schedule	1:00 to 7:00 and 18:00 to 24:00 for weekday, 1:00 to 24:00 for weekend	Daily operation schedule	13:00 to 22:00 for living room, 13:00 to 7:00 for bedroom
	Yearly operation schedule	May 15th to Oct 1st	Yearly operation schedule	April 1st to Oct 31st

In the Chinese codes, the prescriptive requirements, including the indoor design temperature, U-values for the building façade, the fresh air supply, the coefficient of performance (COP) for the air-conditioners (AC), and the shading coefficient (SC) of the glass in different orientations, are explicitly given. The window-to-wall ratios, the lighting power intensities, the occupation densities and the equipment power intensities are listed for reference and the maximum permissible energy use for air-conditioning is used as an "energy budget".

In the HK-BEAM, although the compliance criteria are not explicitly given, the equivalent values for the U-values of the building façade and the SC of the glass can be determined from the construction details of the baseline buildings which present the assumption of the envelope material, the thickness, the density, the thermal conductivity specific heat and the solar absorptivity of the exposed surface of the baseline buildings. The COP of the air-conditioners is one of the prescriptive requirements.

Moreover, there is no fresh air supply requirement for the energy budget of residential baseline buildings in the HK-BEAM, but 1 time/h is required in the Chinese codes. The daily and yearly operation patterns are supposed to be different in the two schemes. Three patterns, i. e., occupancy pattern, lighting pattern and equipment operation pattern, which are different in living rooms and bedrooms, are distinguished between on weekdays and on weekends in the Chinese codes while they are same in the HK-BEAM. The AC operation period in the HK-BEAM is longer than that in the Chinese codes. Furthermore, the hourly variations in the HK-BEAM are defined more elaborately than those in the Chinese codes, especially in the equipment operation pattern.

2 Energy Budget Benchmarking

To benchmark the Chinese codes against the Hong Kong codes, a 40-floor residential building is chosen as the reference building in this study. Considering the wide variations in the operation pattern, the internal heat gain intensity and the construction details of different residential units, the baseline building is subdivided into different operating zones. Each zone is treated as an independent space. According to an extensive survey conducted during the development of the HK-BEAM for residential buildings, it is found that the room-type air-conditioners(RAC) are mostly installed in living/dining rooms and bedrooms while common areas such as kitchens and bathrooms are not air-conditioned. The input files are prepared for each space in the HTB2 simulation to determine the thermal performance and the cooling load profile. BECRES is used to predict the electricity consumptions in the different zones. Fig. 1 shows the layout of the baseline residential building.

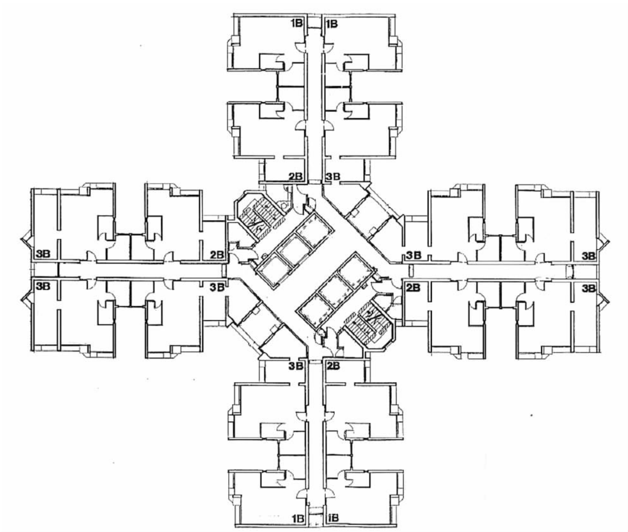

Fig. 1 Layout of baseline residential building

3 Results and Discussion

To benchmark the Chinese codes against the Hong Kong codes, the relevant compliance criteria are substituted into the reference residential building. HTB2 and BECRES are used to predict the annual cooling load and annual energy consumption for air-conditioning. OTTVCAL, originally developed for calculating the OTTV of commercial buildings, is modified for the calculation of the OTTV of residential buildings. The results are summarized in Tab. 2. It can be seen that the OTTV of the reference building in the Chinese codes is lower than that in the HK-BEAM. The difference amounts to 6 W/m^2, which is equivalent to 32%. This is reasonable because the Chinese codes require higher criteria on the envelope than the HK-BEAM. As for the annual energy use for air-conditioning, the predicted value according to the Chinese codes is higher than that according to the HK-BEAM, but the difference equivalent to 13. 4% is not very significant. The peak power consumption increases sharply according to the Chinese codes and the peak power consumption difference is 43. 87%. Moreover, the annual cooling load of the building in the Chinese codes is higher than that in the HK-BEAM, and the difference equivalent to 37. 4% is significant. These results are consistent with other studies which reveal that the OTTV is not a good indicator of the energy use of buildings because the interacting effects among heat gains from different envelope elements and internal sources, the impacts of room configuration and the AC performance are ignored.

The sensitivities of the energy consumption and the cooling load to the indoor temperature setpoint, the envelope design, the AC features, the ventilation rates, the occupation densities, the lighting power intensities, the inter equipment intensities and the operation characteristics are evaluated. In each simulation, only one input parameter of the reference building is varied to satisfy the Chinese codes. The results are summarized in Tab. 3 and Figs. 2 and 3.

As shown in Fig. 2, it can be seen that the energy consumption is the most sensitive to the ventilation rate of the residential building. According to Tab. 1, the fresh air supply rate is set to 1 time/h in the Chinese codes while no fresh air supply rate is set in the HK-BAEM. Therefore, when the ventilation rate is changed to satisfy the Chinese codes, the annual energy use sharply increases which results in a huge difference equivalent to 115. 9%. The next items are the indoor design temperature and the AC features including COP and operation patterns. With the increase in the indoor design temperature, the energy consumption decreases by nearly 26. 9%. However, the decrease in the yearly operation

Tab. 2 Benchmarking of energy performance of two baseline buildings

Standards	OTTV/ (W·m^{-2})	Annual power consumption/(kW·h)	Annual cooling load/(kW·h)	Peak power consumption/(kW·h)
China BEC	12. 662	3.316×10^6	1.018×10^7	2 964. 15
HK-BEAM	18. 647	2.923×10^6	7.481×10^6	2 060. 35
Difference/%	−32. 09	13. 4	37. 4	43. 87

Tab. 3 Benchmarking of criteria in Chinese BEC and HK-BEAM kW·h

Item	Annual power consumption	Annual cooling load	Peak power consumption
Indoor design condition	2.140×10^6	5.031×10^6	1 775. 170
Envelope feature	2.735×10^6	6.791×10^6	1 984. 950
Occupation density	2.895×10^6	7.293×10^6	2 087. 535
Ventilation rate	6.310×10^6	1.596×10^7	4 454. 063
Lighting power density	2.837×10^6	7.157×10^6	2 079. 490
Equipment power density	2.998×10^6	7.653×10^6	2 079. 490
AC feature	2.198×10^5	6.808×10^6	2 087. 540

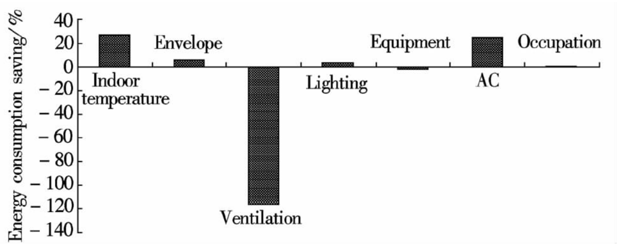

Fig. 2 The sensitivity of annual energy consumption to the requirements in Chinese BEC

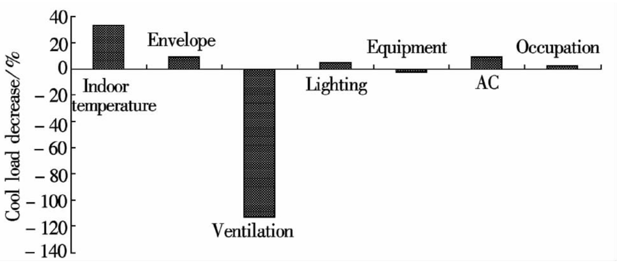

Fig. 3 The sensitivity of annual cooling load to the requirements in Chinese BEC

period and the increase in COP stipulated in the Chinese codes induce about a 24.8% decrease in the energy consumption. The influences of the envelope design, the lighting power characteristics and the occupation densities on the energy consumption are the same. However, the inter equipment intensities are relative to the areas and the number of the rooms in the Chinese codes and the HK-BEAM, respectively; thus, the total heat gain from the equipment in the Chinese codes is greater than that in the HK-BEAM. Therefore, the inter equipment intensities cause the increase in the annual energy.

The sensitivities of the cooling load to the indoor design temperature, envelope design, AC features, ventilation rates, occupation densities, lighting power intensities, inter equipment intensities and operation characteristics are presented in Fig. 3. The results are the same as the energy consumption. But the sensitivity of the cooling load is more significant than that of the energy use.

According to the previous estimations, all the compliance criteria except the ventilation rate and the equipment power characteristics in the Chinese codes are set higher than those in the HK-BEAM, which results in a lower energy budget for residential buildings. The compliance criteria of the ventilation rate and the equipment power characteristics are reversed. Especially, the ventilation rate set in the Chinese codes can result in the increase in the energy consumption. Accordingly, the total annual energy budget in the Chinese codes exceeds that in the HK-BEAM.

The results of this study estimate the effectivity of the Chinese codes for the energy efficiency of residential buildings. Moreover, so far no mandatory codes are used as residential building efficiency codes of practice in Hong Kong. The research can provide some insights for the further development of the energy codes on residential buildings in the future.

4 Conclusion

The new energy efficiency national standards of residential buildings in all the climate zones in China are comprehensively presented and the compliance criteria are compared with those in HK-BAEM, a voluntary scheme implemented in Hong Kong. In order to benchmark the Chinese codes against the HK-BEAM, a 40-floor Harmony-type residential building is chosen as the baseline building to evaluate the energy budget. The relevant compliance criteria are substituted into the reference residential building. The OTTVCAL is modified for the calculation of the OTTV of residential buildings. HTB2 and BECRES are used to predict the annual cooling load and the annual energy consumption for air-conditioning.

The simulation results show that in the Chinese codes, the OTTV of the residential building is lower by 32%, but the annual energy consumption and the annual cooling load are higher by 13.4% and 37.4% than those in the HK-BEAM. The peak power consumption increases by 43.9%. All the compliance criteria except the ventilation rate and the equipment power characteristics in the Chinese codes are set higher than those in the HK-BEAM, which results in a lower energy budget for the residential building. But the compliance criteria of the ventilation rate and the equipment power characteristics cause more energy consumption, especially the ventilation rate.

References

[1] Lang S W. Progress in energy-efficiency standards for residential buildings in China [J]. *Energy and Buildings*, 2004, **36**(11): 1191 − 1196.

[2] China Academy of Building Research. JGJ 26—1986 Energy conservation design standard for new heated residential buildings [S]. Beijing, China: Ministry of Construction, 1986. (in Chinese)

[3] China Academy of Building Research. JGJ 75—2003 Design standard for energy efficiency of residential buildings in hot summer and warm winter zone [S]. Beijing, China: Ministry of Construction, 2003. (in Chinese)

[4] Zhu Y, Lin B. Sustainable housing and urban construction in China[J]. *Energy and Buildings*, 2004, **36**(12): 1287 − 1297.

[5] Chan A T, Yeung V C H. Implementing building energy codes in Hong Kong: energy savings, environmental impacts and cost[J]. *Energy and Buildings*, 2005, **37**(6): 631 − 642.

[6] Buildings Department. Code of practice for overall thermal transfer values in buildings [S]. Hong Kong, China: Hong Kong SAR Government, 1995.

[7] Building Environment Council. HK-BEAM: an environment assessment for air conditioned office premise [S]. Hong Kong, China: Building Environment Council, 1996.

[8] BREEAM. An environmental performance assessment for existing offices [S]. London, UK: Building Research Establishment, 1996.

[9] Alexander D K. *HTB2 user manual version* 2.0[M]. Cardiff, UK: University of Wales Press, 1994.

[10] Yik F W H. *BECRES(BECON for residential buildings) user manual* [M]. Hong Kong, China: Hong Kong University Press, 1999.

中国住宅建筑能耗评估标准比较

陈　华[1]　　李慧玲[2]

([1] 天津商业大学天津市制冷空调重点实验室,天津 300134)
([2] 香港理工大学屋宇设备工程学系,中国香港)

摘要:为了校验中国的节能标准,采用能耗预算法,对中国标准和 HK-BEAM 中基准建筑的年能耗及建筑总传热数值进行了计算和比较. 结果表明,与 HK-BEAM 相比,中国标准中基准建筑的总传热数值偏低,年能耗和冷负荷偏高,两标准中的基准建筑年能耗相差 13.4%. 中国标准中除了通风率和设备功率外,其他节能标准项都比 HK-BEAM 标准设定得高. 然而,由于通风率和设备功率 2 项节能标准(尤其是通风率)会导致建筑耗能较多,因此中国基准住宅建筑的年能耗预算偏高.

关键词:中国节能标准;香港建筑环境评估标准;能耗预算法;住宅建筑

中图分类号:TU111