Journal of Energy Challenges and Mechanics
http://www.nscj.co.uk/JECM/
ISSN 2056-9386
Volume 1 (2014) issue 1, article 1

The effects of future climate change on energy consumption in residential buildings in China and retrofitting measures to counteract

未来气候变化对中国住宅的能耗影响及相对改造措施

D. H. C. Chow[1*], M. Kelly[2], Huiyang Wang[1], J. Darkwa[2]

[1]*School of Architecture, University of Liverpool, Liverpool L69 7ZN, UK*
[2]*Centre for Sustainable Energy Technologies (CSET), University of Nottingham Ningbo China, 315100, China*

David.Chow@liverpool.ac.uk

Accepted for publication on 22th July 2014

Abstract - **At present, China is going through a rapid rate of mass urbanisation, and this poses a number of challenges for the building sector. On one hand, under new directives from the government, new buildings will have stricter energy requirements and existing buildings will also need to lower their rate of energy consumption, on another hand, the lifetime of buildings are now intended to last longer, meaning that building designers will also need to account for effects of future climate change when assessing the performance of building schemes. This paper investigates the effect of future climate change on energy consumption in typical residential buildings in different climate regions of China. These include the "Cold" region in the north, which includes Beijing; the "Hot Summer Mild Winter" region in the south, which includes Guangzhou, and two regions from the "Hot Summer Cold Winter", one along the coast in the east, which includes cities such as Shanghai and Ningbo; the inland region, which includes cities such as Wuhan and Chengdu. Using data from the climate model, HadCM3, Test Reference Years are generated for the 2020s, 2050s, and 2080s, for various IPCC future scenarios for these cities. These are then used to assess the energy performance of typical existing residential buildings, and also the effects of retrofitting them to the standard of the current building codes. It was found that although there are reductions in energy consumption for heating and cooling with retrofitting existing residential buildings to the current standard, the actual effects are small compared with the extra energy consumption that comes as a result of future climate change. This is especially true for Guangzhou, which currently has very little heating load, so there is little benefit of the reduction in heating demand from climate change. The overall effects of retro-fitting in other selected cities depend largely on the specification of current existing buildings. In general, more improvements in building standards in all four regions are required to significantly reduce the effects of future climate change.**

Keywords - **Climate Change, Energy Consumption, Residential Buildings, Retrofitting, Urbanisation.**

I. INTRODUCTION

Since the opening of its market in 1978, the Chinese economy has grown at a staggering pace, leading to a drastic increase in energy consumption. The building sector is responsible for around 27.5% of the national total energy consumption [1-3]. And this could even rise to 40% over the next 20 years as more buildings are constructed [4]. Occupants too, are demanding a higher level of indoor comfort which will lead to a steeper increase in heating and cooling loads. In 2010, China has over 43 billion m^2 of constructed area, but just 4-5% meet the national building energy standards, the rest are classified as "intensive energy consumers" [5-6].

In China, the lifespan of most buildings is relatively short, compared to European and North American standards. This high turnover rate, along with the recent construction boom, has resulted in an existing building stock that is fairly young. Zhu and Lin [7] project that by 2015, half of China's existing building stock will have been built after 2000.

Effects are being made by the government to reduce the amount of energy consumed by buildings in China with more and more stringent building codes for residential, commercial and public buildings. However, despite the comparatively high rates of construction and demolition, most buildings in China do not comply with the latest national building codes. This paper aims to investigate the benefits of retrofitting existing residential buildings to the standard of the current building code in four main cities (Beijing, Shanghai, Wuhan and

Guangzhou) in China's main climate regions, and investigate if retrofitting to the current standard can nullify effects of future climate change in these regions in the next 100 years. Data from the climate prediction model, HadCM3, and impacts of climate change in the next 100 years will also be investigated.

1.1. Climate Zones in China

There are five main climatic zones in China: "Severe Cold", "Cold", "Hot Summer and Cold Winter", "Moderate", and "Hot Summer and Warm Winter", as shown in figure 1 [8]. They have distinctive characteristics, and thus different national building codes. This paper will investigate the situation in the "Cold" zone by using weather data for Beijing, the "Hot Summer and Warm Winter" zone with the city of Guangzhou. For the "Hot Summer and Cold Winter" zone, two cities are investigated, Shanghai which is a coastal city, with less varying temperatures between summer and winter, and Wuhan, which is located inland, and prone to even more extreme weather.

Fig.1, Climate zones in China and cities investigated

II. Climates in the Four Chosen Cities

The cities of Beijing, Shanghai, Wuhan and Guangzhou were selected to represent situations in three different climate zones in China. The buildings in each zone have very different heating and cooling needs. For example, Guangzhou in the "Hot Summer Warm Winter" zone has very little heating demand, as its winters are relatively mild. Wuhan, on the other hand, has significant heating and cooling loads. Shanghai is in the same climate region as Wuhan, but as it is located on the coast, thus it can be considered relatively milder over the whole year. Beijing also has hot summers, especially around August and early September, and winters are extremely harsh too. The changes in the next 100 years due to climate change for the three climate zones are also significantly different.

2.1. Current Climates

Long running series of real observed data from weather stations in the four cities were not available for this study, so in-depth study of the characteristics of different weather parameters could not be conducted. However, data can be extracted from the existing Test Reference Years, from the Energy Plus program. Fig 2 shows the average monthly range and values for daily maximum and minimum temperatures for the four selected cities.

2.2. Future Climate Change

The Hadley Centre model (HadCM3) [9] is used to provide future climate data for this study. HadCM3 is a global climate model developed at the Hadley Centre of the Met Office in the UK. It is a Coupled Atmosphere-Ocean General Circulation Model (AOGCM), in which the globe is divided into grid boxes, each measuring 2.50° x 3.75°. The gridboxes used in this paper are gridbox numbers 1952 (which encloses the area with latitude from 38.75°N to 41.25°N, and longitude from 114.375°E to 118.125°E, and includes the city of Beijing), 2337 (which encloses the area with latitude from 28.75°N to 31.25°N, and longitude from 118.125°E to 121.875°E, and includes the city of Shanghai), 2335 (which encloses the area with latitude from 28.75°N to 31.25°N, and longitude from 110.625°E to 114.375°E, and includes the city of Wuhan), and 2623 (which encloses the area with latitude from 21.25°N to 23.75°N, and longitude from 110.625°E to 114.375°E. and includes the city of Guangzhou).

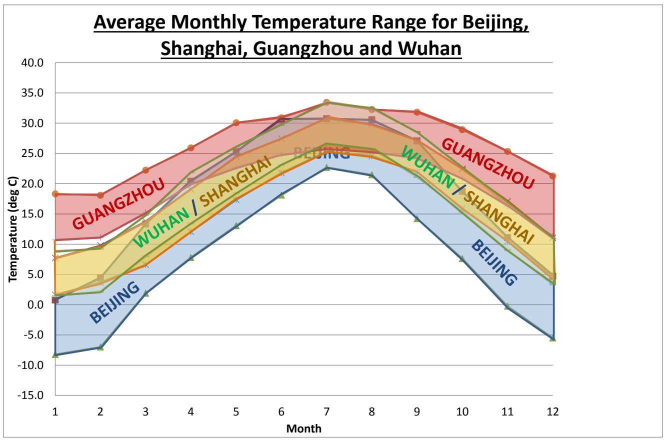


Fig.2, Current monthly average temperature range for Beijing, Shanghai, Wuhan and Guangzhou

Fig. 3 shows the extent of the gridbox for Shanghai. Unlike weather data from typical weather years, HadCM3 only provide daily values for parameters such as maximum, minimum and average temperatures, humidity, wind speed and downward short-wave flux (solar radiation), based on 4 main future scenarios on carbon emissions, A1F, A2, B2 and B1 [10]. For example, the A2 scenario describes a very heterogeneous world where slow and fragmented economic growth is assumed, together with a continuation of population growth and continued increase in CO_2 emission into the twenty-first century [11].

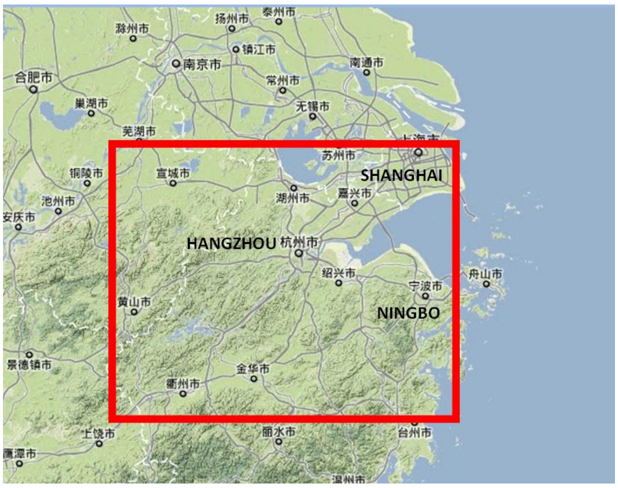


Fig.3, Area covered by gridbox 2337 of HadCM3

2.3. Compilation of Future Test Reference Years

Future Test Reference Years for Beijing, Shanghai, Wuhan and Guangzhou were constructed using the "morphing method" [12], which uses differences between monthly averages from "historical periods" and "future periods", and impose these onto existing Test Reference Year. For this study, data from HadCM3 are separated into four periods: 2000s (which includes all data from 1990-2009); 2020s (which includes data from 2010-2039); 2050s (which includes data from 2040-2069) and 2080s (which includes data from 2070-2099), and the average monthly temperatures under the A2 scenario from resulting TRYs for Shanghai is shown in Fig. 4

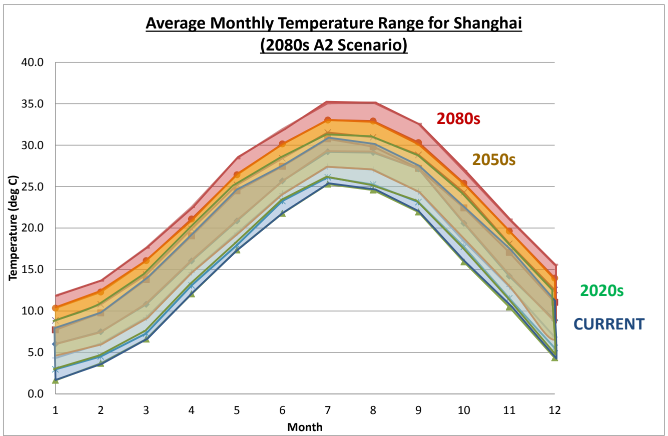


Fig.4, Changes in Temperature Range for Shanghai in current and future TRYs (A2 Scenario)

III. Methodology

The study used a typical residential building in the four cities and the whole year heating and cooling demands were calculated for buildings under the existing building specifications as well as standards complying with the latest building codes. This was conducted for current Test Reference Years and also Test Reference Years for 2020s, 2050s and 2080s, under different IPCC future scenarios.

3.1. Typical Building Used for Study

This study targets a mid-size multi-family residential apartment complex built in 2003, the first year that residential building energy codes were adopted in all four study cities. The selection of this particular building form is intended to be both realistic and strategic. A cheap and quick-to-construct answer to increasing housing needs, these types of buildings are ubiquitous in Chinese cities. These apartment buildings are in a 'grey area' of cultural value—although lacking in the prestige of historic structures or the glamour of new designs, they form the foundation for daily urban life for many people.

Fig.5, Isometric view of the study building

The standard of early building codes within which these buildings were constructed are quite low compared to current codes a decade later, and they are likely to be inadequately prepared for future climate change. Additionally, buildings constructed in the midst of the construction boom, which focused on speed over quality, are now showing severe maintenance problems which require refurbishment and repair. Figure 5 shows an isometric view of the building type being studied.

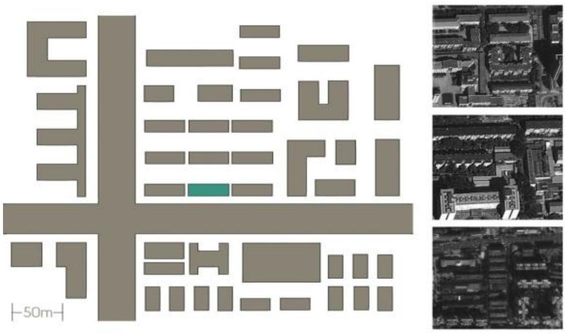


Fig.6, Theoretical site for the study building

TABLE 1, UPDATED ENVELOPE ELEMENT REQUIREMENTS IN THE MOST RECENT BUILDING CODES

U-Value ($W / m^2 K$)	Beijing		Shanghai / Wuhan		Guangzhou	
	Existing Building	Current Reg (JI2070-2012)	Existing Building	Current Reg (JGJ-134-2010)	Existing Building	Current Reg (DBJ15-51-2007)
Windows	2.7	1.8	3.2	2.8	3.8	3.5
Roof	0.54	0.35	0.8	0.8	1.0	0.9
Ext. Walls	0.76	0.40	1.0	1.0	1.5	1.5
Ground	0.53	0.45	1.5	1.5	1.5	1.5

The building and project site are both designed to be as generic as possible to facilitate high levels of comparison between the study cities. The buildings surrounding the project site are a composite of similar sites in each of the four cities, and represent a primarily-residential neighbourhood. The apartment complex itself, located on the corner of the main streets, consists of nine identical buildings with a north-south orientation. Each building is six stories tall and contains five apartments per floor. Based on the average values from surveys of similar apartment buildings conducted by Chen et al. [13, 14], Gu et al. [15], and Hu et al. [16], each apartment has 85 m2 of floor space, including two bedrooms, a bathroom, and a living room.. One building in the apartment complex, highlighted in blue in Figure 6 was used for the evaluation of retrofitting options.

3.2. Specification for “Current” Buildings

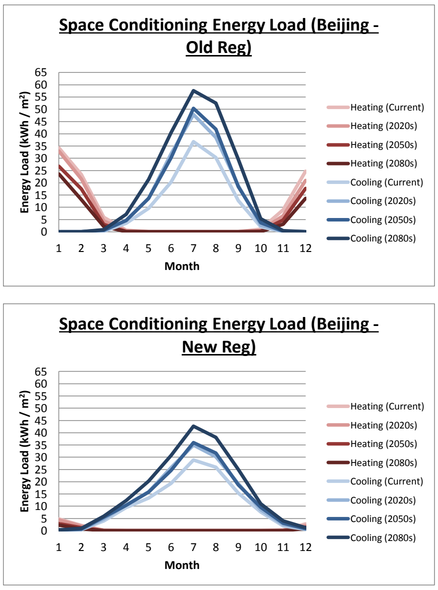
Although Rousseau and Chen [17] describe older apartment buildings as having solid brick construction with concrete floors, bricks were banned for construction in 1999 due to the increasing environmental impacts associated with their demand. Fernández [18] and Huang, et al. [19] report that most multi-family residential buildings constructed in the past two decades are made from reinforced concrete. The demand for concrete in China’s building sector in general [20] also lends confidence that reinforced concrete is the most representative material for this building type.

3.3. Specification for Renovated Buildings

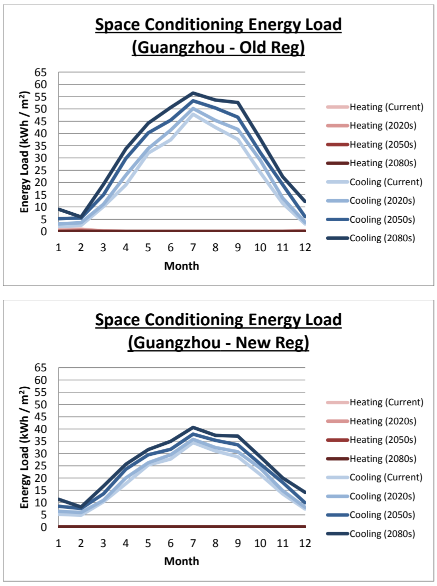
While the most recent residential building codes in China are stricter than those in 2003, they have nonetheless been developed based on historic climate knowledge. While lower current energy consumption may indicate greater climate resiliency, it cannot be taken for granted that buildings built to current codes will maintain higher performance levels under future conditions. To compare the climate vulnerability of the study building against a newer structure, an equivalent but code-compliant building was also modelled. This building represents both a building of the same size constructed in 2014, which could replace the existing structure entirely, and the study building if it were retrofitted to meet cur-rent codes without any other measures. Table 1 lists the envelope requirements which have improved since 2003. The comfort range where no heating and cooling would be supplied to the building was set as 16°C to 24°C for all four cities, and the design air-tightness in renovated buildings are improved from 3.0 ach to 1.0 ach. Heating was assumed to use gas boiler, with a total efficiency of 0.83, and fan-coil units used for cooling, with a COP of 1.67.

IV. Results and Discussion

Fig 7a shows the monthly space conditioning (heating and cooling loads) requirements for the tested existing and retrofitted residential building in Beijing, under the A2 future scenario. It can be seen that with the existing building specification, the ratio between cooling and heating starts to drift in the direction of more cooling with climate change, and with the same building, but retrofitted to the latest building regulation for Beijing, there is a major decrease in heating demand, but the effect on cooling demand is relatively small in comparison. The cooling period also appears to have extended more to include the months of March and November. Similar results were achieved in Shanghai and Wuhan, though with a much smaller peak cooling load in Shanghai than Wuhan and Beijing. The results for Guangzhou is shown in fig 7b, where it can be seen that the benefit of the new building code does not benefit the reduction of heating much, as Guangzhou has minimal heating demand anyway. The peak cooling demand in summer for a retrofitted building reaches approximately the same level as an existing building under the current climate, so the retrofitting can just about nullify the effects of future climate change here.



(a)



(b)

Fig.7, Changes in Heating and Cooling Loads in the Residential Building in Beijing (a) and Guangzhou (b) under Future Climate Change (A2 Scenario)

Fig 8 shows the range of changes in cooling consumption in future periods under various scenarios for typical existing residential buildings (in grey), and those that have been retrofitted to the standard of the current building code for the respective region (in blue). Under the current climate, the energy consumption for cooling is actually higher for a retrofitted building in Beijing and Shanghai. The overlap occurs in the 2020s and after that the retrofitted building performs better. No overlap occurs for either Wuhan or Guangzhou. It is also worth noting that the range for cooling energy consumption is smaller in a retrofitted building, suggesting that these are less susceptible to different future scenarios.

The effect of retrofitting has a major effect on the reduction of heating demand, and there are large gaps between the ranges of heating energy consumption between existing and retrofitted buildings in all four cities, usually by a factor of 6 to 8. Apart from the reduction in U-Values of some of the external elements, the main contribution to a much lower heating demand is attributed to the better air-tightness specification of the retrofitted buildings. The effect of which on reducing cooling load is not as effective (solar radiation can still enter, and it is also more difficult to remove other internal heat gains with better insulated external elements).

V. Conclusion

This paper studied the effects of retrofitting residential buildings in cities in three major climate zones (with four cities) of China, from building standards set in 2003 to the current building codes, and seeing how this would perform under climate change in the next 100 years. The effects of retrofitting was most profound for reducing heating energy consumption, but this may be due to the effects of having introduced much tighter building envelopes which may not be as well incorporated in practice. Guangzhou, with practically no heating demand in its warm winters, does not benefit from the reduced heating demand with climate change, and with retrofitting to the current code, there is only a small amount of reduction in cooling loads, which is not enough to counter the effects of future climate change, regardless of which scenario the world follows in the future. The same could be said for cooling in all four cities as even with the least severe future scenario, the cooling energy demand in a retrofitted building is higher than that for a non-retrofitted building under the current climate. This happens before the 2020s for Beijing and Shanghai, slightly later for Wuhan (just before the 2050s) and at around 2050s for Guangzhou. With more severe future scenarios, this will happen even quicker.

With all four cases, it is clear from the results that the current building standards will not be able to nullify the effects of future climate change, as far as cooling is concerned, and more studies are required to investigate optimum building standards for each different climate region in China, which must also be economically feasible. This study has not taken the effects of urban heat islands, which will make the quest for producing low-energy buildings even more challenging, and further work is required to investigate the effects of more reasonable assumptions of air-tightnesss in residential buildings in China.

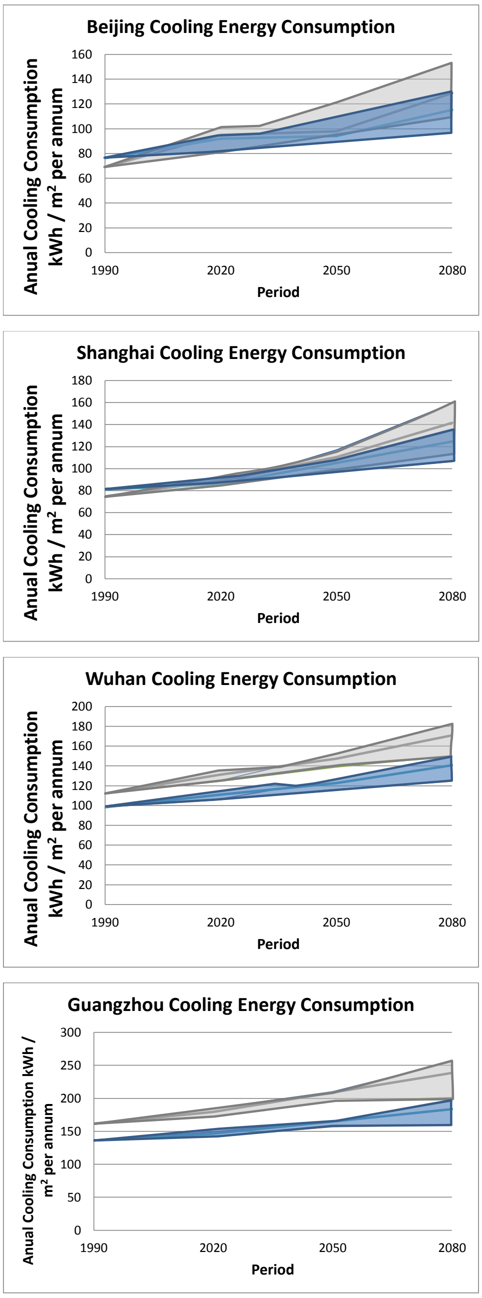


Fig.8, Changes in Heating and Cooling Loads in the Residential Building in Guangzhou under Future Climate Change (A2 Scenario)

REFERENCES

[1] Y. Wu, "China Building Energy Efficiency: Current Status, Issues, and Policy Recommendations" China Ministry of Construction, 2003.

[2] N. Zhou, "Energy Use in Commercial Buildings in China: Current Situation and Future Scenarios" 8th ECEEE Summer Study, Lawrence Berkeley National Laboratory, 2007. pp. 1065-1071.

[3] D. G. Fridley, N. Zheng, N. Zhou, "Estimating Total Energy Consumption and Emissions of China's Commercial and Office Buildings" IBNL-248E, Lawrence Berkeley National Laboratory, 2008.

[4] J. Zhong, J. "Development Approach of Renewable Energy and Building Integration Technology" Solar Energy Vol. 5, 2007. pp. 40-43.

[5] Y. Zheng, "Energy-Efficiency in Buildings:- An Imminent Task" Environmental Economy Vol. 11, 2007. pp. 23-24.

[6] T. Hong, "A Close Look at the China Design Standard for Energy Efficiency of Public Buildings" Energy and Buildings, Vol. 41, Issue 4, 2009. pp. 426-435.

[7] Zhu, X. and Lin, B., "Sustainable housing and urban construction in China" Energy and Buildings, Vol. 36, 2004, pp. 1287-1297.

[8] G. Heggelund, A. Meier, S. Ohshita, S. Wiel, "Cooperative Climate", International Institute for Sustainable Development, 2008, Chapter 5.

[9] C. Gordon et al. "A Simulation of SST, Sea Ice Extents Ocean Heat Transports in a Version of the Hadley Centre Coupled Model without Flux Adjustments", Climate Dynamics, Vol. 16, 2000. pp. 147-168.

[10] N. Nakicenovic "Emissions Scenarios" Intergovernmental Panel on Climate Change, Cambridge University Press. ISBN 0521 80493 0. 2000.

[11] WMO, UNEP "IPCC Climate Change 2001, Summary for Policy Makers and Technical Summary of the Working Group I Report", 2001. pp. 63-65.

[12] S. Belcher, J. Hacker, D. Powell, "Constructing design weather data for future climates" Building Services.Engineering Research and Technology Vol. 26.1, (2005) pp.49–61.

[13] Chen, S., Yoshino, H., Levine, M. D. & Li, Z., "Contrastive analyses on annual energy consumption characteristics and the influence mechanism between new and old residential buildings in Shanghai, China, by the statistical methods." Energy and Buildings, Volume 41, 2009. pp. 1347-1359.

[14] Chen, S., Yoshino, H. & Li, N., "Statistical analyses on summer energy consumption characteristics of residential buildings in some cities of China." Energy and Buildings, Volume 42, 2010. pp. 136-146.

[15] Gu, Z., Sun, Q. & Wennersten, R., "Impact of urban residences on energy consumption and carbon emissions: An investigation in Nanjing, China." Sustainable Cities and Society, Volume 7, 2013. pp. 52-61.

[16] Hu, T., Yoshino, H. & Jiang, Z., "Analysis on urban residential energy consumption of Hot Summer & Cold Winter Zone in China." Sustainable Cities and Society, Volume 6, 2013. pp. 85-91.

[17] Rousseau, D. & Chen, Y., "Sustainability options for China's residential building sector." Building Reearch & Information, Vol. 29, Issue 4, 2001. pp. 293-301.

[18] Fernández, J. E., "Resource Consumption of New Urban Construction in China." Journal of Industrial Ecology, Vol. 11, Issue 2, 2007. pp. 99-115.

[19] Huang, T. et al., "Materials demand and environmentla impact of buildings construction and demolition in China based on dynamic material flow

analysis." Resources, Conservation and Recycling, Volume 72, 2013. pp. 91-101.

[20] Chang, Y., Ries, R. J. & Wang, Y., "The embodied energy and environmental emissions of construction projects in China: An economic input-output LCA model." Energy Policy, Vol. 38, 2010. pp. 6597-6603.

[21] Wang, Y., Huang, Z. & Heng, L., "Cost-effective assessment of insulated exterior walls of residentail buildings in cold climate." International Journal of Project Management, Vol. 25, 2007.pp. 143-149.

[22] Aden, N., Qin, Y. & Fridley, D., "Lifecycle Assessment of Beijing-Area Building Energy Use and Emissions: Summary Findings and Policy Applications (LBNL-3939E)", Berkeley, CA: China Energy Group, Lawrence Berkeley National Laboratory. 2010.

[23] Chen, S. et al., "Statistical analyses on winter energy consumption characteristics of residential buildings in some cities of China." Energy and Buildings, Vol. 43, 2011. pp. 1063-1070.

[24] Anderson, B., "Thermal properties of buliding structures." In: K. Butcher, ed. CIBSE Guide A: Environmental Design. 7th ed. Norwich: The Chartered Institution of Building Services Engineers, 2006. pp. 3-1 - 3-46.