

The Effects of Future Climate Change on Energy Consumption in Residential Buildings in China

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ABSTRACT

China is currently going through a phase of rapid mass urbanisation, and it is important to investigate how the growing built environment will cope with climate change, to see how the energy consumption of buildings in China will be affected. This is especially important for the fast-growing cities in the north, and around the east and south coasts. This paper aims to study the effects of future climate change on the energy consumption of buildings in the three main climate regions of China, namely the “Cold” region in the north, which includes Beijing; the “Hot Summer Cold Winter” region in the east, which includes cities such as Shanghai and Ningbo; and the “Hot Summer Mild Winter” region in the south, which includes Guangzhou. Using data from the climate model, HadCM3, Test Reference Years are generated for the 2020s, 2050s and 2080s, for various IPCC future scenarios. These are then used to assess the energy performance of typical existing 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 very small compared with the extra energy consumption that comes as a result of future climate change. This is especially true for Guangzhou, which currently have very little heating load, so there is little benefit of the reduction in heating demand from climate change. The effects of retrofitting in Beijing are also limited, and only in Ningbo was the effect of retrofitting able to nullify the effects of climate change up to 2020s. More improvements in building standards in all three regions are required to significantly reduce the effects of future climate change, especially to beyond 2020s.

Keywords: Climate Change; Energy Consumption; Residential Buildings; Retrofitting; Urbanisation

1. Introduction

Over the last 30 years, the rapid growth in the Chinese economy has led to a drastic increase in energy consumption, where the building sector is responsible for around 27.5% of the national total energy consumption [1-3]. Zhong has shown that this percentage could rise to 40% over the next 20 years as more buildings will be constructed [4]. This together with occupants demanding a higher level of indoor comfort will lead to a steeper increase in heating and cooling loads. At the end of 2010, the whole of China has over 43 billion square metres of constructed area, however, only 4% - 5% meet the national building energy standards, and the other 95% - 96% are classified as “intensive energy consumers” [5, 6].

In China, the lifespan of most buildings is short even by modernist 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. Chen Huai, director of the policy research centre at the Ministry of Housing and Urban-Rural Development, stated himself in 2010 that “Only those homes built after 1999 are likely to be preserved in the longer term” due to perceived safety and functionality deficits in older buildings [8].

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 cities (Beijing, Ningbo and Guangzhou) in three of China’s main climate zones, and see 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, will be the impacts of cli-

mate change in the next 100 years will also be investigated.

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** [9]. They have distinctive characteristics, and therefore separate national building codes. This paper will investigate the situation in the “Cold” zone by using weather data for Beijing, the “Hot Summer and Cold Winter” zone with the city of Ningbo, and the “Hot Summer and Warm Winter” zone with the city of Guangzhou.

2. Climates in Beijing, Ningbo and Guangzhou

The cities of Beijing, Ningbo and Guangzhou were selected to represent situations in the 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. Ningbo, on the other hand, has significant heating and cooling loads, but overall, it can be considered relatively mild over the whole year. Beijing also has hot summers, especially around August and early September. Winter temperatures can be very cold. 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 three 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. **Table 1** shows the average monthly values for daily maximum and minimum temperatures for the three selected cities.



Figure 1. Climate zones in China.

Table 1. Current monthly average T_{\max} and T_{\min} for Beijing, Ningbo and Guangzhou.

Month	Average Daily Max Temp (°C)			Average Daily Min Temp (°C)		
	BJ ^a	NB ^b	GZ ^c	BJ ^a	NB ^b	GZ ^c
Jan	6.6	8.2	18.3	-7.3	1.2	10.7
Feb	-3.1	8.9	18.1	-11.5	2.5	11.1
Mar	6.8	11.5	22.2	-2.5	5.9	15.2
Apr	9.9	20.2	25.9	5.7	10.8	19.9
May	16.3	23.3	30.1	8.3	16.8	22.7
Jun	23.6	27.1	30.9	11.5	21.5	24.7
Jul	27.6	30.2	33.4	20.6	24.2	25.7
Aug	34.6	29.2	32.3	29.1	24.7	25.3
Sep	35.0	25.0	31.8	22.7	20.0	24.1
Oct	21.3	22.4	28.9	13.2	16.8	20.8
Nov	12.8	16.2	25.3	0.1	8.8	16.3
Dec	7.6	10.0	21.3	-4.1	1.7	11.3

^aBJ denotes Beijing; ^bNB denotes Ningbo; ^cGZ denotes Guangzhou.

2.2. Future Climate Change

The Hadley Centre model (HadCM3) [10] 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 $2.50^\circ \times 3.75^\circ$. The gridboxes used in this paper are grid-box 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 Ningbo and Shanghai), 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). **Figure 2** shows the extent of the gridbox for Ningbo. 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 [11]. 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 [12].

2.3. Compilation of Future Test Reference Years

Test Reference Years for Beijing, Ningbo and Guangzhou were constructed using the “morphing method” [13], which uses differences between monthly averages from “historical periods” and “future periods”, and impose these



Figure 2. Area covered by gridbox 2337 of HadCM3.

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 Ningbo is shown in **Figure 3**.

2.4. Changes in Temperature and Solar Radiation

For the three selected gridboxes from HadCM3, the increases in temperature are steady from 2000s to 2020s, and then subsequent increases to 2050s and 2080s. However, there are significant differences in the changes between the gridboxes. For the Beijing gridbox, the increases are more rapid for daily maximum temperature values, and also faster for the summer months than the winter months. The opposite is true for the Guangzhou gridbox, where rises for daily minimum temperatures are faster, and increases are also bigger for the winter months. For the Ningbo gridbox, the rises are similar between months and also between daily maximum, average and minimum values.

For future changes in solar radiation, there are reductions in all three gridboxes, particularly during the winter period. For the Guangzhou gridbox, there is also significant and continuing decrease in solar radiation in the summer months. For the Beijing and Ningbo gridboxes,

there are slight increases in summer, but the increases are lower than the decreases in winter. The general increases in summer could be explained by a possible reduction in cloud cover in the future. However, as the future atmosphere becomes more turbid, the general trend of solar radiation in the future is one that is decreasing. **Figure 4** shows the changes in daily maximum temperature and solar radiation changes in the Guangzhou gridbox from 2000s to 2020s, 2050s and 2080s.

3. Methodology

The study used a typical residential building in the three cities and ran the whole year heating and cooling demands for 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 various 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 three 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

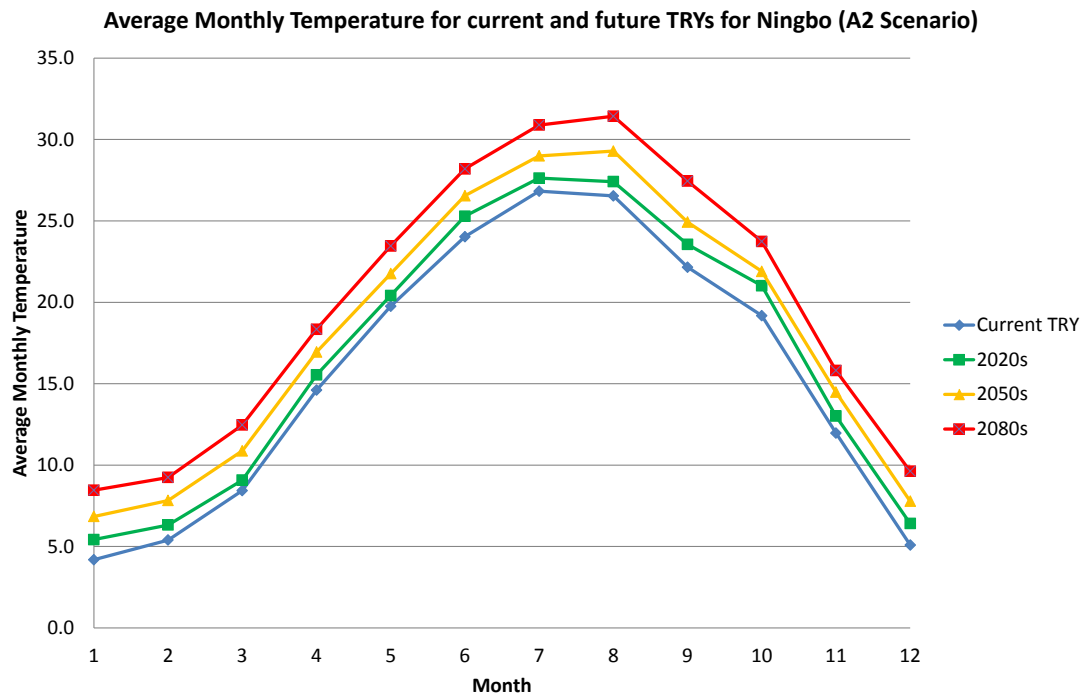


Figure 3. Average monthly temperature for current and future TRYs for Ningbo (A2 scenario).

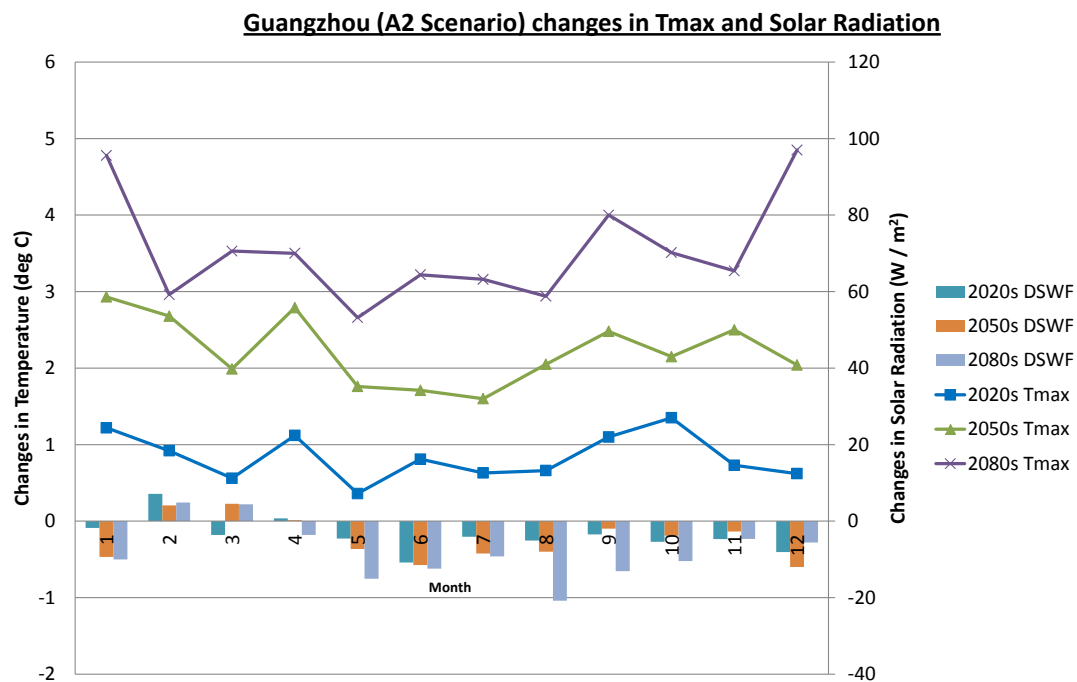


Figure 4. Changes in daily maximum temperature and solar radiation under the A2 scenario for Guangzhou.

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.

Although not the worst-performing building type, the early building codes within which these buildings were constructed are quite low compared even 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



Figure 5. Isometric view of the study building.

building type being studied.

The building and project site are both designed to be as generic as possible to facilitate high levels of comparison between the three study cities. The buildings surrounding the project site are a composite of similar sites in each of the three cities, and represent a primarily-residential neighbourhood with buildings of different ages. 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 eight stories tall and contains sixty-four apartments. Based on the average values from surveys of similar apartment buildings conducted by Chen *et al.* [14,15], Gu *et al.* [16], and Hu *et al.* [17], each apartment has 85 m² of floor space, including two bedrooms, a bathroom, and a living room. For realism, it is assumed that the balcony space was originally designed as a balcony, and was later enclosed to provide additional living space in the apartment and raise its marketability; this is a common refurbishment strategy [18]. 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 [19] 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 [20] and Huang, *et al.* [21] 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 [22] also lends confidence that reinforced concrete is the most representative material for this building type. Generally, the assemblies selected for the study building are adapted directly from the material intensities for residential buildings compiled by

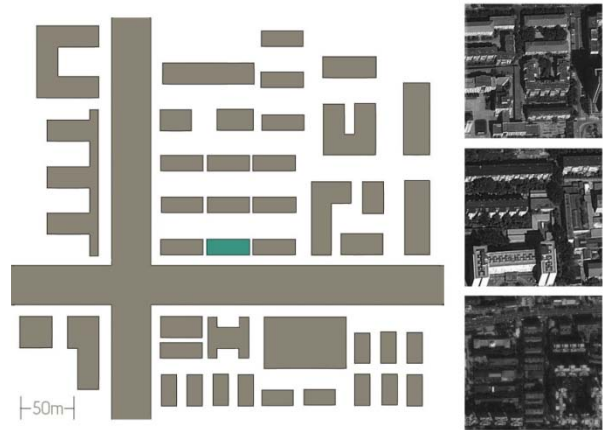


Figure 6. Theoretical site for the study building.

Fernández [20], with confirmation or modifications as needed from other studies and based on building code requirements for each city. Wang, *et al.* [23], Aden, *et al.* [24], and Chen, *et al.* [25] report on the use of expanded polystyrene (XPS) insulation in buildings, and where insulation is required to meet the building code, XPS insulation was added in 10 mm increments until the maximum compliant U-value was reached. All material properties were adapted from Anderson [26].

For windows and the glazed balcony doors, double-paned glazing with aluminium frames were assumed for Beijing and Ningbo, as single-glazed panes do not meet the building codes. Guangzhou’s residential building code does not specify an insulation level for glazing, but instead mandates shading coefficients as solar gains are more important than thermal losses in its warmer climate. Thus, for Guangzhou, single-pane reflective glass was assumed for all glazing. **Figure 7** summaries the construction specifications for the building in each city.

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 modeled. 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 current codes without any other measures. **Table 2** lists the envelope requirements which have improved since 2003; all other elements of the existing building remain compliant. Because no new residential code has yet been published for

	EXT. WALLS	INT. WALLS	ROOF	FLOOR	GROUND FLOOR
BEIJING	10mm plaster 200mm reinforced concrete 20mm XPS 200mm hollow concrete blocks 10mm plaster U = 0.76 W/m ² K	10mm plaster 200mm hollow concrete blocks 10mm plaster U = 1.56 W/m ² K	75mm cast concrete 40mm XPS 10mm plaster U = 0.54 W/m ² K	10mm ceramic floor tiles 100mm cast concrete 10mm plaster U = 1.47 W/m ² K	10mm ceramic floor tiles 100mm cast concrete 40mm XPS U = 0.53 W/m ² K
NINGBO	10mm plaster 200mm reinforced concrete 200mm hollow concrete blocks 10mm plaster U = 1.34 W/m ² K		75mm cast concrete 20mm XPS 10mm plaster U = 0.80 W/m ² K	10mm ceramic floor tiles 100mm cast concrete 10mm plaster U = 1.47 W/m ² K	10mm ceramic floor tiles 100mm cast concrete U = 1.47 W/m ² K
GUANGZHOU					

Figure 7. Construction specifications for the study building in each city.

Table 2. Updated envelope element requirements in the most recent building codes.

Element	Beijing		Ningbo		Guangzhou	
	existing	J12070-2012	existing	JGJ134-2010	existing	DBJ15-51-2007
Window						
U-Value (W/m ² K)	2.7	1.8	-	-	6	3.5
Window SC	-	-	18.1	-11.5	-	-
Roof						
U-Value (W/m ² K)	0.54	0.35	0.8	0.45	-	-
Ext. Walls						
U-Value (W/m ² K)	0.76	0.40	1.34	1.0	-	-
Ground Floor						
U-Value (W/m ² K)	0.53	0.45	-	-	-	-

the “Hot Summer Warm Winter” region, the most recent public building standard is used as a substitute representation of current practices.

The comfort range where no heating and cooling would be supplied to the building was set as 18°C to 26°C for all three cities.

4. Results

Figure 8 shows the monthly space conditioning (heating and cooling) requirements for the residential building under the current climate, and also for 2020s, 2050s and 2080s under the A2 scenario. Figure 9 shows a comparison between the predicted heating and cooling energy consumption of the existing and equivalent code-compliant buildings, under the A2 scenario, together with the most severe A1F and the least severe B1 scenarios. While the new code results in some stabilization, ultimately the underlying patterns of increasing risk are preserved. In Guangzhou, the code improvements lower cooling loads by 6.2%, rising to a maximum of 10.7% by 2080 in the A1F scenario and 8.5% in the A2 scenario. For the building in Beijing, the results are mixed, with a

less than 1% reduction in heating loads under the A1F and A2 scenarios. In the B1 scenario, heating loads are predicted to increase compared to the existing building. Cooling loads follow an opposite pattern, with a decrease in cooling energy under the B1 scenario and little effect otherwise. The effect of reducing direct solar gains in the most recent “Hot Summer Cold Winter” zone code increases heating loads by 9.7% in 1980. However, as existing cooling loads are reduced by 46.1% and 2080 cooling loads are reduced by 31.0% - 34.0%, the result is largely positive when viewed over the entire century.

5. Conclusions

This paper studied the effects of retrofitting residential buildings in cities in three major climate zones 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. Guangzhou, with 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

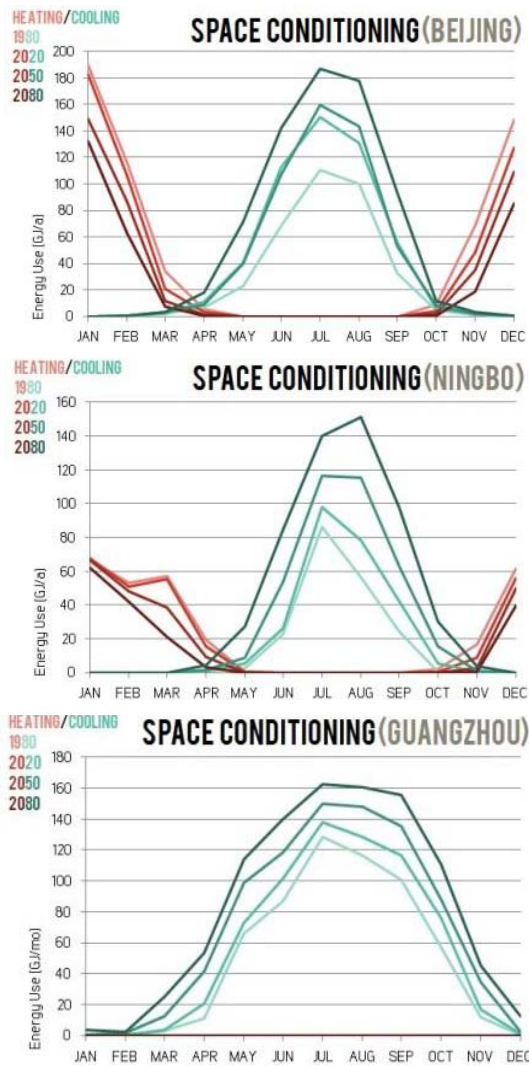


Figure 8. Predicted monthly heating and cooling energy consumption at each horizon year under the A2 scenario.

enough to counter the effects of future climate change, regardless of which scenario the world follows in the future. For the case of Beijing, the differences between existing and retrofitted buildings are not great, for both heating and cooling demands, and there is greater increase in cooling load than the reduction in heating load, meaning that future energy consumption in the future will increase significantly, even with retrofitted buildings. As for Ningbo, this showed the biggest reduction in energy consumption with retrofitting. For both heating and cooling loads, a retrofitted building will have lower energy demands in 2020s compared with the existing building standard under the current climate. Depending on the scenario, this benefit may even extend to the 2050s for cooling demands.

With all three cases, it is clear from the results that the current building standards will not be able to nullify the effects of future climate change, and more studies are

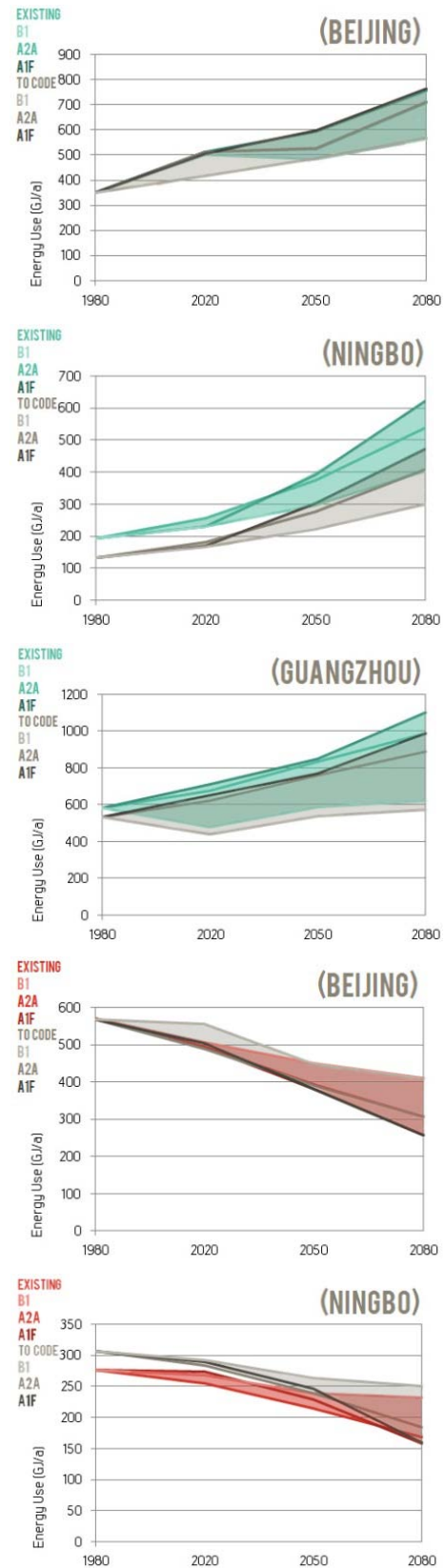


Figure 9. Projected heating and cooling loads of the existing (blue and red) and equivalent code-compliant (grey) buildings under all three scenarios.

required to investigate optimum building standards for each different climate region in China, which are also 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.

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