

## Conference Paper

# Energy Modelling and Retrofit of the Residential Building Stock of Jiangsu Province

Marco Cimillo<sup>1</sup>, Filippo Calcerano<sup>3</sup>, Xi Chen<sup>1</sup>, David Chow<sup>2</sup>, and Elena Gigliarelli<sup>3</sup>

<sup>1</sup>Xi'an Jiaotong-Liverpool University, China

<sup>2</sup>University of Liverpool, United Kingdom

<sup>3</sup>Italian National Research Council, Italy

## Abstract

The contribution discusses the energy use and characteristics of the residential building stock in Jiangsu Province (China), with a focus on the potential of large-scale energy retrofit to mitigate environmental impact and running costs of its most inefficient vintages, while improving occupant comfort and reducing the need for demolition and reconstruction in the upgrading of the stock.

While the historical part of the residential stock is profoundly rooted in the local traditions and adapted to the climate of the region, the development of the newer building typologies, that currently constitute the majority of the extant buildings, has been drastically shaped by different international influences starting from the 20<sup>th</sup> century.

The study is part of a research conducted mainly by means of bottom-up energy modelling and simulation. The methodology involves the identification of representative typologies that can be modelled in detail and be assigned a statistical weight to typify the behaviour of the entire stock. Different sets of simulations can then predict the performance of the entire stock in different scenarios. Preliminary results indicate a significant potential of relatively simple retrofit interventions to reduce energy use and, more in general, the environmental impact of the construction and demolition industry in the province.

**Keywords:** Energy retrofit, Energy simulation, Building Stock

Corresponding Author:

Marco Cimillo

marco.cimillo@xjtlu.edu.cn

Received: 15 March 2019

Accepted: 25 May 2019

Published: 20 November 2019

Publishing services provided by

Knowledge E

© Marco Cimillo et al. This article is distributed under the terms of the [Creative Commons Attribution License](#), which permits unrestricted use and redistribution provided that the original author and source are credited.

Selection and Peer-review under the responsibility of the Architecture across Boundaries Conference Committee.

## 1. Introduction

Buildings in China are responsible for about 25% of the national energy consumption, and the residential stock represents about 80% of the total floor area. While the current residential floor area is projected to increase by 68% by 2050 [1], the energy used by households is likely to grow even more, as it appears to be largely affected by the (increasing) available income. The country is also the largest CO<sub>2</sub> emitter in the world and the whole building sector is estimated to contribute by 30-40% of the total [2]. However, China's energy intensity by GDP dropped from 13.14 tce/10,000 Yuan in 1980

 OPEN ACCESS

to 0.59 tce/10,000 Yuan in 2016 [2]. By ratifying the Paris Agreement - COP21, the country has pledged to enhance low-carbon urbanization by improving energy efficiency and extending lifespans of buildings, by applying integrated renewable energy and increasing the share of green buildings to 50% in new constructions by 2020 [3]. The understanding of energy use in residential buildings is critical to the implementation of such policies, and building stock modelling can contribute in this respect, and can inform effectively energy retrofit and policy making.

Jiangsu Province, with 5.8% of the population of the country, represents 10.4% of its GDP and around 9.5% of the electricity consumption. With several important cities in the Yangtze Delta area, connecting to the Greater Shanghai, the urban development in the province is among the most dynamic in the world, with 18% of the building floor area completed (754.5 million m<sup>2</sup>) and under construction (232 million m<sup>2</sup>) in China in 2017. Jiangsu's urban population grew from 55.6% in 2009 to 68.76 in 2017 and the building stock of the province is among the largest in China, over 3.3 Billion m<sup>2</sup>. For most part, its climate is characterised by cold winters and hot summers (CWS region), with significant energy demand for both heating and cooling, whilst the northernmost portion of the territory falls in the "cold region" category [4].

Currently, a clear understanding of the energy performance of such stock is lacking because the available statistical data are incomplete on both building floor space and building energy intensity, due to data grouping (e.g. building energy consumption not differentiated, collective housing not counted in per capita floor space in the annual yearbook etc.) and its variability over time [5].

Therefore, a detailed stock energy model can provide a better comprehension of the current and future performance and trends.

## 2. The Residential Building Stock in Jiangsu Province

For two thousand years the interconnection between Chinese climate and culture have produced vernacular housing types optimised in terms of environmental energy which, although in a multitude of variants, have maintained a substantial conceptual unity [6-7], governed by the courtyard scheme (siheyuan), that is the result of the interaction between a generalised climatic contrast between cold and dry winters and hot and humid summers and the philosophical-cultural dualism between yin and yang [8] included in the ideal model of Feng Shui (Mak e So 2015; Tang et al. 2012). The spatial characteristics of the court typologies vary from large courts with single level buildings to guarantee solar access and protection from winter winds in cold climates,

to narrower courtyards and multi-level buildings to make the most out of the summer breezes while allowing solar control in warmer climates [8].

In the climatic area of the Jiangsu province, characterised by hot summers and cold winters [7-8] the siheyuans are more compact than those of the North, and are often organised in groups (arranged in series with the commercial side facing the main streets). Such a layout creates narrow streets with white walls and shaded spaces capable of shielding the sun’s rays while allowing wind cooling during the warm seasons [7].

In more modern times, and especially since 1949, the urban residential buildings have been developed rapidly along with significant changes on not only urban housing system, but also building types. Multiple factors have contributed to the transforming of city residence forms of China and Jiangsu province, including the China’s urban housing system reform and a series of improvements on urban housing regulations.

At the early stage of the development of new China, a low-rent welfare oriented housing system was developed, in which houses were essentially built and distributed by the government. Due to the particular economic conditions and to the ‘producing before living’ approach, there was a very strict limit on housing construction, which by 1977 had led to a severe shortage and poor quality of environmental living conditions [9-10-11]. Residential building realised during that period were low-rise dwellings (below 3 storeys), with no individual bathroom and kitchen and lack of public facilities [12].

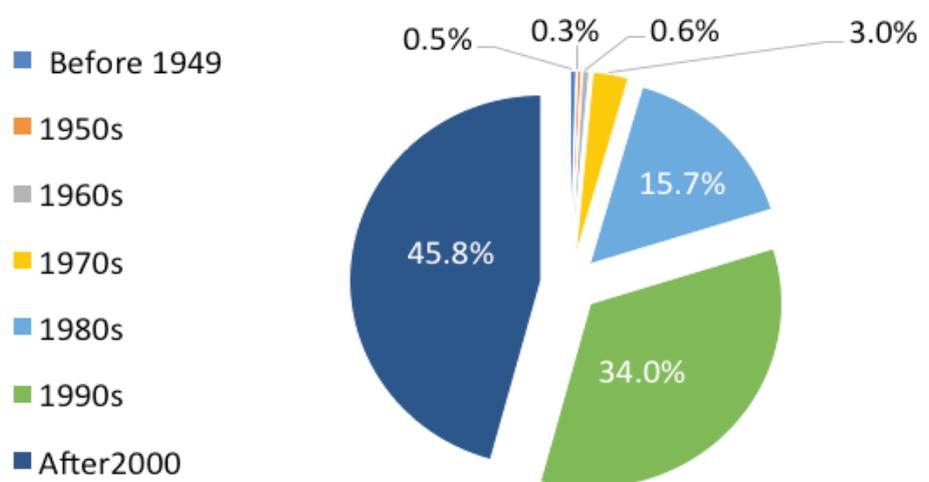


Figure 1: Jiangsu Province housing stock by age of completion.

After the Economic Reform and Open Up in 1987, the urban housing system reform started a phase of experimentations. The distribution housing system was phased out to be replaced by a farther-supply of affordable multi-storey urban housing by 1998 [9]. Numerous residential neighbourhood units were built with increased living area, diversity of building layouts, individual bathroom and kitchen, resulting in substantially

improved living conditions [12]. However, the main focus during 1988 to 1998 was to solve the housing shortage problem, which led to a lack of attention to the indoor living environment and to the energy performance. These became more important factors from 1998, affecting significantly building form, layout, materials and construction. As a result, buildings that were constructed between 1978 and 1998 have their very own unique characteristics, conceived as a modern residence, but poorly realised in terms of construction and environmental performance. These buildings are thus still reasonably adequate in terms of spaces (and can have their lifetime extended if retrofitted) and have at the same time great potential to reduce their current energy consumption. Hence, this portion of the building stock was selected to start the modelling process.

### 3. Regulations and Standards

China's vast territory and complex terrain bring very complex climate systems which have critical influence on the architectural designing. *The code for design of civil building (GB50352-2005)* (Ministry of construction of the People's Republic of China, 2005) has classified the whole country into 7 architectural climate zones (building climate), and most of Jiangsu Province lies in the hot summer-cold winter zone. The current classification of architecture climate zone is based on the *Standard of climatic regionalization for architecture (GB50178-93)* and *Thermal design code for civil building (GB50176-93)*.

China's first regulation on urban housing design was published in the early 1950s, which was adopted from the Soviet's housing design standards. It was a design standard for general building design, but not specific for housing. It was not until 1987, the first design regulation on urban housing was published, which established detailed requirements, including housing areas, individual kitchen and bathroom, shading system. The following regulation was published in 1999, with modifications to staircases, building areas and kitchens and bathrooms. In 2003, a new regulation, revised from the 1999 version, emphasised the convenience and security of living environment. More recent regulations are more focused on the function, living quality and sustainability [12]. Therefore, buildings in 80s and 90s have similar form in whole China since they followed the same design regulation.

From an energy performance standpoint, the first important national energy conservation law was approved in 1989, promoting efficiency in design (shape and orientation) envelope and systems. Chinese standards were then progressively raised until the publication in 2015 of the MoHURD's Technical Guidelines for Passive Ultra-low Energy

use Green Buildings, which provides a clear definition and energy consumption indexes differentiated by climatic zones, set for a trial implementation in residential buildings [13].

In recent years, the policies on energy retrofit were strengthened as well, with the MOF's "Interim Regulation on Subsidy Funds for Energy-saving Renovation of Existing Residential Buildings in Hot Summer and Cold Winter Zone: public subsidies for energy-saving renovations in CWSH regions" in 2012, and the NDRC and MoHURD's "Action Plan for Urban Adaptation to Climate Change: comprehensive measures for passive and active building design, water efficiency and renovation standards" in 2016. Yet, previous studies found that compliance with energy codes has been poor in China until 2008, when only 50% of the buildings adhered the regulations [14].

## 4. Methodology

The model under development adopt a "bottom-up" approach already validated in several different countries and climatic contexts [15], and consisting in the selection and modelling of a limited number of representative typologies which are assigned a statistical weight in the whole building stock, and can constitute a reliable projection of the whole. Such model makes possible to analyse in detail the current energy performance, but also to project it multiple future settings, including different climate change scenarios, and the assessment of alternative retrofit strategies. The modelling process is at the initial stage, and two typologies were selected as a starting point from those comprised in the stock built in the 1980s-90s for the reasons stated above. These were also use to test the response of energy saving measures on the thermal envelope.

The majority of building stocks constructed in 1980s and 1990s are multi-storey residential apartments, and they are usually classified by the building geometry. The most common building types are 'Danyuan' apartment, tower building, small-patio building and corridor buildings.

'Danyuan' apartment in Chinese stands for two or more household sharing one staircase, and two or more Danyuan can be combined in one building (see Figure 2). This type of building usually came in leaner and simple shape.

A tower building stands for those who have several households sharing one Danyuan, and the building shape can be very complex according to the number of household on one storey (see Figure 3).

The small-patio buildings usually look similar with Danyuan apartments and tower buildings, but with a small courtyard inside each Danyuan, which gives its unique thermal

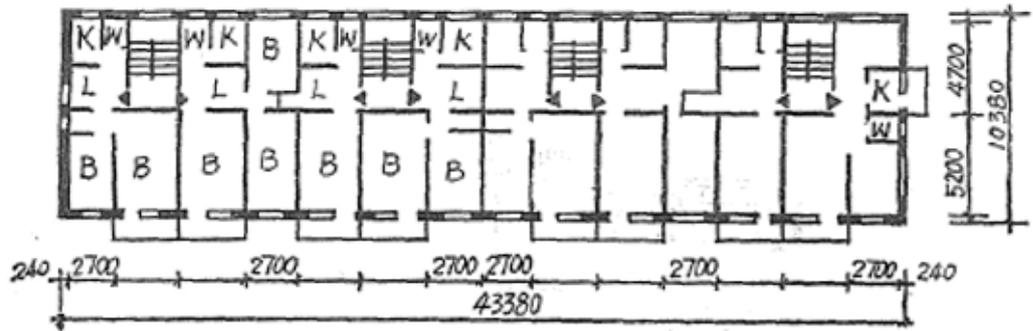


Figure 2: A four-Danyuan apartment building plan (one of the two selected typologies).

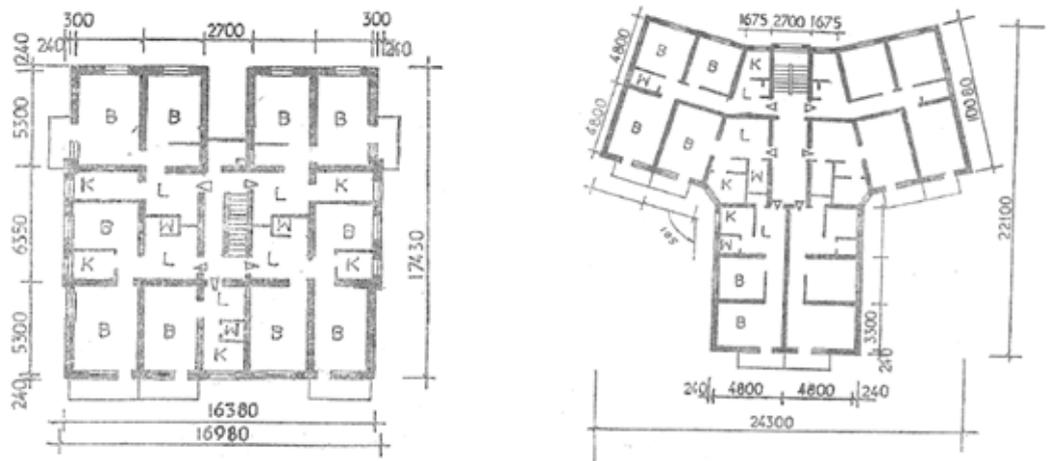


Figure 3: Tower buildings in square-shape (one of the two selected typology), and Y-shape.

and energy performance due to the stack effect. However, the small-patio building have the similar building geometry with Danyuan apartment, so the specific differences of these two building types need to be found through digital modelling and simulation.

Corridor buildings also have similar shape with Danyuan apartments which is linear shape on one direction. Corridor buildings usually have one public corridor in the middle or northern side of the building, and the apartments are located on one or two sides of the corridor. In addition, the ground floor of this type of buildings sometimes are commercial level, known as small shops on the ground level, which may have different layout and structures, and can be regarded as no heat transfer from the residential space to the ground. The four-Danyuan in Figure 2 and the square tower in Figure 3 where selected to start the study, for their different geometry and compactness.

## 4.1. Climate data and future scenarios

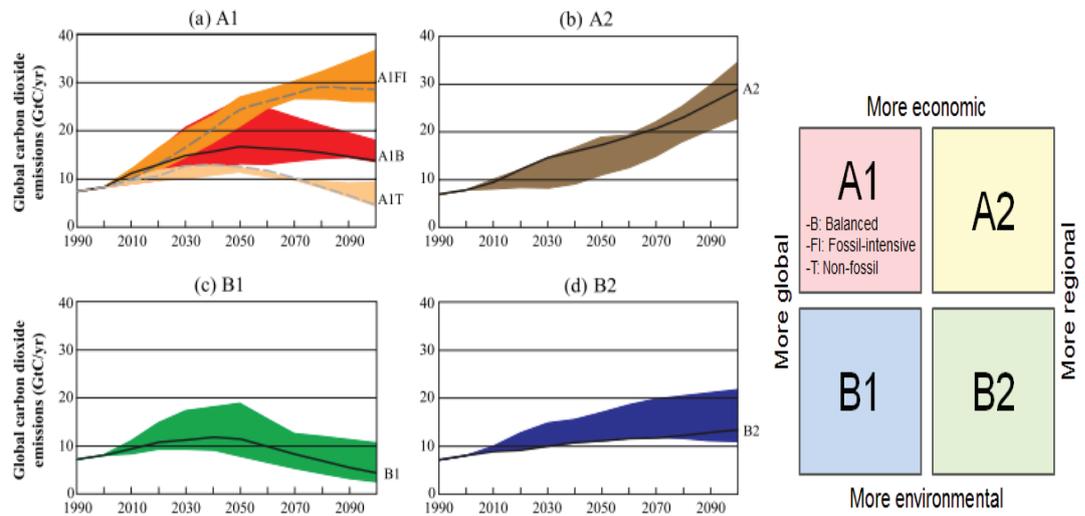
Climate data used for this study were generated using the Meteonorm 7.3 software ([www.meteonorm.com](http://www.meteonorm.com)), which is a product by Meteotest, based in Switzerland. This software has a database for over 30 current weather parameters such as global, direct and diffuse irradiation on horizontal and inclined surfaces, air temperature, relative humidity and wind speed, taken from the period 1961-1990 and 1991-2010. The same was also used to generate future climate data for years 2020 to 2100, using the IPCC Special Report on Emissions Scenarios (SRES) A1B, A2 and B1 [16]. The accuracy of using Meteonorm for future climate data is well-documented and well-studied [17-19], and its ability to provide hourly weather data for future periods makes a feasible tool for the study of building performance under climate change [20]. Future scenarios are based on UN's Intergovernmental Panel on Climate Change (IPCC) "The Special Report on Emissions Scenarios (SRES)" [16], where projections regarding future global carbon emissions were estimated from four key future storylines, A1, A2, B1 and B2, where the A scenarios predicted a future that is more economically focused, and the B scenarios more environmentally focused. The 1 scenarios predicted more global development, whereas the 2 scenarios predicted more regional development. These scenarios were used in the IPCC Third Assessment Report (TAR) [21] and also the IPCC Fourth Assessment Report (AR4) [22], and were superseded by Representative Concentration Pathways (RCPs) in 2014 [23], for the IPCC Fifth Assessment Report (AR5). Although SRES scenarios have been replaced, they are still used extensively in climate change studies, due to the vast range of future storylines, and the science behind them are still valid. Figure 4 shows the estimated changes in global CO<sub>2</sub> emissions for the 4 main scenarios, and the three scenarios generated by Meteonorm (A1B, A2 and B1) are able provide the range of feasible scenarios for the future.

Recent research showed that observed emissions are exceeding all projections [24]. Therefore, in spite of the high degree of uncertainty, the worst scenario, and even a higher degree of variation, are still possible.

## 5. Preliminary Results

### 5.1. Current and future energy use in the baseline scenario

The two selected typologies were simulated in the current climate and conditions and in three different future scenarios up to 2050. Due to the above-mentioned poor



**Figure 4:** The four key future storylines for the SRES (right) and the expected Carbon Dioxide Emissions (left).

compliance with building codes in those periods, the thermal characteristics of the external envelope are therefore derived from the reported common practice [25], but not very distant from the prescribed values. The same two typologies were then also tested in retrofitted conditions to assess the potential of simple energy saving measures on the building envelopes, including the external insulation of walls and roofs with 6-cm cork panels, and the replacement of single-glass windows with Low-E double-glass windows (details in Table 1). Even though the two typologies do not represent the entire building stock vintage, they are deemed suitable to provide a valid indication of the general performance of the buildings constructed with similar characteristics.

At this stage, the study does not take into account the efficiency of HVAC systems, nor does it consider other factors impacting the energy consumptions but not related directly to the buildings themselves, such as user behaviour and social changes occurring over time. All simulations were performed using EnergyPlus 9.1, a widely validated program developed mainly by the US Department of Energy and the National Renewable Energy Laboratory [<https://energyplus.net/testing>].

The cities selected represent different climatic conditions of Jiangsu Province are Nanjing, Xuzhou and Shanghai (the latter is just outside the administrative borders of the province, but for the purposes of this study more reliable data are available than in the contiguous areas of Jiangsu). With the two typologies tested in two configurations, three cities and seven climate scenarios, a total of 84 simulations were performed.

TABLE 1: Building envelope characteristics at the current and retrofitted state.

Component	Current State	Retrofitted
External walls U-value (W/m <sup>2</sup> K)	2.08	0.48
Roof U-value (W/m <sup>2</sup> K)	1.88	0.54
Windows U-value (W/m <sup>2</sup> K)	5.89	2.40
Windows SHGC (Solar Heat Gain Coefficient)	0.86	0.65
Air tightness ACH (Air Changes per Hour)	1.5	0.5

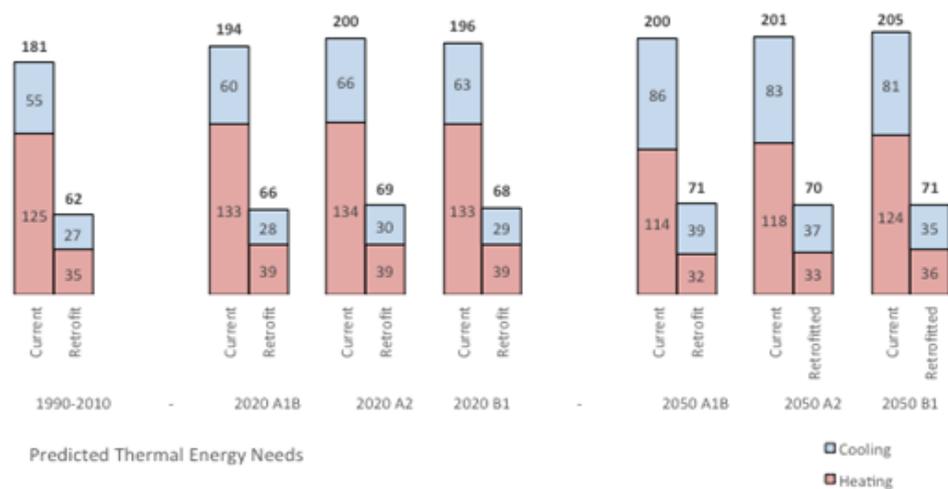


Figure 5: Main of the results of the set of energy simulations in the considered scenarios.

The chart in Figure 5, illustrates the main results of the simulations averaging the figures of the two typologies in the three selected cities. The following observations can be derived:

- The low-rise typology (2storey 4-danyuan), in spite of a lower compactness, performs better than the tower, due to a more effective use of passive solar gains (-20% of the total thermal energy need, not readable from in the figure, the two being combined).
- Without interventions, the total need would rise by 11 to 13% in 2050. However, whilst heating energy is predicted to drop by up to -9%, cooling energy is expected to rise by up to 45%. Cooling demand is therefore expected to account for 43% of the total energy need in 2050.
- Relatively simple retrofit measures on the thermal envelope of the most poorly performing buildings can generate savings in heating and cooling energy of up to 62% in the current climate, and in the projected 2050 scenario.
- Retrofitted buildings would see a rise in cooling energy demand by up to 50% of the total energy need.

## 6. Conclusion

The first phase of the research confirms the importance of developing a model able to represent and to predict the energy performance of the residential building stock in the province. This is missing at the moment and would contribute to a clearer understanding of its dynamic, and provide useful information to govern its future transformations.

Further research is required to increase the level of detail of the models, extend the number of sampled typologies, expand the selection to the other vintages of the building stock, and to validate the data. Nonetheless, the study provides an indication of the size of the expected rise in energy need for heating and cooling in a specific section of the building stock and, at the same time, of the potential of basic measures to reduce the demand.

Large-scale retrofit strategies proved effective in Europe, were the stock develops at a slower pace, and for example Italy has improved the efficiency of its residential stock by 34% between 1990 and 2010 [26]. Given the current dynamics, in China implementation of stricter codes regulating new constructions seems to have a higher impact. However, China's construction and demolition industry is currently responsible of 30-40% of the world's use of steel and cement, and accounts for 30-40% of the national waste production in the country. A mere 10-year extension of the average lifetime of buildings is estimated to be able to save 30% of new construction [27]. A shift towards a wider use of retrofit, as opposed to the current intensive new-building approach would therefore generate much broader and deeper benefits than just improving energy efficiency and thermal control.

## Funding

This work was supported by Xi'an Jiaotong-Liverpool University through the Research Development Fund, Grant n. RDF-16-01-46.

## Conflict of Interest

The authors have no conflict of interest to declare.

## References

- [1] Hong, L., Zhou, N., Feng, W., Khanna, N., Fridley, D., Zhao, Y., & Sandholt, K. (2016). Building stock dynamics and its impacts on materials and energy demand in China. *Energy Policy*, 94(June 2015), 47–55.
- [2] Lin, B., & Liu, H. (2015). CO<sub>2</sub> emissions of China's commercial and residential buildings: Evidence and reduction policy. *Building and Environment*, 92, 418–431.
- [3] Su Wei, National Focal Point of UNFCCC, Director-General, Department of Climate Change, National Development and Reform Commission, People's Republic of China. (2015). Enhanced actions on climate change: China's intended nationally determined contributions
- [4] National Bureau of Statistics of China, China statistical Yearbook 2018, available at <http://www.stats.gov.cn/tjsj/ndsj/2018/indexeh.htm>
- [5] Tengfei Huo, Weiguang Cai, Hong Ren, Wei Feng, Minglei Zhu, Ningning Lang, Jingxin Gao, China's building stock estimation and energy intensity analysis, *Journal of Cleaner Production*, Volume 207, 2019, Pages 801-813
- [6] Almodovar-Melendo, Jose-Manuel, e Joseph-Maria Cabeza-Lainez. 2018. Environmental Features of Chinese Architectural Heritage: The Standardization of Form in the Pursuit of Equilibrium with Nature. *Sustainability* 10 (7): 2443.
- [7] Sun, Feifei. 2013. «Chinese Climate and Vernacular Dwellings». *Buildings* 3 (1): 143–72
- [8] Bouillot, Jean. 2008. «Climatic design of vernacular housing in different provinces of China». *Journal of Environmental Management, Chinese Villages and their Sustainable Future*, 87 (2): 287–99. Nakicenovic, N., et al., Special report on emissions scenarios (SRES), a special report of Working Group III of the intergovernmental panel on climate change. 2000: Cambridge University Press.
- [9] Deng, Y. (2017). Urban housing system reform and real estate market development in China. *Housing Finance International*, Autumn2017, p15-17. 3p.
- [10] 李培, (2008). 中国住房制度改革的政策评析. *公共管理学报*, Vol.5 No.3 July 2008, p47-55.
- [11] Kai, Y, (2009). The Course and Prospect of Chinese Housing Industrialization in the Past 60 Years. *住宅科技*, Vol.2009.10, p01-05.
- [12] Zhang, D & Fan, L, (2005). The Development of Our Country City Residential Standard Revision and Residential Buildings. *Chinese and Overseas Architecture*. Vol. 2013, (6), p56-57.

- [13] Xueliang Yuan et al., The Development of Building Energy Conservation in China: A Review and Critical Assessment from the Perspective of Policy and Institutional System
- [14] Minda Ma, Weiguang Cai, Yong Wu, China Act on the Energy Efficiency of Civil Buildings (2008): A decade review, *Science of The Total Environment*, Volume 651, Part 1, 2019, Pages 42-60
- [15] Loga, T., Stein, B., & Diefenbach, N. (n.d.). TABULA building typologies in 20 European countries—Making energy-related features of residential building stocks comparable. *Energy and Buildings*. JOUR.
- [16] Nakicenovic, N., et al., Special report on emissions scenarios (SRES), a special report of Working Group III of the intergovernmental panel on climate change. 2000: Cambridge University Press.
- [17] Remund, J., Accuracy of Meteonorm. A detailed look at the model steps and uncertainties.[online] Available at: [http://www.meteonorm.com/images/uploads/downloads/Accuracy\\_of\\_Meteonorm\\_7.pdf](http://www.meteonorm.com/images/uploads/downloads/Accuracy_of_Meteonorm_7.pdf) [Accessed 21 Apr. 2016], 2015.
- [18] Remund, J., Quality of meteonorm version 6.0. *Europe*, 2008. 6(1.1): p. 389.
- [19] Remund, J., Chain of algorithms to compute hourly radiation data on inclined planes used in Meteonorm, in *Modeling Solar Radiation at the Earth's Surface*. 2008, Springer. p. 393-410.
- [20] Remund, J., et al. The use of Meteonorm weather generator for climate change studies. in 10th EMS Annual Meeting, 10th European Conference on Applications of Meteorology (ECAM) Abstracts, held Sept. 13-17, 2010 in Zürich, Switzerland. <http://meetings.copernicus.org/ems2010/>, id. EMS2010-417. 2010.
- [21] Metz, B., et al., Climate change 2001: mitigation: contribution of Working Group III to the third assessment report of the Intergovernmental Panel on Climate Change. Vol. 3. 2001: Cambridge University Press.
- [22] Solomon, S., et al., IPCC fourth assessment report (AR4). *Climate change*, 2007.
- [23] Thomson, A.M., et al., RCP4. 5: a pathway for stabilization of radiative forcing by 2100. *Climatic change*, 2011. 109(1-2): p. 77.
- [24] Felix Pretis, Max Roser (2017), Carbon dioxide emission-intensity in climate projections: Comparing the observational record to socio-economic scenarios, *Energy*, Volume 135, 718-725
- [25] Engineering practice, Series of construction projects in Jiangsu Province Atlas of standard design 苏J01-2005. (2006) China Architecture & Building Press
- [26] Odysee-Mure Database 2014

- [27] Lixuan Hong, Nan Zhou, Wei Feng, Nina Khanna, David Fridley, Yongqiang Zhao, Kaare Sandholt, Building stock dynamics and its impacts on materials and energy demand in China, *Energy Policy*, Volume 94, 2016, 47-55