

# Evaluating the Nexus between Housing and Energy Sectors: The Comparison of Urban, Peri-Urban and Rural Housing Areas in Zhuhai, China

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## Abstract

China has developed several housing policy reforms and has, in recent years, progressed further on developing policies to promote green strategies and energy-saving plans. The urban housing has much benefited from such reforms and plans, while rural housing has experienced minimal change in the past few decades. As a result, this study aims to identify and explore these differences, challenges, and implications that exist between three areas of urban, peri-urban, and rural in a particular case study in China. For this study, selected residential areas in the City of Zhuhai and its peri-urban and rural areas are selected as case studies. A questionnaire survey is conducted to analyze energy and housing conditions across the more prosperous urban, the dynamic and transitory peri-urban, and the less prosperous rural areas. The case studies are analyzed as comparative examples in a hot and humid sub-tropical area of Southern China. The study compares energy and housing conditions and argues potential possibilities and challenges for the future development of housing policy reforms that are the result of current housing development patterns and green strategy situation in China.

## Keywords

Energy, Housing, Urban, Housing Policy, Housing Reforms, China

## 1. Introduction to Housing Sector in China

Housing is a significant part of the built environment. In the past three to four decades, the Chinese housing system has drastically changed from one dominant

type of public housing to private house ownership [1]. This includes new development of mid-rise housing, high rise apartments, gated residential communities, and a cluster of low-rise luxury housing (locally known as villa housing) [2]. In regard to this process, Logan *et al.* [3] argue two new ways of housing reform; 1) “*privatization of public housing*”; and 2) “*development of new private housing sector*”. Since 1949, both ways are new to the context of China but have grown immensely at different times and throughout different housing reforms. Additionally, the change in the Chinese housing pattern system and development patterns has a major impact on the overall change of household energy consumption, change of living lifestyle, and change of well-being and quality of life in the living environments [4] [5] [6] [7]. The impact on the geography of space determines the way residents’ living and consumption patterns are shaping. This is, in particular, important to China due to its pace and scale of development and growth. More specifically, there are impacts on non-urban areas that should be taken into consideration. We could refer to these as possible challenges on urbanization and urban development that require careful planning in the next reforms, urbanization plans, and development modes [8].

While in recent years most research on Chinese housing has been on price increase [9]-[15], issues of affordability [16] [17] [18], sustainability [6] [7] [19] [20] [21] and structure of housing development [22] [23] have become critical matters to China’s current conditions and the future phase of development. Some of these studies are developed from earlier critical analysis of China’s housing issues, such as inequality in Urban China [24] [25], multiple stakeholder analysis of benefits [3], housing quality differences [26], market transitions [27], etc. In recent transitions, there are clearly issues of housing inequalities not only between different Chinese cities [28], but also between different areas of the city environments, such as urban, peri-urban, and rural areas of municipalities. This reflects on real estate market supply and demand function [29] [30] as well as efficiency of market [31] [32] [33], development mode in different locals, market-driven mechanisms, and pro-developer approaches to growing urbanisation [34]. Also, the differences between cities of different sizes and their markets are highlighted in China’s recent urbanization plan, called New-Type Urbanization Plan (NUP) [35]. Hence, there are certain transitions that could be taken into consideration for the housing sectors. These transitions are studied through various possibilities, such as housing differentiation issues [36], economic policy uncertainties [37], housing market dynamics [38], dynamics and inequalities in energy efficiency [39] [40] [41], green housing transition [42], the impact of housing price on non-housing matters [43], etc. Some of these could be verified through different structural transitions [44], changes in institutional arrangements or structure [22], socio-economic development and land-use change [45], as well as issues of urbanisation [34] [35], and different scales [46] or spatial levels [47]. For instance, China’s “*transition of the housing model from an administrative system to a market-oriented system*” [48] has changed the social structure in many new developments and is continuously having a major impact on

housing typologies and housing design [2]. Furthermore, the rise of household energy consumption determines a definite need for policymakers, designers, and developers to consider energy-saving approaches in construction and development [2] [6] [35] [49].

The Chinese housing market is a unique, and yet challenging, model in the developing world. The rapid urbanization and huge demand for housing have accelerated the process of construction, resulting in poor quality design (e.g. design type and layout), poor quality material selection, and with less concern about energy-saving principles. Therefore, housing accounts for a major part of China's built environment and construction sectors, particularly in recent years housing construction is expanded significantly. In March 2011, the Chinese government's objective to build 36 million units of housing by 2015 [50] indicates a major housing construction trend, which is both unprecedented and unpredictable. Therefore, it is important to analyze China's current status, more recent transitions, and plans for housing construction, and subsequently evaluate the attributes that will contribute towards the growing energy consumption. All these together will provide a critical overview of China's housing. The current research gaps on energy and housing at multiple scales of municipalities in China could be reviewed, assessed through various comparative perspectives, and suggestions for future policy development and practical implications.

### **1.1. China's Energy Issues and Housing**

The steady rise of urbanization has a direct impact on housing development in the urban, peri-urban, and rural areas. This has been developed even further in the latest urbanization plan introduced in 2014 [34] [35]. In comparison with the Western standards, energy use in housing has been insignificant [51]-[57] but the substantial increase in the past few decades has become one of China's major energy issues [35]. This challenge adds to China's energy load, increasing cooling and heating demand [58] [59], as well as issues of energy supply. The Energy Conservation Law (ECL) in 1997 and then the following policies on the green building since 2000 can be considered as the starting points in recognizing the position of household energy consumption in housing construction. Since then, the policy reform on housing energy efficiency has been insignificant but has now become part of China's 12th five-year plan (the previous FYP), the recent 13th five-year-plan, and highly likely in the forthcoming ones. The three pillars of "energy efficiency", "low carbon", and "green development" in China's 12th and 13th FYP are considered as a direct prescription to the current energy issues in China's construction sector. With the progress on context-specific building code and life-cycle data, the gap in current research on China's housing and energy remain valid and important. As a result, context-specific studies are essential to identify energy-related attributes that are part of future design specification, household energy demand, and consumption. More importantly, a multi-scalar comparison as studied in this research paper could highlight gaps, issues, and implications in different locales and at different spatial patterns [60]

and multiple levels of the municipalities.

Since 1998 and the change of China's welfare housing system, the Chinese housing policy has changed intensely with respect to the issues of affordability and sustainability; one of which is the nationwide (and indeed global) energy issue that is yet to be tackled. In their study on *Dynamics of urban and rural housing stocks in China*, Hu *et al.* [61] examine potential scenarios for new construction activities based on demographic changes that are expected to occur in both the urban and the rural areas of China. In their study, the authors simulate different development paths depending on major parameters of population change, urbanization rate, building durability, and housing demand [61]. In each development path, it is clear that housing demand is shaping as a major attribute to the future of China's development. The resource demand analysis helps to represent scenarios for future challenges that may also involve energy production and consumption. Some data is available in the China Energy Strategy 2000-2050 that project forecasts in the coming decades [62]. Similarly, Yang and Kohler [63] calculated China's material and energy implications as part of its future growth and development. Nevertheless, a modelling technique is probably not the most feasible approach to identifying and understanding the current changes and development trends in the context of China. Therefore, this study aims to undertake a more analytical and critical approach to evaluate a particular case of energy and housing in China. In general, this study highlights the gap in the literature by conducting a data analysis from sample surveys three different areas of urban, peri-urban, and rural of a selective city. This is conducted through on-site surveys rather than the usual methods of statistics-based analysis. This approach is believed to be less generic and more representative of the case study areas.

## 1.2. Objectives of the Survey Study

This is a context-specific housing study for a sub-tropical hot and humid condition in Southern China. Based on existing conditions and patterns of development in three spatial categories of urban, peri-urban, and rural, this study firstly explores the conditions of residential units and then provides a set of data for primary household energy uses during warm and cold seasons. The collected data are then analyzed for further cross-analysis. The questionnaire survey covers several aspects of housing conditions and energy consumption patterns. The survey study is essential for such a study as it includes an observational method to the conditions of housing and living environments. A cross-comparison between housing models of urban, peri-urban, and rural regions promotes a comprehensive understanding of the living conditions and energy-related issues across different social classes of one context. The questionnaire survey includes three attributes of "housing occupancy", "housing typology", and "seasonal household energy consumption".

The objectives of the study are: 1) to develop a cross-analysis between urban,

peri-urban and rural housing in South of China; 2) to analyze between housing models, household occupancy and energy consumption; and 3) to identify trends of housing models and their implications on energy demand and consumption.

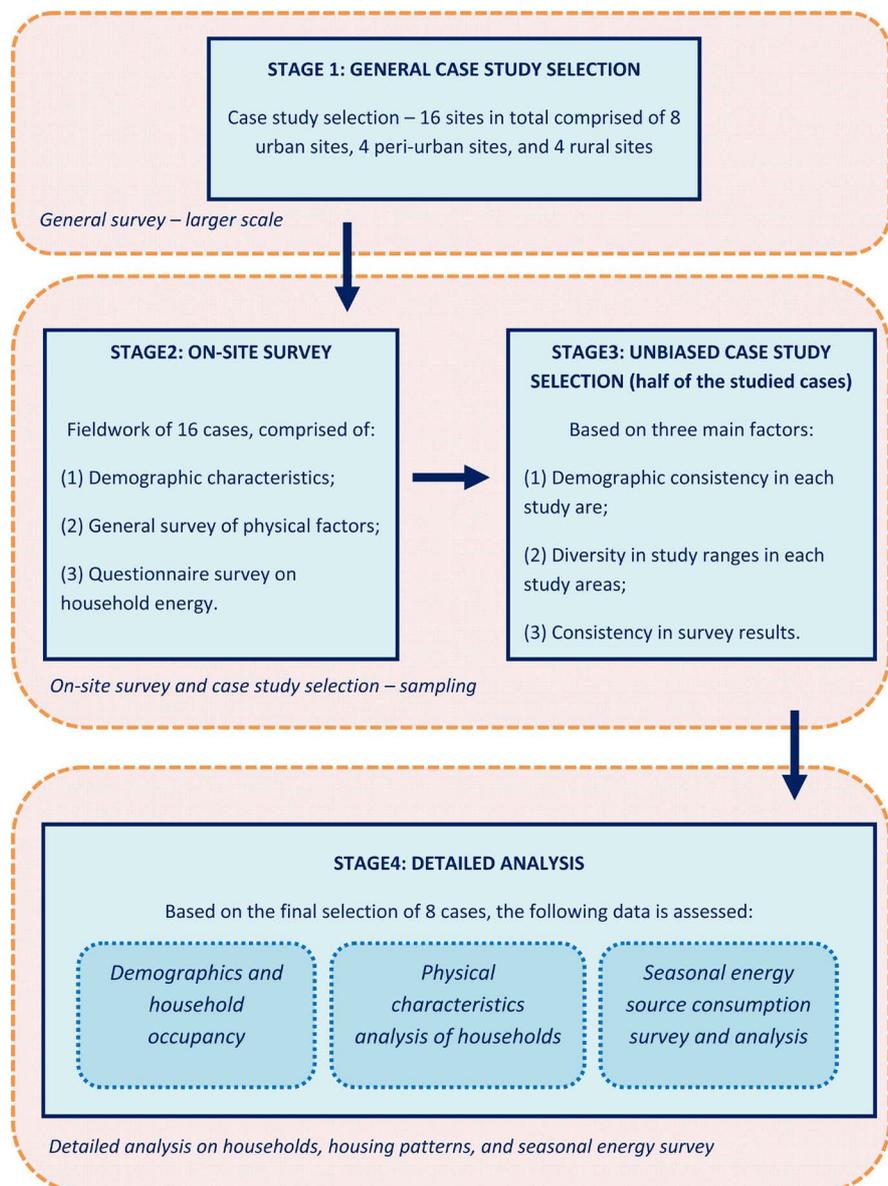
### 1.3. Methodology

This survey study was conducted in eight consecutive days in multiple spatial areas of the city of Zhuhai, south of China. This example is selected based on its hot and humid climatic conditions, growing urbanization, and increasing energy demand (mainly for cooling). The methodological approach includes both questionnaire and observational study of selected residential areas. The participants of the study are residents of three spatial categories in one region, *i.e.* urban, peri-urban and rural, in Zhuhai. The criteria for this selection are based on the fact that they represent three main areas of municipalities, and all three represent different social classes. In this study, however, all participants are selected from low to middle class social groups in one unitary area, as they represent the growing population of cities in developing contexts. The questionnaire approach (see Appendix A for details) is aimed to highlight key aspects of energy and housing demand, household conditions, and household energy consumption patterns. The consideration of multiple scalar analysis is used as part of the overall energy and housing evaluation, which highlights the differences between housing energy issues and household energy consumption patterns in various levels of unitary or municipality areas. The findings would contribute to better understanding of energy matters at multiple scales of cities as well as variables and implications of energy supply and demand at those levels.

The study intentionally does not use statistical data on the consumption of energy resources and sampling as such data often are generic across all social groups of different backgrounds. In existing studies, the statistical data suggest general results that may not be truly representational of different social groups. In light of this matter, the depth of demographic differences could not be simply highlighted through statistical data and analysis. Hence, the study's data collection is based on multiple case studies initially taken from 16 locations across one city example and in three different study areas of urban, peri-urban, and rural. In this study, to reduce the risk of generating bias, the representative case study areas were then selected. From the initial eight urban areas, four representative study areas are selected to ensure consistency and accuracy across collected data. Similarly, from the initial four peri-urban areas, two representative study areas are selected to ensure selection is made based on accurate and unbiased collected data. This is also repeated for rural areas, where four case examples were studied, and two representative study areas are then selected. In this regard, the data is assessed across all cases in each category (*i.e.* urban, peri-urban, and rural) to ensure only selecting the ones unbiased and consistent. This selection is made by voiding half of the case studies, ensuring that each case study example is consis-

tent with other collected data and represents the actual demographic patterns of the city. The number of participants from the selected study areas is concluded in a similar range between 132 and 143 (*i.e.* higher than 130 and lower than 150) per case study example. This has taken into consideration a 10% potential inaccuracy, which is already voided from the data analysis.

The schematic diagram below (**Figure 1**) represents the study's methodology in four stages. In stage 1, the study starts with a general case study selection based on three specific context areas and demographic categories, which is then assessed through a general survey study. The on-site survey was conducted during eight consecutive days (2 case study per day), through which three main factors were assessed, namely 1) demographic characteristics, 2) general survey of



**Figure 1.** Schematic diagram of flow chart for the research study stages from general case study selection to on-site survey, sampling of case study selection, and detailed analysis.

physical factors, and 3) questionnaire survey on household energy (seasonal survey). In stage 3 of the study, unbiased case study selection is conducted, which is a selection of half of the originally studied cases. Finally at stage 4, a detailed analysis of the data is conducted to provide a representative sampling of the case study areas across three studied areas of urban, peri-urban, and rural.

## 2. Case Study Overview: Zhuhai's Urban, Peri-Urban and Rural Study Areas

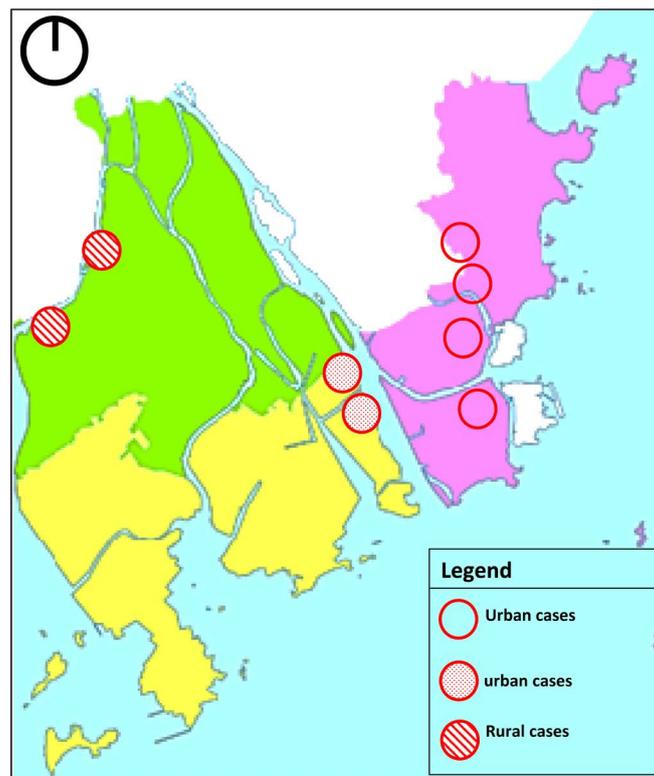
The City of Zhuhai is one of the earliest and original Special Economic Zones in China and is located on the southern coast of Guangdong Province, which is also known as the Pearl River Delta (PRD). At the latitude of 22.27°N, Zhuhai has a hot and humid climate. It is one of the key urban areas of Southern Guangdong as it borders Macau Special Administrative Region (by land) and Hong Kong Special Administrative Region (by water). In 1998, Zhuhai was “*recognised by the United Nations as the Best model of International Residential Environment Improvement*” [64]. This was mainly due to the local government’s focus on quality living environments and sustainable development. With three main districts of Xiangzhou District, Doumen District, and Jinwan District, most of current and proposed development areas are mainly considered as coastal areas (Figure 2).

The city’s steady economic growth and attraction for tourism activities in recent years, has helped to promote the city’s restructuring as a major urban hub. In return, the population for the city’s temporary residents is increasing faster than before, which is studied for the period between 1979 and 2010 [64]. This indicates growing service-based and industry-based employment opportunities, including the job market in both the urban and the peri-urban areas of the city. This demographic change is important to housing demand and construction of mass housing in some parts of the city.



**Figure 2.** Zhuhai’s main districts and the larger context of Pearl River Delta where Zhuhai is located between the four points of Macao, Hong Kong, Shenzhen, and Guangzhou.

With Zhuhai's energy industry only developed in 2002, the city has had a steadily annual increase in energy consumption over the last two decades with a higher increase in more recent years. The data from Zhuhai's local government from 2007 indicates an increase of 12.2% in 2006 alone [65]. Similar growth patterns are also seen and recorded in recent years, specifically with the growing energy demand and use. These figures are indeed remarkable in terms of how urban developments are major contributors to the rise of energy consumption, demand, and supply. Also with the existing Zhuhai Free Trade Zone (Zhuhai FTZ) and five new high-tech and heavy industries, one may argue the city's expansion on its migrant-oriented housing developments or new projects that are mainly in peri-urban and sub-urban areas of the city and are close to the industrial areas in the region. The rural areas, being under pressure as a result of such expansion and development, are experiencing a decline. In cases, there are also signs of city physical expansion, which may reverse decline but changes the demographics, land-use patterns, densities, and housing market of those areas. Challenges mean potential gentrification, inequality, and issues of affordability and labour movement. In years to come, there is a potential possibility for such rural areas to become new peri-urban areas or the outskirts areas of a larger Zhuhai. The same trend has been seen in recent years, especially from 2012 onwards. As a result, this survey study explores a variety of residential development in several built-up communities in three regions/areas of urban, peri-urban, and rural (Figure 3).



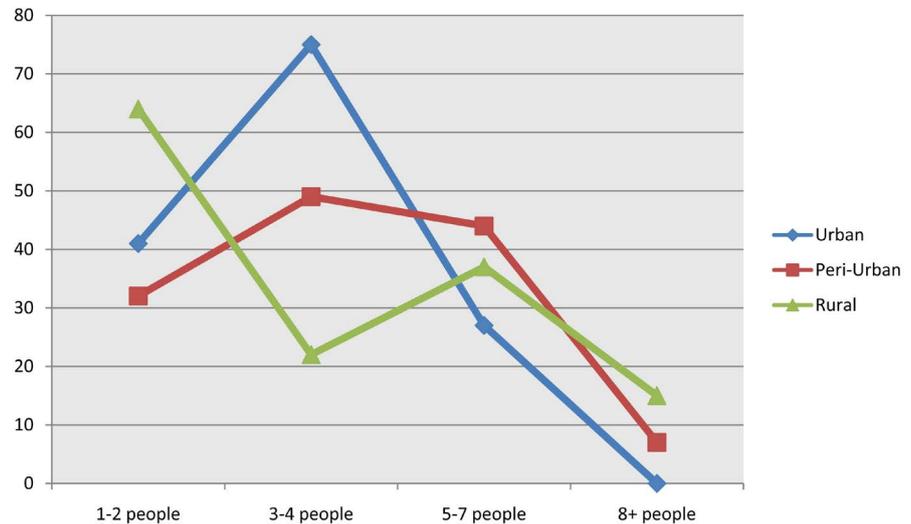
**Figure 3.** Selected study areas for the conducted survey in the Zhuhai mainland areas.

For this study, the survey areas comprise: 1) four urban residential areas in Xiangzhou District; 2) two distinct peri-urban communities in between the city core and Jinwan District; and 3) two rural communities in the Western part of the city. These areas are shown in **Figure 3**, distributed in fringe areas of urban core zones where urban migration is booming and the housing market is increasing, peri-urban transitory areas between urban and outskirts areas, and rural areas outside the city's main areas and on the edge of the main city districts. The analysis is comparative between the three survey areas but is divided into three parts of "household occupancy", "residential conditions", and "seasonal household energy consumption". In doing so, the research findings provide a holistic overview of housing conditions, energy-related factors, and household demands in multiple scales of the city at three specific and different regions. In each part, the study provides a thorough evaluation of housing across three study areas, which are shown in the following sub-sections. The survey study includes 143 urban participants, 132 peri-urban participants, and 138 rural participants; who are all temporary and permanent residents in the selected study areas of Zhuhai. This study is recognised as a sample-based study to represent housing conditions of specific parts of the city, and approach that could be utilised for future research or different locales.

### **2.1. The Analysis of Household Occupancy Conditions across Three Study Areas**

The key factor to any housing survey is the analysis of its conditions, one of which is the occupancy analysis. In this part, all participants were asked about the number of residents in their properties. This is specifically important as the collected data indicates a clear overview of demographics in the three regions. The study of housing occupancy is relevant and important to changes in patterns of demographics and energy consumption that are later discussed in the study. The figure below demonstrates the overall data from the questionnaire survey on the topic of household occupancy (**Figure 4**).

In the studied urban residential areas, more than half of the participants live in small family structures of 3 - 4 people per household. This is related to two aspects of the one-child policy in China that existed for decades, and higher cost of living in the urban areas, particularly closer to Zhuhai-Macao borders or central areas of the city. The cost of living can be analyzed on the basis of higher housing prices [66] and/or housing policy reforms since 1998 [7] [67]. Moreover, based on the collected data, there are not many of the larger or extended families living in urban areas. This also can be related to the smaller size of dwellings in comparison with the peri-urban and rural areas. Also based on the survey study, the majority of peri-urban participants live in houses with higher numbers of occupancy. According to the observation, some of the surveyed houses are occupied by groups of young or middle age labours who are employed locally. More than half of the participants under this category are migrants coming



**Figure 4.** Demographics and household occupancy in the studied areas of Zhuhai's urban, peri-urban and rural (Source: author's own data from the survey study).

from other provinces in China. In both urban and peri-urban areas, we can observe similarities in terms of migration and family structure.

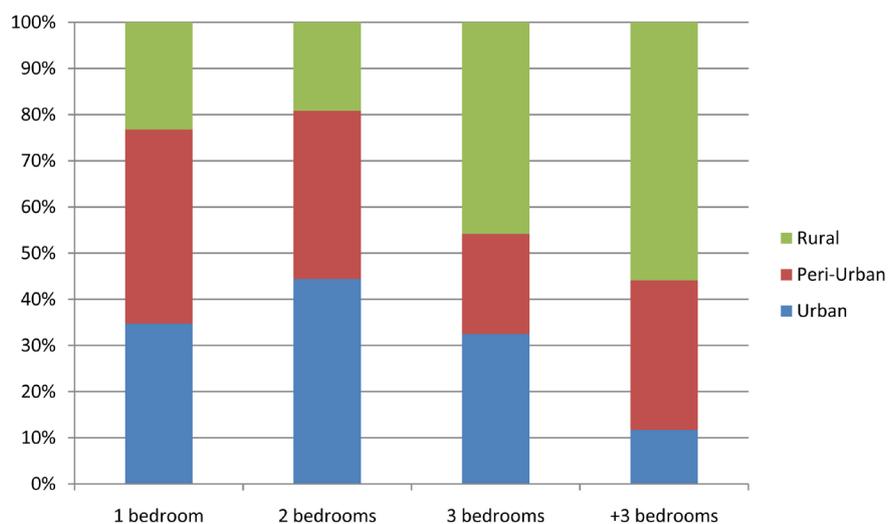
Moreover, it is visible that in the rural areas, the number of people living either alone or in couples is significantly higher than in the urban and peri-urban areas. Subsequently, in rural areas, we can see a drop in households with occupancy of 3 - 4 people, while there is still a higher number of households with larger or extended families. Through observation, it is evident that almost all the houses with fewer residents are occupied by the elderly. Some of the elderly also take care of their grandchildren while their children are working in other parts of the region (particularly in the urban areas, where costs of housing and education are significantly higher). However, there remain a higher number of households with extended families in rural areas. In comparison with the urban, in particular, we can observe more family-oriented households that are still part of the rural communities. This is more evident where there are clusters of family members in particular parts of the rural areas. Traditionally, this pattern of living is part of family structure, family businesses, and family employment (including farming). Nevertheless, with the current trend of migration from the rural to the urban areas, particularly for the younger generations, these family structures and living patterns are subject to change and even decline. With disparities between the rural and urban residents (e.g. Hukou System), this will remain a major concern in the context of China. There are signs of transitions introduced in the New-Type Urbanization Plan (NUP) [34] [35]. On the other hand, the aging society of rural communities is a major threat to sustaining the maintenance and management of such less-affluent areas. As the rural expenditure is still much lower than the urban expenditure, the older residents of the rural areas are expected to stay in their communities unless allocated to nearby towns or peri-urban areas.

## 2.2. The Analysis of Residential Conditions across Three Study Areas

Based on the survey studies, it is identified that there are significant differences in residential conditions of the three studied areas. Each of the three areas has distinct housing development patterns that are subject to detailed study and analysis. The relationship between living conditions and household occupancy can help us to better understand the patterns and demands that are emerging in each area. In this part of the study, the survey covers two aspects of residential conditions: the first is the analysis of the number of bedrooms in the residential units/houses, and the second is the number of stories for the surveyed residential units. These two aspects are both important to a better understanding of potential development patterns and living conditions across three study areas of urban, peri-urban, and rural.

While there is a perceptible growth of China's urban housing stock, which is having a severe impact on shrinkage of rural housing [61], urban housing is significantly smaller than the ones in the peri-urban and rural areas. In the urban areas, most housing development projects for low to middle-class populations are comparatively smaller than in suburban and peri-urban areas (Figure 5). This is due to the increasing rental and purchase prices in recent years. Similarly, Wang and Xu [66] have studied the case of China's housing prices and have analyzed the relationship between urban development and housing prices. In their study, the authors question the requirement for affordable housing as part of the sustainable development of China. This has become a more popular research trend in housing studies, some that touch on the issues of energy from the demand and supply perspectives.

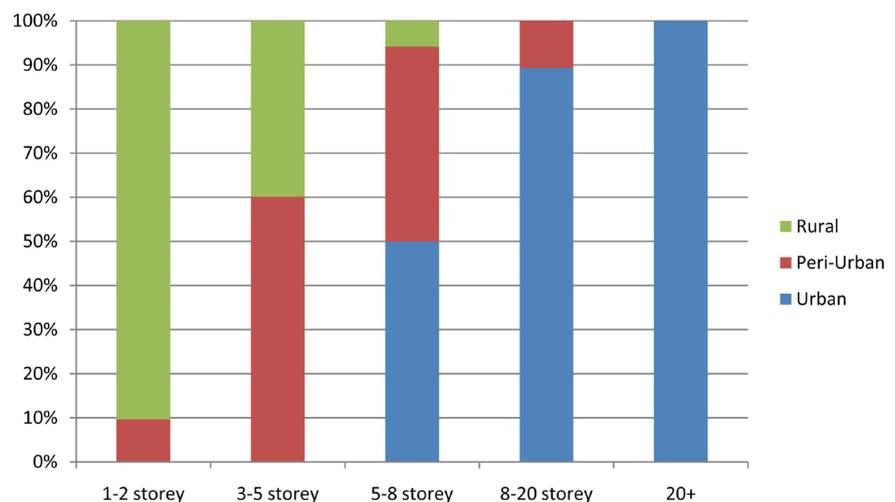
Also in this study, it is evident that a trend in urban housing is towards 2 to 3 bedroom dwellings that are suitable for smaller and younger families. In the past two decades, the shift from a "socialist welfare system to a marketized system"



**Figure 5.** Number of bedrooms for residential units in the studied areas of Zhuhai's urban, peri-urban and rural (Source: author's own data from the survey study).

[68] and housing policy reforms have, to some extent, supported poor urban residents but have not yet tackled housing and poverty issues of the rural migrants. As a result, some of the observed urban residential areas with a higher number of rural migrants are populated areas with smaller indoor living environments. Similarly for the peri-urban, apart from the extended family housing, the majority of larger households that were studied were occupied by industrial labour groups and temporary workers. Yet, in the rural areas houses remain significantly larger due to the traditional family structure and living patterns. Although from the empirical data of the study, rural and peri-urban houses are relatively larger than urban housing, the trend in which the marketized housing system is developing in the urban areas is considerably better than the previous socialist welfare system. This is due to better maintenance and a more reasonable spatial configuration of living environments. Furthermore, the demand for smaller housing in the urban areas is deriving the urban housing market towards smaller housing units and compact development patterns.

Also as part of the housing analysis, the heights of residential units were observed and recorded (Figure 6). In this respect, we can analyze an overall overview and trend of housing development in three studied areas of urban, peri-urban, and rural. Based on the empirical data, the trend of housing is obvious and similar to any other growing city. While the urban has fewer low-rise houses, we still do not see many high-rise housing developments in peri-urban and rural areas. However, this is not the case in some other parts of China. The mid-rise and high-rise development in urban areas has now become the primary urban housing development pattern in most major cities in China. Zhuhai's case is no different. Also, a trend of mid-rise housing development is appearing in the context of peri-urban areas. While in the rural majority of housing are still low-rise, neighbouring townships (that are larger) often have new mid-rise developments to attract new residents to the regional industrial areas where the



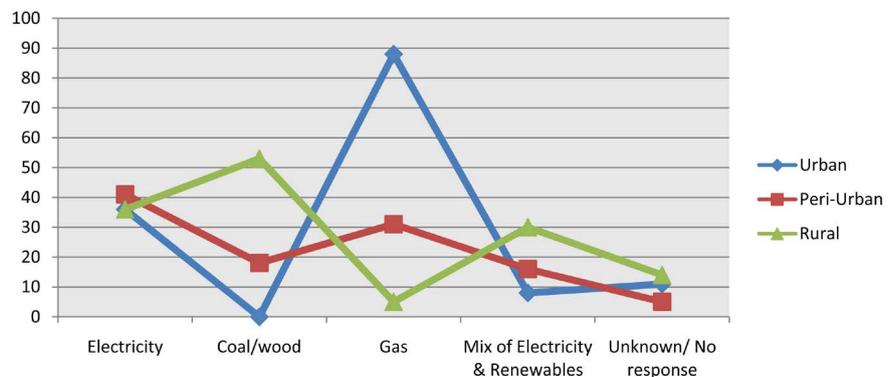
**Figure 6.** Number of stories/floors for surveyed residential units in the studied areas of Zhuhai's urban, peri-urban and rural (Source: author's own data from the survey study).

employability rate is often high. In the past two decades, in particular, the change in urban housing, from low to mid-rise and then to high-rise, has changed housing typology, housing layout, and the housing market of China's urban areas. In the rural, however, the primary development pattern in the housing sector is still below five storey buildings but are mostly replacing the traditional one to two storey dwellings.

### 2.3. The Analysis of Seasonal Household Energy Consumption across Three Study Areas

A major part of the survey study focuses on the analysis of seasonal household energy consumption that fits well with the previous analysis of household occupancy and residential conditions. Based on the questionnaire survey, four key primary sources of household energy consumption were identified in the region of Zhuhai, Southern Guangdong. Unlike many parts of China, gas usage is still cheap (due to subsidized prices) and popular for households. Apart from gas, electricity, combined electricity and renewable energies [69], Coal (also sometimes firewood) are some of the main sources of household energy consumption. Nevertheless, consumption is different between urban, peri-urban, and rural areas. It is also significantly different between the two seasons of winter and summer.

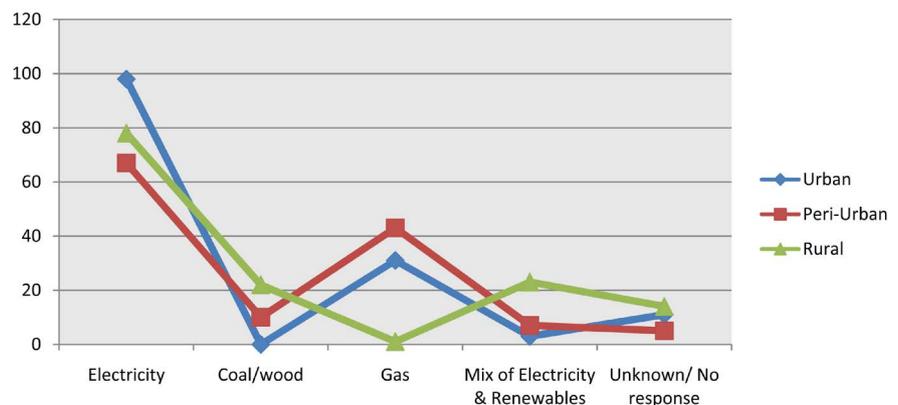
During winter, the household energy consumption for gas is significantly higher in urban areas (Figure 7). On the other hand, in rural areas, gas consumption is minimal and is mainly replaced by coal (and firewood). Since heating is not required or is less required in the region of Southern Guangdong Province, the majority of household energy consumption during winter is for the purpose of cooking and lighting. Hence, gas usage is high for cooking and water heating. Figure 7 above indicates that electricity usage is similar between the three areas of urban, peri-urban, and rural. However, if to take into consideration the amount of usage based on energy consumption measurement, urban areas would have a higher percentage of electricity use in comparison with peri-urban and rural areas. One indicator and perhaps a major difference between



**Figure 7.** Primary source of household energy consumption (including, lighting, cooking, heating, cooling and other electrical uses) during winter.

rural and urban is the use of coal in cooking that is still very common in rural areas. Also during the study survey, it was observed that in the rural areas more solar panels are used for water heating. This is mainly related to the height of dwellings and the importance that the solar panels are more effective in low-rise housing. In the urban areas, only a few apartments in the higher floors of mid-rise and high-rise residential units can benefit from the use of solar panels. In general, the overall patterns between the three areas are very similar apart from differences in gas and coal usage. Rural energy development is still one of the crucial energy-related studies in the context of China. Previous studies [70] [71] [72] have discussed the topic of rural energy as part of China's policy reforms and development plans.

As part of the seasonal analysis of energy consumption, the questionnaire survey also covers the energy usage of the summer period. This is studied predominantly because, during the summer period, household cooling is a major matter for the indoor thermal comfort of the residents. In general, household cooling becomes a major demand throughout the region, particularly that relative humidity is high during the summer period and the effectiveness of natural cooling is minimized. This increased demand for cooling changes the energy consumption patterns of all three contexts (Figure 8). The electricity usage uplifts substantially as the majority of households use either air conditioning or electric fans for the purpose of indoor cooling. In the compact areas, such as compact urban residential areas, this is expected to be higher. In summer, gas usage is no longer the primary source of energy consumption as it is mainly used for cooking and water heating. In rural areas, coal (also firewood) is mainly used for cooking purposes. While the gas usage in urban households is dropped during summer, peri-urban households have a slight rise in gas consumption. Electricity, however, remains the main source of household energy consumption. Renewable energies are not effectively operative for the purpose of cooling, and as a result, are mainly used for water heating purposes (*i.e.* solar panels). Overall, the comparison between seasonal energy consumption signifies the increasing demand for cooling during the warmer period of the year.



**Figure 8.** Primary source of household energy consumption (including, lighting, cooking, heating, cooling and other and electrical uses) during summer.

### 3. Results and Discussions

This study has touched on a few relative aspects of change in lifestyle patterns, demands and requirements, seasonal sources of energy consumption, and etc. In this study, the focus is on both “energy” and “housing conditions” in the context of Zhuhai. The comparison between the three areas of urban, peri-urban, and rural is necessary to identify the gaps and analyze the trends of housing development and requirements. In Chinese urban-rural studies, energy issues, including policy reforms, development, affordability, access, and security, identify the gaps between different social classes of the country (*i.e.* the urban and the rural residents). The peri-urban areas are mostly industrial areas of cities and have similarities with both contexts of rural and urban. However, the housing development patterns are still very different in between the three areas.

The conditions of the urban housing can be generalized as the followings: 1) development pattern of mid-rise and high-rise housing with the majority of the new housing being gated communities; 2) increasing energy consumption with relatively small spatial layout (particularly for the low to middle-income class) and small family structure; and 3) significant consumption of gas and electricity for the purpose of cooking and cooling. In addition, the conditions of the peri-urban housing can be generalized as the followings: 1) development pattern of low-rise to mid-rise with the majority of houses being individual or in small communities; 2) increasing energy consumption with mid-size housing and diverse household structures (*i.e.* family size or a number of residents in one property); and 3) generally the moderate level of energy consumption with increasing demand for cooling during the summer period. Finally, the conditions of the rural housing can be generalized as the followings: 1) low-rise housing pattern and traditional settlement pattern with the new housing constructed as low-rise or under five stories; 2) generally low energy consumption with larger family structure (*i.e.* mainly extended families); and 3) minimal and often no gas consumption but the high consumption of coal/firewood for the purpose of cooking.

The cross-referencing between occupancy level and a number of bedrooms in houses indicate a lack of spaces for the majority of houses in the rural and peri-urban areas. Although larger in size, space remains crucial in some parts, particularly in peri-urban housing. However, for urban housing the relationship between occupancy level and a number of bedrooms is fairly reasonable. While Zhuhai’s trend of urban housing is mostly mid-rise to a high-rise with less number of bedrooms, the rural housing remains low-rise (mostly 1 to 2 stories) with more bedrooms in dwellings. Most of these rural dwellings are occupied by extended families. On the other hand, peri-urban housing is moving towards mid-rise with either small or very large dwellings (in terms of a number of bedrooms). The mid-size housing is less common in the peri-urban areas where residents are mostly labours or migrants from the other regions. In rural areas, we can observe a gradual shrinking pattern to the family structures, where ener-

gy consumption is minimal. In urban areas, we can observe a higher consumption of gas for cooking and water heating. This is due to having an indoor kitchen and also indoor bathroom, wherein the rural both are often outside of the main living indoor areas (*i.e.* bedrooms and living rooms). The poorer rural housings mostly have semi-open or detached kitchen facilities where coal and firewood are used considerably. According to the collected data, the primary source of household energy consumption in between the urban and the peri-urban is following a similar trend. This indicates the considerable transformation of demands and patterns for energy consumption that are taking place in the non-urban areas (*i.e.* peri-urban in particular).

Finally, based on the analysis of the field survey, there are certain housing characteristics in three studied areas of urban, peri-urban, and rural. These characteristics can simply indicate the overall housing development patterns that are specific to the context of South China. The results from seasonal household energy consumption analysis show the raise of energy consumption for the purpose of cooling during the summer. This signifies the need for energy-saving plans that are required as part of housing design specifications. Nevertheless, the energy-saving development plans are mainly focusing on the urban areas, where a huge market of housing is under progress.

### Complications and Challenges of Housing in China

Since land ownership is still very different between the urban (*i.e.* owned by the state) and the rural (*i.e.* owned by collectives) areas [73] [74], it is expected to have two clearly different modes of transformation in housing affordability and land development. The peri-urban housing is expected to follow a mid-rise housing pattern, which is probably more affordable than the urban housing due to the contextual conditions and locations. However, in the sub-urban areas, new low-rise housing is developing as a new pattern, which almost represents the Western urban sprawl. The considerations of energy and housing in China are currently happening at a slow pace and small scale. Since the dynamics of housing stocks keep changing in the past three decades, we anticipate further changes in housing development and energy-saving patterns. The widespread urban development and the rapidly increasing provision of housing [67] are key players to China's future housing reforms. In their study on *Sustainable Housing and Urban Construction in China*, Zhu and Lin [19] start to argue on the energy efficiency of housing, preserving energy security, and optimization of energy structure that are essential factors in China's housing development.

The empirical data from the survey studies indicate complications such as space and occupancy and point out major challenges of energy and housing development patterns. Although the study's focus is on energy and housing conditions in a particular context, it provides an analytical understanding of how these conditions can develop into potential cases for consideration of design patterns for future development and regional strategic plans. In this respect, we

can argue that the main challenges of housing in China are still “affordability”, “energy-saving plans”, and “new design specifications”. All of these attributes are vital to China’s community of developers who play an effective role in the housing stock market and development patterns.

In addition, this study has developed a platform to further understand the energy and housing conditions in the region of Zhuhai’s urban, peri-urban, and rural areas. This comparative study of housing in the three studied areas is essential to further analyze: 1) what affordability measures are required and where?; 2) how we should proceed with energy-saving plans that include not only the urban but the peri-urban and rural areas; and 3) how we may develop new design specifications that are suitable to specific contexts?. In this sense, the case of Zhuhai is a general representation of the conditions in Southern China, where the potential influence on energy and housing policies are strongly required and essential for future housing development patterns, housing conditions, and energy-efficient plans. A similar case is the development of China’s “Green Strategy Plan” [20], which is proposed to improve China’s current practices and technologies in building design and development [8] [35]. Yet, the current proposals are mainly focused on urban areas than rural. Therefore, there remains a substantial gap in housing reforms, strategy plans, and implementation mainly between the urban and the rural areas.

This study provides a better comparative understanding of housing in three areas of urban, peri-urban, and rural. This is rarely done in research studies of cities, especially from the perspective of energy source and consumption analysis. This is done through a non-statistical analysis to reflect the realities of growing areas in city environments of developing contexts, particularly from the low-to-middle social classes. The collected data from the questionnaire survey covers the basic knowledge of housing conditions in these studied areas. The cross-analysis of data is aimed to identify the needs, demands, and trends that are subject to further detailed analysis. The limitations of the study, based on time and access to energy-related data, indicate potential research in the fields of energy efficiency [6] [75] and cross-contextual energy saving plans, specific to housing development and support for future design specifications and housing policy reforms. Unlike statistics-based research or those studies that rely on statistical data, this study highlights the realities of three specific zones/study areas in a growing city with high migrant populations, growing energy demand, and high-level cooling load. Hence, even though the average consumption pattern in the energy sector was verified, the data that is used for the analysis is focused mostly on the nexus between housing and energy source, as well as household differences between the selected study areas. The results also indicate a variety of environmental impacts (such as ecosystem and pollution) that may result from various urbanization trends or specific end-user consumption patterns. For the first time in scholarly research, this study offers an empirical comparative analysis of multiple regions/areas of the city, especially that it highlights the relation-

ships between housing and energy sectors. Also, unlike statistics-based studies, this study suggests provides sampling from fieldwork and collected data of selected case study examples that resemble the growing demand for the energy use of various sources in different locations. It is important to note these differences and take into consideration the transitions and potential gaps and opportunities in between housing developments in three specified areas of urban, peri-urban, and rural. Future research studies could learn from such differences and not generalize the results based on singular spatial levels, regions, or social classes.

#### 4. Conclusions

This study identified key elements for housing conditions in the region of Southern Guangdong Province, in various areas in the region of the City of Zhuhai. As part of the specific survey study, the collected empirical data represent trends of development and housing conditions in various cases. The housing conditions between the urban, the peri-urban, and the rural are not only related to the visual dimension of the built environment but related to their occupancy, living styles/structures, energy source, and consumption. The study also pointed out the directions for current development patterns and the essential need for housing reforms. This study is also a suitable platform for energy-specific studies in the region of Zhuhai, where the focus is on measuring energy consumption, development of energy-saving plans, and improvement of housing's energy efficiency.

Furthermore, we can conclude how the current housing conditions can help policymakers to come up with strategies and energy saving plans that are comprehensive, detailed, and context-specific. Therefore, we can argue that the next housing reform in China needs to incorporate conditions of housing in all areas of urban, peri-urban, and rural, where various parameters and approaches are necessary for better implementation and development that are aimed for a more sustainable future. Based on the study survey and analysis of the collected data, it is important to consider three pillars of “affordability”, “sustainability” and “design specifications” and develop them into a holistic framework of housing reform strategies that include various elements of living quality, energy-saving plans, and efficient design or even planning. Finally, it is important to consider the cross-contextual analysis of both energy and housing conditions in order to respond effectively to future housing and development strategies that are expected to include major elements of energy consumption plans, energy resource analysis, and low-carbon considerations.

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## Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

## References

- [1] Wu, F. (2012) Housing and the State in China. In: *International Encyclopaedia of Housing and Home*, Elsevier, Amsterdam, 323-329. <https://doi.org/10.1016/B978-0-08-047163-1.00062-X>
- [2] Cheshmehzangi, A. and Butters, C. (2016) Chinese Urban Residential Blocks: Towards Improved Environmental and Living Qualities. *Urban Design International*, **21**, 1-17. <https://doi.org/10.1057/s41289-016-0013-9>
- [3] Logan, J.R., Fang, Y. and Zhang, Z. (2010) The Winners in China's Urban Housing Reform. *Housing Studies*, **25**, 101-117. <https://doi.org/10.1080/02673030903240660>
- [4] Novianto, D., Gao, W. and Kuroki, S. (2015) Review on People's Lifestyle and Energy Consumption of Asian Communities: Case Study of Indonesia, Thailand, and China. *Energy and Power Engineering*, **7**, 465-476. <https://doi.org/10.4236/epe.2015.710045>
- [5] Novianto, D., Kano, A., Fan, L., Wang, J., Wang, M., Wang, Z., Ge, J., He, Y. and Gao, W. (2015) Survey and Field Measurement on Residential Lifestyle and Energy Use in Rural China. *Engineering*, **7**, 610-624. <https://doi.org/10.4236/eng.2015.710055>
- [6] Cheshmehzangi, A. and Butters, C. (2017) *Designing Cooler Cities: Energy, Cooling, and Urban Form—The Asian Perspective*. Palgrave Macmillan Publishers, Singapore.
- [7] Cheshmehzangi, A. (2018) The Changing Urban Landscape of Chinese Cities: Positive and Negative Impacts of Urban Design Controls on Contemporary Urban Housing. *Sustainability*, **10**, 2839. <https://doi.org/10.3390/su10082839>
- [8] Xie, L., Cheshmehzangi, A., Tan-Mullins, M., Flynn, A. and Heath, T. (2020) Urban Entrepreneurialism and Sustainable Development: A Comparative Analysis of Chinese Eco-Developments. *Journal of Urban Technology*, **27**, 3-26. <https://doi.org/10.1080/10630732.2019.1680940>
- [9] Liang, Y.-F. and Gao, T.-M. (2007) Empirical Analysis on Real Estate Price Fluctuation in Different Provinces of China. *Economic Research Journal*, **8**, 133-142.
- [10] Wang, X. and Wen, Y. (2012) Housing Prices and High Chinese Saving Rate Puzzle. *China Economic Review*, **23**, 265-283. <https://doi.org/10.1016/j.chieco.2011.11.003>
- [11] Zhang, Y., Hua, X. and Zhao, L. (2012) Exploring Determinants of Housing Prices: A Case Study of Chinese Experience in 1999-2010. *Economic Modelling*, **29**, 2349-2361. <https://doi.org/10.1016/j.econmod.2012.06.025>
- [12] Dreger, C. and Zhang, Y. (2013) Is There a Bubble in the Chinese Housing Market? *Journal of Urban Policy and Research*, **31**, 27-39.

- <https://doi.org/10.1080/08111146.2012.711248>
- [13] Hui, E.C.M. and Wang, Z. (2014) Price Anomalies and Effectiveness of Macro Control Policies: Evidence from Chinese Housing Markets. *Land Use Policy*, **39**, 96-109. <https://doi.org/10.1016/j.landusepol.2014.04.003>
- [14] Li, Y.-Y. (2014) Demand Driving and Ripple Effects of Housing Prices Rising: On Strategies to Deal with the Problems of Housing Price. *China Economic Quarterly*, **2**, 443-464.
- [15] Wu, G.L., Feng, Q. and Li, P. (2014) Does Local Governments' Budget Push Up Housing Prices in China? *China Economic Review*, **35**, 183-196. <https://doi.org/10.1016/j.chieco.2014.08.007>
- [16] Dang, Y., Liu, Z. and Zhang, W. (2014) Land-Based Interests and Spatial Distribution of Affordable Housing Development: The Case of Beijing, China. *Habitat International*, **44**, 137-145. <https://doi.org/10.1016/j.habitatint.2014.05.012>
- [17] Zhang, C. (2015) Income Inequality and Access to Housing: Evidence from China. *China Economic Review*, **36**, 261-271. <https://doi.org/10.1016/j.chieco.2015.10.003>
- [18] Deng, W., Hoekstra, J. and Elsinga, M. (2017) Redistribution, Growth, and Inclusion: The Development of the Urban Housing System in China, 1949-2015. *Current Urban Studies*, **5**, 423-443. <https://doi.org/10.4236/cus.2017.54024>
- [19] Zhu, Y. and Lin, B. (2003) Sustainable Housing and Urban Construction in China. *Energy and Buildings*, **36**, 1287-1297. <https://doi.org/10.1016/j.enbuild.2003.11.007>
- [20] Zhang, X., Platten, A. and Shen, L. (2011) Green Property Development Practice in China: Costs and Barriers. *Building and Environment*, **46**, 2153-2160. <https://doi.org/10.1016/j.buildenv.2011.04.031>
- [21] Yu, T., Shen, G.Q., Shi, Q., Zheng, H.W., Wang, G. and Xu, K. (2017) Evaluating Social Sustainability of Urban Housing Demolition in Shanghai, China. *Journal of Cleaner Production*, **153**, 26-40. <https://doi.org/10.1016/j.jclepro.2017.03.005>
- [22] Zhao, W. and Ge, J. (2014) Dual Institutional Structure and Housing Inequality in Transitional Urban China. *Journal of Research in Social Stratification and Mobility*, **37**, 23-41. <https://doi.org/10.1016/j.rssm.2014.02.002>
- [23] Zhang, Q. and Mei, D. (2015) An Empirical Research on Interactive Relationship of Urban Housing Prices in China: Analysis of Six Major Cities. *Low Carbon Economy*, **6**, 64-72. <https://doi.org/10.4236/lce.2015.62008>
- [24] Logan, J.R., Bian, Y., *et al.* (1999) Housing Inequality in Urban China in the 1990s. *International Journal of Urban and Regional Research*, **23**, 7-25. <https://doi.org/10.1111/1468-2427.00176>
- [25] Luo, C.L. (2013) Inequality of the Housing Reform, Income Divergence and Urban Housing. *Economy and Management*, No. 5, 5-10.
- [26] Pan, Z.F. (2003) Housing Quality Differentials in Urban China 1988-1995: Evidence from Two National Surveys. *International Journal of Social Economics*, **30**, 1070-1083. <https://doi.org/10.1108/03068290310492869>
- [27] Zhou, M. and Logan, J.R. (1996) Market Transition and the Commodification of Housing in Urban China. *International Journal of Urban and Regional Research*, **20**, 400-421. <https://doi.org/10.1111/j.1468-2427.1996.tb00325.x>
- [28] Yi, C. and Huang, Y. (2014) Housing Consumption and Housing Inequality in Chinese Cities during the First Decade of the Twenty-First Century. *Housing Studies*, **29**, 291-311. <https://doi.org/10.1080/02673037.2014.851179>
- [29] Zax, J. (1997) Latent Demand for Urban Housing in the People's Republic of China. *Journal of Urban Economics*, **42**, 377-401. <https://doi.org/10.1006/juec.1996.2034>

- [30] Wang, J.M. and Gao, T.M. (2004) The Dynamic Analysis of Chinese Real Estate Market Supply and Demand Function. *China Soft Science*, No. 4, 69-74.
- [31] Gao, T.M. (2001) Information and The Real Estate Market Efficiency. *Journal of Monetary Economics*, No. 8, 37-39.
- [32] Guo, X.L. (2003) The Housing Market Efficiency in China: Measurement, Evaluation and Countermeasures. *Journal of Economics and Management*, No. 2, 40-41.
- [33] Hu, J.C. (2006) The Real Estate Market Efficiency Theory. *Journal of Shanghai Economic Studies*, No. 12, 124-126.
- [34] Cheshmehzangi, A. (2015) The Urban and Urbanism: China's New Urbanization and Approaches towards Comprehensive Development. *International Journal of Interdisciplinary Environmental Studies*, **8**, 1-12.  
<https://doi.org/10.18848/2329-1621/CGP/v08i3-4/53310>
- [35] Cheshmehzangi, A. (2016) China's New-Type Urbanisation Plan (NUP) and the Foreseeing Challenges for Decarbonisation of Cities: A Review. *Energy Procedia*, **104**, 146-152. <https://doi.org/10.1016/j.egypro.2016.12.026>
- [36] Wei, Z., Liu, Y., He, S. and Mo, H. (2020) Housing Differentiation in Transitional Urban China. *Cities*, **96**, Article ID: 102469.  
<https://doi.org/10.1016/j.cities.2019.102469>
- [37] Huang, W.-L., Lin, W.-Y. and Ning, S.-L. (2018) The Effect of Economic Policy Uncertainty on China's Housing Market. *The North American Journal of Economics and Finance*. (In Press) <https://doi.org/10.1016/j.najef.2018.09.008>
- [38] Ng, E.C.Y. (2015) Housing Market Dynamics in China: Findings from an Estimated DSGE Model. *Journal of Housing Economics*, **29**, 26-40.  
<https://doi.org/10.1016/j.jhe.2015.05.003>
- [39] Lin, B. and Du, K. (2015) Energy and CO<sub>2</sub> Emissions Performance in China's Regional Economies: Do Market-Oriented Reforms Matter? *Energy Policy*, **78**, 113-124. <https://doi.org/10.1016/j.enpol.2014.12.025>
- [40] Yao, X., Zhou, H.C., Zhang, A.Z. and Li, A.J. (2015) Regional Energy Efficiency, Carbon Emission Performance and Technology Gaps in China: A Meta-Frontier Non-Radial Directional Distance Function Analysis. *Energy Policy*, **84**, 142-154.  
<https://doi.org/10.1016/j.enpol.2015.05.001>
- [41] Xiao, H.J. and Mei, L.H. (2019) Dynamics and Inequalities in Energy Efficiency in China. *Energy and Power Engineering*, **11**, 132-148.  
<https://doi.org/10.4236/epe.2019.113008>
- [42] Jiang, H. and Payne, S. (2019) Green Housing Transition in the Chinese Housing Market: A Behavioural Analysis of Real Estate Enterprises. *Journal of Cleaner Production*, **241**, Article ID: 118381. <https://doi.org/10.1016/j.jclepro.2019.118381>
- [43] Liu, L., Wang, Q. and Zhang, A. (2019) The Impact of Housing Price on Non-Housing Consumption of the Chinese Households: A General Equilibrium Analysis. *The North American Journal of Economics and Finance*, **49**, 152-164.  
<https://doi.org/10.1016/j.najef.2019.04.010>
- [44] Yang, Y., Zhang, D., Meng, Q., Yu, W. and Yuan, L. (2017) Stratified Evolution of Urban Residential Spatial Structure in China through the Transitional Period: A Case Study of five Categories of Housings in Chengdu. *Habitat International*, **69**, 78-93. <https://doi.org/10.1016/j.habitatint.2017.09.004>
- [45] Long, H., Heilig, G.K., Li, X. and Zhang, M. (2007) Socio-Economic Development and Land-Use Change: Analysis of Rural Housing Land Transition in the Transect of the Yangtse River, China. *Land Use Policy*, **24**, 141-153.

- <https://doi.org/10.1016/j.landusepol.2005.11.003>
- [46] Li, T., Long, H., Liu, Y. and Yu, S. (2015) Multi-Scale Analysis of Rural Housing Land Transition under China's Rapid Urbanization: The Case of Bohai Rim. *Habitat International*, **48**, 227-238. <https://doi.org/10.1016/j.habitatint.2015.04.002>
- [47] Deng, W. and Cheshmehzangi, A. (2018) Eco-Development in China: Cities, Communities, and Buildings. Palgrave Macmillan, Singapore.
- [48] Zhang, X.Q. (2000) Privatization and the Chinese Housing Model. *International Planning Studies*, **5**, 191-204. <https://doi.org/10.1080/13563470050020185>
- [49] Yang, Z., Liu, B. and Zhao, H. (2004) Energy Saving in Building Construction in China: A Review. *International Journal of Green Energy*, **1**, 209-225. <https://doi.org/10.1081/GE-120038753>
- [50] The Economist (2011) Social Housing in China: No Way Home. <http://www.economist.com/node/21532334>
- [51] Wirtshafter, R. and Song-Ying, C. (1987) Energy Conservation in Chinese Housing. *Energy Policy*, **15**, 158-168. [https://doi.org/10.1016/0301-4215\(87\)90123-6](https://doi.org/10.1016/0301-4215(87)90123-6)
- [52] Haas, R. and Schipper, L. (1998) Residential Energy Demand in OECD-Countries and the Role of Irreversible Efficiency Improvements. *Energy Economics*, **20**, 421-442. [https://doi.org/10.1016/S0140-9883\(98\)00003-6](https://doi.org/10.1016/S0140-9883(98)00003-6)
- [53] Gillingham, K., Newell, R.G., Palmer, K., *et al.* (2009) Energy Efficiency Economics and Policy. *Annual Review of Resource Economics*, **1**, 597-620. <https://doi.org/10.1146/annurev.resource.102308.124234>
- [54] Brounen, D., Kok, N. and Quigley, J.M. (2012) Residential Energy Use and Conservation: Economics and Demographics. *European Economics Review*, **56**, 931-945. <https://doi.org/10.1016/j.euroecorev.2012.02.007>
- [55] Allcott, H. and Wozny, N. (2014) Gasoline Prices, Fuel Economy, and the Energy Paradox. *The Review of Economics and Statistics*, **96**, 779-795. [https://doi.org/10.1162/REST\\_a\\_00419](https://doi.org/10.1162/REST_a_00419)
- [56] Eurostat (2017) Energy Consumption in Households. European Statistics Reports. [https://ec.europa.eu/eurostat/statistics-explained/index.php/Energy\\_consumption\\_in\\_households](https://ec.europa.eu/eurostat/statistics-explained/index.php/Energy_consumption_in_households)
- [57] Aydin, E., Brounen, D. and Kok, N. (2020) The Capitalization of Energy Efficiency: Evidence from the Housing Market. *Journal of Urban Economics*, **117**, Article ID: 103243. <https://doi.org/10.1016/j.jue.2020.103243>
- [58] Butters, C. and Cheshmehzangi (2017) Cities, Climate and Cooling. In: Cheshmehzangi, A. and Butters, C., Eds., *Designing Cooler Cities: Energy, Cooling, and Urban Form—The Asian Perspective*, Palgrave Macmillan Publishers, Singapore, 5-20. [https://doi.org/10.1007/978-981-10-6638-2\\_2](https://doi.org/10.1007/978-981-10-6638-2_2)
- [59] Cheshmehzangi, A. and Xie, L. (2017) Reducing Cooling Loads in Hot-Humid Climates: A Best Practice Research Building in China. In: Cheshmehzangi, A. and Butters, C., Eds., *Designing Cooler Cities: Energy, Cooling, and Urban Form—The Asian Perspective*, Palgrave Macmillan Publishers, Singapore, 23-36. [https://doi.org/10.1007/978-981-10-6638-2\\_3](https://doi.org/10.1007/978-981-10-6638-2_3)
- [60] Yue, P. and Rong, P.J. (2019) Spatial Patterns and Driving Factors of Urban Residential Embedded Carbon Emissions: An Empirical Study in Kaifeng, China. *Energy and Power Engineering*, **11**, 58-75. <https://doi.org/10.4236/epe.2019.112004>
- [61] Hu, M., Bergsdal, H., Voet, E.V.D., Huppel, G. and Muller, D.B. (2010) Dynamics of Urban and Rural Housing Stocks in China. *Building Research and Information*, **38**, 301-317. <https://doi.org/10.1080/09613211003729988>

- [62] Shen, L., Cheng, S., Gunson, A.J. and Wan, H. (2005) Urbanization, Sustainability and the Utilization of Energy and Mineral Resources in China. *Cities*, **22**, 287-302. <https://doi.org/10.1016/j.cities.2005.05.007>
- [63] Yang, W. and Kohler, N. (2008) Simulation of the Evolution of the Chinese Building and Infrastructure Stock. *Building Research and Information*, **36**, 1-19. <https://doi.org/10.1080/09613210701702883>
- [64] Sheng, N. and Tang, U.W. (2013) City Profile: Zhuhai. *Cities*, **32**, 70-79. <https://doi.org/10.1016/j.cities.2013.02.006>
- [65] Zhuhai's Local Government Website (2007) Report on Energy. <http://www.zhuhai.gov.cn>
- [66] Wang, X. and Xu, M. (2009) The Relationship between Urban Development and Housing Prices in China. *Asia Pacific Journal of Social Work and Development*, **19**, 83-94. <https://doi.org/10.1080/21650993.2009.9756065>
- [67] Chow, C.S. (1998) The Intended and Unintended Consequences of Housing Reform Policies in the Pearl River Delta. *Asian Geographer*, **17**, 91-100. <https://doi.org/10.1080/10225706.1998.9684037>
- [68] Ping, W.Y. (2012) Housing the Urban Poor in a Marketised System in China. *Urban Policy and Research*, **30**, 423-441. <https://doi.org/10.1080/08111146.2012.738192>
- [69] Cai, M.H. and Tang, L. (2013) Analysis of Renewable Energy Utilization Potential in Buildings of China. *Energy and Power Engineering*, **5**, 291-293. <https://doi.org/10.4236/epe.2013.54B057>
- [70] Keyun, D. (1994) Coherent Development of Rural Economy, Ecology and Energy County-Level Integrated Rural Energy Development Has Achieved Obvious Benefits. *International Journal of Sustainable Energy*, **14**, 117-126. <https://doi.org/10.1080/01425919408909804>
- [71] Zhen, F. (1994) Rural Energy Resources: Applications and Consumption in China. *Energy Sources*, **16**, 229-239. <https://doi.org/10.1080/00908319408909074>
- [72] Aden, N.T. and Sinton, J.E. (2006) Environmental Implications of Energy Policy in China. *Environmental Politics*, **15**, 248-270. <https://doi.org/10.1080/09644010600562542>
- [73] Ding, C. (2003) Land Policy Reform in China: Assessment and Prospects. *Land Use Policy*, **20**, 109-120. [https://doi.org/10.1016/S0264-8377\(02\)00073-X](https://doi.org/10.1016/S0264-8377(02)00073-X)
- [74] Ding, C. (2007) Policy and Praxis of Land Acquisition in China. *Land Use Policy*, **24**, 1-13. <https://doi.org/10.1016/j.landusepol.2005.09.002>
- [75] Buluş, A. and Topalli, N. (2011) Energy Efficiency and Rebound Effect: Does Energy Efficiency Save Energy? *Energy and Power Engineering*, **3**, 355-360. <https://doi.org/10.4236/epe.2011.33045>

## Appendix A: Questionnaire Survey Packages

The survey study explores a variety of residential developments in several built-up communities in three areas of urban, peri-urban, and rural in the City of Zhuhai, south China. The original questionnaire (English version) is shown here, which is used to conduct the survey results.

### Questionnaire Package 1: Demographics and household occupancy

Demographic characteristics and Household Analysis	
Age	19 - 30 years
	31 - 45 years
	46 - 55 years
	Over 56 years
Gender	Female
	Male
Income Category (per calendar month)	less than 5000 RMB per month
	5000 to 10,000 RMB per month
	10,000 or 25,000 RMB per month
	More than 25,000 RMB per month
Household structure	1 - 2 people (Single or Couple)
	3 - 4 people (often Couple and children)
	5 - 7 people (often Couple, children and parents, or shared household)
	8+ people (either extended family, or shared household)
Education level	Primary or less
	Secondary
	Junior college
	Bachelor and above

### Questionnaire Package 2: General Survey of Physical Factors

Residential Development Physical Factors	
Age of the property	New (less than one year)
	2 - 5 years old
	5 - 10 years old
	10+ years old
No. of bedrooms in the house	1 bedroom
	2 bedrooms
	3 bedrooms
	More than 3 bedrooms
No. of storeys/floors	1 - 2 floors (often individual houses, rural houses, or villa houses)
	3 - 5 floors (often known as town housing)

**Continued**


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	5 - 8 floors (often known as older urban housing)
	8 - 20 floors (mid-rise housing)
	20+ floors (mid-to-high rise housing)
	Urban
Observed category	Peri-Urban
	Rural
	Others

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**Questionnaire Package 3: Seasonal Energy Source and Consumption Analysis**

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<b>Energy Source and Consumption Surveys</b>	
	Electricity
	Coal/Wood
Primary energy source during summer	Gas
	Mix of electricity and renewables
	Unknown/No response
	Electricity
	Coal/Wood
Primary energy source during winter	Gas
	Mix of electricity and renewables
	Unknown/No response
	Air conditioning (AC) units
	Electric Fan
	Electric Heater
Type of appliances for cooling/heating	Floor Heating
	Natural ventilation
	Others
	No response
	Below 100 RMB per calendar month
Energy Consumption Expenditure in Summer	100 - 200 RMB per calendar month
	200 - 500 RMB per calendar month
	More than 500 RMB per calendar month
	Below 100 RMB per calendar month
Energy Consumption Expenditure in Winter	100 - 200 RMB per calendar month
	200 - 500 RMB per calendar month
	More than 500 RMB per calendar month

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