

# Making the Clean Energy City in China: Year 2 Report

Massachusetts Institute of Technology  
Center for Advanced Urbanism

School of Architecture and Planning



The Energy Foundation



# Making the Clean Energy City in China: Year 2 Report

Massachusetts Institute of Technology  
Center for Advanced Urbanism

School of Architecture and Planning



Dennis Frenchman  
Christopher Zegras

June, 2012



The Energy Foundation

## Credits

### *Principle Investigators*

Dennis Frenchman, Leventhal Professor of Urban Design and Planning MIT  
Christopher Zegras, Associate Professor of Transportation Planning, MIT

### *Contributing Investigators*

Jan Wampler, Professor of Architecture, MIT  
Mao Qizhi, Professor of Urban Planning and Design, Tsinghua University  
Zhang Jie, Professor of Urban Planning and Design, Tsinghua University  
Shao Lei, Assistant Professor of Urban Planning

### *MIT Research Assistants, 2010-2011*

Yang Chen  
Daniel Daou  
Reza Darbari  
Shani Sharif

Rosie Sherman  
Nah-yoon Shin  
Jue Wang  
Ira Winder  
Aspasia Xypolia  
Heshuang Zheng

### *Research Assistants 2011-2012*

Cressica Brazier  
Yang Chen  
Yang Chu  
Rosie Sherman

Bill Dong Wang  
Ira Winder  
Feifei Yu  
Judy Zheng

### *Report Editors*

Ira Winder  
Rosie Sherman

© 2012. MIT / Dennis Frenchman, Christopher Zegras

### *Acknowledgements*

The research team wishes to thank the Energy Foundation, China for its generous support of Making the ‘Clean Energy City’ in China, a research project of Massachusetts Institute of Technology. Partners in the research include: Tsinghua University, Shandong University and Beijing Normal University who were responsible for field work in the City of Jinan. We also wish to thank the City of Jinan for its assistance and cooperation with the project. This report would not be possible without the many years of contributions from students.

## Contents

### *Section 1: Neighborhoods and Energy*

1. Introduction: Designing Clean Energy Cities	1
2. Current Approaches to Clean Energy Development	12
3. Neighborhoods and Energy: A Life Cycle Approach	31

### *Section 2: The Case of Jinan, China*

4. The Evolution of Urban Development of Jinan	43
5. Urbanization Forces and Trends in Jinan	52
6. Neighborhoods in Jinan	62

### *Section 3: Empirical Investigations*

7. Introduction to Empirical Analysis	76
8. Energy Consumption in Jinan	81
9. Urban Form and Energy Consumption	115

### *Section 4: Patterns, Proforma, and Policy Recommendations*

10. Developing the Clean Energy City: Patterns and Tools	120
11. Measuring Neighborhood Energy Performance: Energy Proforma <sup>©</sup> Version 2.0	153
12. Policy Recommendations	168

<i>Works Cited</i>	178
--------------------	-----

### *Appendices*

A. Travel Energy Consumption	
B. Embodied Energy Consumption	
C. Sun and Wind Related Urban Form Indices	
D. The Renewable Energy Potential Estimation and Urban Form	
E. Cluster Analysis of Clean Energy Urban Design	
F. Energy Sources in the Residential Sector of Jinan	
G. Energy Proforma User Guide	



## **Section I**

### **Neighborhoods and Energy**



# 1 Introduction: Designing Clean Energy Cities

This report presents the results of year two of a three year research effort being undertaken at the Massachusetts Institute of Technology, entitled, “Making the Clean Energy City in China,” sponsored by the Energy Foundation. The work has been undertaken with the assistance of partner institutions in China including Tsinghua University, Beijing Normal University, and Shandong University. Together, we are seeking to implement cleaner, more energy efficient, and higher quality patterns of urban development to house the hundreds of millions of people who will come to live to Chinese cities in the coming decades. The forms in which they are housed will have a profound impact on their day-to-day lifestyles and, in turn, overall energy consumption across China.

## 1.1 Neighborhoods and Energy

That neighborhood form is linked to energy consumption is intuitive. Neighborhoods with ‘walk-able’ streets can save energy because they encourage residents to get out of their cars. Neighborhoods that orient to the sun, or wind, or minimize paved surfaces, can save energy because they reduce the need for heating, or cooling. Many energy saving strategies such as these are now being encouraged in the design of neighborhoods around the world, including China. But, how effective are they? How do we measure the results? More importantly, how can we compare the performance of one urban form verses another in terms of their energy consumption? These are the central questions addressed by “Making the Clean Energy City in China”.

To date, numerous studies and research efforts have addressed issues of urban energy utilization and opportunities to reduce consumption. These have focused primarily on either the vast scale of metropolitan regions, or the small scale of individual buildings. However, there are almost no studies of energy consumption at the scale of urban development. This is the scale of neighborhoods, commercial districts, and real estate projects, which are the fundamental building blocks of urban growth. How can we hope to make a meaningful impact on reducing energy consumption in cities without addressing the issue of how energy is consumed at the scale at which the city is actually being built? Furthermore, while we may understand how energy is consumed within individual buildings, or by cars, it is less clear how this consumption is affected by the daily choices and patterns of behavior of individuals living, working, and moving within the geographic scope of their environment, or neighborhood.

Do all urban forms lead to behavior that consumes energy in equal amounts, or are there differences among the forms? What is the source of the differences? These questions have yet to be answered, as well as those such as: How can designers and developers choose among a vast array of variables to design more energy efficient scenarios in

particular circumstances? How can they assess the energy consumption of their project or alternatives? And finally, how can they do this in a way that is comparable to other projects to provide a basis for some kind of energy policy about the built environment?

As China's urbanization continues over the next decades, building hundreds of millions of new homes, answers to these questions, and scenarios for clean energy neighborhood development will become increasingly critical. The next two sections of this chapter briefly introduce the scale and dimension of this challenge – both that of increasing urbanization and energy consumption in Chinese cities, and the lack of appropriate tools for designers, developers, and policymakers to use in creating more energy efficient projects at the urban neighborhood scale. The final section describes the research objectives and key findings from Year 2 of the 'Making the Clean Energy City in China' and outlines the organization and chapters of this report.

## 1.2 The Need for Clean Energy Cities in China

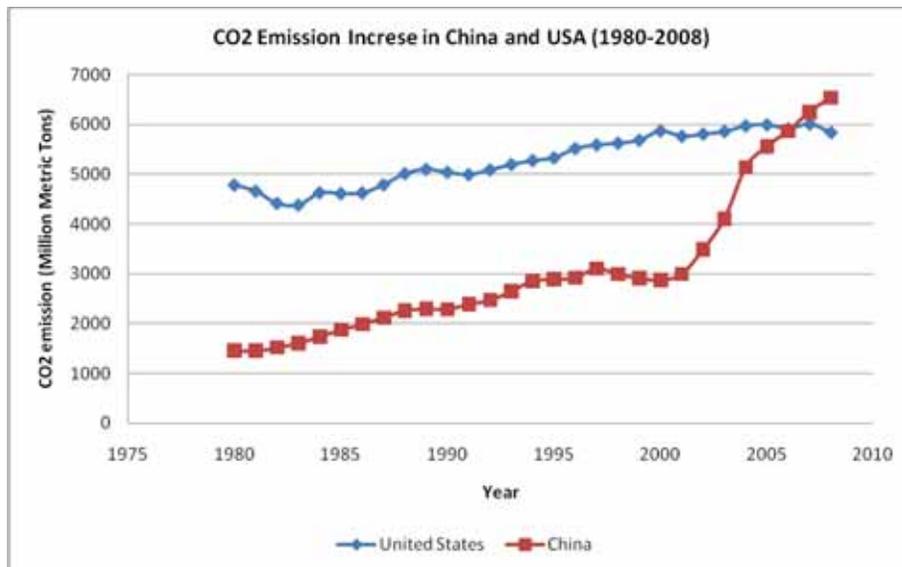
Since the beginning of the industrial revolution, the by-products of burning fossil fuels to produce energy -- greenhouse gases -- have been accumulating in the atmosphere and are now known to be affecting the world's climate. To avoid anthropogenic disasters from climate change, there is a widely accepted consensus that the increase in global temperature increase must be contained to within two degrees Celsius of pre-industrial levels. A recent study has shown that to achieve this goal, green house gas emissions will need to be cut by more than 50% worldwide over the next 40 years (Meinshausen et al, 2009).

With its rapid social and economic transformation, China has now become the world's largest emitter of greenhouse gases, and forecasts almost guarantee that China will become an even bigger contributor to emissions in the future. Acknowledging this, as the world's most populous developing country, China promised at the recent World Climate Summit in Copenhagen to reduce its carbon intensity (emissions per GDP unit) by up to 45% over the next 10 years. To achieve this goal, if it is even possible, will require significant efforts in all possible areas, making the institution of clean energy development strategies all the more urgent.

Energy intensity is entwined with economic growth and development. Since late 1970s, China's economic growth has been accelerating rapidly, reaching an annual growth rate of over 9% by 2008, a ten-fold increase since the 1980's. In parallel, China's energy consumption has increased 4.3 times over the same period, an average annual growth rate of 5.7%. This far exceeds the global average annual growth rate in energy demand, which grew only 1.4 times since the 1980's, and annual increase of only 1.6% (RCSD, 2007).

**Figure 1-1. The CO2 Emission Increase of China and USA**

Source: (U.S. Energy Information Administration, 2010)



Today, China contributes over 20% of annual world total greenhouse gas emissions, more than any other nation, having surpassed the USA in 2006 (Figure 1-1) (IEA, 2011). China is also projected to have the highest annual emissions growth rate of 2.8% over the next 20 years (EIA, 2009).

Urbanization is both the manifestation and driver of economic growth and development. It is also a key driver of China's carbon emissions because it is a highly energy intensive activity that is dominating China's economy. Over the past two decades, the percentage of the population living in cities has grown from 26% to 47%, and this growth is projected to continue by at least 1% per year over the next twenty years (McKinsey, 2009). As discussed later in this report, urbanization massively increases energy consumption in several sectors, particularly construction, transportation and buildings. Furthermore, energy consumption stemming from these sectors is increasing much faster than other sectors of the economy. From 1998 to 2007, construction energy consumption grew annually at a rate of 11.93%, 5% greater than the total energy growth rate in other sectors of the economy. The residential sector (energy consumed in the operation, heating, and cooling of residential buildings) has become the second largest energy-consuming sector following industry (RCSA, 2007).

Finally, the improvement of people's living standard has been rising dramatically in China and this is reflected in the way cities are built and used by residents. Increased residential energy consumption from appliances and private car usage are the key drivers in China's carbon emission scenario. The building and appliances and transportation sectors are projected to have the fastest carbon emission growth in the next twenty years

– quadrupling by 2030, while the total emissions will only double (U.S. EIA, 2010, McKinsey 2009). Clean energy urban development for China turns out to be extremely critical for dealing with the climate change challenge and national goals.

### 1.3 The Need for Clean Energy Design Tools

In response to these trends, the Chinese government has gradually built up an energy policy system in recent years designed to mitigate energy demand and fossil fuel dependence. This energy policy does not, however, focus specifically on urban development. Rather, the major focus of energy planning in China to date has concentrated on the industrial sector, to reduce energy consumed by power plants, and on industrial production and on fuel efficiency.

Although urban development is regarded as a key driver in China's total energy use, it receives little attention in the overall policy structure. Existing regulations concerning energy and development which do exist are focused almost exclusively on building scale energy consumption, leaving the neighborhood and regional scales unconsidered. As our research will show, this leaves a huge gap in the potential for energy savings as China urbanizes in the coming years, whereas systematic energy and urban development policies including the neighborhood scale would help to facilitate low-carbon lifestyles with far-reaching benefits.

China will have to be innovative to acquire the necessary tools to craft and enforce neighborhood scale energy regulation. Policy that requires new neighborhoods to comply with a 'clean energy standard' (like cars), for example, will require tools that can evaluate and validate the potential energy consumption of different clean energy neighborhood *designs*. While it is possible to estimate energy consumption at the scale of an isolated building through modeling software, the challenge at the neighborhood scale is far more complex. First, the scale of neighborhood development introduces interrelationships of urban form, embodied in tradeoffs such as the solar gain verses shading that results from spacing, height, and massing of multiple buildings. More importantly however, the behavioral component of neighborhood energy consumption – how individuals *choose* to use energy in, outside, and among buildings in the process of daily life – adds new layers of complexity toward estimating the holistic, life-cycle energy consumption of a neighborhood, regardless of whether individual buildings and transportation systems are designed to be energy efficient. Consequently, urban designers have no comprehensive measurement tool to quantify or visualize the energy consequences or trade-offs of their decisions or to give feedback during the design process at this time.

Efforts to address this need globally can be seen in the propagation of pilot clean energy neighborhood demonstration projects that have been sponsored in many countries, primarily in Europe, and the private sector in the US and Britain. A new program to develop 100 such pilot cities has recently been launched in China. Demonstration projects are valuable because they illustrate different strategies that can be deployed in

designing clean energy neighborhoods. However as each is situated in a different context – climate, geography, income profile, etc – it is difficult to combine project attribute data in order to create clean energy design standards or measurement tools that can be used across projects. In fact, there is currently no agreed upon protocol or standards to measure and compare the performance of these projects in a consistent way, so the lessons learned are of limited value.

A second approach has been the promulgation of clean energy design assessment and rating systems (such as LEED Neighborhood Development) that espouse clean energy principles. Rating systems, are highly limited as a design or policy tool for neighborhood energy, because they are prescriptive yet based on subjective criteria; in other words, they are not based in empirical measurements of energy consumption. They draw primarily from the general thinking of experts and practitioners about the characteristics of sustainable design, rather than systematic research; criteria for clean energy design are generally stated as design features or principles, rather than clear metrics with measurable units. Furthermore, their validation rely heavily on the judgment of certified assessors and the evaluation process is therefore a black box for designers and developers. Ratings only reveal a project's performance against the rating system itself, but do not provide much information regarding the project's energy performance in the real world relative to other projects.

Since the importance of criteria and standards for clean energy neighborhood development lies in their ability to influence future developments, they first and foremost must be a tool for design instruction and whose criteria is based in quantifiable research. To create such a tool is a key objective of this project.

## 1.4 Research Objectives

Making the Clean Energy City in China aims to achieve several interconnected objectives:

1. ***To understand the relationship between energy consumption and urban form in China*** -- Existing neighborhoods in China have evolved with little consideration of energy consumption. Nevertheless, we hypothesized that there is a relationship between the different physical forms of neighborhoods and the energy consumed by people living within them. In other words, some urban forms are inherently more energy efficient than others. To test this hypothesis extensive empirical studies were undertaken of prototypical neighborhoods in the city of Jinan. Energy consumption was assessed using various sources of data in four key areas: a) *Transportation and mobility*: How do the neighborhood forms affect the amount and type of transportation used and therefore energy consumed by households in these neighborhoods? b) *Operational energy*: How much energy is consumed by heating, cooling, elevators, distribution, and lighting in different neighborhood forms, and

how much can these demands be reduced by taking advantage of passive solar radiation, wind, and natural ventilation? c) *Embodied energy*: How much energy is embodied in the construction and life cycle of the buildings and site? d) *Renewal energy*: What is the potential for on-site renewable energy generation given different form typologies?

2. ***To identify prototypical examples of high quality clean energy urban form*** – This research identifies and analyzes best-practice design of clean energy neighborhoods by drawing on the expanding global experience with developing clean energy neighborhoods and from experience designing new neighborhoods in an academic design studio context. The prototypes -- distilled into a “pattern book” – provide for the first time: a) a common language of clean energy development, b) examples and inspiration as a starting point for designers; and c) a comparable database on the energy performance of different design approaches. A synthesis of these prototypes provides a taxonomy of neighborhood design typologies that display high energy performance.
3. ***To create a commonly accepted tool for assessing of energy performance at the neighborhood scale*** – The lack of such a tool and related terms and measures is hindering research and development of more energy efficient cities, as well as neighborhood energy standards and policies. On the development side, designers need practical tools to provide feedback on the performance of alternative development schemes, enabling them to make optimal choices among a huge set of design variables affecting energy use. On the research side, tools are needed for policymakers, who with a commonly accepted protocol and unit for measuring energy at the neighborhood scale can understand norms across many projects and set targets without prescribing solutions. The role of the assessment tool we envision parallels the universally accepted role of a *financial proforma* in real estate development. The financial proforma collapses a wide array of factors – market demand, construction systems, costs, sources of capital, mix of activities, and effects over time – into a single number: the net present value or rate of return on the project. Similarly, the *energy proforma* will collapse transport, operational, and embodied energy use of a neighborhood, along with its potential for energy production over time, to a single number: its *net present energy value*.

If such a tool can be successfully applied in China, we believe it will have wide applicability for urban design and development practice as well as policy-making around urban development and energy. The aim is to produce a Chinese model for assessing and encouraging clean energy urban form that can become the common practice for development worldwide.

4. ***To present different policy recommendations that help adapt existing energy and urban development policy regimes over the short and long term toward enabling development of clean energy neighborhoods*** – The recommendations presented in

this research provide policy avenues through which a pattern book of clean energy neighborhood designs and the *Energy Proforma* can best be deployed to achieve the wide-scale proliferation of clean energy neighborhood development in China. The range of actors and processes involved in urban design, implementation of real estate projects, and energy policy-making is broad and complex. Also, despite the need for energy-related policies for urban development, these areas do not necessarily intersect in policy or regulatory processes.

In order to ascertain how the suite of tools developed through this research may be best deployed, it is essential to first paint a comprehensive picture of the current energy policy and urban development regime. In the research, this process included analyzing where policy gaps exist and trigger points where new policies may be introduced that will influence urban-development scale energy consumption. This process also requires a consideration of how the tools developed through this research do or do not fit into current policy regimes and what barriers they would face toward adoption. The resulting policy recommendations developed in this research present short, medium and long-term options for introducing ‘Clean Energy City’ findings and tools into existing and new policies and processes.

## 1.5 Chapters and Findings

The contents of *Making the Clean Energy City in China: Year 2 Report* are summarized below, along with key findings to date. Note that the research is on-going, and so some of the findings are preliminary; others are incomplete. A final report at the conclusion of Year 3 will bring all work of the project together.

### *SECTION 1: Neighborhoods and Energy*

- **Chapter 2** – Reviews the state of practice related to energy assessment of urban development based on rating systems. This is compared to the existing energy policy regime in China from the national to individual building scale, demonstrating the gap in energy and urban development policies which exists at the neighborhood-scale.
- **Chapter 3** – Introduces our approach to researching how urban form and energy are correlated. We first outline the different categories of ways energy is consumed in neighborhoods on a holistic, life-cycle basis. We then use these categories to describe the current state of energy consumption in Chinese neighborhoods. Finally, we describe our hypothesis about why form matters in the energy consumption of neighborhoods.

**Key Findings:** *Because rating systems are neither based in research nor measurable in terms of energy consumption, we conclude they are of limited value in moving towards broad based clean energy design and policy in China.*

*Despite China's ambitious goals to reduce greenhouse gas emissions, and the fact that urbanization is the major driver of energy use in China, there is a wide gap in energy policy related to the performance of development at the neighborhood scale.*

## **SECTION II: The Case of Jinan, China**

- **Chapter 4** – Introduces the city of Jinan, describing the history of urban development and transportation networks, and the historical forces that led to four distinct neighborhood typologies found in Jinan today. The presence of these discreet neighborhood form typologies – traditional, grid, walk-up enclaves, and tower-in-park -- has facilitated empirical studies of the relationship between urban form and energy consumption.
- **Chapter 5** – Describes contemporary trends in housing and transportation choices in Jinan and evaluates the demand and supply side forces driving these trends. The chapter also describes how these trends are shaping the most recent development projects in Jinan, including the site used for the demonstration designs of clean energy neighborhoods conducted by MIT and Tsinghua University.
- **Chapter 6** – Describes the urban form characteristics of the twenty-three neighborhoods in Jinan analyzed for this research. Neighborhoods are grouped according to typologies identified in Chapter 4 and compared according to different metrics for describing density, use, and urban design characteristics.

**Key Findings:** *The entire city of Jinan has been developed using four principal neighborhood design types, reflecting successive national policies towards urbanization. These types provided the basis for empirical studies to understand their energy consumption. Current social and political forces, related to increasing wealth and lifestyles, are driving urban development towards only one of these neighborhood design types: the Tower-in-Park “Superblock” form.*

*Despite the popular assertion by planning authorities that “Superblock” communities are the most efficient means to accommodate housing demands, these neighborhoods do not achieve appreciably greater population density (FAR) than other neighborhood forms in Jinan. The “Superblock” communities are predominantly single use, gated developments, with fewer streets, services, and urban amenities than other forms.*

## **SECTION III: Empirical Investigation of Relationships between Urban Form and Energy Use in Jinan**

- **Chapter 7** – Summarizes results of the empirical analysis, including total neighborhood energy consumption and GHG emissions on a per-household and per-unit construction area basis for each of the prototypical forms. This chapter also

presents the summary results of the impact of urban form on on-site renewable energy generation potential.

- **Chapter 8** – Presents the detailed analysis and results of the empirical investigation of the relationship of neighborhood form to operational, transportation, and embodied energy consumption as well as on-site renewable energy production.
- **Chapter 9** – Evaluates the results of the empirical analysis and suggests what these results may indicate in terms of guiding clean energy neighborhood development in the future. New methodologies and areas of future investigation are also discussed.

**Key Findings:** *The analysis of additional neighborhoods in Year 2 of the study confirmed the finding of Year 1 that urban form has a substantial effect on energy consumption. Most importantly, the analysis of the sample 23 neighborhoods shows that Tower-in-Park “Superblock” developments consume almost twice as much energy per household as any other development form..*

*With respect to urban design, the empirical analyses suggest that, all things constant, the discreet urban form variables that are unique to Superblocks – i.e. highly porous ground plane, low building coverage, low grid density with limited access, underground parking – contribute to increased neighborhood energy consumption. On the other hand, characteristics such as small blocks, high levels of pedestrian amenities and uses, moderate building height and coverage, yet higher density – are likely to reduce energy consumption. These indicators are critical for informing urban designers how design tradeoffs will impact energy consumption. Since the Grid, Traditional, and Enclave typologies demonstrate different combinations of these energy reducing design characteristics, it seems clear that there are multiple neighborhood form patterns that can achieve high levels of energy performance. Conversely, “Superblock” neighborhoods would require significant adjustments in their form – adding the latter set of characteristics – to improve their energy performance. As we will see in the demonstration design studies, this is not as difficult as it may seem.*

*One interesting result of the Year 2 analysis was that the energy consumption per square meter of building (as opposed to household) did not vary significantly across the four form types. This can be explained by the fact that the different typologies in Jinan were constructed almost wholly at different times in history and therefore were built at different levels of construction sophistication (insulation, central heating) and are supplied by different energy sources. Therefore, energy consumption data is not fully comparable across a level playing field. Nevertheless, it is striking that , the energy consumed on a per meter basis in new Tower-in-Park “Superblocks” is not less than 100 year old traditional Houtongs. Or conversely, older neighborhood typologies performed as well as the new Tower-in-Park “Superblock” projects , despite the fact that the older projects were built to far less efficient construction standards and that their energy is supplied with more carbon-intensive fuel sources. Factoring in adjustments for these*

*deficiencies will almost certainly show the other typologies of form to be more energy efficient on a per square meter as well as per household basis, even if it were not yet statically demonstrable given the empirical data we have. The Energy Proforma tool (discussed below) allows users to hold factors such as building efficiency, fuel supply and energy use mix constant and observe solely the impact of urban form changes on energy performance.*

#### **SECTION IV: Developing the Clean Energy City – Patterns, Tools, and Policy Recommendations**

- **Chapter 10** – Examines the relationship between neighborhood form, design and energy consumption as demonstrated by current best practice. We first analyze the global experience with neighborhood scale development projects that aim to be energy efficient. We then develop a series of new demonstration neighborhood designs for Jinan using the *Energy Proforma*. The clean energy qualities and design characteristics of all neighborhoods – both existing and demonstration – are then synthesized to produce a taxonomy of six basic approaches to clean energy neighborhood design.
- **Chapter 11** – Introduces version 2.0 of the *Energy Proforma*, which has progressed in substantially from the year 1 beta version. The new structure and web-based interface of the *Energy Proforma* is described in detail (a comprehensive user guide appears in the Appendix). Following this, we present the results of an initial sensitivity analysis comparing actual energy consumption data of existing neighborhoods (both in Jinan and abroad) to energy consumption results simulated by the *Energy Proforma*. This provides a first step toward assessing the performance of the tool in comparing the relative energy performance of neighborhoods and calibrating it for use in different situations. This is work that will continue in Year 3 of the study with the aim of publishing a web-based tool that can be widely employed.
- **Chapter 12** – Considers the full scope of analysis in the previous chapters – the empirical analysis of neighborhoods in Jinan, the design analysis of clean energy neighborhoods globally, and the analysis of the current energy and urban development policy regime in China – and outlines a suite of potential policy recommendations to enable clean energy neighborhood development in the short, medium, and long term.

**Key Findings:** *Through several iterations, we have defined six development form types representing fundamentally different avenues to clean energy neighborhood design. The important physical characteristics of these types have been defined across a series of comparable variables and in terms of their energy performance assessed using the Proforma, providing baseline data for designers seeking to create clean energy neighborhoods.*

*The improved Energy Proforma can now estimate the key components of transport, operational, and embodied energy as well as impacts of sun and wind on operational energy use and the potential of designs to incorporate renewable energy sources (photovoltaics and wind), to give a comparative measure of energy performance. The viability of the Proforma as a design tool is tested and described. Finally, we are now converting the tool into a web-based application to provide a more refined and intuitive interface for Proforma users. This will allow short-cut analyses of potentials designs, with the goal of taking most variables directly from 3-D modeling software commonly used by designers and planners.*

*Given the limitations of current energy policy at the neighborhood scale and the relative rigidity of current statutory processes and regulations of urban design and development at the local level, we suggest a suite of policy options to enable clean energy city development in the short and long term. For the short term, we use the empirical analysis to construct design guidelines that, if implemented, will achieve an incremental improvement in energy performance through the incorporation of specific design features. Concurrently, we have used the characteristics of clean energy neighborhood prototypes to define a preliminary set of qualitative design guidelines that address height and density, cluster shape, connectivity of roads and blocks, land use mix, construction, and energy systems. Finally, we consider how to practically apply the tools we are developing under long-term policy scenarios. To help ground this research, we added to the work scope of Year 2 a series of discussions with planning officials and developers in Jinan and Shenzhen to assess how new energy guidelines and standards at the neighborhoods scale might be most effectively introduced.*



## 2 Current Approaches to Clean Energy Development

In this chapter, we examine the relationship between energy policy and clean energy urban development as demonstrated globally and in China. From the international perspective, the chapter first reviews existing sustainable urban development rating systems for their value in assessing energy performance. We then discuss the basics of China's energy policymaking process today, giving examples of current energy efficiency policies and programs, and projecting what alternative future energy policies in China may look like. We focus particularly on what these policy trends mean in terms of the need for data-driven local energy planning for sustainable urban development. As we will show, the focus of national energy policy to date has predominantly been discrete in strategy, targeting individual industrial firms, energy generators, and buildings. However in the past few years, ambitious plans have been established in China for the development of low-carbon city demonstration projects where multiple energy- and carbon- saving interventions can work in tandem to achieve even greater wins. What the design characteristics of these new cities will be and how the results will be measured are open questions. We conclude that without tools to measure and compare the energy performance of these projects and enable creative design, the effort is unlikely to succeed.

### 2.1 Assessment Systems for Energy-Efficient Development

Existing assessment and rating systems are a bridge between the theory and practice of clean energy design. The most well known systems, which we review below, began as voluntary efforts to encourage sustainable building, launched by public interest groups in the US and Britain. The ratings have been developed and promoted drawing on common knowledge and experience, rather than systematic research, and are not specifically focused on energy. Nevertheless, these systems have gained in popularity and their scope has expanded in recent years from buildings to neighborhood scale development.

#### 2.1.1 *The Role of Rating Systems*

These rating systems are significant to our research for several reasons. First, they are expanding awareness and motivating trends in practice. Although not mandatory like building and zoning codes, achieving a US Green Building Council LEED certification is seen as an acknowledgement by experts that a project is of high quality, which can increase its marketability. Beyond this, several US state and local governments have created tax and grant incentive programs to encourage certified development. Second, rating systems, to some extent, reflect the general thinking of experts and practitioners about the characteristics of sustainable design; standards have been developed by drawing on the diverse experience of industry, practitioners and experts, tempered by what is acceptable to the market and the real estate industry.

For our research, rating systems represent a baseline, summarizing the state-of-the-art in the field. We conclude that the ratings are limited as a design or policy tool for neighborhood energy, because they are prescriptive yet neither comprehensive nor based in measurements of energy consumption. Going beyond the limitations of such systems to achieve broad scale clean energy development in China defines the challenge we seek to overcome.

### **2.1.2 Review of Major Rating Systems**

In Year 1 of this research, a detailed review was conducted of three rating systems: *LEED-ND* (Leadership in Energy and Environmental Design for Neighborhood Design, by U.S. Green Building Council), *BREEAM Communities* (Building Research Establishment Environmental Assessment Method in the UK), and *ESGB* (Evaluation Standards for Green Building), which are building scale sustainability guidelines for the residential sector in China (no neighborhood scale rating system exists). This review can be found in the *Making the Clean Energy City in China: Year 1 Report*. The findings with regards to how the rating systems specifically address the issue of energy consumption and its relation to urban form are summarized below. We first examine the standards within four areas of concern (see chapter 3): energy consumed by transport, building and site operations, the lifecycle of materials and construction, building and site operations, transport, and renewable energy production. Second, we examine the implications of these rating systems as effective tools for designers and developers and consider their applicability to our goal of clean energy cities in China.

**LEED-ND** is currently the most known neighborhood-based rating system, however there are only 12 certified projects completed to date and 28 in the planning stages. (LEED list, 12-14-11). Four Chinese projects are certified and completed and two are in the planning stages. LEED-ND combines the idea of “smart growth”, “new urbanism” and “green building”, reflected in its three sections: “Smart Location and Linkage”, “Neighborhood Pattern and Design”, and “Green Infrastructure and Buildings”. There are four certification levels: Certified, Silver, Gold, and Platinum based on total points earned and the fulfillment of prerequisite items.

**BREEAM Communities** targets the planning stage of both residential and mixed-use projects. It is comprised of two elements: 1) *A Regional Sustainability Checklist for Developers* (<http://southeast.sustainability-checklist.co.uk/>), an online tool for decision making during preliminary planning stages, and 2) *BREEAM Communities Assessment* to evaluate detailed final plans (breglobal 2009). There are plans to also include post-construction and post-occupancy evaluations in the future. (skmconsulting.com). BREEAM Communities has five certification levels: Pass, Good, Very Good, Excellent and Outstanding based on the total credits earned. Credits are regionally weighted allowing for geographic variation. The rating system is now in the pilot stage of development with test cases including Athlete Village in London and MediaCity:UK in Manchester.

**ESGB** in China, is a non-mandatory rating system drafted and issued by the Ministry of Housing and Urban-Rural Development (住房和城乡建设部). It targets homes and public buildings with no reference to neighborhoods or mixed-use projects. The standards were drafted in 2006 and expanded in 2007-8. ESGB has three certification levels denoted by stars. For each level, corresponding benchmarks need to be met across eight categories. Since the first round of evaluation in 2008, 13 projects have been certified as “Green Buildings,” including four residential projects.

### *2.1.3 Comparison*

**LEED-ND** is the most comprehensive, covering all four dimensions of clean energy neighborhoods, noted above. With regard to embodied energy, LEED-ND values brownfield redevelopment, but does not consider the energy consumed by materials or construction. With respect to operational energy, LEED-ND gives special attention to solar gain (winter) and shading (summer) with images illustrating design strategies. Heat island effect is also emphasized, with recommended design solutions focused on shading, paving and plantation. However, it does not consider the impact of wind/natural ventilation on reducing energy consumption and heat island effect. Considering transportation, there is a special emphasis on designing for “walkability.” Finally, on-site energy production is not required in LEED-ND.

**BREEAM Communities** echoes LEED-ND. It places greater emphasis on transportation issues including availability of public transit, cycling facilities, car-share, and parking. BREEAM advances the concept of a “home zone” including safe walking space, streetscape and connectivity, however, it misses the importance of a pleasant and convenient walking environment to save energy. In fact, BREEAM Communities is the least energy conscious among the three systems. BREEAM’s consideration of operational energy is limited to reduction in heating demands with no concern for cooling. Both passive solar and wind/natural ventilation are highly valued. Finally, compared to LEED-ND, BREEAM Communities puts slightly more emphasis on incorporation of on-site renewable energy.

**ESGB** ignores transportation energy issues aside from encouraging “public transit” and “compact development”, “节地” in Chinese, which has been consistently emphasized in China’s planning regime. Natural lighting, ventilation and solar gain, achieved through prescribed arrangements of buildings, play a stronger role than in the other two standards. “Heat island” is listed as a concern, however no rating category is included. ESGB’s deep concern for embodied energy efficiency is a distinct feature, which is reflected in its emphasis on the use of local materials and reduced consumption in building construction. Use of renewable energy is encouraged but not prescribed in detail.

#### 2.1.4 From Ratings to Design Guidance

The rating systems provide a form of design guidance through either quantifiable or non-quantifiable instructions. Criteria for non-quantifiable methods either involve a yes-no answer or a professional judgment. For example, BREEAM Communities urges designers to “design to enable air-flow through the development,” but provides no definition, measurement or design instruction. Quantifiable ratings involve either performance estimates or the presence of design features. The former compares the estimated performance of one element of the project as given by expert analysis (for example, VMT) against desirable benchmarks. The latter assesses physical design characteristics, for example “at least 50% of dwelling units and nonresidential building entrances are within a 1/4-mile walking distance of bus or streetcar stops” (LEED-ND, SLL-C-3). While specific, the outcome of achieving these benchmarks on the consumption of energy in a particular neighborhood is unknown.

Comparing the three standards, LEED-ND has the most clearly defined criteria and measurements. It interprets abstract principles and goals such as “walkability” and “heat-island-reduction” into measurable quantities. However, a number of these quantities – such as the example given above about building entrances and bus stops – are not derived from research; they are a judgment of good practice by the raters. In comparison, goals in BREEAM Communities fail to go beyond principles and the criteria rely heavily on the judgment of certified assessors. The evaluation process is therefore a black box for the general public as well as designers. ESGB tries to quantify most of its criteria; however, it fails to interpret design features into measurable units; examples include “simple design” and “smart arrangement of building orientation.”

This disconnect between energy and design goals versus the criteria to achieve the goals is the single greatest limitation of these rating systems. Even when abstract goals and principles are interpreted into quantifiable design measurements, no causality or correlation is discussed. For example, LEED-ND claims that “compact development” can “reduce vehicle miles traveled (VMT)” and therefore credits can be earned according to the density of the project. However, information regarding “by what extent does one unit increase in density contribute to the reduction in VMT” is not provided anywhere in the criteria; the credits are largely a reflection of informed opinions. The consequence is that *the rating only reveals the project’s performance against the rating system itself*, but does not provide much information based on measurement regarding the project’s (energy) performance in the real world.

Even with well-designed criteria, the synthesis of clean energy design components is highly complicated and the delicate interrelationships, embodied in tradeoffs such as solar gain in winter verses shading in summer, cannot be addressed solely with rating systems. Even for quantifiable design measurements, confusions arise when the designer tries to fulfill several criteria simultaneously. Finally, unlike building-level ratings that are often supplemented by accepted engineering-based simulation tools, designers

following LEED-ND or BREEAM have *no comprehensive measurement tool to quantify or visualize the energy consequences or trade-offs of their decisions or to give feedback during the design process*. Since the importance of criteria and standards lies in their ability to influence future developments, they first and foremost must be a tool for design instruction that is iterative and whose criteria is based in quantifiable research. To create such a tool is one objective of this research.

## 2.2 National Energy Policy in China

Turning to China, the ESGB standards mentioned above are only a small part of an expanding and evolving policy framework related to energy consumption. Beginning with efficiency standards for power plants and heavy industry, emphasis is now shifting to include aspects of the built environment, as urbanization and rising standards of living demand more and more of the country's resources. This section reviews the energy and development policies in China and current initiatives affecting the neighborhood scale.

### 2.2.1 History and Structure of China's Energy Policymaking

China's energy policymaking, like China's policymaking of all forms, is guided by the goals set forth within the national Five Year Plan (FYP). At the time of this writing, China is entering its 12<sup>th</sup> FYP which spans the years 2011-2015. Mao Ze Dong established the First FYP in 1953, as a top-down method of guiding the country toward Soviet-style industrial and economic growth. In the Sixth FYP (1981-1985), environmental goals were established within the FYP next to its traditional goals of economic growth. This was when China fully adopted the first energy conservation policies (Levine 2010).

The details of the FYPs are decided within the National People's Congress (NPC). The NPC is the world's largest parliament, the legislative branch of the Chinese government, and the venue through which the Communist Party shapes the political direction of the country as a whole. After the NPC defines each FYP, the document is passed through the State Council, China's chief administrative authority, and on to management institutions including Ministries, National Academies (public think tanks), and the National Development and Reform Commission (NDRC), among others. These key actors collaborate with each other and with supporting bureaus<sup>1</sup> and academies<sup>2</sup> to design targets or special programs (we will discuss these in detail in the next section). After these national-level working groups decide on actionable next-steps, they assign tasks to their provincial counterparts, who then in turn delegate work to urban and rural municipalities.

---

<sup>1</sup> Notably the National Bureau of Statistics, or NBS.

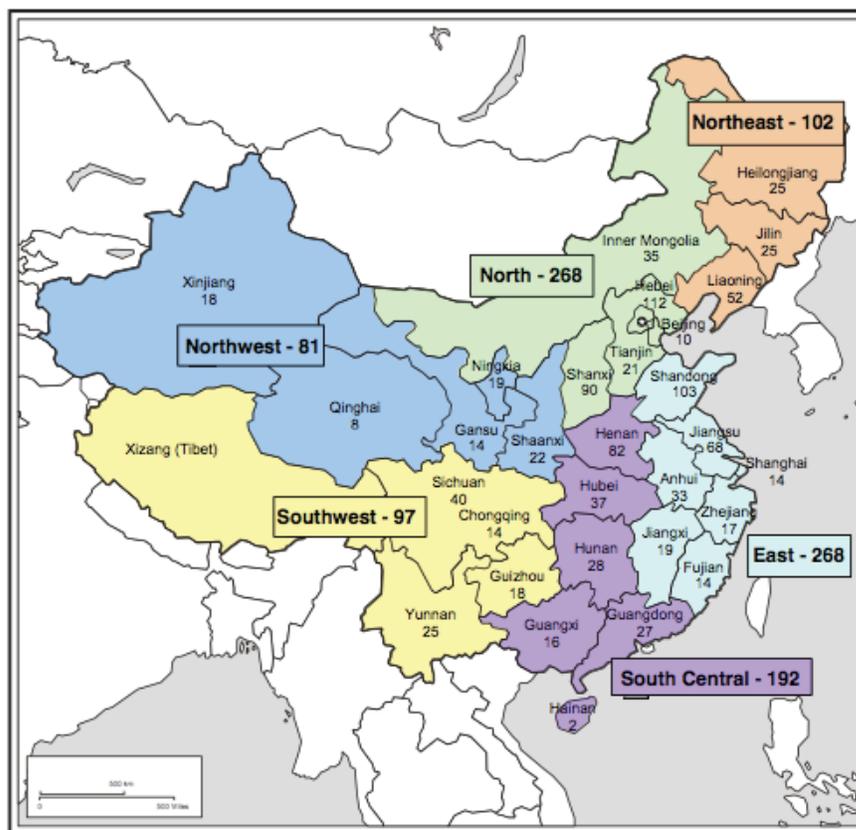
<sup>2</sup> These include the Chinese Academy of Sciences (CAS), the Chinese Academy of Social Sciences (CASS), the Chinese Research Academy of Environmental Sciences (CRAES), the Chinese Academy of Environmental Planning (CAEP), among others.

In the 11<sup>th</sup> FYP (2006-2010), China set a target of cutting energy intensity, or the amount of energy used per unit growth in gross domestic product (GDP), by 20 percent on 2005 levels. This goal was achieved (Xinhua 2011) through general provincial-level energy intensity targets, and specialized national-level energy conservation initiatives, the most notable of which are detailed below.

**2.2.2 The Top-1000 Energy-Consuming Enterprises Program**

The Top-1000 Energy-Consuming Enterprises Program (Top-1000 Program) was established in April 2006. As the name suggests, it mobilized 1000 of the heaviest energy consuming enterprises throughout China to cut down on energy use. In 2004, these enterprises comprised 33% of total national energy consumption. The goal of the Top-1000 Program was to reduce this by 100 million tons of coal equivalent (MTCE) for the 11<sup>th</sup> FYP period, which depending on GDP growth can contribute between 10 to 25 percent of the energy savings required to meet the 20% energy intensity reduction target by 2010 (Price, Wang and Yun 2010).

**Figure 2-1. Location of Top-1000 Enterprises**



Source: (Price, Wang and Yun 2010)

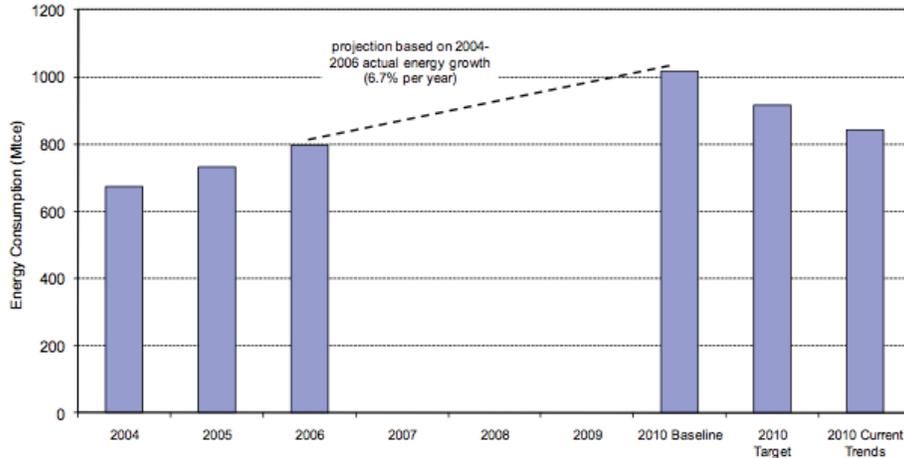
Like the European voluntary agreement programs upon which it is based, the Top-1000 Program hinges upon energy conservation agreements signed between NDRC and the provincial-level governments, and then between the provincial-level governments and the participating enterprises under their jurisdiction. In this way, the 100 MTCE national target is distributed to each of the 1000 enterprises, and both enterprise leaders and local government officials are under contractual obligation to meet the targets. If the targets are not met, year-end rewards, honors, and titles are confiscated, enterprise leaders lose their annual bonuses, and local officials are barred from promotion. Conversely, MOF and NDRC reward enterprises for documented reductions in the amount of 200RMB/TCE/Year for East China, and 250RMB/TCE/Year for Middle and West China. This is akin to \$12-\$15 per ton of CO<sub>2</sub> emissions reduced (Price, Wang and Yun 2010).

The participating enterprises are located all over China and most of the major provinces are involved. Shandong Province, the target of our study, played a key role in piloting and supporting the Top-1000 Program through its local initiatives. In 2003, Shandong Province entered into an energy conservation pilot project and set targets with Jinan Iron and Steel and Laiwu Iron and Steel, which achieved over 9% reductions in energy use by 2005 over 2002. After this effort was scaled into the Top-1000 Program, Shandong Province continued to play a leadership role and offered \$304 million for local energy conservation projects through a special provincial fund (Price, Wang and Yun 2010).

In the Top-1000 Program, enterprises were responsible for administration of the program within their existing firm structures, including formulating goals, establishing reporting systems, conducting audits, investing in improvements, and general planning. Though the local governments supervised the activities, the resulting energy conservation data was reported directly to the National Bureau of Statistics (NBS) through quarterly online reporting forms. This was supposed to improve reporting efficiency and reduce the workload of the local government officials, but bypassing local authorities caused accuracy issues and also hindered participation and transparency.

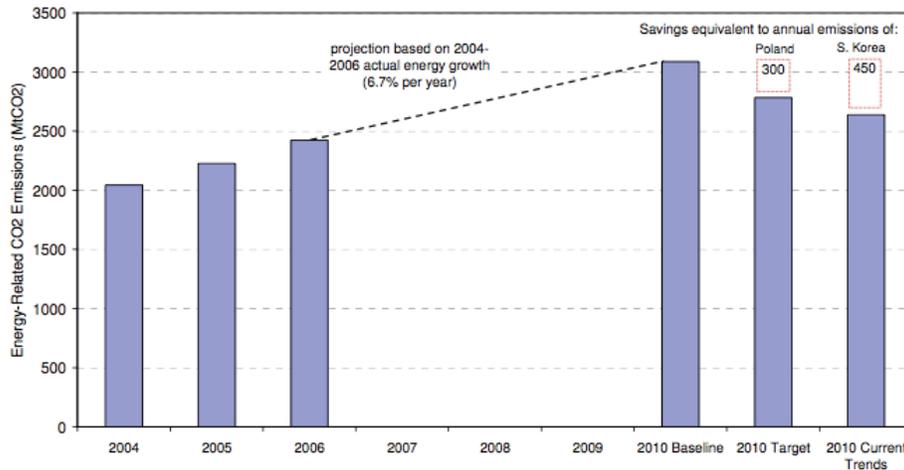
For one, the enterprises were unfamiliar with the online reporting system and would have benefited from local-lead capacity building and training sessions to ensure uniform use and accurate reporting. Central reporting also resulted in NBS and NDRC monopolizing all multi-enterprise-level data. Without ready access to this information, Individual provinces and the participating firms could not conduct their own place-specific analysis of the data from their activities, and so were barred from taking the lead on planning for further energy savings. At the national level, the information from this program was only released once over the course of the entire five-year period, in the form of a summary report in 2007, with no third party verification or review at any level. Working within this lack of transparency, the Lawrence Berkeley National Laboratory in California projected the official NDRC data from 2007 into 2010 (Figure 2-2 and Figure 2-3).

**Figure 2-2. 2006 Energy Consumption (MTCE) Projected into 2010**



Baseline Scenario = annual energy growth based on 2004-2006 actual (6.7% per year)  
 Target Scenario = 20 Mtce savings per year 2006-2010 to achieve 100 Mtce target  
 Current Trends Scenario = 20 Mtce savings in 2006, 38 Mtce savings per year 2007-2010

**Figure 2-3. 2006 Carbon Emissions Projected into 2010**



Baseline Scenario = annual energy growth based on 2004-2006 actual (6.7% per year)  
 Target Scenario = 61 MTCO2 (20 Mtce savings) per year 2006-2010 to achieve 300 MTCO2 (100 Mtce) target  
 Current Trends Scenario = 97 MTCO2 (32 Mtce) savings per year 2007-2010  
 Note: Emissions based on 2006 fuel mix; electricity reported as source, accounting for generation, transmission, and distribution losses

Source: (Price, Wang and Yun 2010)

The graphs show that not only will total energy use for the Top-1000 Program exceed the program’s goals for the 11<sup>th</sup> FYP, the carbon savings associated with the reduction is equal to the entire carbon output of a small country. This kind of information and analysis can be extremely valuable to China’s foreign policy, especially in international climate

negotiations. That it took an American organization to create the graphs above is a sign of China's leadership not yet grasping the powerful political and policy implications of data-backed reporting. The question of "Measurable, Reportable, Verifiable" data (MRV) took center stage in the Copenhagen climate discussions of COP15, where the transparency issue ambushed China's negotiators and held China hostage to countries with more proactive public relations practices (Hsu and Zhao 2011). In the recent COP17, Chinese leaders preempted criticism by publishing a white paper on its climate change mitigation activities to date (Xinhua, CRI English 2011). This is a step in the right direction. The next step is for China to develop a practice of releasing continuous information that is rigorously backed by data and verified by third parties. Only then can China fully participate in the international conversation around energy and climate issues.

### 2.2.3 Building Energy Standards

China adopted its first National Building Energy Standard (BE Standard) in 2007. The BE Standard required a 50 percent reduction in operational energy use in all new residential and commercial buildings compared to average 1980s building stock within the same climate regions (Jin and Alysas 2010). The map below shows the climate regions as defined by the Ministry of Housing and Urban Rural Development (MOHURD).

Figure 2-4. MOHURD Climate Regions



Source: Huang and Deringer, 2007.

The Cold and Severe Cold regions combined designate MOHURD's Central Heating Zone, where the government mandates central heating and allocates coal and coal-equivalent fuels to stoves and boilers at a rate of 34 kilograms per year per square meter served (Sathaye and Tyler 1991). The Central Heating is a policy remnant from China's 1950-1980 central planning era, and needs to be reevaluated. In the Cold and Severe Cold

regions, Central Heating is extremely inefficient due to lack of end-user control. Fees associated with this central heating are charged to households on a per square meter basis, not metered like more modern methods, so there is no incentive to conserve the heat once delivered. Heat is provided 24/7 for four months of the year regardless of if anyone is actually using the heated space. The only way to control the temperature is by opening exterior windows, a practice that wastes seven percent of total heat (Zhang 2007).

Furthermore, the system of heat delivery that focuses on Central Heating chronically disadvantages already underserved communities. Residents of rural areas not covered by Central Heating lack safe alternatives and resort to coal-burning stoves and heated beds, which emit noxious fumes and can result in death. Impoverished urban residents who live in centrally heated dwellings find that central heating bills are an overwhelming expense that cannot be alleviated through adopting a more economical lifestyle due to the payment structure (Zhu 2005). Meanwhile, residents living outside the Heating Zone, particularly in the Hot Summer Cold Winter region, find that alternative heating methods are not enough to combat the winter cold. Shanghai residents among others have found that insulation standards are too low and have started to demand their own central heating to combat the drafty effects of the inadequate national standards (He 2010).

#### **2.2.4 Power Generation**

The 11<sup>th</sup> FYP saw a push for making China's fossil-based energy generation more efficient through a nation-wide consolidation effort that replaced dirty small coal-fired power plants with larger plants to take advantage of better management, newer equipment, and economy of scale efficiency gains. There was also a ramp-up in the mix of non-fossil energy under the Renewable Energy law starting 2006. Most pronounced was China's development of wind energy, which grew 30-fold in the 11<sup>th</sup> Five Year Plan period to make China the world's biggest wind energy generator at the time of this writing (Economist 2011).

Both wind and solar energy in China is disproportionately sourced from the country's west and northwest, particularly Inner Mongolia and Xinjiang provinces. This makes nation-wide investment in physical and managerial energy transmission infrastructure critical to shifting China's energy mix away from coal toward non-fossil sources. The current state of China's transmissions mechanisms is far from ideal. Due to China's inability to manage its provincial grid networks, local officials take advantage of incentive loopholes to boost its local wind investments regardless of actual ability to capture the electricity for the grid. Losses from China's inability to harness its generated wind capacity amounts to US\$5.4billion, and it is estimated that a third of China's wind power projects lack grid access (Ma and Fu 2011).

### 2.3 Connecting National Energy Policy to the Neighborhood Level: Local Sustainable Development Pilots / Eco-Cities

Going forward into the 12<sup>th</sup> FYP, China continues its strategy of a national energy intensity target, planning an additional 16 percent reduction in energy use per unit of GDP by 2015. In the 12<sup>th</sup> FYP, China also for the first time adopts a national carbon intensity target of 17 percent reduction in carbon output per unit of GDP on 2010 levels by 2015. This is intended as a first step in realizing China's COP15 pledge to cut carbon intensity by 40-45 percent on 2005 levels before 2020 (Finamore, Lin and Davidson 2011).

To reach these goals, and with the lessons from the 11<sup>th</sup> FYP in mind, China's policies are trending toward more holistic approaches, building up the capacity of local authorities to implement national directives, with the potential to lead the country in a structural shift toward sustainable development. Most notable is China's new wave of pilot programs for location-based energy and carbon management experiments.

The genesis of low-carbon and eco-city initiatives in China can be traced to the 1994 policy document *21st Century Agenda of China* (21 世纪议程), which focused on the need for ecological sensitivity, sustainable development and environmental protection. These ideas were founded on work of three key professors, Shijun Ma, Rusong Wang, and Guangyu Huang, who led early research on eco-cities in China. The first two jointly developed the idea of cities as a complex ecological system composed of social, economic and natural sub-systems in 1987, with Wang further advancing "the integrity of nature and city" as the basis of eco-city development in 1994. Huang, suggested that livability, economic efficiency, and ecological sustainability should be the three primary goals of eco-cities, achieved through the comprehensive study of the three systems.

Thereafter, a series of nationwide programs have been launched to encourage the development of low-carbon and eco-cities. Among these was the "Construction of Model Eco-City/Regions (生态示范区建设)", which was originally proposed in 1995 by State Environmental Protection Administration (国家环保总局). Though many cities in China since announced their intentions to become eco-cities (three representative plans for eco-cities were announced in 2007: Tianjin Eco-City, Dongtan Eco-City, and Caofeidian International Eco-City) the effort has most recently been revived as a nation-wide policy.<sup>3</sup> In mid-2010, as the 11<sup>th</sup> FYP drew to a close, the NDRC launched a national low carbon pilots program that included an initial eight cities (Tianjin, Chongqing, Shenzhen, Xiamen, Hangzhou, Nanchang, Guiyang, Baoding) and five provinces (Guangzhou, Liaoning, Hubei, Shaanxi, Yunnan). The National Energy Administration stated that under the 12<sup>th</sup> FYP China's stock of low carbon pilots will expand to include 100 cities, 200 counties, 1,000 districts, and 10,000 townships (Xinhua, China Pledges its

---

<sup>3</sup> A companion document to this report, *Low-Carbon and Eco-Cities in China* discusses the Chinese experience with low energy design.)

Urbanization Drive to be Low Carbon 2011). This bottom-up approach to low carbon development planning is supposed to complement the top-down energy and carbon targets of China's central plans.

**Figure 2-5. China's Existing Low Carbon Pilots**



Source: Wang, 2011.

The pilots committed to emphasizing climate change mitigation in their development plans, adopting low-carbon policies and industrial structures, and promoting low carbon lifestyles and consumption patterns. However, the detailed plans for the more mature pilots (stated above) suggest that their conception of eco-cities is not aimed primarily at reducing energy, but achieving a balance of sustainable approaches, including water and waste reduction as well as compact development and protection of sensitive ecosystems and agricultural land. All the three eco-cities aimed at reducing CO<sub>2</sub> emissions, echoing the central government's emphasis on clean energy for a better environment. Despite the promises of these cities, it is unclear from the fantasy drawings how these goals would actually be achieved or results measured.

Furthermore, the Eco-City concept will prove to be an empty promise unless the pilots can actually break new ground in defining, managing, and *measuring* low carbon development in China. If cities and provinces are going to truly take the lead in pioneering new forms and strategies of low-carbon urban development, as well as learn from one another, they will need tools and processes to benchmark and measure relative energy performance of their low carbon cities. Without access to these, individual provinces and the participating cities cannot conduct their own place-specific analysis of

the data from their activities, or compare them to others in a systematic way, and will struggle to improve upon their plans.

Defining ‘low-carbon’ across these pilots will also be a challenge. Unfortunately, much as the pilots attempt to act as low carbon exemplars for the rest of the country, there is still a long ways to go. Kejun Jiang of the Energy Research Institute has raised numerous warnings that China still does not have a good grasp of what low carbon development entails. Provincial governments mistakenly believe that the trappings of American-style modernity – like wide roads, tall buildings, and golf courses – indicate progress and pursue these urban forms in the name of low carbon development. In reality they are perpetuating environmentally unsound practices while failing to develop real low carbon indicators like energy and carbon monitoring (Liu 2010).

## 2.4 Local Policies in China Affecting Energy and Urban Form

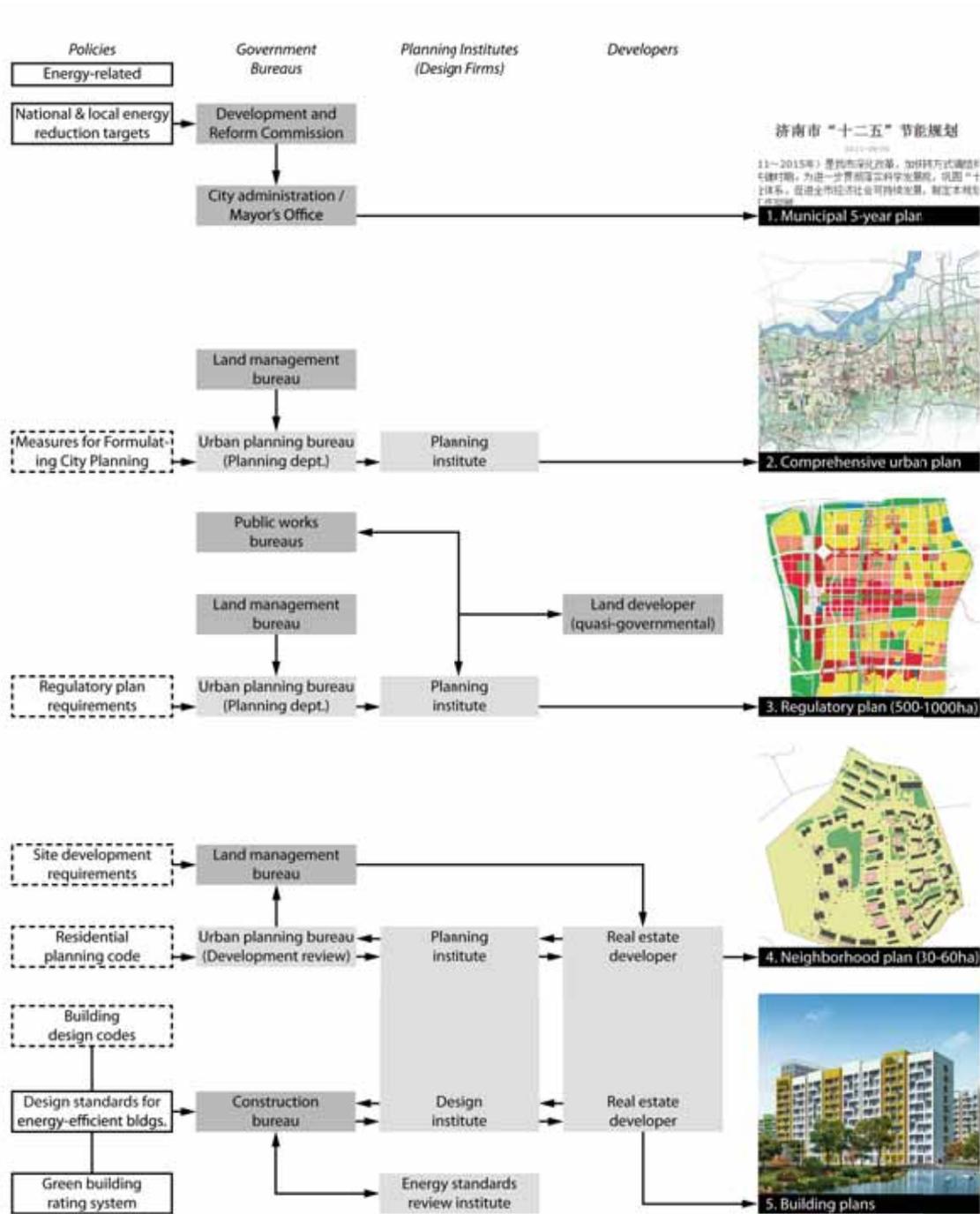
At the local level, municipal governments and developers could incorporate energy efficiency goals into the process of urban development at four key planning stages: municipal implementation plans, comprehensive urban plans, sub-district regulatory plans, and neighborhood development plans. However, neither the central government nor municipal authorities have developed plans or guidelines that specifically target energy efficiency in neighborhood-scale urban form. In **Table 2.1**, we illustrate some of the gaps in the regulations and codes related to energy and the built environment. Among the four dimensions of a clean energy city—embodied, operational, transportation, and renewable energy—dispersed sections of building codes and renewable energy laws regulate only a few of the parameters related to neighborhood energy consumption.

Two main reasons for the absence of neighborhood-level energy planning are insufficient model guidelines and the challenge of coordination across multiple stakeholders who would be affected by these energy-related guidelines. First, even international standards for neighborhood-level energy efficiency are poorly developed (see Section 2.1.2 above); Chinese planning regulators have not codified this limited professional knowledge in an actionable format for local authorities. Second, in the current urban planning system, a diverse set of development stakeholders would have to agree on an energy-focused agenda, which even at the neighborhood scale can appear to conflict with economic and quality-of-life objectives, and then coordinate to enforce the new guidelines and standards across the four planning stages. In **Figure 2.6**, we chart the stakeholders and current energy planning context according to these planning stages and scales. Although limited in its scope and participants, the policy development cycle for the *Design Standard for Energy Efficiency in Residential Buildings*, described in **Section 2.4.5** below, does demonstrate of how national ministries could draw on the experiments of local jurisdictions to develop an energy performance standard, beyond the building scale, at the neighborhood level.

**Table 2-1. Summary of national building and planning codes affecting energy and urban form, by energy use dimension**

<i>Code Type</i>	<b>Embodied Energy</b>	<b>Operational Energy</b>	<b>Transportation Energy</b>	<b>Renewable Energy</b>
<i>Energy-related codes and regulations</i>		Building envelope insulation (Civil Buildings energy efficiency regulation)  Heating level and control (Civil Buildings energy efficiency regulation)  Daylight access (energy-related rule in urban planning code)		Building-integrated solar power (Renewable Energy Law)
<i>Urban planning codes that affect energy but are not currently linked to energy</i>		Neighborhood minimum density (urban planning code)	Mixed-use buildings and land development (urban planning code)  Building minimum coverage (urban planning code)	
<i>Policies not included in current codes and regulations</i>	Life-cycle energy of building materials  Construction processes and site earthwork	Water energy use and heating  Wind factors	Walkability and sustainable transport  Transit-oriented development	Geothermal, biomass energy sources

Figure 2-6. Current policies related to energy and urban form, and stakeholders affected by energy-related planning, by urban planning stage



### ***2.4.1 Municipal Policies and Five-Year Plans***

In addition to the energy-related pilot projects that the NDRC has assigned to specific cities, city administrators can incorporate energy or low-carbon targets into the local economic, urban development, or environmental plans. For example, Jinan's 12<sup>th</sup> Five-Year Plan takes note of the city's total and peak energy consumption and states a commitment to upgrading and expanding the hot water heating districts, above the current 50% central heating system penetration rate. Energy goals, linked to economic and social planning objectives in municipal-level five-year plans, provide influential guidance for the next stages of planning below.

### ***2.4.2 Comprehensive Urban Plans***

The national planning ministry, the Ministry of Housing and Urban-Rural Development (MOHURD), formalized the fundamental responsibilities of the local planning bureau in its *Measures for Formulating City Planning*, which begin with the city's comprehensive urban plan. Many of the urban development decisions that can enable or preclude energy-efficient planning on a broad scale, such as the siting of new residential districts, commercial zones, or major transport hubs, are fixed at the comprehensive plan level. Beyond some attempts to promote compact growth, urban and regional land use policies do not take energy consumption into account, and municipalities have poor control over low-density urban expansion in peri-urban 'new towns' and 'development zones'. Planning bureaus should model the impact of regional form on energy consumption to provide a more rational basis for comprehensive planning and development control, but this step is beyond the scope of this neighborhood energy study. Jinan's most recent comprehensive plan was formulated in 2005 and adopted in 2006, and we describe the plan in **Chapter 4**.

### ***2.4.3 Regulatory Plans***

The regulatory plan, or detailed control plan, is the most significant determinant of a neighborhood's potential for energy-efficient design. MOHURD's *Measures for Formulating City Planning* also designates the legally required components of regulatory plans for all Chinese cities. The regulatory plan establishes a set of boundary lines—the 'six control lines' of red, yellow, green, orange, blue, and purple, respectively designating the boundary of the road, infrastructure, green space, public facility, water, and historical conservation zone—that seek to balance between the interests of public resources and real estate developers. The planning parameters for each of the resulting land parcels are also listed on the regulatory plan, to strongly enforce parameter values that developers might change to their advantage (land use, constructed floor area, FAR, building density, coverage, height, and some public amenities), and to provide guidance for parameters that MOHURD considered less critical to the development outcome (green space ratio, some residential amenities). Additionally, the regulatory plan development process often incorporates a preliminary urban design, to coordinate and evaluate the regulatory plan's proposed zoning, overall building massing, and public space. In 2006, the Jinan planning

bureau laid out 53 regulatory plan zones in which land use, roadways, detailed boundaries, and special projects would be reevaluated and planned.

At both the regulatory planning and neighborhood planning stages, the planning codes for mobility and neighborhood design are effectively car-oriented. The codes do not emphasize the importance of pedestrian street life, and tend to encourage the use of cars in large-scale residential developments. For example, road intersection design guidelines primarily serve the automobile and do not support bikers or pedestrians. The Shanghai planning bureau, among other cities, have started distributing supplementary guidelines for residential road section design and landscape design, which in future versions could incorporate better integrated transport systems for bikes, dedicated public transportation lands, and pedestrians, in addition to more options for street scale and storefronts.

Urban planning bureaus do find opportunities to innovate within the two-dimensional ‘control lines’ and land use designations of the regulatory plans. For example, the Shenzhen planning bureau has successfully incorporated the following additions to the detailed regulatory plans, beyond the legal requirements laid out in the national *Measures for Formulating City Planning*. Although the Shenzhen planning bureau did not explicitly link these additional development requirements to energy planning, these requirements are related to improved energy efficiency in neighborhood form and provide a promising basis for incorporating energy concerns into future regulatory plans:

- Public access routes through superblocks
- District-scale transportation amenities (i.e. local street-level tram that connects superblock entrances to mass transit)
- Publicly-accessible, privately-maintained green space
- Pedestrian streets and special commercial zones between and within developments
- Form-based codes, including three-dimensional massing and elevation requirements for developers
- Mixed-use building requirements, which enable a range of uses while adhering to land use requirements

#### ***2.4.4 Neighborhood-Scale Real Estate Development Plans***

At the real estate parcel level, regulations affecting the energy efficiency of neighborhood form include: daylight access requirements, which vary by urban administrative zone; green space ratios; security guidelines that often result in fewer access gates into a neighborhood; allocation of parking spaces and car circulation, to ensure sufficient parking spaces based on the target household income level; and residential support facilities. These regulations affect the interrelationship of buildings within a neighborhood, which in turn impacts the quality of outdoor space, solar gains, ventilation, and the travel decisions and modes of residents due to the placement and functionality of public facilities.

MOHURD wrote formulas and standard ranges for these design parameters into the residential zone planning regulations, such as floor area ranges for basic public facilities and commercial space, with the intention of providing enough flexibility for nationwide application of the regulations. Local jurisdictions have the opportunity to redefine or add new requirements to the national code, to incorporate local development objectives and climatic needs. For example, the Jinan planning bureau has established a narrower range of floor area required for commercial use in residential developments, and the bureau promotes a higher range of parking spaces per household. Both of these requirements may work against energy efficiency and need to be guided toward values that might reduce transport energy consumption.

In general, neighborhood planning codes are not spatially oriented, and a developer can satisfy the code requirements with a poorly-arranged spatial plan that, for example, separates uses and access to alternative transportation. Moreover, the modernist, towers-in-the-park model that is the *de facto* residential real estate standard, promoted by developers and generally supported by planning bureaus, will usually be approved under the current planning regulations. Certain planning code parameters, especially the regulations for building spacing and sunlight access, have consistently resulted in south-facing rows of slab or tower buildings and have limited the potential for more compact and innovative neighborhood layouts. By factoring energy efficiency into the neighborhood form equations established by current codes and practice, we may be able to suggest more spatial controls that lead to reduced energy consumption.

Although planning bureaus in China have not yet developed guidelines that specifically target neighborhood energy efficiency, planning bureaus are beginning to integrate ‘smart growth’ principles into local planning guidelines. In 2009, the Shanghai Urban Planning and Land Resources Bureau reissued the *Shanghai Large-Scale Residential District Planning and Design Guidelines* to district planning departments, land developers responsible for local urban designs, real estate developers, and local planning and design institutes. The revised guidelines clearly defined new key priorities that span both regulatory planning and neighborhood design stages for residential developments, including:

- Mixed-use functions (i.e. commercial space on the perimeter of gated communities, and ‘small office-home office’ programming, possibly to improve street utilization and to allow flexible mixed-use within developments)
- Higher-density housing surrounding transit hubs and core districts
- Road network distribution (i.e. Typical gated residential blocks should be 250m long, and not exceed 350m in length, possibly to improve pedestrian and transport access)
- Area limitations for floor plans (i.e. 2-bedroom apartments should not exceed 75 sq.m., and 3-bedroom apartment should be limited to 90 sq.m.)

#### **2.4.5 Energy-Efficiency in Buildings**

China's *Energy Conservation Law*, amended in 2008, has been adopted as a “basic policy” by the State Council, which indicates the central government's increasing emphasis on energy efficiency across all building sectors. The *Regulation on Energy Conservation in Civil Buildings* further details the law for residential buildings, and MOHURD has been actively revising the accompanying *Design Standard for Energy Efficiency in Residential Buildings* to provide clear guidance to design firms and developers on how to conform to the law and regulation. Initially, the regulations required that buildings should consume 50% or less of the energy that a comparable building in the same climate zone would have consumed in the 1980s. Following the Beijing municipality's lead of improving the standard to a 65% minimum reduction in building operational energy (which has been further improved to a 75% minimum in late 2011), most cities claim to exceed the building energy efficiency requirements.

The *Energy Conservation Law* and the *Regulation* outlines a top-down system of accountability and enforcement, which has been implemented as follows. The local construction bureau—not the urban planning bureau—initially reviews the building plans for compliance with the energy efficiency standards, and an approved building energy consultant (usually national or provincial design institutes) conducts an independent review of the standardized checklist of each building wall section component's thermal performance. Construction site inspectors follow up to ensure compliance with the approved building envelope materials. New construction projects reached a nationwide compliance rate of 80% by 2008, but this rate varies substantially by local jurisdiction (Ni 2011).

#### **2.4.6 Renewable Energy in Buildings**

According to the 2005 *Renewable Energy Law*, updated in 2009, developers are required to consider on-site renewable power generation for buildings, including solar thermal and PV, ‘where applicable’. In contrast to the *Energy Conservation Law*, a national chain of implementation and enforcement has not yet been created. Although numerous smaller cities have successfully enforced this requirement for residential solar thermal panels, Beijing is the first major city to set the precedent of requiring developers to make the initial capital investment for a complete solar water heating system. This regulation was only recently announced by the Municipal Commission of Housing and Urban Rural Development, in December 2011.



### 3 Neighborhoods and Energy: A Life Cycle Approach

What and how we build not only consumes energy today, but also will affect people's behavior and use of energy in their daily lives for decades, even centuries into the future. Once built, the physical form of a city is almost impossible to change. This chapter explores the relationships between neighborhood form and energy utilization over time. As urbanization accelerates in China, it will be increasingly important to understand these relationships to create tools by which neighborhood energy consumption may be measured and policy to encourage more enlightened design and development.

#### 3.1 How Does a Neighborhood Consume Energy?

The ways in which residential neighborhoods consume energy are numerous and complex. Life-Cycle Assessment (LCA) offers a commonly used framework to understand and quantify energy consumption. Through identifying the myriad environmental impacts of a service or product over the course of its entire usable life, LCA is employed to evaluate potential ways of minimizing these environmental impacts (ISO 2006).

LCA has been frequently used for estimating the energy consumption and greenhouse gas emissions (GHG) of individual dwellings (Buchanan and Honey 1994; Adalberth 1997a; Fay et al. 2000; Chen et al. 2001; Norman et al. 2006; Duffy 2009; Aden et al. 2010). However, in this research we seek to understand the life-cycle performance of residential *neighborhoods*, arguing that these are the driving force behind urban development and the major contributor to energy consumption in cities. Due to the complexity of urban neighborhoods – that include multiple buildings that interact with each other, the sites and spaces between them, movement networks and modes, and a whole range of activities -- a number of life cycles must be considered at the neighborhood scale. Hence, the scope of the LCA must incorporate multiple dimensions.

In considering *how* residential neighborhoods consume energy, one could generalize that total energy use derives from household activities, both *in-home* and *out-of-home*. Essentially, households, living in a neighborhood, aim to maximize their quality of life, given their capabilities. Or, more formally, households choose their daily in-home activities (e.g., eating, sleeping, watching TV) and out-of-home activities (e.g. going to work, attending school, entertainment) to maximize their utility subject to time, money, physical and other constraints. These activities result in energy consumption. In addition, households implicitly consume energy “embodied” in the materials of the physical structures they inhabit and utilize– that is, the energy invested in constructing the physical spaces we inhabit and physical infrastructure we use.

Therefore, a simplified LCA scope of a neighborhood may partition into four dimensions:

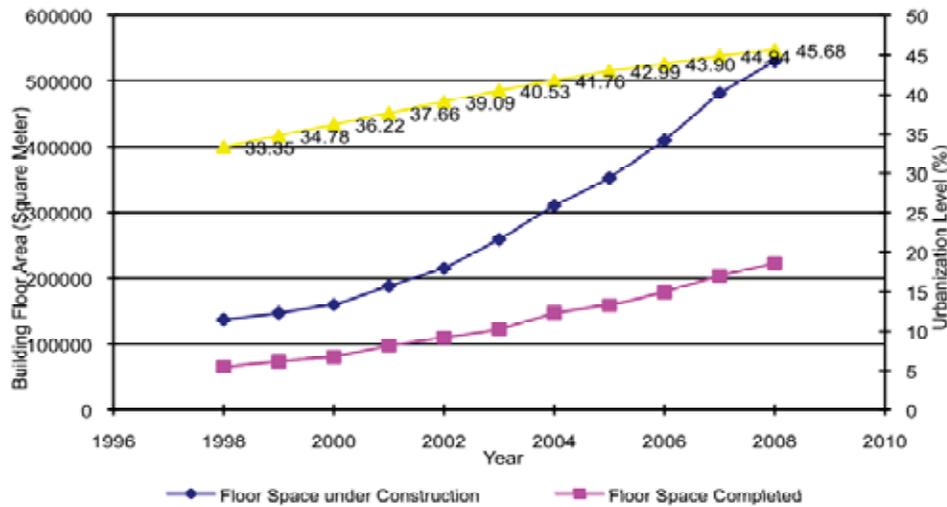
1. ***Embodied energy use*** – The total energy used in manufacturing construction materials, transporting materials to and processing them at the construction site; this includes not only buildings, but also site improvements, from earth moving to drainage, paving, and site structures.
2. ***Operational energy use*** – The energy consumed to maintain the operations and daily-life-supporting functions of the neighborhood, including residential units as well as common areas of buildings and the public realm.
3. ***Transportation energy use*** – The energy consumed in travel by households in the neighborhood to meet their daily needs.
4. ***On-site renewable energy production*** – In measuring these flows of energy consumption in a neighborhood, an LCA can also take into account new stocks of energy produced on-site. The potential of a neighborhood to accommodate renewable energy is largely a function of its form. Photovoltaic panels require solar oriented surfaces, wind needs high buildings, and geothermal wells require open space. While on-site renewable generation may not reduce total energy consumption per se, it does reduce the total GHG emissions from that consumption by replacing fossil fuel energy with cleaner sources.

While these factors apply to all urban environments including residential, commercial or industrial sites, for the purpose of this research, we will focus primarily on energy consumed in urban residential neighborhoods, since neighborhoods are fundamental unit of urban form, encompassing a large portion of any city, and because residential development drives urbanization. General conditions affecting each of these dimensions of energy consumption are discussed below, focusing on China. For each, we also discuss how the physical form of neighborhoods – their design and composition of uses, may affect energy use.

### **3.2 Urbanization and Energy Consumption in China**

Urbanization has emerged a major and growing determinant of energy consumption in China (McKinsey, 2009). Over the past two decades, the percentage of the population living in cities has grown from 26% to 47%, and this growth is projected to continue by at least 1% per year over the next twenty years (McKinsey, 2009) (see **Figure 3-1**).

**Figure 3-1. China Urbanization Rate and Building Area Increase**



Source: China Statistic Yearbook 2009.

To illustrate the dimensions of this change, by the end of 2007, the urban road area per capita and the urban residential area per capita reached 11 square meters and 28 square meters respectively, which is 3 times and 4 times of the levels in 1980 (RCSD, 2007).

### 3.2.1 Embodied Energy

It is no surprise that the energy consumed by the construction of this amount of development has been growing much faster than other sectors of the economy. From 1998 to 2007, construction energy consumption increased by an annual rate of 11.93%, growing 5% greater than the total energy growth rate in other sectors of the economy.<sup>1</sup> This does not take into account the vast energy needed to mine, process, and make the materials utilized.

Activities of manufacturing construction materials such as concrete, cement, steel, brick and glass are highly energy intensive (Huang and Hsu, 2003). In Australia, for example, the construction sector accounted for 10-20% of the nation’s primary energy consumption and greenhouse gas emissions during the 1990s (Ballinger et al. 1995; Treloar 1996). Such relationship has been particularly significant in China. Peters and his colleagues (2007) found that 712 million metric tons increase in CO<sub>2</sub> emissions from capital investment is responsible for 52% of China’s total CO<sub>2</sub> emissions in 2002, and that 78% of such increase was due to construction. Similarly, the study of Chang et al. (2011) found that embodied energy in construction projects accounts for nearly 30% of the total energy consumption in China.

<sup>1</sup> The economy of China is divided into three industries in statistic record, which are: agriculture, industry and tertiary sector. Industry, includes: mining and quarrying, manufacturing, electricity power generation and construction.

A major driver of these emissions is the use of cement - the most widely-used building material in China. Its production is highly energy intensive because clinker, an important component, is made in kilns heated to 1450 degrees C. China is the world's largest producer of cement with production of 1,330 million metric tons (Mt) in 2007 (LBL-CEG, 2010). While urbanization has driven this demand, so have Chinese construction techniques, which use much more concrete per square meter of building than in developed countries. In total, the energy consumption for producing building material accounts for over 16% of the total energy consumption.

By 2030, the urban population in China is projected to reach one billion (McKinsey, 2009). To cope with such a massive increase in urban population, China will need to construct 1.6 to 2 billion square meters of building area per year, so that the total increase of new construction over the next ten years will reach 20 billion square meters (Deqi, 2010). Energy consumed through building construction will pass one billion tons SCE<sup>2</sup>. In addition to new buildings there will also be thousands of miles of new roads and up to 170 new mass-transit systems, compared to 70 in Europe (McKinsey, 2009). As urbanization progresses, embodied energy consumption and related GHG emissions will continue to increase.

### 3.2.2 *Operational Energy*

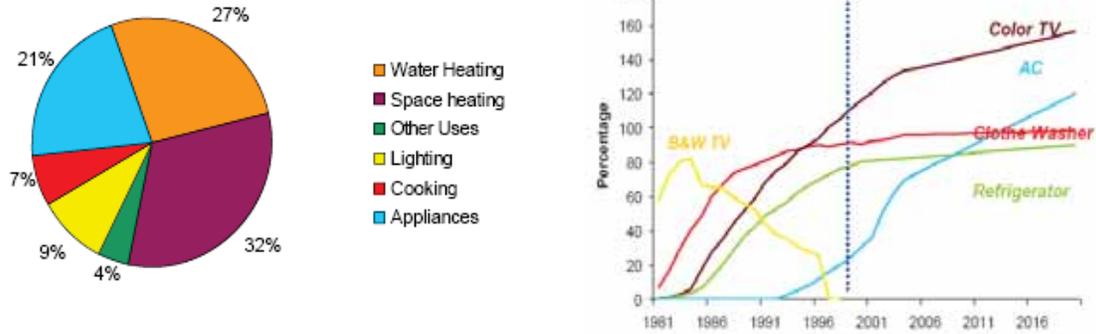
Energy consumed in the daily use and operation of buildings and neighborhoods also has been rising dramatically in China. This is a factor not only of urbanization, but also people's rising standard of living fueling a demand for more and higher quality living space space per household. . The residential sector has become the second largest energy-consuming sector following industry, contributing over 11% of the total energy consumption in 2006, and rising by 4.1% per annum (RCSA, 2007). Urban areas and regions are responsible for the majority of this increase. Urban residents consume 2.5 times more energy than rural residents, accounting for 60.5% of total residential energy end-use. As the urban population increases in the future years, residential energy consumption will continue to go up. Meanwhile, due to the geographic climate differences, in the northern regions of China, where our case city of Jinan is located, energy intensity is much higher.

For Chinese households, activities such as water and space heating are the dominant energy-consuming end uses, with 79% of total in-home energy directly or indirectly powered by coal (Zhou et al. 2009) (**Figure 3-2**). From the home appliance perspective, Zhou also predicts that the driving force of increased household energy consumption in the future will be air conditioners, the numbers of which are expected to rise dramatically compared to other appliances. Here, the form of a neighborhood, with regard to sun exposure and cooling winds, could dramatically affect demands for air conditioning.

---

<sup>2</sup> The Building-relative Energy Consumption Has Accounted for Over 46% in total. (2007). From <http://news.sina.com.cn/c/2007-10-29/001514181433.shtml>

**Figure 3-2. A) End-use Energy Share of Chinese Households; B) Appliance Ownership Projection of Chinese Households**

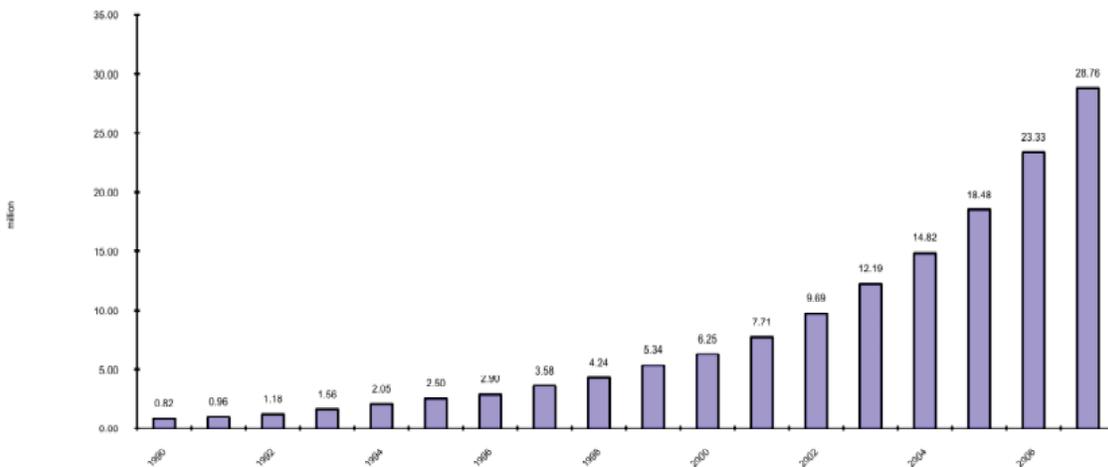


Source: Zhou et al. LBNL, 2009

### 3.2.3 Transportation Energy

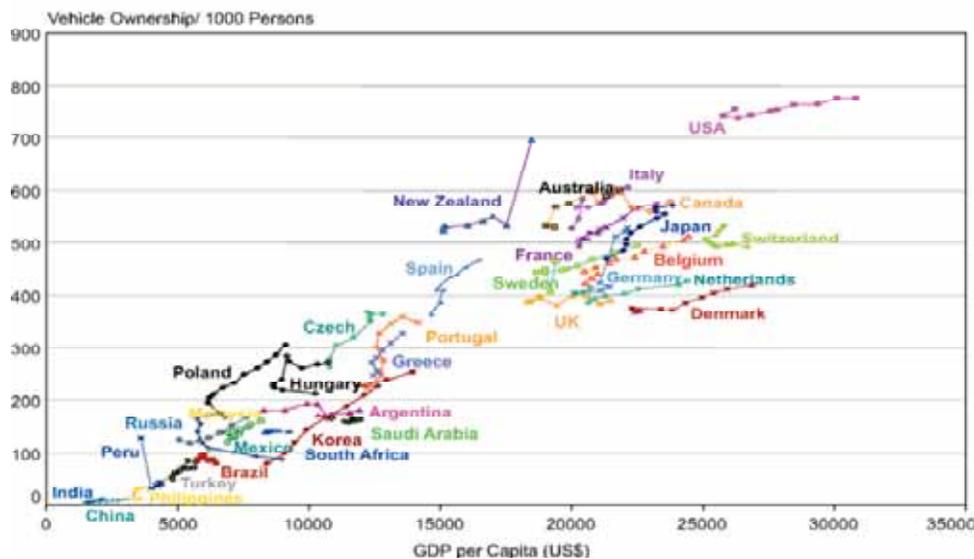
Another significant trend accompanying urbanization and driving up energy consumption in China is the popularization of private cars, along with the kinds of urban environments that support them. As shown in **Figure 3-3**, the total number of vehicles in China is approaching 30 million, an increase of 35 times over 20 years. These vehicles are concentrated in primary cities such as Beijing, where the car ownership has reached 30%. In Jinan, our case city, car ownership is over 15% and growing, in part because of rising living standards.

**Figure 3-3. Increase in Private Cars in China: 1990 – 2007**



Source: China Statistic Yearbook 2009

**Figure 3-4. Vehicle ownership as a function of per capita income**



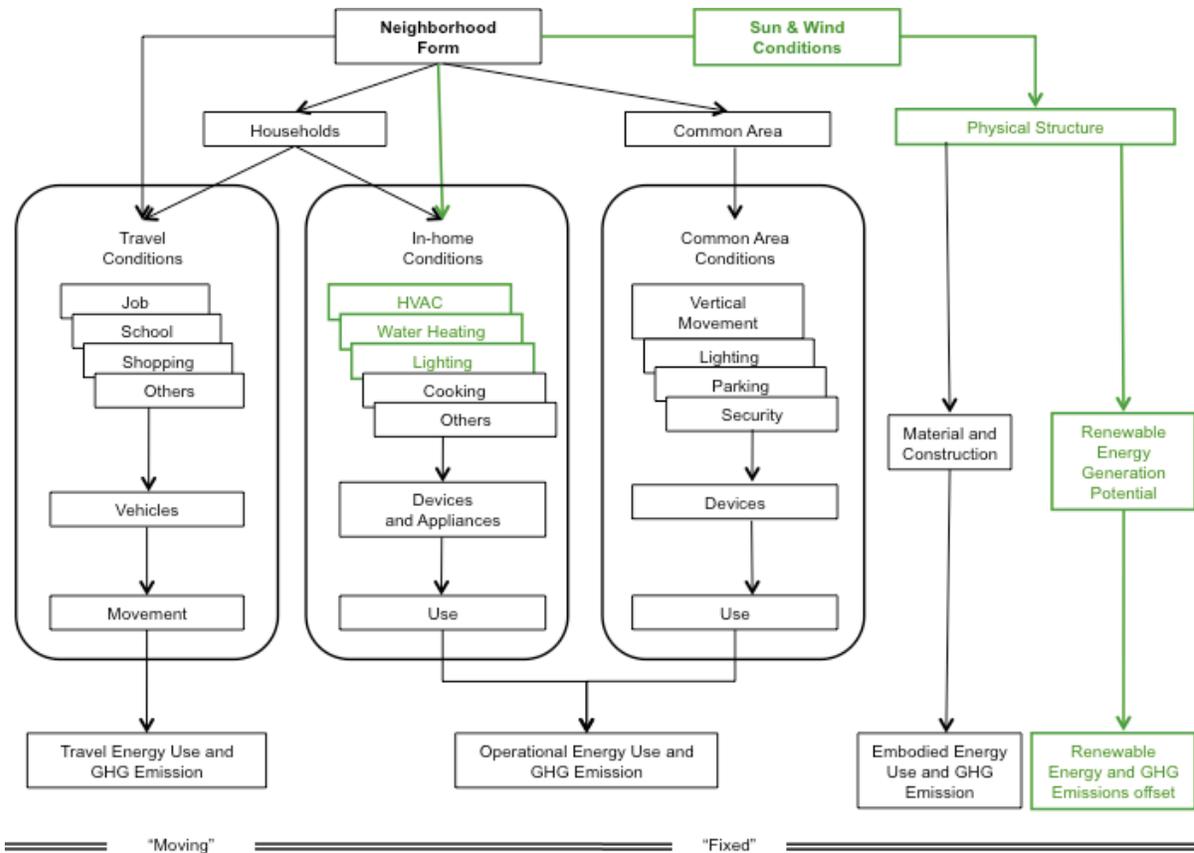
Source: IPCC Fourth Assessment Report: Climate Change 2007

An underlying contributor to the increase in private cars is the recent change in urban development patterns designed to accommodate exponential growth. Vast new urban areas are being designed – by policy – to separate different functions from one another, resulting, for example, in suburban housing districts with no jobs nearby, shopping centers removed from residences, and poor access to public transportation. These patterns of growth virtually require families to own a car to carry out the daily functions of life, and so in the next twenty years, the vehicle fleet in China is projected to grow ten-fold. Once built, these patterns of urban form and lifestyle will be almost impossible to change. So, to achieve low-carbon travel in cities, more efficient forms of urban development that reduce reliance on the car will be essential.

### 3.3 Why Does Neighborhood Form Matter?

As shown in this the work of this study, urban form – by which we mean the design and arrangement of buildings, spaces, uses, and infrastructure in a neighborhood – influences all four dimensions of residential energy use and GHG emissions. The key relationships are represented conceptually in **Figure 3-5** and described in detail in the sections below.

Figure 3-5. Conceptual Framework: Neighborhood Form and Energy Consumption



### 3.3.1 Embodied Energy

As we have seen, the scope of activities considered in a LCA of the embodied energy in a neighborhood can range from energy consumed in the manufacturing process of construction materials to the energy consumed in transporting them to the site, and processing the materials into finished buildings and site features. It may also include site improvements such as earthmoving and excavation.

Many studies of embodied energy in the literature focus on only buildings, including LCA study of: 1) Building material production processes; and 2) building construction processes (Ortiz et al. 2009). As an example of the former case, Buchanan and Honey’s (1994) analysis of embodied energy required to construct buildings includes energy consumed for manufacturing the construction materials but not the energy consumed in transporting the materials or constructing the building. Conversely Adalberth’s (1997) analysis has much broader scope and subsystem boundary. He estimated energy consumed during “all temporal phases or stages, from the point where the construction materials are produced until the building is to be demolished.” Similarly, Chen et al.

(2001) developed an LCA model that has three sub-systems: energy used for building materials, energy required for transporting the materials, and energy use in various processes of construction at the site.

While a host of literature suggests that urban development and embodied energy consumption are related, the detailed picture of how they may be related is not crystalized. Therefore, key questions are: Is the embodied energy consumption affected by various forms of urban development and if so, how? Why are some neighborhood typologies less or more energy intensive than others? Several hypotheses emerge regarding these inquiries. The most obvious is that larger amount of embodied energy may be associated with higher levels of density. The underlying assumption here is that more building materials are required to enclose and support a greater amount of activity – or floor space – on a given unit of property; thus, the higher the floor area ratio (FAR) of a neighborhood, the greater the embodied energy. Another hypothesis relates to the form or compactness of the neighborhood. In this case, buildings which are clustered more tightly together – requiring fewer exterior walls or roofs to enclose the same amount of space would presumably use less material (at least less structural material) and have lower embodied energy. Finally, there is the issue of height – and depth. Taller buildings require deeper foundations and basements and stronger frames to resist compression and wind loads, all requiring more materials per square foot than low-rise construction and therefore consuming more embodied energy. Furthermore, high-rise developments (particularly in China) may include parking or site modifications requiring excavation and relocation of soil, adding substantially to energy consumption.

### ***3.3.2 Operational Energy***

The operation of a neighborhood to serve human needs is the most energy-consuming phase in the life cycle. . In a building scale LCA, the operations account for 80% to 90% of building life-cycle energy consumption and greenhouse gas (GHG) emissions (Blanchard and Reppe 1998, Wang 2007, etc.). At the scale of a neighborhood, where transport energy also comes into play, operational energy consumption still significantly outweighs transportation and embodied use, accounting for 60% to 80% in total energy consumption and GHG emission (Duffy 2009, Norman et al. 2006).

The operational energy consumption of a neighborhood can be divided into two categories: in-home energy consumption of individual households and common area energy consumption. ‘In-home’ refers to energy consumed in residents’ homes from activities such as lighting, cooking, electronic appliances, and heating. ‘Common Area’ refers to the energy consumed in the operation of buildings (e.g. elevators and pumps), parking garages and public spaces (e.g. lighting) in the neighborhood at large.

At the household level, neighborhood form affects energy demand by modifying the need for in-home and common area “services” such as climate control (e.g. HVAC) or lighting. For example, some neighborhood forms enable more natural lighting or ventilation than others, thereby decreasing household energy demand. Therefore,

neighborhood form can affect households' choice in two ways: both the number and types of 'in-home' equipment to install, as well as how often and how intensively to use that equipment.

Solar radiation and wind flow are also major determinants of operational energy use, as they impact indoor and outdoor temperature, lighting conditions, heat transfer and ventilation. The relative impact of wind and solar radiation is dependent on the geometric configuration of the built environment. An appropriate configuration of buildings can increase the potential for cooling convection from wind, which can decrease cooling energy load in the summer. Conversely, a poorly designed configuration could inhibit wind flow into the fabric, and potentially increase urban heat island effects, increasing in the cooling energy load in summer. Site configurations that leave buildings exposed to cold winter winds can increase heating energy loads, caused by air leakage through windows and other façade openings.. Wind flow also decreases the R-value of facades air film, contributing to heat loss and greater energy use in winter. Meanwhile, solar radiation absorbed by building surfaces or through windows can add beneficial heat gain in the winter, while shading from other buildings or façade elements can reduce heat gain in the summer. The combination of all these physical form characteristics can significantly affect total energy consumption.

Note that there are many theories for energy efficient design as well as computational simulation tools for solar radiation and wind flow. (T.J. Chandler, Gideon Golan, T.R. Oke, Victor and Aladar Olgyay, and Baruch Givoni Nick Baker and Koen Steemers, Joseph Clarke, Nick Baker and Koen Steemers). However, almost all of these focus on the performance of individual buildings in isolation, rather than the interplay among multiple buildings at the neighborhood scale. They also stop short of quantifying the extent to which specific design properties potentially impact energy use. Only a slim body of work has been dedicated to this topic and from an engineering perspective (Alberto Martilli, Yasunobu Ashie). Therefore this research also seeks to measure the relationship of the geometric properties of neighborhoods to: 1) their shading and ventilation conditions, and 2) solar gain and wind flow and furthermore, to understand effects of these properties on operational energy use. This pioneering area of the research is detailed in **Chapter 8**.

Lastly, urban form can impact energy consumption at the neighborhood scale through density and how it is configured. Norman et al. (2006) conducted LCA on two residential developments of different density in Toronto, and found that the high-density case consumed less than half of the operational energy and produced half GHG compared to the low-density case. The research of Duffy (2009) in Dublin also found that high-density apartments consumed much less operational energy compared to detached and semi-detached residential types. Stone et al. (2001) examined the impact of residential density on urban heat island formation in Atlanta, and found that low density development contributed more radiant heat energy to surface heat island formation than high density development. Ewing et al. (2008) emphasized the relationship between urban form and

people's housing choice in US, and found that households in sprawling regions are more likely to live in large-size single houses thus consume more operational energy than those in more compact, urbanized regions. Most research in this field reaches identical conclusion that higher-density, more compact residential development is more favorable with regard to energy savings and GHG reduction.

It should be noted, however, that energy savings from higher density development does not necessarily translate into taller buildings. As buildings increase in height, other operational factors come into play such as increased use of elevators and water pumps. Therefore, high-density, lower-rise neighborhoods may offer the greatest opportunity for operational energy savings.

### 3.3.3 *Transportation Energy*

Relationships between land use, neighborhood configurations, and travel behavior is a relatively new but increasingly well-documented area of study. In sum, neighborhood form can influence both travel costs (“disutility”) and potential activity realization benefits (“utility”) of travel (Maat, *et al.*, 2005). Such “net” effects on travel behavior impact perceived attractiveness of varying transportation modes and in the long-term affect vehicle ownership decisions, such as the number and type of bicycles or cars, which a household will acquire.

For example, mixed land uses or conveniently located services make destinations closer to each other thereby shortening travel distances and reducing energy consumption and emissions per trip. The shortening of trip distances also makes walking and non-motorized modes more attractive. People may therefore change their travel behavior and walk or bicycle rather than ride, further reducing energy consumption and emissions. Dense and well-connected road/transit networks also make travel distances shorter, while making walking, non-motorized transport, and mass transit easier and more attractive. Facilities and urban design features that support non-motorized transport modes -- such as sidewalks, cul-de-sacs, and trees, also make walking and non-motorized transport more attractive. Similarly, features that restrict car usage, such as parking and traffic calming designs, make driving less attractive and other modes more attractive.

A key element of this research was to test whether these claims hold in an empirical context like Jinan. To understand this, we quantified an array of urban form indicators to represent urban design features such as: Residential density, average building height, land use mix, building coverage, building function mix, parking provision, average distance between neighborhood entries, tree coverage, and number of public transit lines, and then evaluated the magnitude of their effect on travel energy consumption and GHG emissions.

### 3.3.4 *Renewable Energy*

A clean energy urban form should be more than energy-efficient. It should be productive. It should facilitate the potential for renewable energy production on site. Such energy sources not only reduce the need for fossil fuels, but reduce the loss of energy which occurs when it is transmitted over long distances from centralized power-plants. To date, most studies and projects for on-site renewable energy focus on how to add panels and windmills onto existing buildings which may or may not be suited to them. However, neighborhoods can be designed from the beginning to either include or have the potential to include solar hot water, photo-voltaics, wind, or geothermal power. To understand the critical factors of form that will maximize this potential is a key element of this research. Encouraging these characteristics in development could provide an entirely new framework for designing sustainable neighborhoods.

Just as neighborhoods can be designed to take advantage of natural lighting and heating from the sun, and ventilation and cooling from wind, so too can they be designed to take advantage of sun and wind to produce energy. Renewable energy production creates, in a sense, a new function for urban form, requiring: 1) physical space for installation, and 2) particular characteristics of building height, spacing, surface angles, and orientation to maximize energy production.

For simplicity, this research explores the potential of incorporating characteristics that will maximize photovoltaic and wind power, only, assuming that that one unit of onsite renewable electricity offsets one unit of grid-based electricity.. The aim is to measure and rate the potential of various neighborhood designs to accommodate these renewable energy sources, as part of the overall clean energy assessment. We hypothesize, first, that many of the moves designed to increase sun and wind savings to operational energy, will also facilitate renewable energy production, multiplying the benefits of particular urban forms; and second, that different neighborhood forms will have different renewable energy potential at the same location. In Jinan, for example, low-rise, high-density neighborhoods with large roof areas will have higher energy potential than high-rise towers. Finally, on a broader scale, the urban design of a city affects its potential to incorporate renewable sources in a way that is predictable and quantifiable.

## 3.4 Conclusion

While we can hypothesize the relationship between individual form characteristics and neighborhood energy consumption, the totality of energy consumed by a neighborhood is the resultant of complex and technical and behavioral variables. Sometimes the results of changing the form may be counterintuitive as impacts ripple through the system. For example, we may design a neighborhood to promote more walking among its residents by reducing travel distances through increased density and land use mix. In this neighborhood, residents may indeed walk more, but we can't know whether they will

drive more or less. Total travel demand would *increase*, for example, if individuals use the saved time/money to travel to more distant destinations and/or “do more things.”

Nevertheless, it is clear from the above analysis that there are a multitude of strong connections between neighborhood form and energy use. Many of these – the energy embodied in construction, the effects of sun and wind, potentials for renewable production, and the operational impacts of height and density are not related to behavior. Those relationships that are related to behavior can best be understood through empirical study of how existing neighborhood forms consume energy in a particular context. This highlights the importance of the empirical study, described in **Chapters 4 - 9**, that we have done in Jinan to provide the base data for evaluating the performance of new neighborhoods. Accelerating urbanization in China, and the growing proportion of energy being consumed by development, underscores the need to understand these relationships so that we may devise more efficient forms of neighborhoods and cities.

## **Section II**

### **The Case of Jinan, China**



## 4 The Evolution of Urban Development of Jinan

The city of Jinan, capital of Shandong Province was chosen as the demonstration city for our study of the relationship between neighborhood urban form and energy use. There were several reasons for this selection. First, Jinan is an important city experiencing rapid urbanization typical of many locations in China; in particular a planned new expansion of the city around the Jinan West high-speed Rail station, provided an opportunity to investigate the design of new forms of clean energy neighborhoods. Secondly, Jinan has a very clear structure of neighborhood form, reflecting distinct periods of China's residential development; in fact the entire city may be classified into four distinctive form types, that we discuss in detail later in **Chapters 4-5**. This provides a perfect laboratory for studying the relationship between energy consumption and urban form. Finally, the Jinan planning department, city administration, and Shandong University have been very supportive of our research, for which we owe them a great deal of thanks.

### 4.1 Context

Located in the heart of Shandong province Jinan, is one of 15 provincial capitals in China (**Figure 4-1**), with jurisdiction over an area of 8177 sq. kilometers. Just over half the population, around 3.4 million, lives in six city proper districts (Jinan Statistical Yearbook, 2011). A typical medium-sized Chinese city, Jinan has a much smaller urban population and density than tier 1 cities such as Beijing, Guangzhou, and Shanghai. The

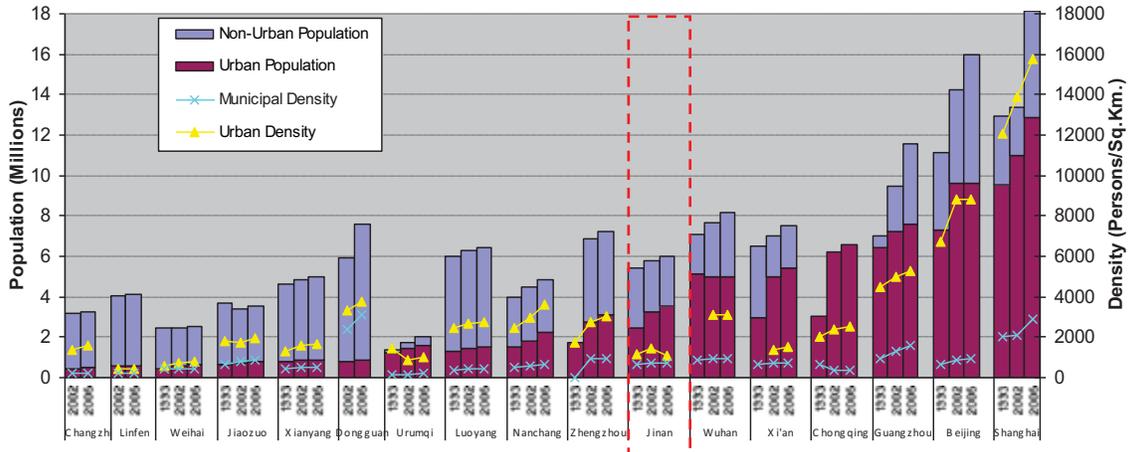
**Figure 4-1. Location of Jinan, Shandong Province**



Source: Asia Times, 2005

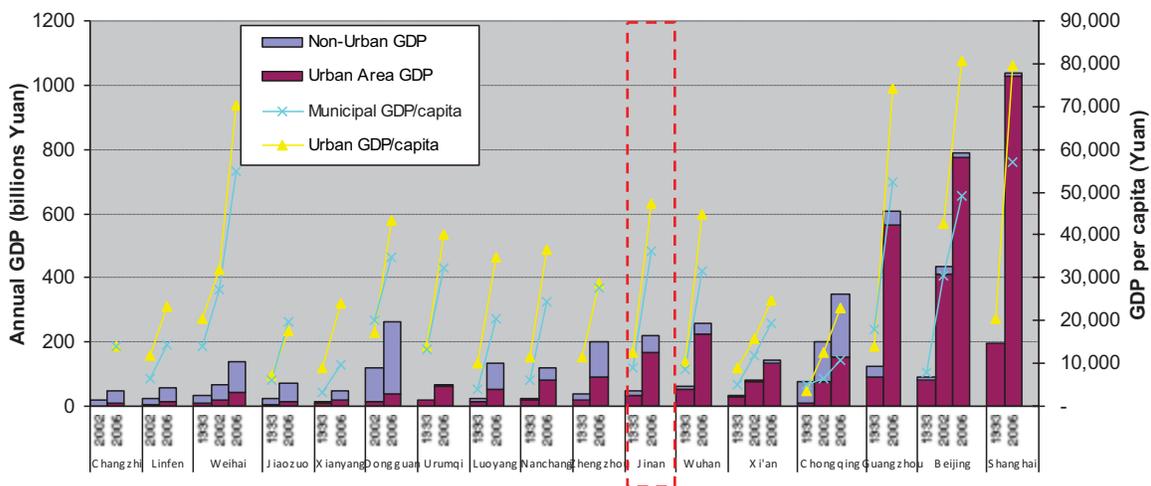
city's urban density is modest even by many tier 2 cities (Figure 4-2). In recent years, Jinan's economy has grown markedly, as much of the rest of China. While only about half as wealthy as the large Chinese cities, Jinan is among the wealthier tier 2 cities, with a GDP per capita in 2011 of approximately US\$9,960<sup>1</sup> (Figure 4-3)

Figure 4-2. Population Trends in Chinese Cities



Source: Darido, et al. (2009)

Figure 4-3. Economic Trends in Chinese Cities



<sup>1</sup> Jinan Statistical Bureau, March 2012

## 4.2 Development of Jinan's Neighborhoods

### 4.2.1 Early History

The city of Jinan was founded south of the Yellow River. Though human settlement in Jinan goes back over 2,000 years, the old city expanded very slowly – its area only increased from 0.64km<sup>2</sup> to 2.4km<sup>2</sup> in the 2000 years before the Qing Dynasty.

During this period, residential buildings were constructed in the traditional northern courtyard house style, just as in Beijing (**Figure 4-4A**). However, unlike Beijing, most of the courtyard houses in Jinan take a simpler form with only one courtyard. In many commercial streets in the old city, the gates of the courtyard houses were built for commercial use. The water supply was supported by the rich spring waters of Jinan. One still finds springs and wells in almost every courtyard in the old city neighborhood. However, the vast majority of traditional courtyard housing has been destroyed over the past several decades; only a few hutongs remain at the center of the old city.

**Figure 4-4. A) Traditional Courtyard**



Source: photos by Tsinghua University

**B) Western-style Building**



Source: photos by Tsinghua University

### 4.2.2 1904–1948

Western countries and Japan colonized Jinan from 1904 to 1948. During this period several plans promoted the city's expansion. The most important established a new, early modern commercial and residential area near the new train station. The station opened in 1904 to serve the city's first line and main transit corridor, Jiaoji, which connected Jinan to the eastern port city of Qingdao, and subsequently to Beijing. The new district, designed using a conventional western grid, developed quickly and consequently formed a virtual new town to the west of the old city.

Within the “grid district”, this period saw the emergence of buildings drawing architectural elements from both western and traditional Chinese styles (**Figure 4-4B**).

These buildings hosted foreign firms, international consulates and homes for bankers, officials, merchants and missionaries. Many were villas in rectangular form, occupying larger tracts of land than conventional Chinese courtyard homes with ornate landscaping. The grid district with its western style architecture still survives in Jinan, although it has become home to a wide variety of additional housing types, as well.

#### 4.2.3 1949-1977

After the foundation of the People’s Republic of China, Jinan grew quickly. The old city and the early modern, gridded city continued to expand, eventually merging. Meanwhile, the government focused on developing industrial areas outside the city and satellite residential communities slowly emerged to support those activities (**Figure 4-5**). This urban growth was supported by the Jiaoji rail line and expansion of Jinan’s railroad system to Tianjin in the north and Jiangsu Province in the south.

**Figure 4-5. Jinan’s Land Use Change from 1948 to 1977**

**A) Jinan Land Use in 1948**

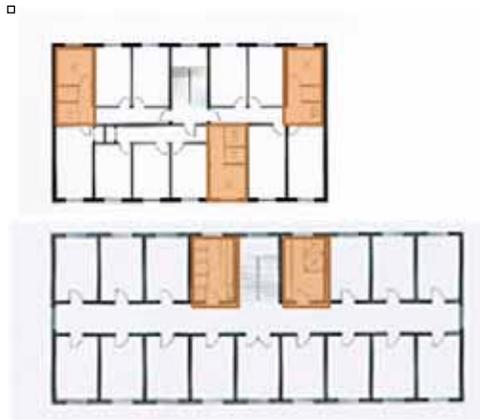


**B) Jinan Land Use in 1977**



Source: Based on 2006-2020 Jinan Central City Master Plan and 1977 Jinan Central City Land Status Map (Xibo Wang, 2003)

In addition to worker housing built near the new factories, other residential buildings were constructed in underutilized spaces in the center city. Meanwhile, many formerly decrepit houses along the railways and main roads were rebuilt. Residential buildings constructed during this period were generally influenced by residential design in the Soviet Union. Long double-loaded corridor buildings of three to four floors with shared bathrooms and kitchens were typical. Kindergarten, elementary schools, middle schools and commercial service facilities were also built into the residential districts (**Figure 4-6**). Substandard from the beginning, almost none of this housing survives in the city.

**Figure 4-6. Typical Building Form built in 1949-1977 in Jinan****A) Typical Building Plan**Source: *Urban Housing in China 1840-2000***B) Typical Building Photo**

Source: photo by Tsinghua University

**4.2.4 1978-1995**

Starting from the re-opening of China in 1978, Jinan developed at a much higher speed with unprecedented urban expansion. Initially, new housing construction occurred mainly in and around the original old city; these development projects were integrated with urban renewal -- clearing the old hutongs -- to improve the living conditions of low-income residents in the center city. Government-led housing developments were also launched in rural areas east and south of the city (Master and Strategy Planning of Jinan, 2002). A new technology development zone was also planned and constructed at the city's eastern edge and industrial satellite towns continued to expand.

After the reform of the housing system in the 1990s, housing construction generally fell under two categories: market rate housing to upgrade the living standards of common citizens, and affordable housing to address housing needs of low-income residents. Typical residential buildings built during this period are six stories with a single stair serving multiple housing units of diverse layout (**Figure 4-7**). Some residential projects, such as Foshanyuan, were built with independent restroom, kitchens and centralized heating system. The buildings were developed in groups forming distinct enclaves, and arranged in repetitive rows, with space for recreation, parking and storage in between and commercial shops and services on the edges, facing major streets. Hundreds of such projects were built in Jinan and they form one of the city's most prevalent neighborhood types. Over time, the simple buildings have been adapted and changed by the residents to add apartment space, amenities, and retail space on the ground level, enhancing livability.

**Figure 4-7. Typical “enclave” neighborhood form built in 1978-1995 in Jinan****A) Building Plans****B) View**

Source: Urban Housing in China 1840-2000

Source: photo by the author

**4.2.5 1995-2005**

In the two decades bookending the turn of the of the 21st century, the reform of China's housing system and a privatized housing market drove rapid urban development in Jinan. After 1995, many large-scale urban renewal projects were carried out; factories in the city center were moved out to Jinan's exurbs and their original sites were gradually converted to large residential neighborhoods. As large-scale satellite settlements and industrial development zones were constructed at the eastern edge of the city, the central city expanded eastward to meet them until both became integrated. In the southern area of the city, urban development crept all the way to the mountains. This process of rapid expansion and development of satellite towns transformed a large amount of suburban agricultural land to urban uses. Between, 1979 and 2004, the urban coverage of Jinan doubled (Fengyun Mu, et. al., 2008).<sup>2</sup>

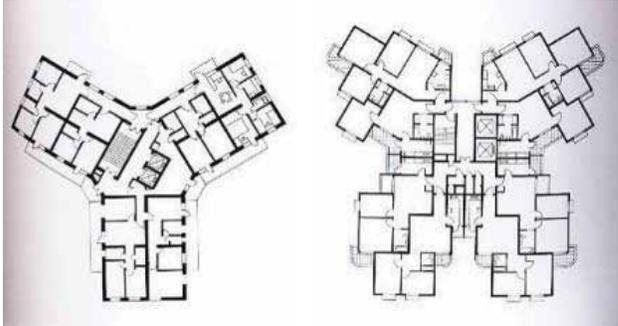
Much of this growth was facilitated by the construction of new highways between 1995 and 2000 that encircled the center city and connected it to the two industrial clusters in the east and the southwest. Between 2000 and 2010, the city undertook a comprehensive upgrade of its highways and road network, further spurring urban development and expansion.

Housing developments designed during this period in Jinan are typically between nine and twelve stories or more with ground floor commercial uses along major commercial corridors. Single, gated housing development projects can comprise a medium-to-large

<sup>2</sup> The main built-up area of Jinan City in 1979, the earliest available remote sensing data about Jinan's spatial extent, was about 96.32 km<sup>2</sup>. By 2004, the city area had reached 199.93 km<sup>2</sup> (Fengyun Mu, Zengxiang Zhang, Bin Lu, Changyou Wang, 2008).

**Figure 4-8. Typical Building Form built in 1995-2005 in Jinan**

**A) Typical Building Plan**



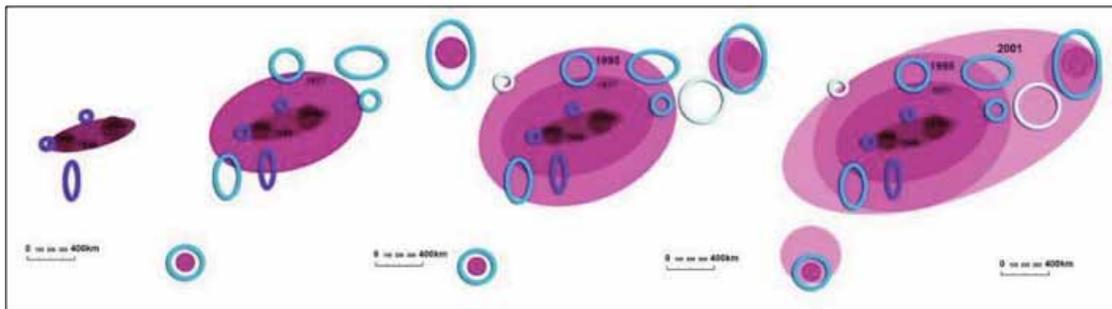
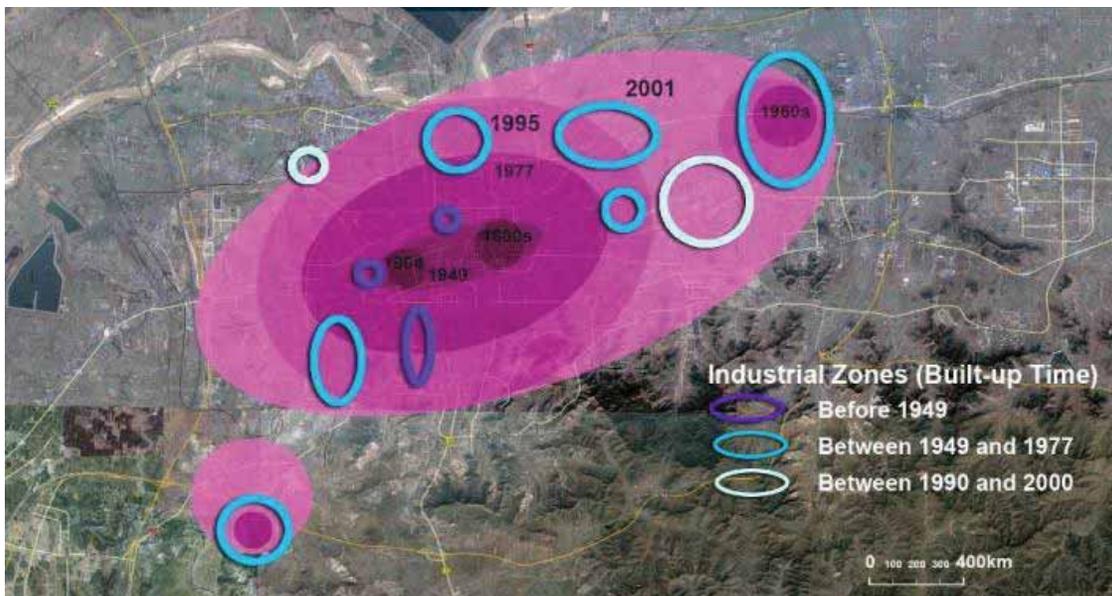
Source: Urban Housing in China 1840-2000

**B) Typical Development**



Source: photo by the authors

**Figure 4-9. Industrial Zones and Urban Growth of Jinan**



Source: Refer to Jianqiang Wang, 2004

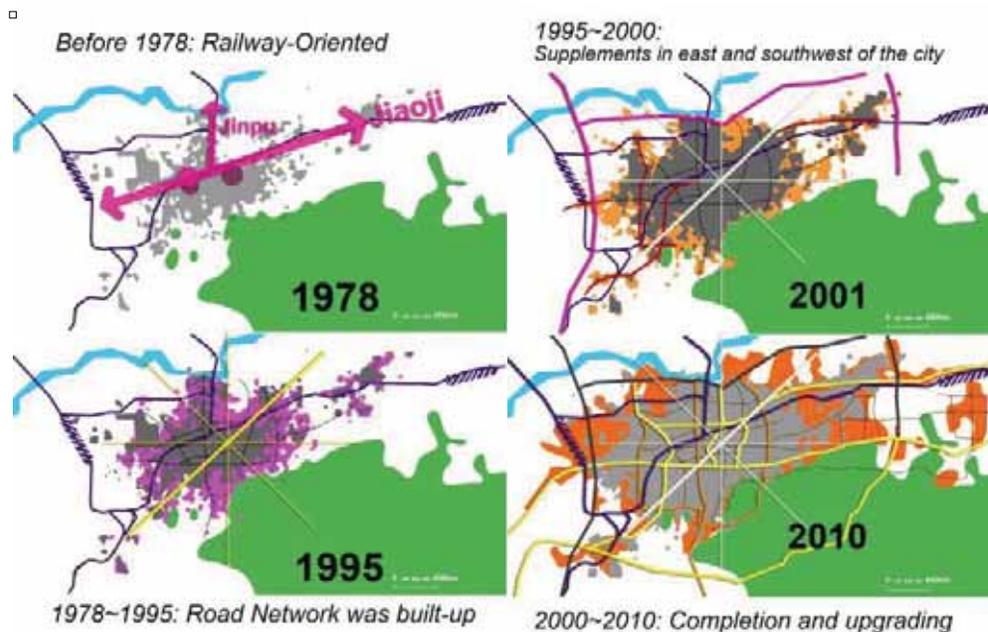
Scale neighborhood and are generally developed by a single entity (**Figure 4-8**). Most of the neighborhoods have underground parking and a few have supporting uses built into the development such as commercial and educational facilities. These high-rise superblock developments follow the modernist “tower-in-park” typology, which has become the standard for virtually all new housing in Jinan, as elsewhere in China.

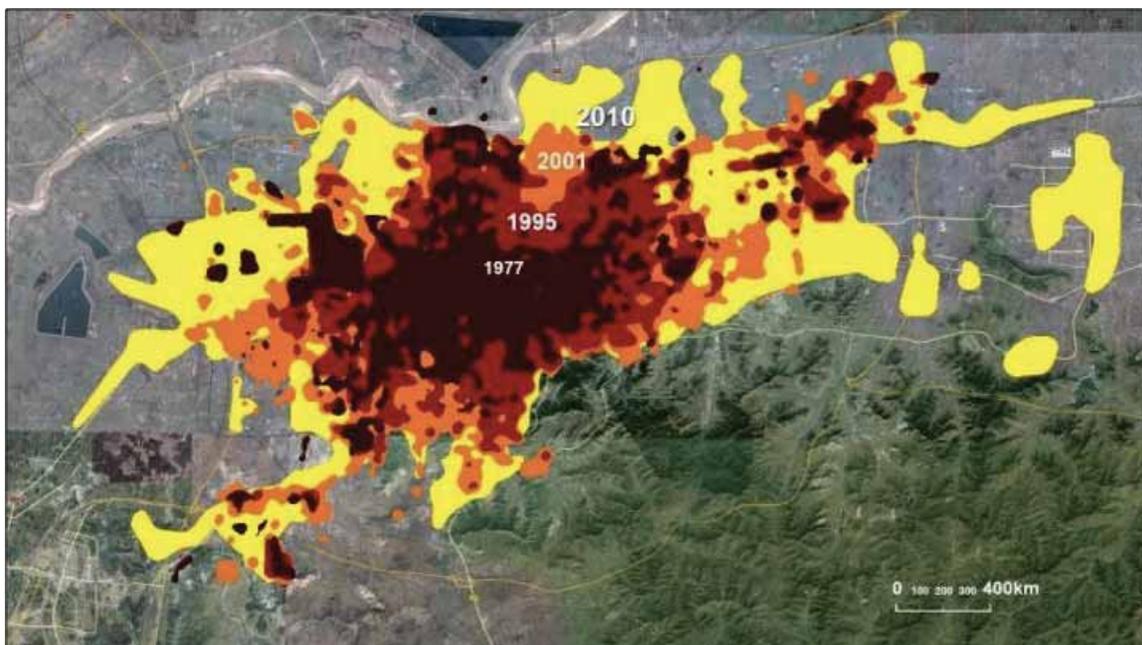
### 4.3 Patterns and Dynamics of Development

Three patterns in the growth of Jinan’s urban areas in the last century are evident. First, Jinan has generally grown in a “leap-frog” manner, in which industrial zones and new satellite towns were built outside the city, followed by expansion of both the new towns and the center city until both eventually merged (**Figure 4-9**).

Secondly, the perpetuation of this sprawling pattern of urban development can largely be traced to decision-making from central government, either by expanding Jinan’s transportation network or planning new urban areas, such as the gridded Early Modern City in 1904, the Wang Sheren industrial cluster in the 1950s, and the Dang Jiazhuang industrial cluster developed in the 1960s (**Figure 4-10, 11**). Finally, as a result of these policies and two natural latitudinal boundaries—the Mount Tai foothill to the south and the Yellow River Plain to the north – Jinan has mainly grown along a northeast-southwest axis.

**Figure 4-10. Developments in transportation and urban form of Jinan**



**Figure 4-11. Phases of Urban Growth in Jinan (1977 – 2010)**

Source: Land use map of Jinan City in 1977, 1995, 2001 and Google earth map of Jinan City in 2010

The following Chapters will provide more detail on the recent supply and demand-side dynamics underlying Jinan's growth and its physical and energy implications, including the changes in urban composition, housing typologies and transportation networks.

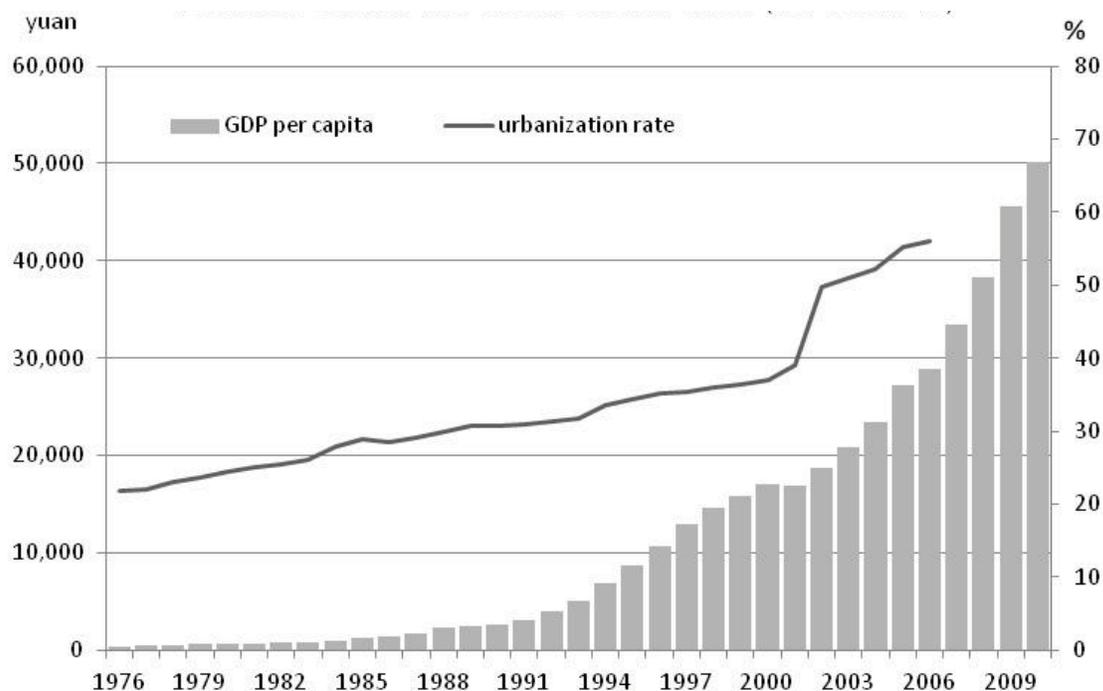


## 5 Urbanization Forces and Trends in Jinan

### 5.1 Urbanization, Motorization, Residential Development and Lifestyle Change

As described in the Chapter 4, Jinan has undergone rapid urbanization since the Reform and Opening-up of China's economy. The non-agricultural portion of the population grew from one fifth to a majority, which transformed the city physically, socially, and economically. The economy also grew rapidly, with people moving to the city for new jobs in industry and services (**Figure 5-1**). These urban households, with increasing wealth and expectations, demand more products, more living space, faster and more convenient ways to move around, and more opportunities of all types; the public and private sectors have responded with larger homes, wider roads, and more facilities.

**Figure 5-1. Economic Growth and Urbanization in Jinan (1976 to 2010)**



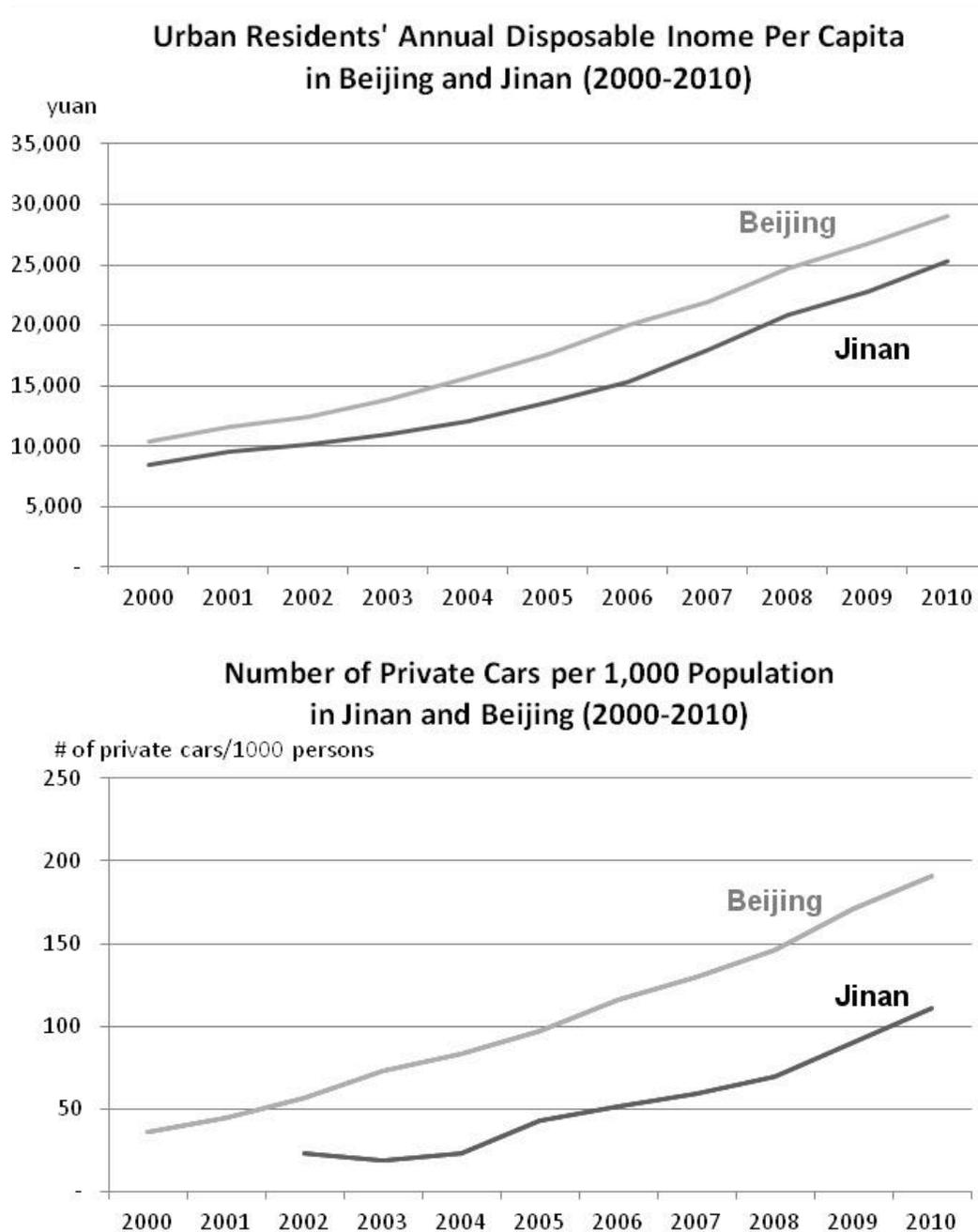
Source: Jinan Statistical Yearbook 2011

#### 5.1.1 Household Mobility

Growth in road transportation and motorization have accompanied these broader economic and urbanization trends, although automobile ownership in Jinan remains lower than in the largest Chinese cities (e.g., Beijing, Guangzhou). Jinan's household

income and auto ownership have been increasing at about the same rate as in Beijing in recent years, although income levels are about two years behind Beijing and vehicle ownership about four years behind (Figure 5-2).

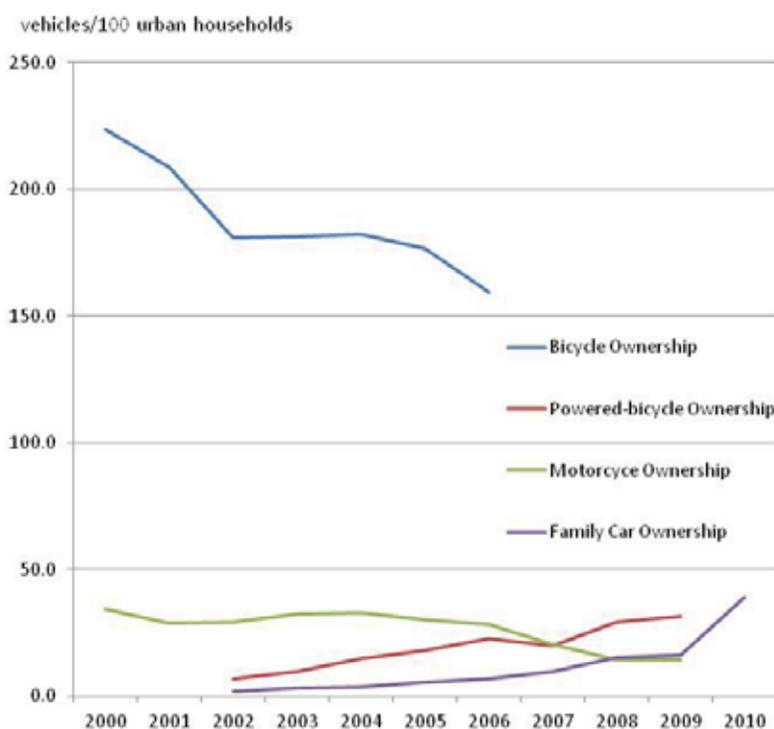
**Figure 5-2. Urban Household Income and Private car ownership in Jinan and Beijing**



Source: Jinan Statistical Yearbook 2011, Beijing Statistical Yearbook 2011

Available evidence suggests that family cars and electric-powered bicycles are taking the place of motorcycles and bicycles within urban households (**Figure 5-3**). Automobile ownership is no longer a luxury or a status symbol when nearly one in two households owns a car. Between 2005 and 2008, the average annual increase in the vehicle fleet in Jinan was about 16% (SDUTC, 2010). Interviews among Jinan households reveal the underlying decision-making dynamics.<sup>1</sup> While interviewees cited income as a major factor in the decision to purchase a car, household lifecycle and broader family and social networks also play an important role: having a child, taking kids to school, and going home for Spring Festival were cited as among the most pressing reasons for car purchase. This reveals the broader urbanization and lifestyle dynamics at work: people move to the city to find a job and raise a family, but they still have relatives (mostly parents) in rural areas. Given the limited transportation alternatives provided, owning a car becomes a necessity to maintain familial and broader social links. Even if inter-city travel is an important force driving vehicle ownership; once a household has a car, its tendency to use it for urban trips inevitably increases. In the future, both car and public transit use are expected to increase significantly (Montgomery, 2008).

**Figure 5-1. Vehicle Portfolio of Urban Household in Jinan from 2000 to 2010**



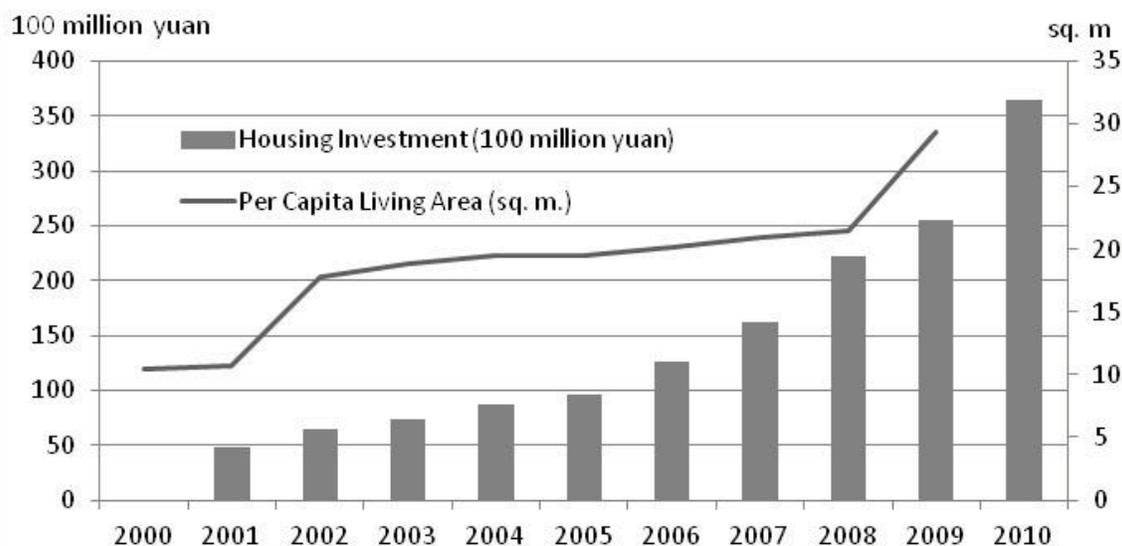
Source: Jinan Statistical Yearbooks 2001-2011

<sup>1</sup> Thirty-five families in Jinan were interviewed in March 2011 to try to understand the decision-making mechanisms of home and vehicle purchasing behavior as well as other lifestyle choices concerning energy consumption. For detailed descriptions and quotes see Appendix.

### 5.1.2 Residential Living

On the residential development front, like most large cities in China, real estate development has been extremely hot for the past decade. In less than ten years, per capita living space tripled from 10 sq. m to almost 30 sq. m (**Figure 5.4**). Despite this growth, home size remains far from what people deem as “ideal”— the household interviews<sup>2</sup> revealed that a typical family with two parents and one child considered 150 sq. m. (i.e., 50 sq. m. per person) to be large enough. Relevant demographic and lifestyle and lifecycle forces include: younger people struggling to move out of their parents’ home in order to get married or have a baby, middle-aged couples buying bigger homes so that their parents and in-laws can move in with them, and retired older generations buying new or additional homes close to their children and grandchildren. Almost all urban residents interviewed believed home ownership to be a good investment in China.

**Figure 5-4. Housing Investment and Living Area Per Capita in Jinan, 2000 – 2010**



Source: Jinan Statistical Yearbooks 2001 to 2011

### 5.2 Transportation Supply and the Composition of Residential Growth

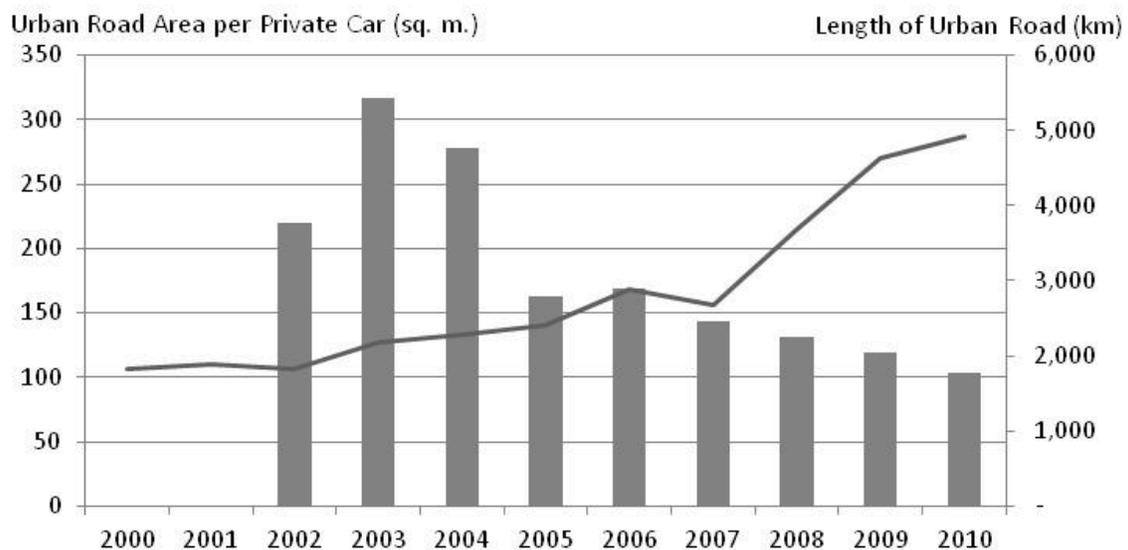
Aiming to establish a “safe, efficient, ecological and diverse” urban transportation network, the city government has set ambitious goals for 2020: more than 95% of Jinan residents will spend less than 45 minutes per trip; more than 60% will travel less than 30 minutes per trip; and the public transit mode share for trips will increase to 45% (SDUTC, 2010). Forces, possibly countervailing in the achievement of these goals, include local and regional investments in road and rail.

<sup>2</sup> See footnote 1.

**5.2.1 Road Expansion**

Jinan has been expanding its roadway infrastructure at an unprecedented pace. From 2000 to 2010, the total length of urban roads almost tripled and the total road area more than tripled. Nonetheless, private car ownership and use have grown even more rapidly. From 2003 to 2010, the average road area per private car dropped by a third, from 317 sq. m. to 103 sq. m. (Figure 5-5), leading, naturally, to increased congestion. Today, the average speed of vehicles operating on arterials in Jinan central areas is as low as 24.5 km/hr during peak-hours (SDUTC, 2010). The ongoing roadway expansion and the increasing congestion in centralized areas will further accelerate the trends of urban outgrowth.

**Figure 5-5. Length of Urban Road and Road Area Per Private Car in Jinan**



Source: Jinan Statistical Yearbooks 2001 to 2011

**5.2.2 High-Speed Rail Networks**

Another major force of growth in Jinan is the construction of the high-speed rail (HSR) network across and beyond the greater region. At the turn of the century, after the construction of the Jiao-ji Line, rail was the main transportation mode in Jinan City and subsequently guided the direction of urban development. Throughout the 20th century however, road development and use displaced rail development and use. The advent of HSR in Jinan may introduce a new urban development era, a rail-dominated age, but at a totally different speed and, thus, scale of development impact.

The Jing-Hu High-Speed Railway, which passes through the western portion of the city, began operations in 2011.<sup>3</sup> Jing-Hu line is one of the longest high-speed railways in China, and also one of the most important north-south transportation corridors in the country, linking Beijing and Shanghai. Jinan is a transfer hub at the intersection of Jing-Hu HSR and the Ji-Qing HSR (**Figure 5-6A**), which will raise the city's regional strategic importance.<sup>4</sup> As both of the HSR lines utilize the Jinan West rail station, the area around the station will likely experience increased economic activity. The Jinan West station is currently serving over 10,000 passengers every day. In its 2002 Master Plan, the Jinan Planning Bureau called for transit-oriented development (TOD) next to the Station, and massive redevelopment of the area is now underway (**Figures 5-7, 8**).

**Figure 5-6. Key Lines and Stations**

**A) Jing-Hu and Ji-Qing HSR B) Transportation Network in Jinan**



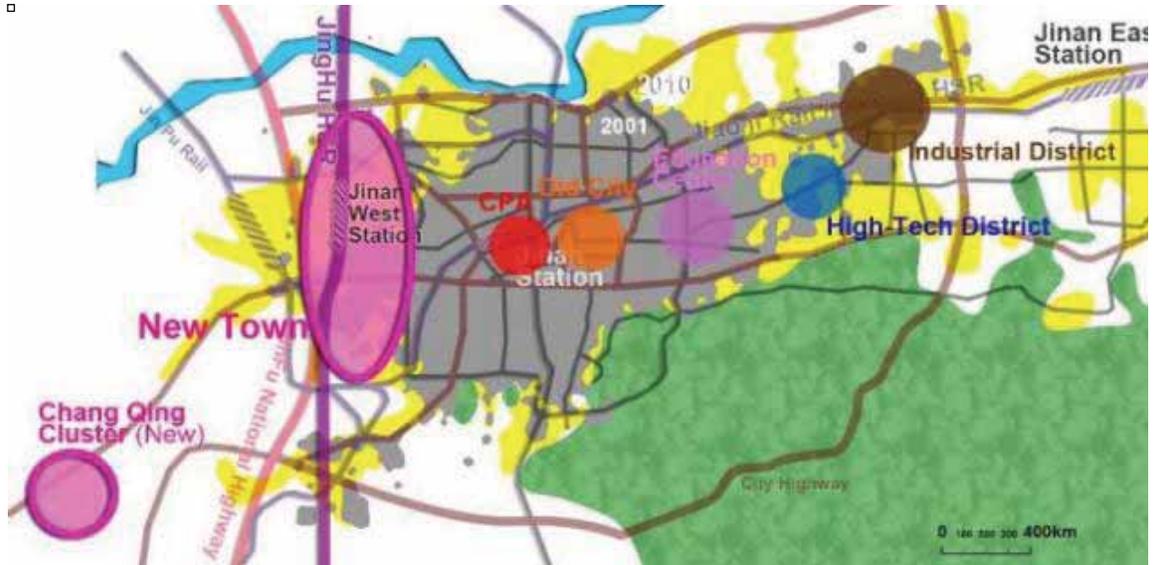
Source: Master and Strategy planning of Jinan, 2002

Although the main terminal of Ji-Qing HSR will remain at the Jinan West Railway Station, the Jinan East station now will serve some of the high-speed commuting trips between Jinan and Qingdao (**Figure 5-6B**). Although the Jinan East station has a smaller service radius, urban growth in the east side of the City will also likely be accelerated from increased travel flow. The rise of Jinan West and Jinan East means two new expansion nodes for the city (**Figure 5-9**) While the HSR stations do present important nodes of TOD in Jinan itself, the HSR may be a larger expansionary force across the region, which could have important broader transportation demand and energy impacts.

<sup>3</sup> Jing-Hu HSR starts from Beijing and ends at Shanghai, passing Tianjin city, and Hebei, Shandong, Anhui and Jiangsu provinces. The construction of Jing-Hu HSR started in April 2008, and the line opened to the public for commercial service on June 30, 2011. The total mileage is 1318 km, and general investment involved is about 220940 million Yuan, which is about 31563 million dollars. As of April 2012, the trains on the Jing-Hu HSR line are running at two speeds: 300km/h, and 250km/h.

<sup>4</sup> The speed of Jiao-Ji rail line was upgraded to 250 km/ hour in September of 2009, which reached the standard for HSR, and the high-speed commuting line is usually named as Ji-Qing HSR, for connecting Jinan and Qingdao. The line is about 500 km long and the commuting time between Jinan and Qingdao is about 2 hours.

**Figure 5-7. The planned spatial structure of Jinan with New town (2002)**



Source: Master and Strategy planning of Jinan, 2002

**Figure 5-8. Conceptual Development Plan for West Station New Town**



Source: City of Jinan

With the planned new town and new cluster, the city’s development focus and infrastructure investment will likely move westward. The Jinan West new town was selected as the location of the MIT-Tsinghua demonstration project to design energy efficient neighborhoods.

**Figure 5-9. The locations of the growth areas in Jinan**

### 5.2.3 Local Public Transportation Development

While rail infrastructure will play a backbone role in the regional transportation system and have important local development impacts, what happens with urban public transportation serving travel within the metropolitan area will clearly influence residents' behavior and, most likely, development patterns. Toward this end, city officials are attempting to increase public transportation quality and supply. Jinan has already embarked on a plan to build a comprehensive bus rapid transit (BRT) system. In 2005, the city began planning the system and the Chinese central government then named it a "BRT Demonstration City." As of April 2012, Jinan has six BRT lines that are in operation. (Figure 5-10). Although the number of transit vehicles (including common buses, electric buses, and BRT buses) did not increase, the passenger volume boosted—from 681 million annual person trips in 2007 to 1081 million in 2010. On the other hand, taxis, a potential alternative to private car ownership and use, lacked growth momentum (Figure 5-11). In household interviews, many car owners complained about the difficulty of getting a taxi when needed, indicating that those instances stimulated their decision to purchase a car.

Plans indicate that by the end of 2015, Jinan will have a BRT network with a length over 120 kilometers (SDUTC, 2010). The BRT corridor development poses an interesting design challenge, to better understand the types of neighborhood forms that should be encouraged when integrating urban development with BRT system expansion. At the same time, the city government has plans to develop rail-based urban public transport – i.e., "light rail." Whether and how that localized light rail occurs, and ultimately replaces or complements other public transit options, remains to be seen.

Figure 5-10. Jinan BRT Corridor Map (2009)



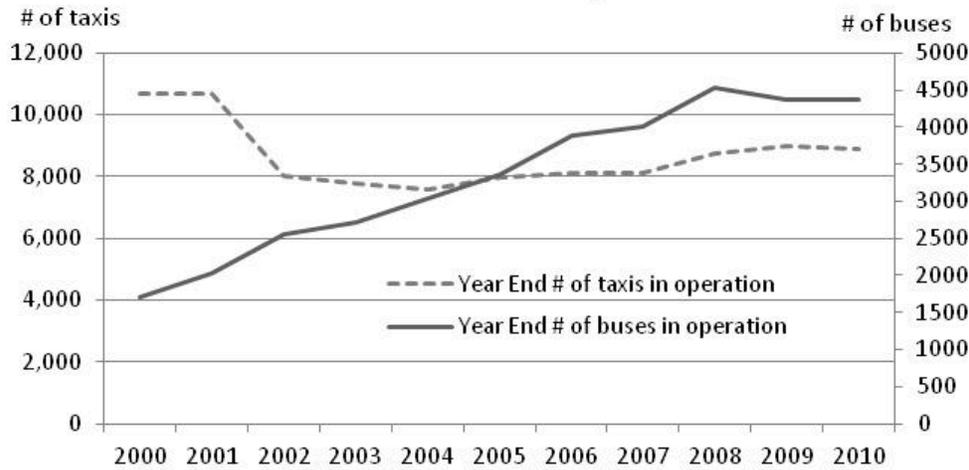
Source: Adapted from local BRT maps provided by Ms. Wu Min at the Jinan Bus Company in 2009.

Figure 5-11. Jinan BRT System Map (2012)



Source: map made by www.84ke.com

**Figure 5-11. Number of Buses and Taxis in Jinan**



Source: Jinan Statistical Yearbooks 2001 to 2011

**5.2.4 Relationships with development patterns**

As discussed in **Chapter 4**, residential growth in Jinan has closely followed the expansion of transportation networks (**Figure 5-12**). Despite the attractiveness of living in the center city, a sample of 167 residential real estate projects in 2007, revealed that the majority were located in suburban areas (Zhaohua Yuan, 2008). The expensive land resource in the central area is one reason. However, the upgrading of the transportation system since 2000 strengthened connections to suburban areas, improving the attractiveness of suburban living. As a result, in 2002, before the reconstruction of the Second Ring Road, there were 68 housing projects along the ring; after the reconstruction, the number increased to 113 (Zhaohua Yuan, 2008). Jinan is, undoubtedly, suburbanizing.

**Figure 5-12. Old (red) and New (purple) Residential Development Corridors**



Source: Zhaohua Yuan, 2008

## 6 Neighborhoods in Jinan

As introduced in **Chapter 4**, Jinan’s history of development over the past century resulted in a small number of distinct neighborhood forms types that collectively make up the fabric of the city. This provided us with an ideal platform to study relationships between neighborhood form and energy performance. To provide a foundation for the research, a detailed analysis of the physical form and function of representative samples of each of the neighborhood type was conducted on-site and using GIS data. In all, 23 neighborhoods were documented; the results are presented in this chapter. The empirical studies of their energy performance are presented in **Chapters 7-9**.

### 6.1 Neighborhood Types

Through field research in Jinan, the team identified the presence of four main neighborhood form typologies: 1) Traditional fabric of Chinese urban villages characterized by courtyards and hutongs, found in many Chinese cities; 2) Grid based development mixing Chinese and western building types introduced by German and Japanese planners in the early 20<sup>th</sup> century; 3) Enclaves of six story walk up slabs developed by the government beginning in the 1980’s; and 4) Superblocks of widely spaced high-rise towers in single use, gated developments. These “tower-in-park” projects have become the standard form for new housing across China. Respectively, these types represent characteristics of urban development in Jinan at it advanced during the different historical periods described in **Chapter 4**. A summary of the form features associated with each typology is shown in **Table 6-1** and discussed below.

**Table 6-1. Summary of Form Features across Four Neighborhood Typologies**

Typology	Building/Street/Function	Access/Parking
<b>Traditional</b>	1-3 story <i>courtyards</i> ; fractal /dendritic fabric off a main <i>shopping street</i> , on-site employment	no cars
<b>Grid</b> (1920s)	Block structure with <i>different building forms</i> contained within each block, <i>retail</i> on connecting streets	Easy access; cars on-street; some parking lots
<b>Enclave</b> (1980-1990s)	<i>Linear six story walk-ups</i> ; housing integrated with communal facilities (kindergartens, clinic, restaurants, convenience shops, sports facilities, etc.)	Moderately gated (walls, fences and sometimes security guards at entries); Scarce on-courts parking lots
<b>Superblocks</b> (-2000s)	<i>Towers-in-park</i> with homogeneous residential use	Completely gated; sufficient parking lots (underground, surface, etc.)

### 6.1.1 Traditional Neighborhoods

Traditional neighborhood forms, illustrated in **Figure 6-1**, can be found in the old hutongs which remain in the historic center of Jinan, and in urban villages that once existed outside of the city but have now been engulfed by urbanization. One to three story buildings with courtyards and narrow alleys characterize this type of neighborhood. A main shopping street provides households with immediate access to local employment and service opportunities. Cars have little access into the neighborhood due to the narrow roads and complicated alley system. Almost no parking spaces for cars are provided.

**Figure 6-1. Traditional Neighborhoods**



Zhang Village



Furong Hutong, Market Street

### 6.1.2 Grid Neighborhoods

The Grid typology, **shown in Figure 6-2**, was introduced in Jinan in the early 1920s. This typology shaped the old commercial district, which is located to the south of the Jinan railway station. The whole district is about two square kilometers. The dimension of a typical block is about 160 meters by 160 meters. Originally, the blocks were composed of traditional courtyards, but they have since evolved into more diverse building forms. As an old commercial district, jobs and housing supply are highly balanced in this area today. Another main feature of the grid neighborhood is its openness: public streets running between small blocks make the whole district very accessible. Retail development and large trees along the perimeter or connecting streets create a walking-friendly street environment. Some on-surface parking lots exist in this district.

**Figure 6-2. Grid Neighborhood**



Old Commercial District

### 6.1.3 Enclave Neighborhoods

The Enclave neighborhood form, illustrated in **Figure 6-3**, originated with a national housing program in the mid-1980s with the goal of achieving “high standards with relatively low cost, high quality with relatively small units, and a pleasant environment despite limited land coverage” (Lü, *et al.*, 2001, p. 230). It is characterized by a north-south layout of six-story walk up slab buildings and an integration of housing with community facilities (e.g., kindergartens, clinics, restaurants, shops, sports facilities, etc.). Internal local roads within the neighborhood provide a safe outdoor space for people. Sometimes, roads have bends and turns, similar to “traffic calming” measures used in the West. Dead-end roads are often found within building clusters, to exclude through traffic. In terms of parking facilities, the Enclave provides plenty of bike storage space and limited surface parking spaces for cars exist (Lü, *et al.*, 2001).

**Figure 6-3. Enclave Neighborhood**



Dong-Cang

### 6.1.4 Superblock, “Tower-in-Park”, Neighborhoods

The Superblock neighborhood has dominated the country’s urban growth pattern since the 1990s including Jinan (Cervero & Day, 2008; Monson, 2008). These neighborhoods are usually composed entirely of housing units (i.e., with little mixed use) and completely enclosed by walls or fences, with few entrances. Such a physical setting combined with security measures at access points (especially in the more affluent neighborhoods) often creates significant isolation between the neighborhood and its surrounding urban space (Bray, 2006; Wu, 2005). Superblocks have high-rise buildings, considerable landscaping, an auto-oriented internal road network, and ample parking for private motor vehicles, both on the surface and in underground garages.

**Figure 6-4. Superblock, “Tower-in-Park” Neighborhood**



Sunshine 100

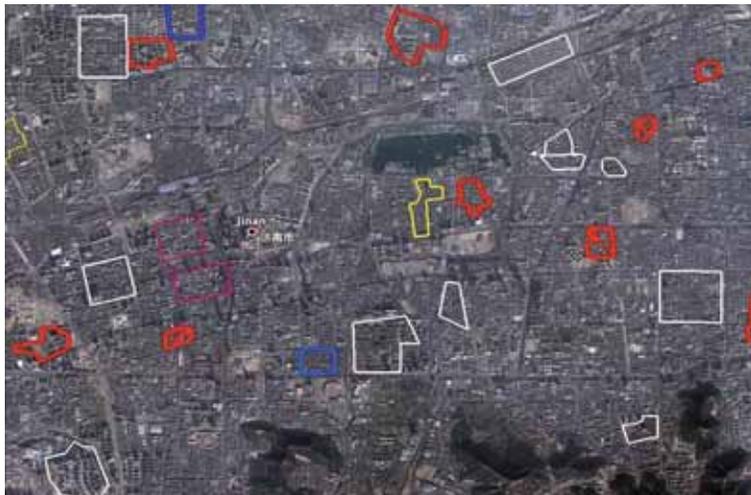
## 6.2 Measures of Neighborhood Form

To further understand the physical definition of these neighborhoods, the characteristics of their residents and their residents’ behaviors, the research team, as well as officials from the Jinan Urban Planning Bureau, selected 23 neighborhoods to examine in detail. The aim was to select a neighborhoods representative of the four typologies discussed above, and with a variety of locational characteristics. **Figure 6-5** illustrates the location of the 23 neighborhoods.

A geographic information system (GIS) database was developed by a technical team from Beijing Normal University. The team first procured a high-resolution aerial photo of the Jinan urban area, used the aerial imagery to identify relevant 2-dimensional information (e.g., building profile, road, open space, trees, etc.) of the neighborhoods, and further geo-coded the information in a GIS platform. Second, the team carried out a visual survey of all 23 neighborhoods to validate existing data and to collect additional physical

data such as building height, parking spaces, etc. that could not be extracted from the aerial photo. Information obtained from the visual survey was then, again, geo-coded into GIS as shown in **Figure 6-6**.

**Figure 6-5. Neighborhood Case Locations**



**Figure 6-6. Sample GIS Maps of Neighborhoods in Jinan**



Produced using the dataset created by the School of Geography and Remote Sensing, Beijing Normal University

### 6.2.1 Density Measures

In our analysis, five indicators are used to measure and compare the density of the 23 neighborhoods: population density, household density, floor area ratio (F.A.R), building coverage, and average building heights. Population and household density are the number of people per square kilometer of land area and are measures of *population* density.<sup>1</sup> Building coverage, average height, and FAR are measures of *urban form* density. Building coverage – the ratio of total building footprint area to neighborhood land area – is a measure of horizontal density of the urban form. Average building height – the average number of stories of buildings in the neighborhood – is a measure of vertical density of the urban form. FAR is an indicator of the three-dimensional density of the urban form. **Table 6-2** shows estimations of these indicators and the average for each neighborhood typology.

**Table 6-2. Density Measures**

Indicator	Unit	Year	Enclave (7)*	Superblock (10)	Grid (3)	Traditional (3)
Population density	# persons/ sq. km	2010	282,000	190,000	93,000	200,000
		2009	234,000	284,000	112,000	67,000
		Average	255,000	218,000	100,000	156,000
Household density	households/ sq. km	2010	17,262	11,406	8,394	16,687
		2009	19,489	16,224	18,909	12,300
		Average	18,535	12,852	11,899	15,221
Building coverage	%	2010	36	23	39	43
		2009	34	22	31	54
		Average	35	23	36	47
F.A.R.	-	2010	1.5	1.8	2.3	1.0
		2009	1.8	2.0	1.7	1.2
		Average	1.7	1.8	2.1	1.0
Average building heights	# of stories	2010	4.2	8.8	6.0	2.3
		2009	5.3	10.1	5.5	2.2
		Average	4.8	9.2	5.8	2.2

\* Indicates the number of neighborhoods.

Overall, Enclave neighborhoods are the most highly populated among all four typologies, measured by both population and household densities, and are characterized by moderate urban form density. Superblock neighborhoods are also highly populated, however the household density is relatively lower, indicating that the average household size in Superblocks is larger than the other neighborhood typologies. Despite having the highest

<sup>1</sup> Population is estimated by dividing the total residential floor area of each neighborhood by the average household unit size. This is then multiplied by the average number of people per household for each neighborhood.

average building height, their FAR is comparable to both Enclaves and Grids. Although they have the lowest building coverage, average building footprints are large (530 m<sup>2</sup>), indicating that Superblocks are comprised of dispersed, high-rise buildings with large building footprints.

Like Superblocks, Grid neighborhoods are built with moderately high-rise buildings. Unlike Superblocks, however, Grids are the least populated despite their high FAR. This is because Grids have less residential floor area relative to the other typologies but more commercial space. Finally, the Traditional neighborhoods are relatively less populated on average compared to the other typologies. In part this is because, despite their high household density, families in these neighborhoods were generally smaller. However, neighborhoods surveyed in 2010 had significantly higher population density than those surveyed in 2009. The Traditional neighborhoods have the highest building coverage ratio; almost half of their surface areas are covered with buildings, however these are only two stories on average. As a result, the FAR of Traditional neighborhoods is relatively low. **Figures 6-7 to 6-10** illustrate these findings.

The distribution of density characteristics suggests that no single neighborhood typology is necessarily denser, or more compact, than another. As Ewing and his associates (2008) argue, neighborhoods with high density do not necessarily imply high-rise or uniformly high density but rather “blended densities.” For example, one may infer that the Superblocks and the Grids are denser urban forms due to their relatively high FAR and building heights. But such argument does not hold when these typologies are examined in terms of either the percentage of building coverage or population density. Similarly, it can be argued that the Enclave and Traditional typologies are very dense when measured

**Figure 6-7. Household Density (Households per Sq. km)**

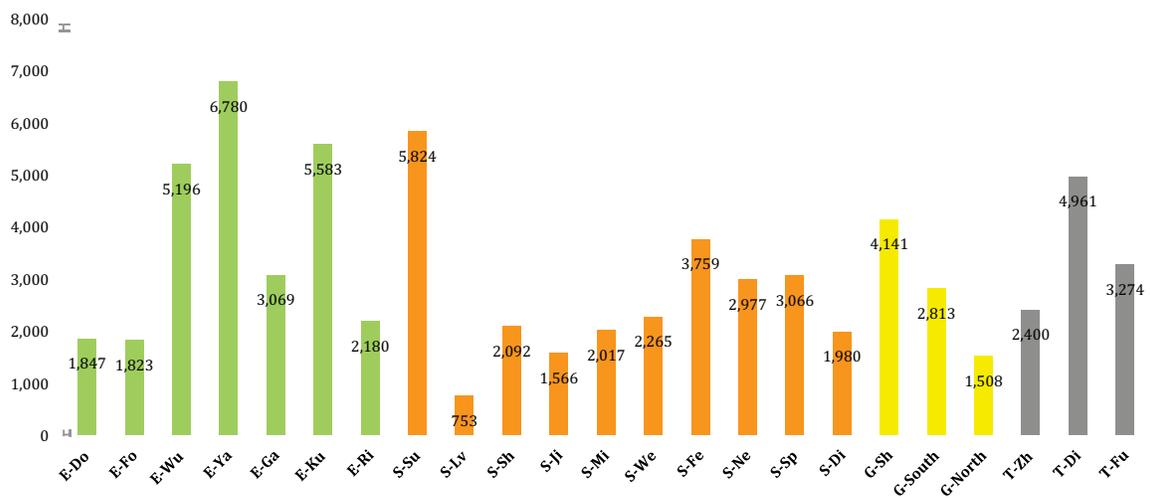


Figure 6-8. Floor Area Ratio (FAR)

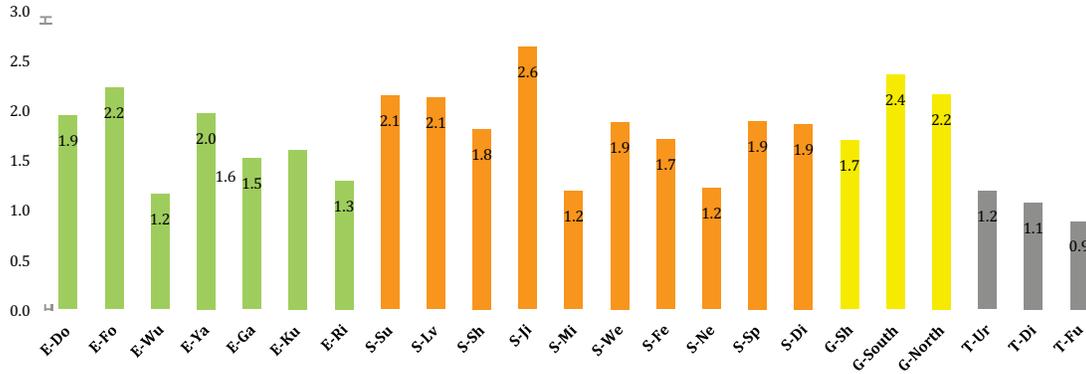


Figure 6-9. Building Coverage Ratio

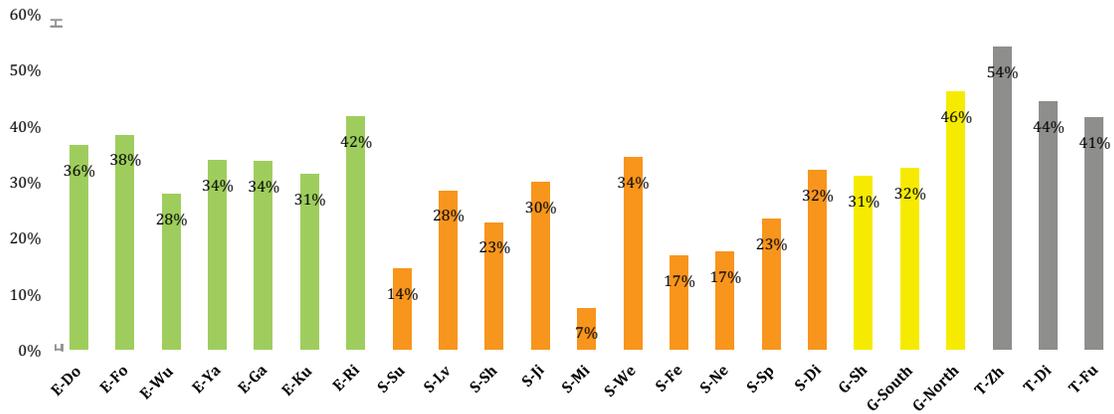
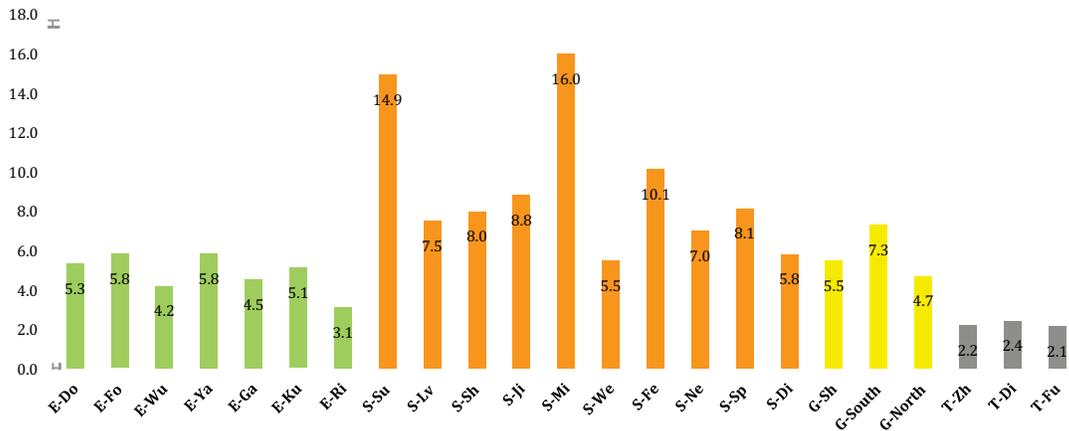


Figure 6-10. Average Building Height



by population density and building coverage indicators, though their FAR and unit size may be lower and they may be perceived differently due to their shorter, more compact buildings.

Utilizing different density indicators to normalize neighborhood-level energy consumption information can therefore produce dramatically different results and subsequent interpretations. For example, neighborhoods with high population density may appear to have relatively low levels of energy consumption if normalized by the number of households. The same neighborhoods, however, may result in the high levels of neighborhood energy consumption when normalized by square meters of floor area. Such neighborhood cases with contrasting density levels need careful examination. We thus present our results in the two different functional units (one with the number of households, and another with square meters of neighborhood size) in following chapters.

It is also important to note that neighborhoods within the same typology do not always share the same characteristics. While building coverage and the average building height shows relatively consistent results across all typologies, household density and F.A.R. within the sample show large variations within the same neighborhood typology. This is particularly prominent in Superblock neighborhoods. The household density of Ming-shi (“S-Mi”) is as low as 7,400 households per square kilometer whereas that of the Spring City Garden is as high as 16,000 households. Similarly, FAR. values range from 1.19 (Ming-shi) to 2.64 at Ji-xiangyuan (“S-Ji”) as shown in **Figure 6-8**.

### 6.2.2 Diversity Measures

Three indicators were used in order to examine the diversity of neighborhood typologies: building height differentiation, building function mix, and land use mix as shown in **Table 6-3** and **Figures 6-11 to 6-13**. Building height differentiation – the standard deviation of building heights in a neighborhood – is a measure of *exterior urban form diversity*, and has implications for sun and wind impacts. Building function and land use mix – 0-1 diversity indices of a range of possible uses – are a measure of *interior urban form diversity*, and have implications for both in-home and transportation related energy consumption.

Enclaves have nearly uniform height differentiation but have a relatively high mix of homes, jobs, industrial spaces and services on the neighborhood scale, as well as the highest mix of uses within individual buildings. Conversely, buildings across Superblock neighborhoods display a range of heights and are overwhelmingly single-use residential buildings; residential floor area accounts for nearly 90% of total building construction area.<sup>2</sup> The Superblock also has the lowest land use mix value, suggesting that in these

---

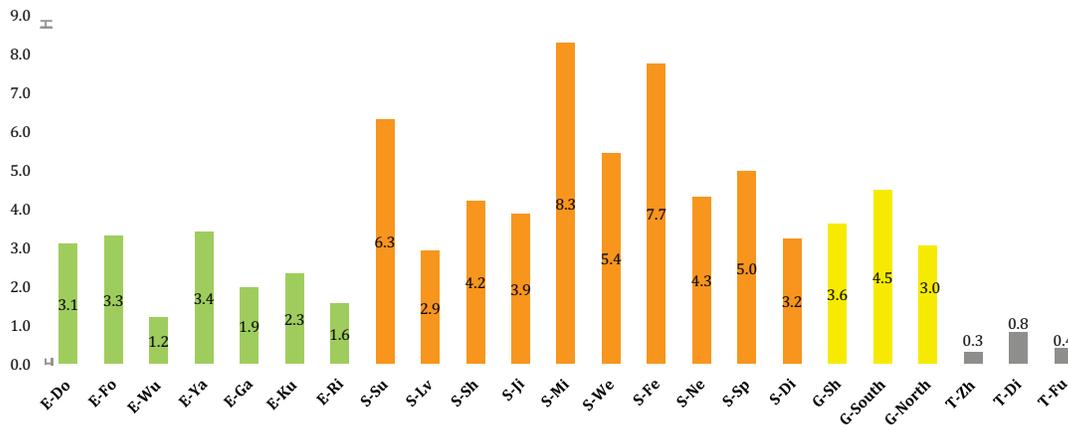
<sup>2</sup> There are a few exceptions. Commercial spaces in some of the Superblock neighborhoods such as Ming-shi (S-Mi), New World Sunshine Garden (S-Ne), and the Digital Center (S-Di) account for nearly 20% of total floor areas (19%, 18%, and 23%, respectively).

neighborhoods, trip distances per household for jobs and services are likely to increase. Interestingly, the Grid is relatively diverse in all measures. It has the highest building function mix and land use mix with total floor area split roughly evenly between commercial and residential uses. Traditional neighborhoods are relatively uniform in terms of their building height. They are fairly mixed-use at the neighborhood scale, though individual building use mix is low.

**Table 6-3. Diversity Measures**

Indicators	Year	Enclave	Superblock	Grid	Traditional
Building Height Differentiation	2010	1.9	5.4	3.8	0.6
	2009	2.8	4.5	3.6	0.3
	Average	2.4	5.1	3.7	0.5
Building Function Mix	2010	13	0.22	0.41	0.17
	2009	0.38	0.04	0.34	0.33
	Average	0.27	0.17	0.39	0.22
Building usage	Residential	80%	88%	44%	83%
	Commercial	11%	10%	51%	15%
	Industrial	5%	0%	1%	0%
	Other	5%	3%	4%	2%
Land Use Mix (within 500m catchment area) <sup>3</sup>	2010	0.69	0.63	0.76	0.66
	2009	0.68	0.57	0.68	0.64
	Average	0.69	0.61	0.74	0.65

**Figure 6-11. Building Height Differentiation**



<sup>3</sup> In general, catchment area refers to an area within walking distance from the neighborhood in the context of this research.

Figure 6-12. Building Function Mix

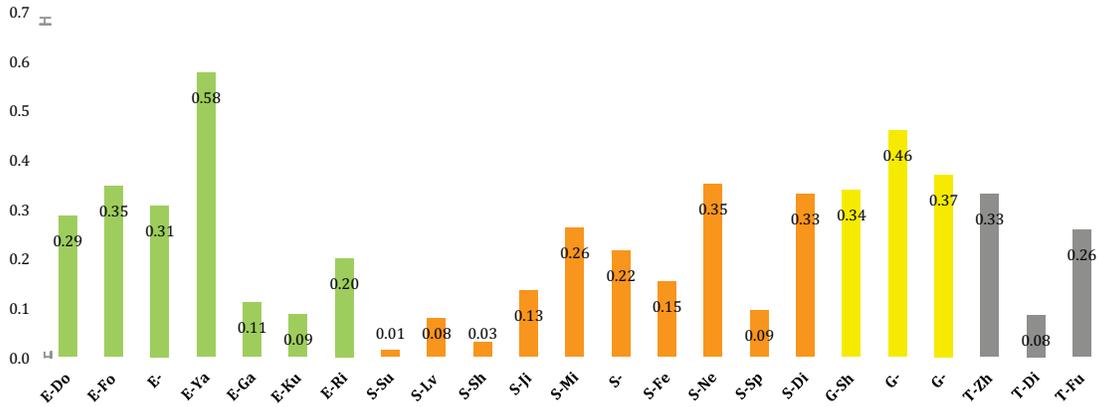
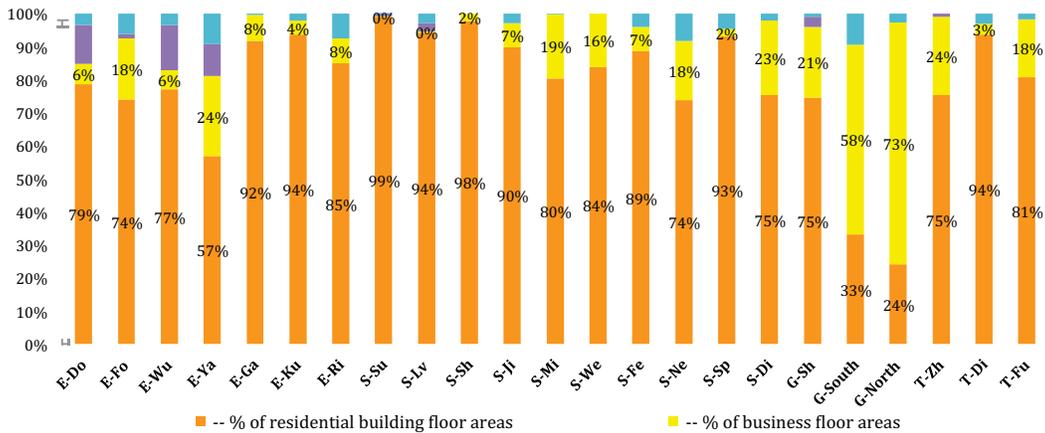


Figure 6-13. Percentage of Building Usage



6.2.3 Design Measures

We measured neighborhoods by ten indicators that examine their various design characteristics. These indicators represent aspects of the pedestrian environment (i.e. walkability, green coverage, etc), which may affect neighborhood-level embodied, operational, and transportation energy consumption. For example, neighborhoods with high numbers of parking spaces allotted per household, high motorways density and wide roads will provide environment that are friendly to private car drivers. Households dwelling in neighborhoods designed as such may thus consume more energy for travel than those in other neighborhoods. It is also likely that these neighborhoods will have high level of per-household embodied energy consumption, as they require the construction of larger infrastructure systems.

Conversely, neighborhoods that have multiple intersections, smaller blocks, a large percentage of roads with walking facilities, and large percentage of residential buildings with street-level shops will provide environment that is relatively more amenable to pedestrians. These neighborhoods may displace vehicle-trip related energy with more walking trips, or may increase both walking and vehicular trips. Neighborhoods that have high green space coverage and roads with trees may help reduce both operational and transportation energy consumption by improving the climate and aesthetic street-level environment for pedestrians, inducing them to spend less time in their homes and cars.

Overall, the Superblock neighborhoods are most auto-oriented (**Table 6-4**). The Superblock case is associated with large per-household parking space, high motorway density, and wide roadways. Such driving-friendly design characteristics may all help increase private car usage. On the contrary, pedestrians are likely to find the Superblock neighborhoods unfriendly for walking. The intersection density is relatively low compared to the Enclave and Traditional cases, suggesting that the size of each block is large (Ewing and Cervero 2010). Distances between entrances are the longest of all neighborhood typologies on average (600m), which indicates that the Superblock neighborhoods have high level of physical isolation. This may create environment favorable for private car users but not for pedestrians.

**Table 6-4. Design Measures**

Indicators	Indicators	Unit	Year	Enclave	Superblock	Grid	Traditional
Driving-friendly Design Indicators	Parking Space per Household	Sq.m / HH	2010	0.6	1.7	3.2	0.3
			2009	0.6	2.5	1.7	0
			<b>Average</b>	<b>0.6</b>	<b>2.0</b>	<b>2.7</b>	<b>0.2</b>
	Motorway Density	Km/ Sq.km	2010	38.2	26.9	17.1	11.8
			2009	17.5	21.9	8.8	0.6
			<b>Average</b>	<b>26.4</b>	<b>25.4</b>	<b>14.3</b>	<b>8.0</b>
	Average Motorway Width	m	2010	5.2	13.8	4.7	10.0 <sup>4</sup>
			2009	8.2	7.9	12.5	5.0
			<b>Average</b>	<b>6.9</b>	<b>12.1</b>	<b>7.3</b>	<b>8.5</b>
	Cul-de-sacs	%	2010	13.9	0	0	0
			2009	41.5	19.0	19.6	21.7
			<b>Average</b>	<b>29.7</b>	<b>5.7</b>	<b>6.5</b>	<b>7.2</b>
Walkability	Intersection Density	# of intersections / km	2010	10.7	7.8	5.0	6.4
			2009	6.9	7.9	9.6	14.0
			<b>Average</b>	<b>8.6</b>	<b>7.8</b>	<b>6.5</b>	<b>8.9</b>
	Entry Interval	m	2010	151	468	235	412
2009			185	912	133	272	

<sup>4</sup> Some of the roads located on the edge of Dikou neighborhood (Traditional) are as wide as 30 m and as a result, the average road width of the Traditional is large.

Distance		Average	170	601	201	365	
Roads with Walking Facilities	%	2010	31.1	36.0	59.7	59.0	
		2009	50.7	64.0	87.3	98.1	
		<b>Average</b>	<b>42.3</b>	<b>44.1</b>	<b>68.9</b>	<b>72.0</b>	
Street-level Shops	%	2010	0	2.0	0	2.0	
		2009	23.7	4.3	18.2	21.3	
		<b>Average</b>	<b>13.5</b>	<b>3.0</b>	<b>6.1</b>	<b>8.4</b>	
Level of Green Space	Green Coverage	%	2010	4.3	9.0	1.3	1.9
			2009	16.6	31.1	12.4	0
			<b>Average</b>	<b>11.3</b>	<b>15.3</b>	<b>5.0</b>	<b>1.2</b>
Roads with Trees	%	2010	46.7	33.6	42.0	21.7	
		2009	42.3	85.4	42.0	0	
		<b>Average</b>	<b>44.2</b>	<b>49.1</b>	<b>42.1</b>	<b>14.5</b>	

The Superblocks have fewer pedestrian pathways and sidewalks, and have far fewer street-level shops within their neighborhoods than the Enclave or the Traditional case. As a result, the Superblock residents are less likely to find occasions for walking. That said, Superblocks do have the highest percentage of green space coverage and trees, due to the significant landscaping that exists between the residential towers. Much of this space is not well used by residents, nor is it accessible to the public at large, and cannot be considered landscaped pedestrian throughways.

Interestingly, our analysis suggests that the Grid design may be favorable for both drivers and pedestrians. They have a relatively high number of per-household parking spaces, wide motorways, and almost no cul de sacs. In the western context, cul-de-sacs tend to indicate more auto-dependent road systems. However in the Jinan context, a high percentage of cul-de-sacs indicates a prevalence of dead-end road networks within building clusters; such road structures may help reduce car road connectivity and prevent through-traffic in local areas. Thus, these conditions may increase driving despite relatively low motorway density. The Grid neighborhoods are also associated with small blocks (the distance between entry points to the neighborhood are low) and high percentages of walking facilities, improving neighborhood accessibility and walkability.

The Enclave and the Traditional neighborhoods are relatively less favorable to drivers and more amenable to pedestrians than Superblocks or Grids. Both typologies have small per household parking, suggesting that their residents are unlikely to have designated parking spaces, and the motorways are narrow and poorly connected. By contrast, these typologies help create pedestrian-friendly environments. In particular, both the Enclave and the Traditional cases have high intersection density, suggesting that the size of each block in these neighborhood typologies is small. The Enclave also has the shortest entry interval distance of all typologies and thus is relatively easy to access to the

neighborhood without driving cars. In the Traditional neighborhoods, one can find more pedestrian pathways and roads that are equipped with sidewalks than any other neighborhood typologies; pedestrian pathways in Zhang village and Dikou account for 98% and 74% of entire roads, respectively. While traditional neighborhoods have the lowest level of green space and tree coverage, enclaves have relatively large green spaces and vegetated roads. In addition to improving the pedestrian environment, green spaces and trees among low-rise building typologies such as these may cool the neighborhood in the summertime and offset per household operational energy usage.

### 6.3 Conclusion

The perceived characteristics of neighborhood are not always what they seems. While the Superblock may seem much more dense due to the height of the buildings, it is in fact almost not appreciably great than the Grid or Enclave forms, and actually houses a lower number of households on average per hectare than other forms. In terms of diversity, only Superblocks have both low building function and land use mix; other typologies incorporate a diversity of uses either vertically or horizontally across the neighborhood. Road networks and urban quality range considerably across typologies perhaps compounding effects on energy. The following **Chapters 7-9** empirically test the relationship between these urban form variables and energy consumption.

### **Section III**

## **Empirical Investigation of Relationship between Urban Form and Energy Use in Jinan**



## 7 Introduction to Empirical Analysis of Jinan

**Chapters 7–9** present results of our empirical investigation of the correlation between neighborhood form and energy, including: Operational, transportation, and embodied energy consumption, and potentials for on-site renewable energy generation. This **Chapter 7** begins by presenting summary findings on energy consumption and GHG emissions for the twenty-three neighborhoods of Jinan described previously. **Chapter 8** analyzes these results in depth, and **Chapter 9** provides an evaluation of what these results indicate for guiding the development of clean energy neighborhoods in the future.

### 7.1 How Do We Research the Impact of Neighborhood Form on Energy?

Our analysis is based both on the urban form data described in **Chapter 6**, as well as on a survey of approximately 300 households in each neighborhood, a total of close to 7000 surveys, as referenced in **Chapter 5**. The survey collected information on household weekly travel activities, in-home energy expenses, fuel choices, vehicle and appliance ownership, individual attitudes, income, and other socio-demographic factors.<sup>1</sup> **Table 7-1** summarizes statistics derived from survey data.

**Table 7-1. Summary of Survey Results**

Mean	Traditional	Grid	Enclave	Superblock
Household size (persons)	2.8	2.8	3.0	3.2
Household employment (workers)	1.4	1.5	1.6	1.8
Household income (\$/month)	759	1,326	1,341	2,157
Household home area (sq. m)	63.9	67.2	70.8	122.7
Car ownership (% HH)	0.1	0.2	0.2	0.7
Motorcycle ownership (% HH)	0.2	0.1	0.1	0.0
E-bike ownership (% HH)	0.5	0.4	0.4	0.4
Bike ownership (% HH)	0.9	0.9	0.9	0.6
Car pride (%)	49%	57%	56%	45%
Transit fan (%)	79%	81%	83%	66%
Bike fan (%)	77%	78%	74%	72%
High value of time (%)	58%	59%	64%	69%

<sup>1</sup> The survey was carried out by faculty and students at Shandong University. We thank, in particular, Prof. Zhang Ruhua and Ms. Zuo Weiwei in Jinan for guiding the household survey and data entering. Appendix B provides a brief description of the survey methodology and an example of the survey content.

For *embodied* energy use, calculations are based on the quantities of five major construction materials – concrete, steel, timber, glass and asphalt<sup>2</sup> – in each neighborhood, estimated using the GIS neighborhood data and the Chinese building code (MOC, 2005).<sup>3</sup> Energy intensity factors for construction materials used in the calculations derive from an extensive review of existing literature. For *operational* energy use, we estimate ‘in-home’ energy consumption from self-reported energy bills (electricity, gas, coal, and centralized heating) collected in the household surveys. Common area energy use is calculated using a deterministic linear estimation using neighborhood physical attributes (e.g. elevators) as inputs. Household *transportation* energy use is estimated from weekly travel patterns (distances by mode) reported by each surveyed household and estimated energy intensity factors for each mode.

Based on these estimates, we compare the energy consumption and GHG emission patterns across neighborhoods, form typologies and income groups. In addition, we attempt to statistically test the relationship between neighborhood form and *household* energy use (travel and in-home energy use only) utilizing multivariate regression techniques, to control for other influencing factors such as household socio-demographics and attitudes, thereby revealing the “pure” impact of neighborhood form. **Chapters 8, 9, and 10** present the methodologies used to calculate the embodied, operational, and transportation energy consumption, respectively. Details on the various regression techniques employed and the estimation results can be found in the Appendices.

## 7.2 Neighborhood energy consumption and GHG emissions

**Figure 7-2** shows both the total and the per dimension energy consumption per household of each neighborhood. The graph confirms that operational energy consumption (in-home and common area) accounts for the largest share in all cases – on average 80%. Embodied and transportation energy account for a roughly equal share of total energy consumption in Enclaves. In Superblocks, transportation energy exceeds embodied energy. In the Grid and Traditional neighborhoods, the sample is mixed.

For comparison, by one estimate for Canadian neighborhoods, transportation energy use accounted for anywhere from 40-70% of total household in-home and transportation energy use (counting only energy used by household private motor vehicles) (NRC, 2009). This result suggests that *as China develops, transportation will account for an increasing share of residential sector energy consumption*. Comparing across neighborhood typologies, we can see that households in the Superblock typology consume much more energy than the others – over twice as much in some cases. Among the non-Superblock neighborhoods, the Traditional typology has the lowest per household energy consumption, with Grid and Enclave typologies showing low to

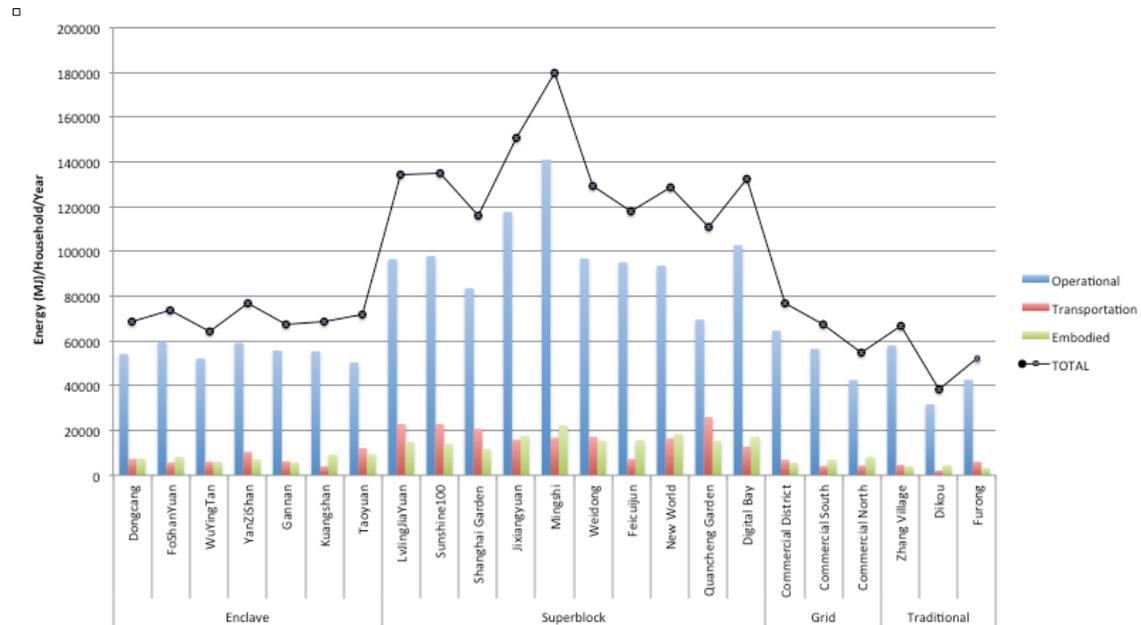
---

<sup>2</sup> While there are many more different types of construction materials associated with urban development projects, we believe that considering these major five materials is reasonably sufficient for estimating embodied energy at this stage.

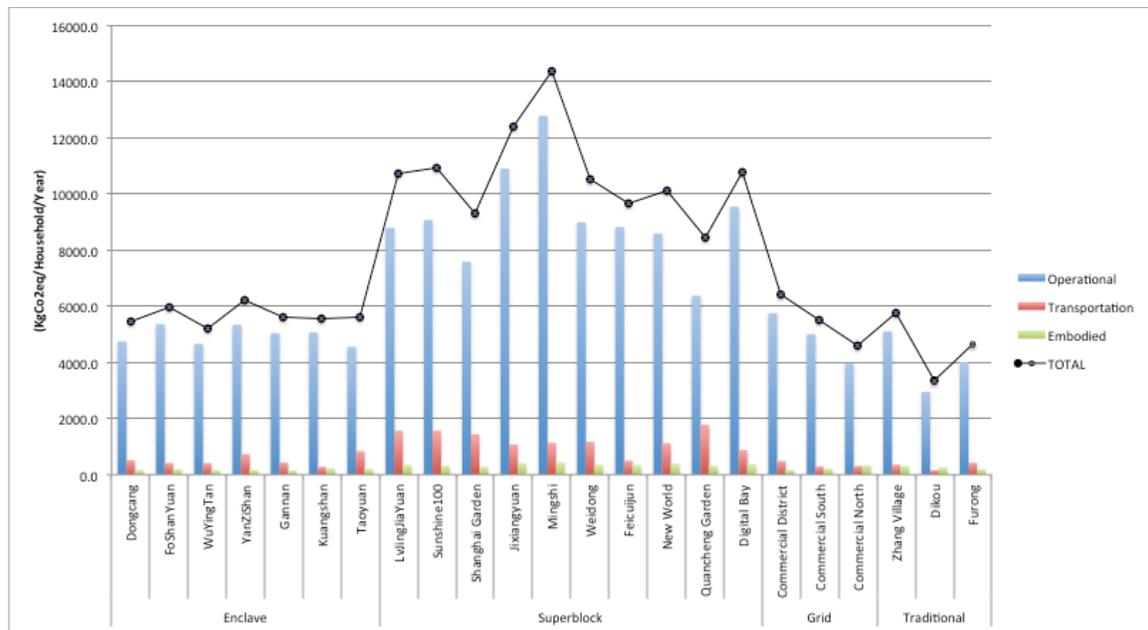
<sup>3</sup> The neighborhood GIS database was developed by Beijing Normal University; we thank, in particular, Prof Zhang Lixin and Mr. Zhang Tao in Beijing for leading the efforts on the building the GIS database.

moderate. Still, there is variation among Superblocks; the Mingshi neighborhood consumes over 1.5 times the energy per household of QuanCheng Garden. Carbon dioxide (CO<sub>2</sub>) emissions per household roughly follow a similar pattern (Figure 7-3).

**Figure 7-2. Per Household Energy Consumption by Neighborhood**



**Figure 7-3. Per Household CO<sub>2</sub> Emissions by Neighborhood**



When total energy consumption and GHG emissions are normalized per square meter of residential floor area, the results show greater variability across neighborhood typologies (Figures 7-4, 7-5). Operational energy consumption shows the highest level of variability, however transportation and embodied energy are still considerably higher on per square meter in Superblocks than in other neighborhoods.

Figure 7-4. Neighborhood Energy Consumption per Sq. M. Residential Floor Area

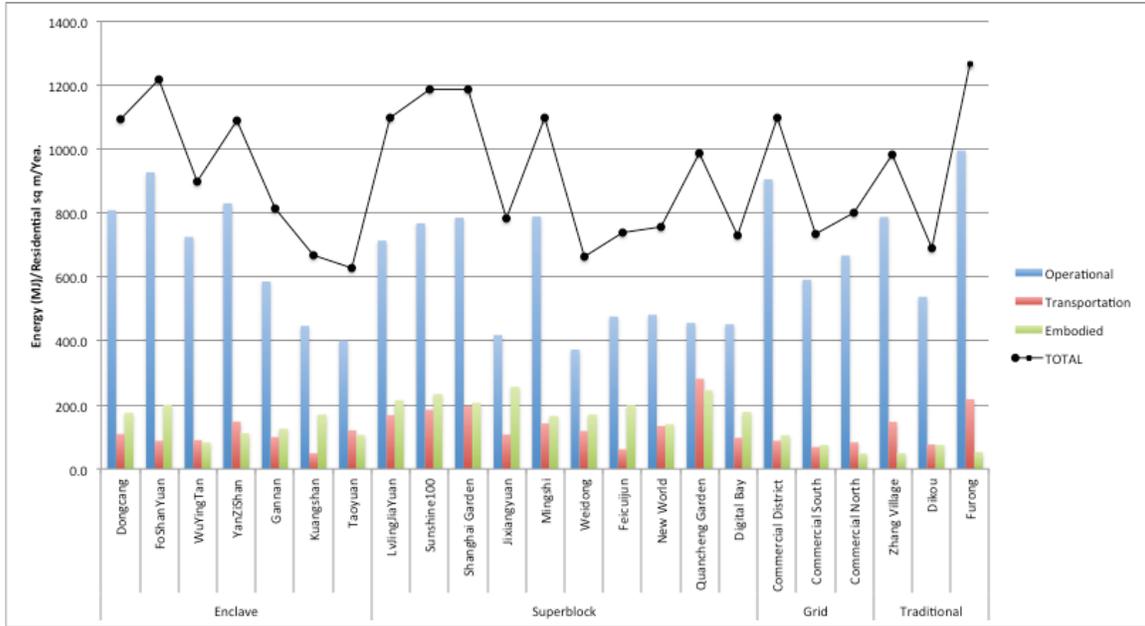
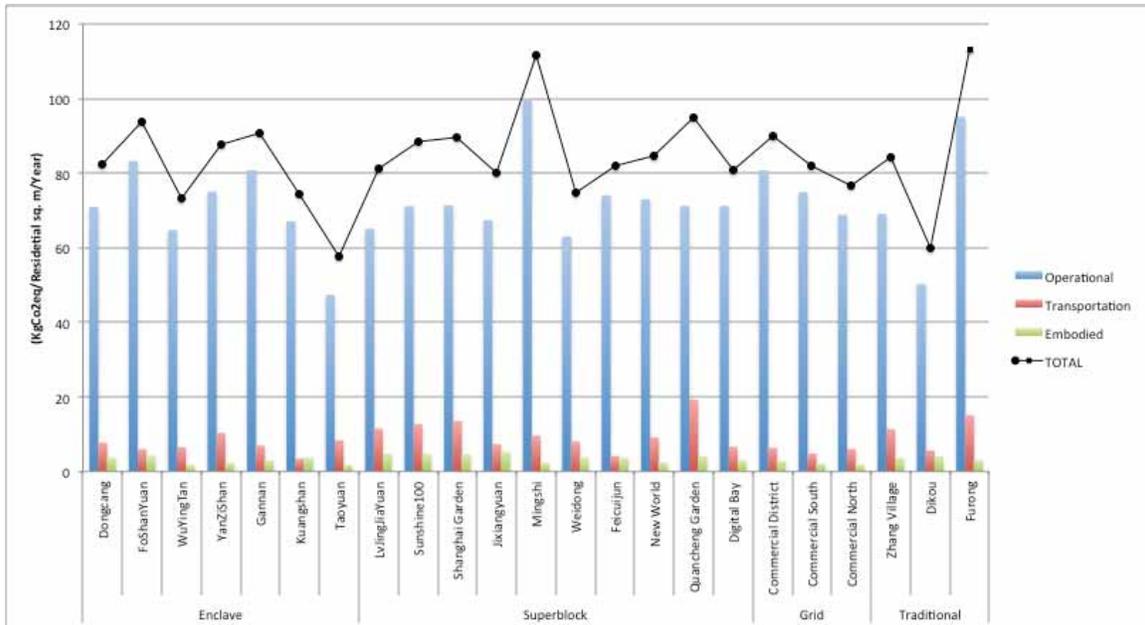


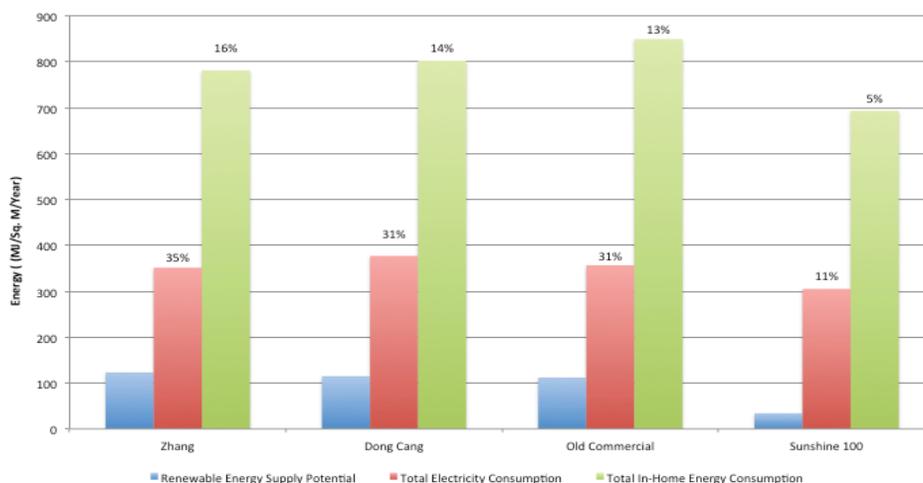
Figure 7-5. Neighborhood GHG Emissions per Sq. M. Residential Floor Area



### 7.3 Renewable Energy Potential

On-site energy generation reduces building energy demand from the grid. Four neighborhoods, one of each typology, were analyzed for their potential to accommodate rooftop and building façade solar photovoltaic panels as well as rooftop micro-turbines. A comparison of this renewable energy supply potential with annual in-home energy consumption indicates that Dongcang (Enclave), Zhang Village (Traditional) and the old Commercial District (Grid) are all capable of incorporating renewable energy technologies that could make a significant contribution toward their energy consumption. As it is shown in **Figure 7-6**, on-site energy production these three neighborhoods could supply 30-35% of electricity consumption 13%-16% of total in-home operational energy. Sunshine 100, by contrast can only accommodate enough onsite renewable energy technology to supply 11% of its electricity use and 5% of total in-home operational energy consumption.

**Figure 7-6. Renewable Energy Potential v. In-home and Electricity Consumption**



### 7.4 Conclusion

The overall energy consumption on a per household basis supports the general hypothesis of this research that contemporary form of urban development in China -- the Superblock, “tower-in-park” form -- is vastly more energy consumptive than other neighborhood typologies, while at the same time offers less potential for generating renewable energy. When normalized by floor area, the picture becomes more ambiguous. The interplay between urban form and the trends demonstrated in this chapter, including the potential for onsite energy generation, are discussed in the following chapter.



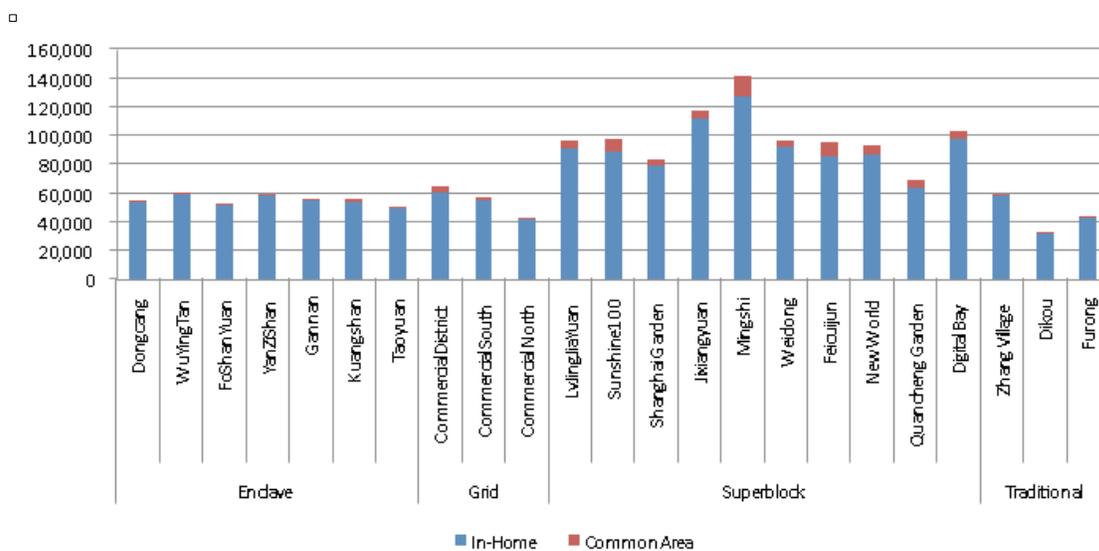
## 8 Energy Consumption in Jinan

This chapter summarizes the quantity of energy consumed (or produced) by households in Jinan. Energy is categorized into four basic types: operational, travel, embodied, and renewable.

### 8.1 Operational Energy Consumption and Emissions

Operational energy consumption accounts for the majority of total neighborhood energy consumption across all neighborhood typologies. Therein, ‘in-home’ operational energy – the energy consumed within individual household units – also accounts for the vast majority of operational energy. **Figure 8-1** shows the absolute value share of the in-home consumption and common area consumption on per household basis. In the Enclave and Traditional neighborhoods, common facilities are few with no corridors, elevators or parking and so they only account for 2% of total operational energy consumption. The share for the Superblocks is higher largely due to the operation of elevators and underground parking lots, ranging up to 10%.

**Figure 8-1. In-home and Common Area Consumption per Household**

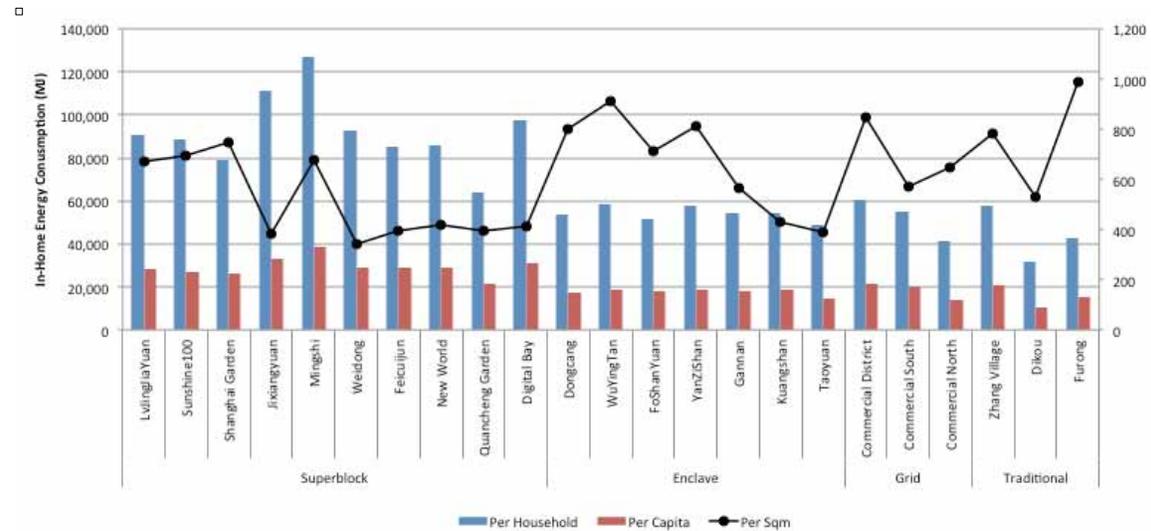


#### 8.1.1 In-Home Operational Energy

Figure 8-2 shows per household, per capita, and per square meter in-home operational energy consumption of the 23 neighborhoods surveyed in 2009 and 2010. Superblocks consume much more energy, approximately 40% to 50%, compared to the other three

types of neighborhoods on per household basis. The difference between the Enclave and the Grid is not significant. Traditional neighborhoods consume the least operational energy among all neighborhood types, and can therefore be considered the most energy efficient typology among those studied in the sample. On per square meter basis however, the consumption pattern is reversed. The Superblocks consume less energy per square meter than the Grid and the Enclave, and the Traditional neighborhoods consume the highest per square meter. This is due in large part to the fact that household units in Traditional neighborhoods are relatively smaller whereas wealthier residents in Superblocks generally have larger homes, yet population density is similar.

**Figure 8-2. Annual In-home Energy Consumption**

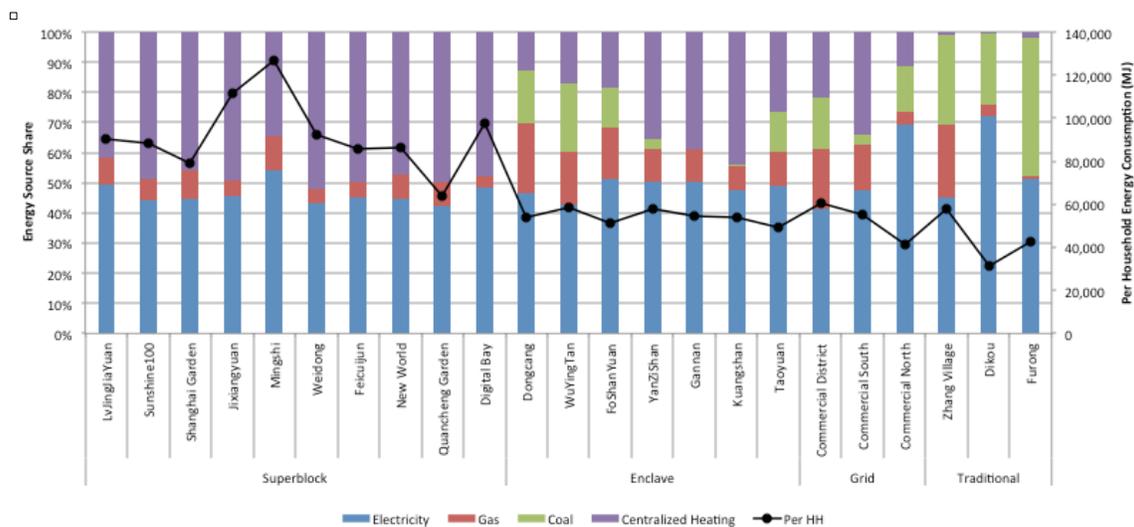


**Figure 8—3** shows in-home energy consumption according to energy source.<sup>1</sup> The consumption of electricity is generally consistent in all types of neighborhoods, accounting for about 50% of total energy consumption. In Superblocks, supplemental coal is completely absent. The dominant energy sources are electricity and centralized heating, each accounting for almost half of the total energy consumption. In the Enclave and Grids, household energy source choices are more diverse. Coal is widely used for space heating in neighborhoods where centralized heating is not available, for example Traditional neighborhoods. Compared to the consumption of centralized heating and coal, the consumption share of gas is more stable around 10%, with the share in the Enclave and the Grid slightly higher than in the other two types of neighborhoods.

<sup>1</sup> These are neither *primary* energy, per se, nor end-use energy, as we do not have the data necessary to estimate either. Electricity comes entirely from coal as of 2009 and can be used for typical end-uses, including heating and hot water; coal, in the Figure, refers to in-home coal use which can be used for cooking and heating; gas can be used for cooking, heating and hot water; centralized heating refers to heating services provided by the building.

A key finding is that the existence of centralized heating system is the determinant influencing the energy sources of the neighborhoods. The energy source of those neighborhoods that have complete centralized heating system, including the Superblock, and part of the Enclave and the Grid neighborhoods, is primarily evenly shared between electricity and centralized heating. Grid and part of the Enclave neighborhoods that have only partial centralized heating systems consume more coal instead. Coal accounts for a large proportion (24% to 46%) of energy consumption in the Traditional neighborhoods, which have no centralized heating system. In the end however, coal combustion accounts for more than 90% of the in-home operational CO<sub>2</sub> emissions, given the fact that 99% of electricity and 100% of centralized heating in Jinan come from coal.

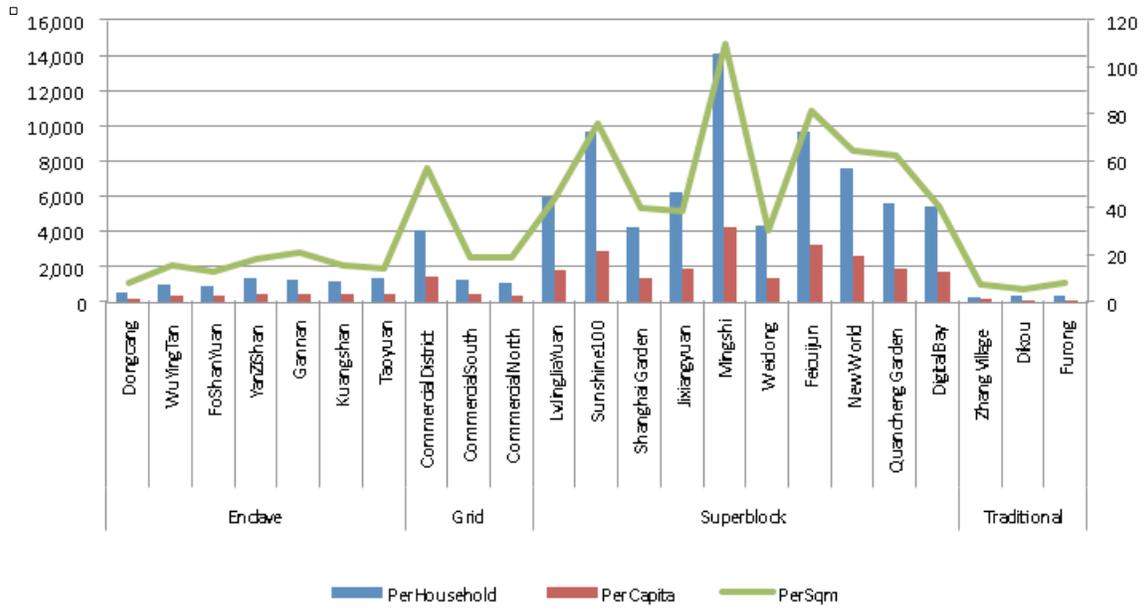
**Figure 8-3. Household In-home Energy Consumption Share by Source**



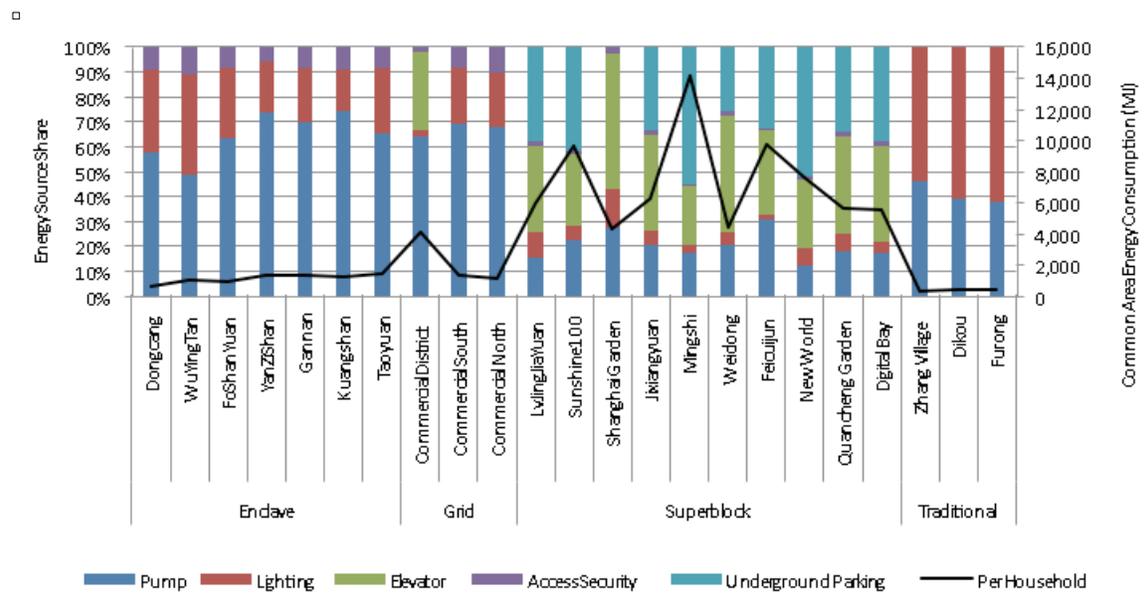
**Figure 8-4** shows the estimated per household, per capita and per square meter common area energy consumption of all neighborhoods. Superblock neighborhoods incur the highest common area energy consumption, followed by the Grids. The consumption in the Traditional is noticeably low as well as Dongcang, one of the Enclaves.

**Figure 8-5** shows the energy consumption share of each common area end use. Each neighborhood typology has its distinctive pattern of common area energy consumption share. Water pumps incur around two-thirds of the total energy consumption in the Enclave neighborhoods while lighting contributes to around 20%. The Grids are characterized by large share of water pump and elevator. The energy consumption share of the Superblocks, which have high-rises and higher automobile ownership, is mostly distributed among water pumps, elevators, and underground parking. The share of the Traditional neighborhoods, the most efficient typology in terms of common area energy consumption among the four, is composed of only water pumps and lightings

**Figure 8-4 Annual Common Area Energy Consumption**



**Figure 8-5. Energy Consumption Share by End Use**



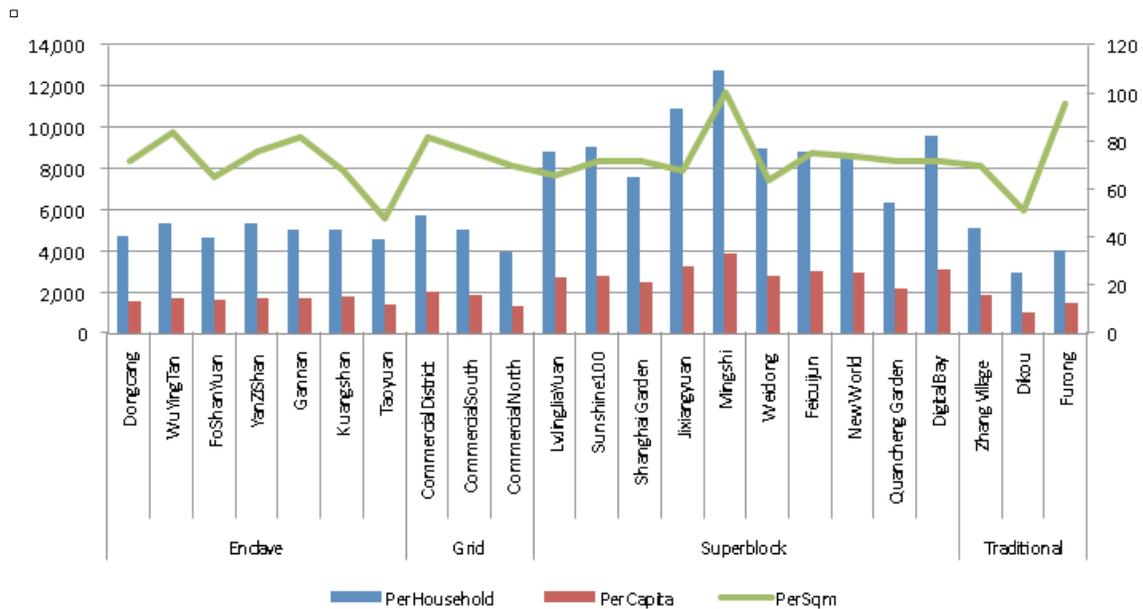
It is important to note that the common energy consumption share of the neighborhoods surveyed in 2010 is estimated through calculations by the energy pro forma due to the lack of available information.

### 8.1.2 GHG Emission Pattern

**Figure 8-6** shows the total operational energy CO<sub>2</sub> emissions of the 23 neighborhoods on a per household, per capita and per square meter basis. The Superblock neighborhoods have higher emission levels compared to other neighborhoods both on per household basis and per capita basis. The averages of GHG emission of the Grid and Enclave neighborhoods are around 5 metric tons per year, while the Traditional neighborhoods have the lowest GHG emission, at around 4 tons per household per year.

The averages of per square meter GHG emission do not vary greatly across the four typologies, all of which are around 70 kilograms per year. However, there is quite large variance within each typology group, which indicates the internal differences of unit sizes and urban forms among the neighborhoods in the same group.

**Figure 8-6. Annual Total Operational GHG Emission**



### 8.1.3 Multivariate Analysis on In-home Energy Consumption

Household energy source choice – especially in-home coal use – influences energy consumption and CO<sub>2</sub> emission patterns. The coal briquette offers a relatively cheap out-of-pocket energy source for low-income households, but the household coal stoves

perform relatively poorly in terms of efficiency due to incomplete combustion, while also posing environmental and health hazards. Therefore household energy source choice has significant impact on household energy consumption and GHG emissions. In our study, a binominal logit choice model is constructed to examine the household choice of coal use.

**Table 8-1. Energy Source Choice Model for Coal**

<b>Variables</b>	
Household Income	-
One Adult	Ref.
Two Adults	+
Three or More Adults	+
Elderly	+
Kid	ns
Rent Unit	-
Natural Log of Unit Area	-
Lowrise (1-3 stories)	+
Centralized Heating	-

\*\*Note: p<0.05

The regression reveals several significant correlations between social demographic features of households and the energy source choice of coal. Generally, households who have two or more adults, have elderly member or live in low-rises are more likely to use coal as one of their energy sources. Households with higher income or larger unit area are less likely to consume coal.

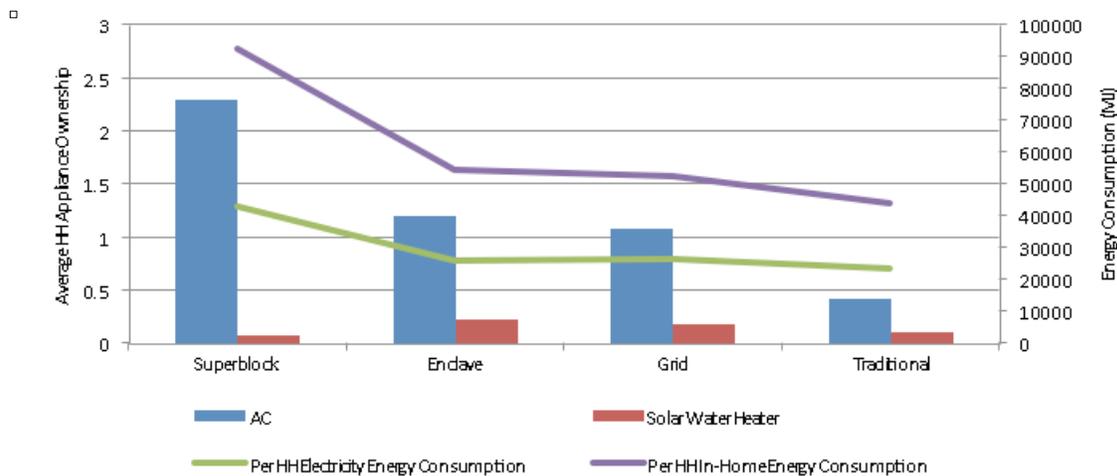
In particular, according to the regression result, households choosing to live in low-rise buildings are more likely to use coal. The coal briquettes, as the most common form of coal used in Chinese households, need to be lifted up to the floor on which the households live. Thus households in mid-rise and high-rise buildings are much less likely to use coal because lifting is a big problem. Also, installing coal stove in mid-rise and high-rise buildings is in some cases technically infeasible, given ventilation and fire prevention concerns. Since the dominant majority of low-rise buildings (1-3 stories) exist in the Traditional neighborhood, this neighborhood typology is associated with higher possibility of household coal use, holding all other variables constant. In other words, the Traditional neighborhood form “encourages” the use of coal. All else equal, in-home coal using households consume about 129% more energy and produce about 142% more CO2 emissions than those who do not use it.

Naturally, an important share of household energy consumption comes from the appliances the household owns. Appliance ownership and appliance usage represent inter-related decisions. That is, we purchase certain numbers and types of appliances based on how much we expect to use them – or the services that the appliances provide us. For example, if we have a very strong preference for a cool home in the summertime, we might be more inclined to purchase a very energy-efficient air conditioner (AC) in

expectation of high use; or, we may even purchase a home in a neighborhood somehow more “naturally” cooler.

Neighborhood form can influence household appliance ownership (e.g., AC) by increasing or decreasing the demand for the service provided (e.g., cool air). Neighborhood physical form influences the thermal and ventilation performance of buildings, with the most important factors being building interrelationships, orientation, and layout, considering the solar gain, wind flow and air exposure. **Figure 8-7** shows average household appliance ownership and energy use across the four neighborhood types. Superblock households tend to own slightly more appliances, on average, primarily due to higher incomes. On the cooling side, Superblock households have a much higher rate of air conditioner (AC) ownership, an effect influenced by income and dwelling unit size, but also, the characteristics of the Superblock typology itself.

**Figure 8-7. Household Energy Consumption versus Appliance Ownership**



Regression analysis indicates that air conditioners and the solar water heaters are the two appliances the ownership of which is most affected by neighborhood form.<sup>2</sup> To examine the impacting factors, a multinomial logit model is constructed for AC ownership, and a binominal logit choice model is constructed for solar water heater ownership, with the Superblock used as the reference case.

After controlling for all other variables, only households living in the Grid neighborhood are more likely to own one AC compared to Superblock households. Moreover, households in the Enclaves and the Traditional are all less likely to buy extra ACs (more

<sup>2</sup> Other electricity-consuming devices (fridge, TVs, desktop computer) are also associated with higher in-home energy use, but neighborhood type does not reflect a statistically significant relationship with ownership of these devices. TV ownership was similar on average across neighborhood typologies. Ownership of refrigerators and desktop computers decline on average from superblocks to enclaves, followed by grids and last traditional neighborhoods.

than one) compared to the Superblock households. This finding suggests that the Superblock and Grid neighborhood typologies “encourage” extra consumption of air conditioners.

**Table 8-2. AC Ownership Model**

AC=1	Variables		AC=2+	Variables	
	Household Income	+		Household Income	+
	One Adult	Ref.		One Adult	Ref.
	Two Adults	ns		Two Adults	ns
	Three or More Adults	-		Three or More Adults	-
	Kid	-		Kid	-
	Elderly	+		Elderly	+
	Rent Unit	-		Rent Unit	-
	Natural Log of Unit Area	ns		Natural Log of Unit Area	+
	Top Floor	+		Top Floor	ns
	Electric Heating	-		Electric Heating	-
	Superblock	Ref.		Superblock	Ref.
	Enclave	ns		Enclave	-
	Grid	+		Grid	ns
	Traditional	ns		Traditional	-

\*\*\*Note: p<0.05

Several potential explanations exist: Superblock households may have fewer out-of-home entertainment options (due to less mixed uses relative to the Enclave, Grid and Traditional neighborhoods), meaning people have fewer opportunities to “cool off” in the immediate neighborhood; the taller Superblock buildings -- exposed to the sun with typically no exterior shading -- accumulate more heat thus requiring more cooling; inoperable windows; and/or the Superblock residents simply have other unobserved lifestyle preferences that drive AC ownership. Another explanation is associated with the apartment size. The units in the Superblock neighborhoods usually have larger average unit areas (and therefore probably more rooms) than the other three typologies, which encourages residents to purchase extra air conditioners.

We find a statistically significant relationship between neighborhood typology and ownership of solar hot water heaters, with Enclave, Grid, and Traditional households having higher likelihoods of owning such devices. Although the model does not provide a good explanation for the variance in household solar water heater (SWH) ownership given a low Pseudo R<sup>2</sup>(0.0343), the neighborhood form implication is still meaningful.

**Table 8-3. Solar Water Heater Ownership Model**

<b>Variables</b>	
Household Income	ns
One Adult	ref.
Two Adults	ns
Three or More Adults	+
Rent Unit	-
Top Floor	+
Low-rise (1-3 stories)	+
Mid-rise (4-12 stories)	+
High-rise(13+ stories)	ref.

\*\*Note: p<0.05

From a building height perspective, the ranking for the likelihood of owning a SWH (high to low) is mid-rise, low-rise and high-rise. Solar water heaters can only be installed on building rooftops, reducing the likelihood that households in high-rise buildings will install the device given limited relative roof area and limited access to it, as in the case of Superblocks. In comparison, their predominantly mid-rise buildings with relatively larger roof areas, and well-organized building layout with moderate building-to-building distance make the Enclaves “solar friendly.” Households in high-rise buildings are much less likely to own solar water heaters. The underlying reason is the technical feasibility of SWH installation, given that SWH can only be installed on building roof. Since high-rise residential buildings primarily exist in the Superblocks, we are confident to conclude that the high-rise superblock neighborhood type “discourages” the use of solar energy. All else equal, households with solar hot water heaters consume about 3% less energy annually.

The solar/wind index and urban form variables are all derived from GIS analysis of the neighborhoods. The summer solar gain index, which is based on shading condition (shadow ratio) and the angle between solar beam and façade, measures the extent of solar gain in the summer. Porosity is defined as the fraction of the volume of pores (void spaces) over total volume. The hypothesis is that the more porous a neighborhood, the higher its heating energy load and the lower its cooling energy load will be.

Holding all other variables equal, the Enclave and the Grid households do not consume more electricity than the Superblock households. The traditional households however, will consume 36% more electricity. The most plausible explanation lies in energy source and building type difference. First, the lack of centralized heating systems in Traditional neighborhoods could result in many households using electricity as their major heating source. Second, low-rise detached or semi-detached buildings are less energy efficient compared to multifamily mid- and high-rise buildings, considering the shape coefficient (surface-volume ratio) impact. Buildings in the Traditional neighborhood are dominantly

**Table 8-4. Electricity Energy Consumption and GHG Emission Model**

Variables	
<b>Social-demographics</b>	
Household Income	+
One Adult	Ref.
Two Adults	+
Three or More Adults	+
Kid	+
Elderly	ns
Rent Unit	-
<b>Home Physical</b>	
Unit Area	+
Top Floor	ns
<b>Usage Control</b>	
Electric Heating	+
<b>Appliance Ownership</b>	
No Air Conditioner	Ref.
One Air Conditioner	+
Two or More Air Conditioner	+
Solar Water Heater	ns
<b>Neighborhood Typology</b>	
Superblock	Ref.
Enclave	ns
Grid	ns
Traditional	+
<b>Solar/Wind Index and Urban Form</b>	
Summer Solar Gain Index	+
Porosity	+
Floor to Area Ratio	ns
Building Function Mix	+

\*\*Note: p<0.05

single detached, thus they are expected to be more electricity-consuming with regard to space heating and cooling. In addition, the model also suggests that higher summer solar gain and porosity of the neighborhood increases electricity usage.

A full model covering electricity, coal and gas energy consumption is constructed, together with the total GHG emission model. Note that these models do not include centralized heating, which is roughly estimated by the unit size of each household due to the fact that centralized heating is not metered in China, and thus no empirical data is applicable to this energy consumption model.

As the models conclude, factors including higher household income, presence of more adults or kid in household, larger unit area, and owning two or more air conditioners are contributing to higher level of total energy consumption. Since electricity is included in

the model while centralized heating is not included in the total energy consumption, the access to centralized heating system decreases total energy consumption as those households save electricity consumption by not using electric heating. Residents in the Grid and Traditional neighborhoods are more likely to use more energy holding other factors constant. The solar and wind indices are also significantly correlated with household total energy consumption. As the previous electricity consumption model suggests, higher solar gain and porosity incurs greater demand for electricity usage for heating, cooling, and lighting.

**Table 8-5. Total Energy Consumption and GHG Emission Model**

<b>Variables</b>		
<b>Energy Sources</b>		
Gas	+	+
Coal	+	+
Centralized Heating	-	-
<b>Social-demographics</b>		
Household Income	+	+
One Adult	Ref.	Ref.
Two Adults	ns	ns
Three or More Adults	+	+
Kid	+	+
Elderly	ns	ns
Rent Unit	ns	ns
<b>Home Physical</b>		
Unit Area	+	+
Top Floor	ns	ns
<b>Appliance Ownership</b>		
No Air Conditioner	Ref.	Ref.
One Air Conditioner	ns	+
Two or More Air Conditioners	+	+
Solar Water Heater	ns	ns
<b>Neighborhood Typology</b>		
Superblock	Ref.	Ref.
Enclave	ns	ns
Grid	+	+
Traditional	+	+
<b>Solar/Wind Index and Urban Form</b>		
Summer Solar Gain Index	+	+
Porosity	+	+
Floor to Area Ratio	ns	ns
Building Function Mix	+	+

\*\*Note: p<0.05

In general, we find socio-demographics and home physical attributes significantly influence household energy source choice, appliance ownership choices, and thus overall energy usage. In terms of neighborhood typology, **Table 8-6** summarizes, qualitatively, the estimated relationship with household coal use, appliance ownership and operational energy use.

**Table 8-6. Qualitative Effects of Neighborhood Form on Fuel Choices, Appliance Ownership and Energy Use**

	Superblock	Enclave	Grid	Traditional
<b>Fuel Choice</b>				
Coal Use	n/a	ref.	ns	+
<b>Appliance Ownership</b>				
AC	ref.	-	-	-
Solar water heater	ref.	+	+	+
<b>In-home Energy Consumption</b>				
Electricity energy	ref.	ns	ns	+
Coal energy	n/a	ref.	ns	+
Gas energy	ref.	ns	ns	ns
Total energy and CO <sub>2</sub>	ref.	ns	+	+

Note: n/a: not available; ns: not significant; ref: reference case, meaning that the effects shown are relative to that case.

### 8.1.4 Conclusion

We find that neighborhood physical form significantly affects household energy use, but primarily through affects on fuel and in-home appliance choice, which in turn impacts final energy use. Holding all other variables equal, households living in Traditional low-rise neighborhoods are more likely to use in-home coal as an energy source, which, in turn, increases household total energy use and CO<sub>2</sub> emissions. Living in Superblock neighborhoods increases the likelihood of households owning more air-conditioners, which are also associated with higher household energy use and GHGs. On the other hand, living in Enclave, Grid, and Traditional neighborhoods increases the likelihood of a household using solar water heaters, which is associated with lower household energy use. We were able to detect through the surveys no *direct* effect of neighborhood typology on overall household energy use, although the sun exposure and wind undoubtedly influence heating and cooling requirements. Relative to in-home operational energy use, common area energy use (for elevators, etc.) represent a relatively low share of the total residential operational energy consumption, though it is more significant for Superblock typologies.

There are several key implications of these findings:

- ***The Enclave is the most energy efficient neighborhood form for Chinese cities.*** -- The Enclave features moderate compactness that is more thermo-efficient than the traditional neighborhood typology while avoiding the energy intensive building operating systems need to support Superblocks. The Enclave neighborhoods are also

more diverse in terms of recreation, communication and entertainment function, which may encourage residents to spend less time indoors using air conditioners and other electricity intensive devices. Enclaves are also the most likely to take advantage of solar energy and install solar water heaters (see also section 8.4)

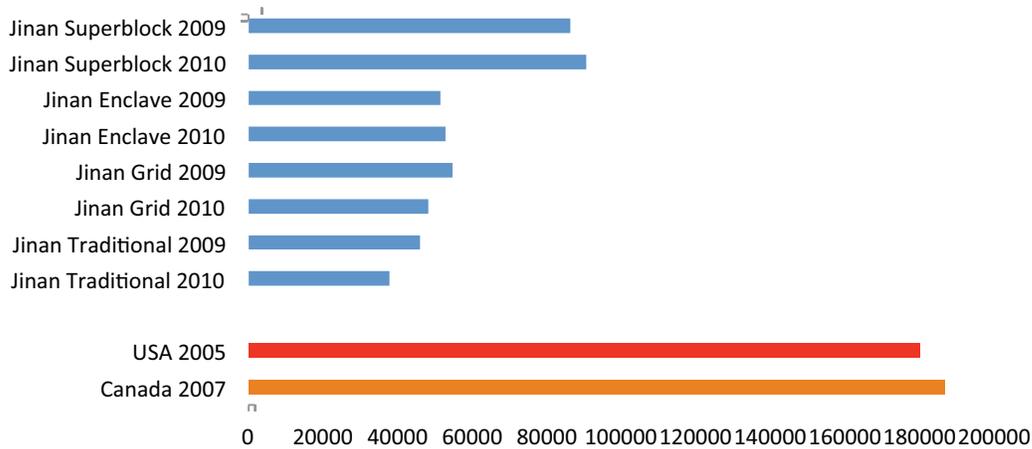
The Grid is also favorable because, as a high-rise community that is not gated, common area energy consumption serves both residents and the public (e.g. street lights) however this lack of privacy and security may be considered a drawback for potential residents. Its street life is also more diverse than the Enclave. As indicated by the AC ownership model however, residents in the Grid neighborhood are more likely to own one air conditioner than those who live in the Superblocks.

- ***Housing choice matters*** -- Operational energy consumption is first and foremost bundled into a household's choice of where and in what kind of neighborhood to live. In this analysis, household unit size was a strong determinant of operational energy consumption; therefore if a household chooses to live in a larger home for various reasons, it is likely their energy consumption will increase. Housing choice also may depend largely on location, which depending on the market and land values may already be driving the size of units in particular areas.
- ***China is catching up in operational energy intensity and emissions*** -- According to the result of our survey, the energy intensity and CO<sub>2</sub> emissions of the Chinese urban residential sector has started to catch up with industrialized countries, although the gap is still large. **Figure 8-8** shows the comparison of per household energy consumption among Jinan, US and Canada (EIA, 2005). Households living in Enclave and Grid neighborhoods represent the median income population group, and they consume less than 1/3 of US and Canada household average. The Superblock households represent the high-income population group, and they consume less than 1/2 of US and Canada household on average. The gap has significantly decreased compared to that in 1997, when Chinese urban households consumed less than 1/4 compared to US average (Zhang, 2004). From an emission perspective, the average Jinan household emission level (5.7 metric ton/year) is less than half of US average (12 metric ton/year). The gap is smaller than the energy consumption, probably because China uses much more coal than the other countries.

The decrease of energy consumption gap between China and industrialized countries can be attributed to the significant increase in urban household income in the past decade and emerging lifestyles. With income increase, Chinese households start to pursue a higher living quality through owning larger homes and more electronic appliances. Meanwhile, new neighborhoods also have more amenities to enable a convenient lifestyle, such as elevators, gyms and recreational landscapes. And almost exclusively they are being constructed as Superblock "tower-in-park" projects, the most energy consumptive form of development. All of these changes result in more intense energy consumption. Jinan is among the high-income mid-sized cities in

China, and its residential energy consumption pattern is highly representative of what other mid-size Chinese cities will be like in near future. Under rapid urbanization, it is expected that the share of residential energy consumption will keep increasing in the energy portfolio of China, along with its GHG emission impact.

**Figure 8-8. Annual Household Energy Consumption Comparison**

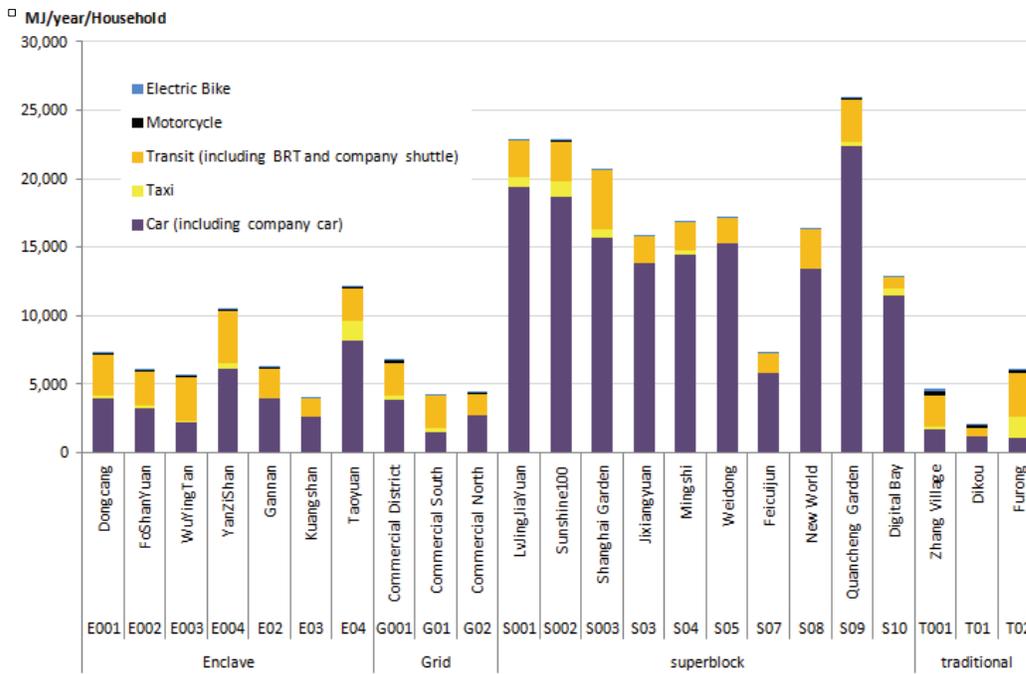


## 8.2 Travel Energy Consumption and Emissions

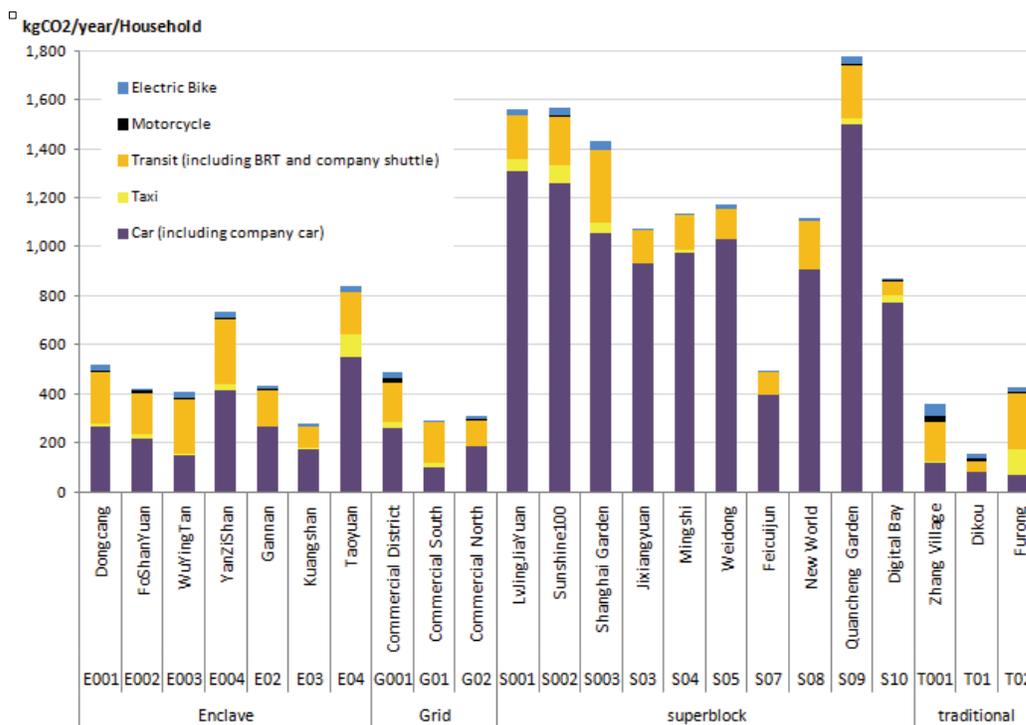
We now turn to energy used by households for travel. A comparison of household transport energy use across neighborhood types seems to suggest a strong connection between the two. Households in Jinan’s Superblock neighborhoods on average consume 2-3 times as much energy as other neighborhood types, while the differences among non-Superblock neighborhood types are relatively modest, with a few exceptions (**Figure 9**). The gap between the “superblock” and others is mainly explained by much higher car use.

Patterns of transportation energy use and GHG emission are also compared. As shown in **Figure 8-10**, the GHG emission pattern looks quite similar to that of energy consumption. Households in Superblocks emit more than twice as much as the amount emitted by households in other neighborhood types, with a few exceptions (e.g. “S07” Feicuijun). That said, one difference between patterns of energy and GHG emission is the contribution of E-bike: the share of E-bike use in total household emissions is larger than that in the total energy consumption. This implies that electricity in Jinan is more carbon intensive than the fuels.

**Figure 8-9. Average Household Transport Energy Consumption by Neighborhood**

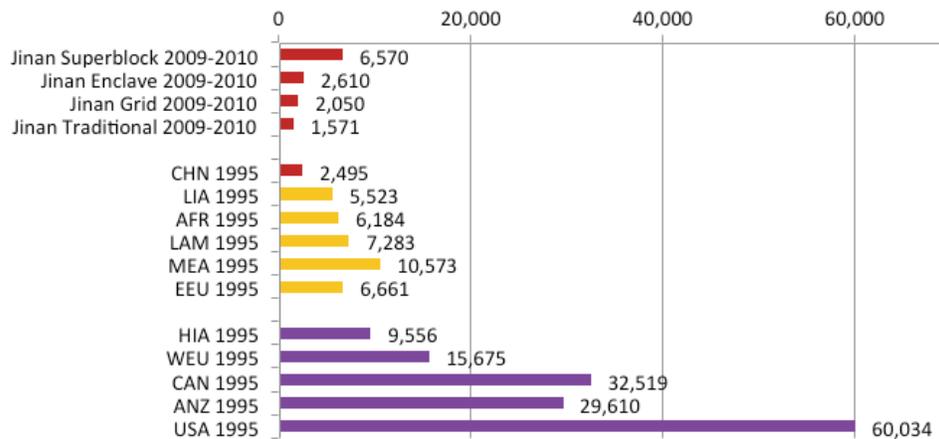


**Figure 8-10 Average Household Transport CO2 Emission by Neighborhood**



To put the estimated travel energy consumption numbers for Jinan into a broader context, we compare the calculated personal annual travel energy use in Jinan with similar figures for international cities. As shown in **Figure 8-11**, although Chinese still consume a relatively low level of transport energy compared to developed countries, consumption levels in the Superblock already comes close to that of affluent cities in Asia.

**Figure 8-11. International Comparison on Personal Annual Travel Energy Use**



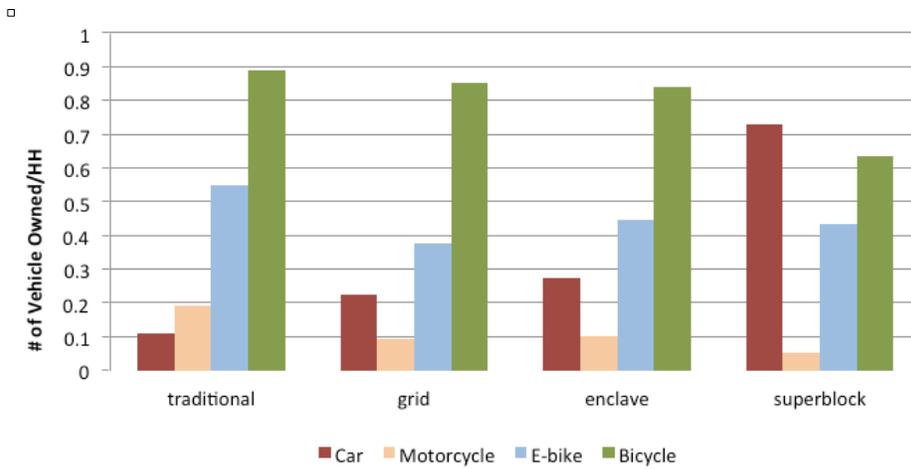
Notes: Data for international cities extracted from (Kenworthy, 2008), p. 215-220. USA- US cities, ANZ- Australia/New Zealand cities, CAN- Canadian cities, WEU- Western European cities, HIA- High income Asian cities, EEU- Eastern European cities, MEA- Middle Eastern cities, LAM- Latin American cities, AFR- African cities, LIA- Low income Asian cities, CHN- Chinese cities

### 8.2.1 The Two-Step Vehicle Ownership and Travel Energy Consumption Analysis

From **Figure 8-12** it is quite clear that urban households make very different vehicle purchase decisions to meet household members’ travel demand. Superblock households tend to own cars instead of motorcycles and bicycles, while e-bike ownership is somewhat consistent across neighborhood types.

It is essential to understand how neighborhood design influences households’ travel energy consumption in two steps by first considering vehicle ownership because: (1) travel energy consumption, which is mode-dependent, is conditioned upon vehicle availability; (2) methodologically, discarding the first step would result in ambiguous interpretation of factor’s marginal effects (if excluding vehicle ownership information) or biased estimates of parameters due to endogeneity (if including vehicle ownership information directly as explanatory variables). Similarly, the travel-related CO2 emission is conditioned on vehicle ownership. Therefore we will also specify a separate step-2 model for emission.

**Figure 8-12 Vehicle Ownership across Neighborhood Types**



Since the ownership of different vehicle types are interrelated due to their substitution nature for mobility (people owning cars are less likely to own motorcycles or e-bikes), we use the concept of “vehicle portfolio” to have a comprehensive set of vehicle ownership with five mutually exclusive alternatives:

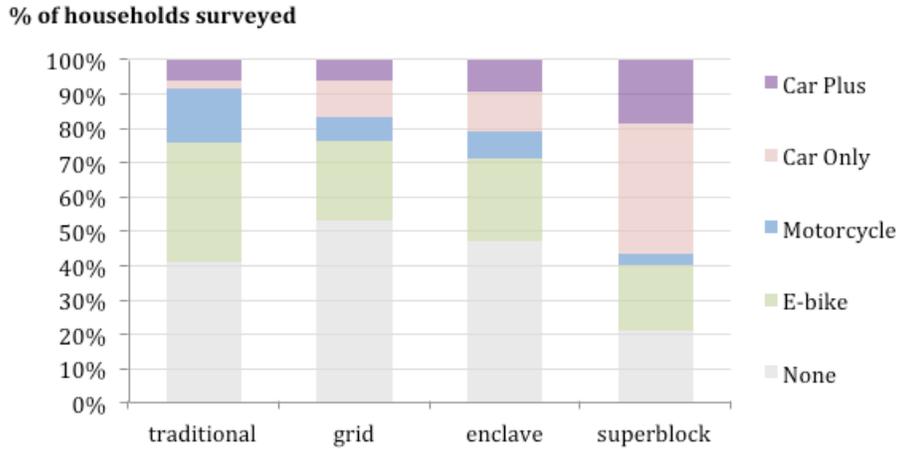
- “None”: owning no motorized vehicles
- “E-bike”: owning electric-bicycles only
- “Motorcycle”: owning motorcycles only or owning motorcycles and electric-bicycles
- “Car only”: owning cars only
- “Car-plus”: owning cars and other motorized vehicles including motorcycles or electric-bicycles, or both.

The vehicle portfolio ownership is shown in **Figure 8-13**. Compared to **Figure 8-12**, using vehicle portfolio we can see more clearly that the majority of households in Superblocks owns cars instead of motorcycles and e-bikes; while those living in Traditional neighborhoods highly depend on motorcycles and e-bikes. Around half of households in enclave and grid type neighborhoods do not own any motorized vehicles, implying their higher dependence on walking and public transit.

It is plausible to assume that richer households have higher travel demand thus consume more energy and emit more GHG emissions. Those rich households are more likely to be found in Superblock neighborhoods. However, **Figure 8-14** shows that even within a certain range of income, households in Superblocks still consume much more energy than those living in other neighborhood types. This suggests that the neighborhood typology

**Figure 8-13. Vehicle Portfolio Ownership Across Neighborhood Types**

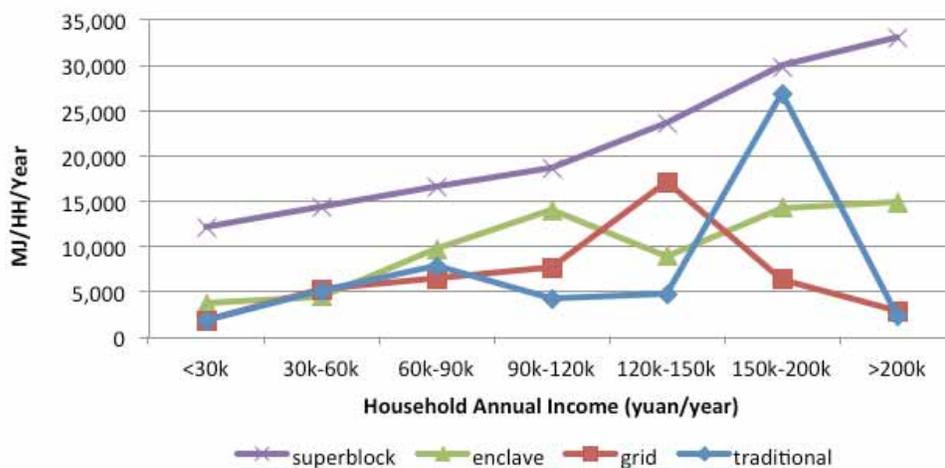
□



has its own impact on household transport energy use on top of the income effect. It is also interesting to see the lines of travel energy consumption and income have very different shapes: with income increasing, households in the Superblocks consume more travel energy monotonically, while the direction is reversed for the other three types at some point. Before we separate individual features of neighborhood type (e.g. design, accessibility, etc.) to better explain the patterns we observe and to help us make better energy-related policy, there are demographic and socioeconomic factors that influence travel energy consumption which have to be controlled for.

**Figure 8-14. Travel Energy Consumption by Income and Neighborhood Type**

□



These confounding factors are (**Table 8-7**):

- Higher household income is associated with higher probability of owning cars and lower probability of owning e-bikes. Higher income is also associated with more travel energy consumption and emission given same vehicle ownership.
- Households with more workers are more likely to own more vehicles, specifically cars; bigger families require more energy for travel, even with the same vehicle ownership.
- Having children in the household increases the likelihood of owning cars and other vehicles.
- Having senior people (>60 years old) in the family decreases the likelihood of owning cars and other vehicles. When senior people are head of household, their travel energy consumption is further decreased.
- Households who are renting are more likely to own motorcycles, but less likely to own cars.
- Having access to a company/business car decreases the probability of owning e-bikes, but increases the probability of owning cars and motorcycles, and it further increases energy consumption and emission even with the same vehicle ownership.
- Household attitudes regarding driving, biking and transit preference and perceived value of travel time seem to have a more direct weight on vehicle ownership than on vehicle use or energy consumption patterns. Car prestige is negatively associated with car ownership and positively associated with e-bike ownership. This perhaps reflects that in a rapidly motorizing society like Jinan, China, more car owners gradually regard the car only as a common travel means, while car status/prestige as a popular perception remains among people without car access yet. People who perceive taking bus convenient are less likely to own cars.
- People with higher value of time tend to consume more travel energy given the same vehicle ownership.

Controlling for household demographic and socioeconomic characteristics, we can then break neighborhood typology into separate design attributes. Marginal effects of neighborhood features on household transport energy use, as shown in **Table 8-8**, are simulated based on the two-step models. All neighborhood features have both direct impact on transportation energy use via vehicle use and indirect impact through the vehicle ownership- to- vehicle use chain. In terms of the magnitude of impacts, neighborhood characteristics are among the most important factors influencing household travel energy use and CO2 emission.

**Table 8-7. Marginal Effects of Confounding Factors**

	Step-1: Vehicle Ownership				Step-2	Step-2	Energy		Emission	
	E-bike	Motorcycle	Cars Only	Car Plus	(a)	(b)	d(ln_t_MJ)	change	d(ln_t_kgCO2)	% change
ln(household annual income in 1,000 rmb)	(0.05)	0.00	0.10	0.07	<b>0.43</b>	<b>0.29</b>	0.960	161.2%	0.724	106.3%
household size (number of household members)	0.03	-	-	0.02	-	-	0.075	7.8%	0.062	6.4%
no household member is currently employed	-	-	(0.13)	-	<b>(1.69)</b>	<b>0.37</b>	(2.281)	-89.8%	(0.102)	-9.7%
2 household members are currently employed	(0.01)	(0.00)	(0.01)	0.04	<b>0.44</b>	<b>0.37</b>	0.458	58.1%	0.390	47.8%
3 or more household members are currently employed	0.00	0.01	0.03	0.04	<b>0.64</b>	<b>0.55</b>	0.826	128.4%	0.709	103.3%
having children (<20 years old) in the family	-	-	0.03	0.04	<b>0.41</b>	<b>0.33</b>	0.598	81.8%	0.487	62.7%
having seniors (>=60 years old) in the family	-	-	-	(0.05)	-	-	(0.079)	-7.6%	(0.071)	-6.9%
renting	-	0.02	(0.09)	(0.05)	-	-	(0.490)	-38.7%	(0.400)	-32.9%
senior household: household head is over 60 years old	-	-	-	-	<b>(0.84)</b>	<b>(0.66)</b>	(0.836)	-56.7%	(0.657)	-48.2%
having access to a company/business car	(0.12)	0.02	0.04	-	<b>1.18</b>	<b>0.99</b>	1.206	234.0%	1.015	175.9%
driving is a sign of prestige	0.04	-	-	(0.02)	-	-	0.010	1.0%	0.002	0.2%
taking bus is convenient	-	0.02	(0.05)	(0.04)	-	-	(0.290)	-25.2%	(0.238)	-21.2%
I like biking	0.01	-	(0.03)	-	-	-	(0.114)	-10.8%	(0.091)	-8.7%
time spent on travel is a waste to me	(0.01)	(0.00)	(0.00)	0.02	<b>0.10</b>	<b>0.07</b>	0.110	11.6%	0.086	8.9%

**Table 8-8. Marginal Effects of Neighborhood Attributes**

	Step-1: Vehicle Ownership				(a)	(b)	Energy		Emission	
	E-bike	Motorcycle	Cars Only	Car Plus	energy	emissi	d(ln_t_MJ)	change	d(ln_t_kgCO2)	% change
residential density (# household per acre of land)	0.00	-	(0.00)	0.00	-	-	(0.007)	-0.7%	(0.006)	-0.6%
green coverage	(0.60)	-	0.52	(0.22)	-	-	1.255	250.9%	0.988	168.7%
average building footprint (sq.m)	(0.00)	(0.00)	0.00	-	-	-	0.001	0.1%	0.001	0.1%
average distance between neighborhood entries (m)	0.00	0.00	(0.00)	0.00	-	-	(0.000)	-0.01%	(0.000)	-0.01%
underground parking (sq.m. of parking space per household)	-	(0.00)	0.01	-	-	-	0.028	2.8%	0.022	2.2%
surface parking (sq.m. of parking space per household)	0.00	0.00	(0.01)	0.00	<b>0.10</b>	<b>0.07</b>	0.061	6.3%	0.037	3.8%
intersection density (# of intersections per km)	0.01	-	0.01	0.01	-	-	0.064	6.6%	0.052	5.4%
regional accessibility	(0.00)	(0.00)	0.00	(0.00)	<b>(0.00)</b>	<b>(0.00)</b>	0.009	0.9%	0.006	0.6%
road density	-	-	0.00	(0.00)	-	-	0.003	0.3%	0.002	0.2%
percentage of road with street-level shops	-	0.07	(0.23)	(0.12)	-	-	(1.283)	-72.3%	(1.043)	-64.7%
percentage of road with walking facilities	(0.08)	0.02	0.04	(0.05)	<b>(0.66)</b>	<b>(0.30)</b>	(0.698)	-50.2%	(0.339)	-28.7%
number of bus routes with stops within 500m radius	-	-	-	-	<b>(0.06)</b>	<b>(0.03)</b>	(0.055)	-5.4%	(0.035)	-3.4%
number of brt routes with stops within 500m radius	-	-	-	-	<b>0.24</b>	<b>0.15</b>	0.243	27.6%	0.151	16.3%

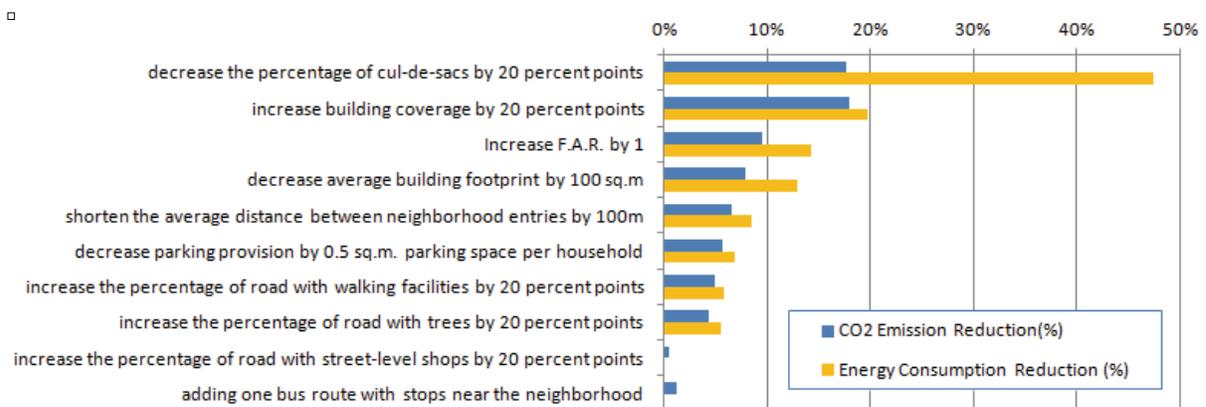
From the results we can see that:

- Higher residential density is associated with lower travel energy consumption and emissions, and it does so by decreasing the probability of owning cars and increasing the e-bike ownership.
- The higher green coverage is associated with greater travel energy consumption due to its association with higher car ownership: this might be explained by the fact that newly-built superblocks have significantly higher green coverage, which attracts many car owners due to some factors that are not controlled in our model.
- Larger average building footprint is associated with more travel energy consumption, also due to its association with higher car ownership.
- More underground parking is associated with higher travel energy use and emissions due to higher probability of car ownership (and lower of owning motorcycles).

- More surface parking provided in the neighborhood seems to be associated with more motorized travel, and also lower car ownership.
- Denser intersections (cul-de-sacs are also included) and denser road network within the neighborhood is associated with more vehicle ownership (both e-bikes and cars), therefore more travel energy use.
- Better regional accessibility is associated with higher car ownership, but given the same vehicle ownership, leads to lower travel energy use and emission.
- Higher percentage of roads inside the neighborhood with street-level shops is associated with lower car ownership and higher motorcycle ownership, which leads to lower travel energy consumption and emission.
- Higher percentage of roads with sidewalks and pedestrian paths is associated with higher ownership of motorcycles and cars, but much less travel energy use given the same vehicle ownership; the compound effect is less total travel energy and emission.
- Given the same vehicle ownership, more buses nearby are associated with less travel energy use but more BRT's are associated with more travel energy use.

The percentage change of household's travel energy consumption shown in the table above is associated with one unit change in the neighborhood attributes, but many indicators cannot change that much (e.g. the percentages). Besides, these neighborhood attributes have different scales and units. Therefore it is more helpful to simulate the effects on household's travel energy consumption and emission caused by the hypothetical change in the neighborhood attributes by a series of possible policy interventions. The results are shown in **Figure 8-15** below.

**Figure 8-15. Effects of Form Indicators on Travel Energy Consumption and CO2 Emissions**



### 8.2.2 *Implications and Conclusions*

From the empirical evidence from Jinan, there are several implications for designers and policy makers to reduce households' travel energy use and related emission:

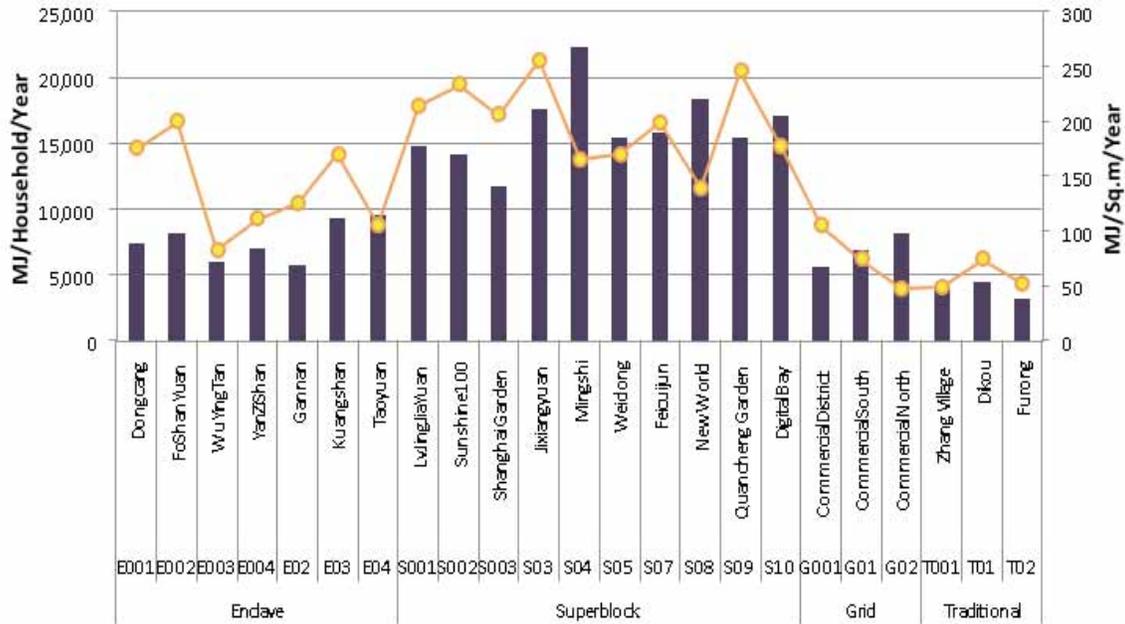
- Limiting parking within the neighborhood seems to be one of the most effective ways to reduce household's travel energy and emission. By limiting the underground parking, people seem to own fewer cars, and by limiting surface parking, people travel less.
- Designers should put an emphasis on walkability: adding roads with street-level shops, pedestrian paths, as well as sidewalks, not only improves the walking experience and quality-of-life for residents, but also reduces travel energy consumption.
- Higher population density does seem to be associated less travel energy use. However, when designing dense neighborhoods with high FAR, neighborhoods could aim for high building coverage but small footprint sizes and a dense road network (e.g. multiple small buildings, rather than one large building and smaller blocks versus superblocks).

### 8.3 **Embodied Energy Consumption and Emissions**

In order to explore the relationship between neighborhood typologies and embodied energy consumption, we first normalized the total embodied energy consumption by both the number of households and the size of each neighborhood. The results of our analysis are expressed in two different functional units: per household and per square meter of neighborhood size. On average, the Superblock neighborhoods have the highest embodied energy consumption both per household and per square meter while the Traditional neighborhoods have the lowest (**Figure 8-16**).

On average, approximately 16,000 MJ of embodied energy is consumed per household and 200 MJ is consumed per a square meter for constructing the Superblock neighborhoods. In particular, Mingshi would require the largest per household embodied energy, followed by Jixiangyuan. Normalized by the neighborhood size, Jixiangyuan have the highest embodied energy, some of the Enclave neighborhoods such as Foshan-Yuan have relatively high embodied energy. The Traditional neighborhoods in general would require only a fourth of the Superblocks' embodied energy consumption. The Grid cases with large commercial areas also have relatively low embodied energy possibly because the embodied energy consumption of commercial buildings was not included in the estimation.

**Figure 8-16. Annual Embodied Energy Consumption**



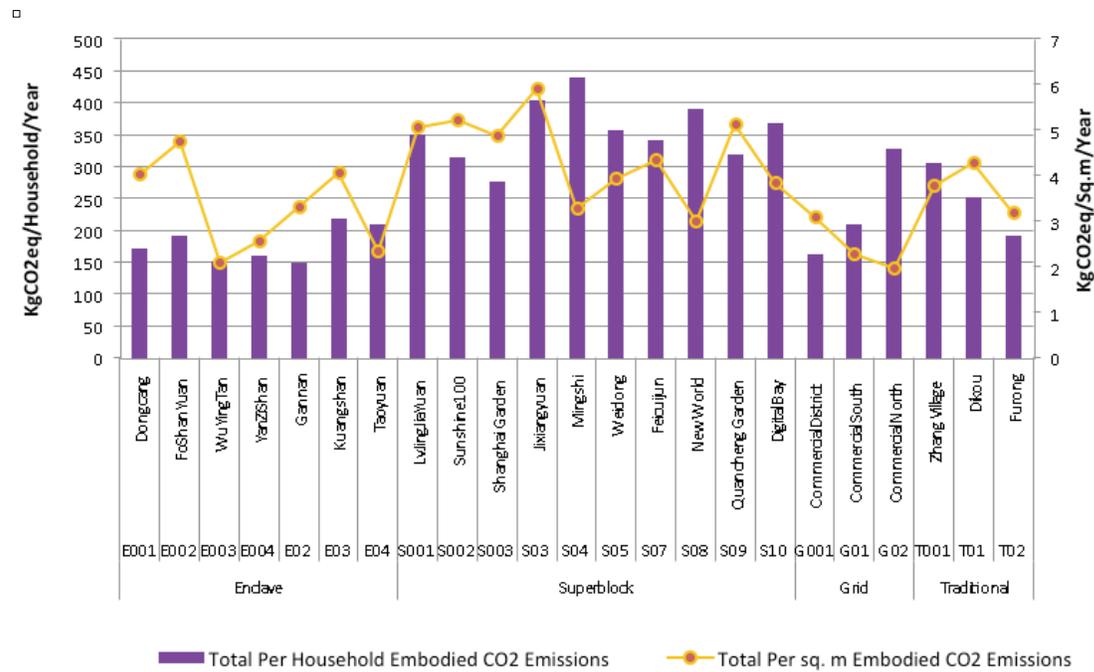
Typology	Enclave	Superblock	Grid	Traditional
Average (MJ/HH/Yr)	7,580	16,250	6,860	3,890
Average (MJ/Sq.m/Yr)	139	201	76	59

Embodied CO<sub>2</sub> emissions show slightly different patterns (**Figure 8-17**). First, the Superblock neighborhoods still have the largest embodied CO<sub>2</sub> emissions among all neighborhood typologies, with an average of 355 KgCO<sub>2</sub>eq per household and 4.5 KgCO<sub>2</sub>eq per square meter. Interestingly, the Traditional cases also have significantly large embodied CO<sub>2</sub> emissions while the Enclaves have the smallest. On a household basis, the Traditional neighborhoods emit 250 KgCO<sub>2</sub>eq and the Enclave neighborhoods emit 180 KgCO<sub>2</sub>eq. Such large difference may be due to the fact that the residential buildings in Traditional neighborhoods are constructed with carbon intensive construction materials such as bricks while residential buildings in the Enclave neighborhoods are constructed with less carbon intensive materials such as concrete.

### 8.3.1 Material Composition of Neighborhoods

Decomposing embodied energy consumption by construction material type suggests that the amount of annual embodied energy consumption per household largely depends on the range of materials used for construction (**Figure 8-18 and 8-19**). First, because the energy and carbon intensity of concrete is lower relative to materials like steel in which it

Figure 8-17. Annual Embodied CO<sub>2</sub> Emissions

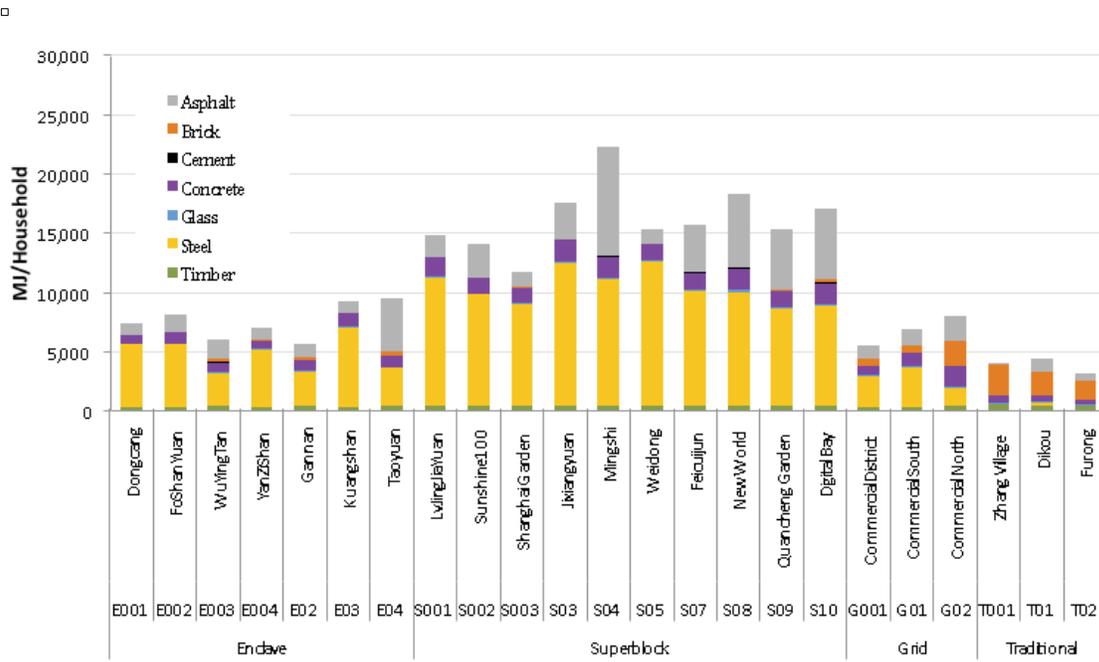


Typology	Enclave	Superblock	Grid	Traditional
Average (KgCO <sub>2</sub> eq/HH/Yr)	180	355	234	250
Average (KgCO <sub>2</sub> eq/Sq.m/Yr)	3.3	4.5	2.4	3.7

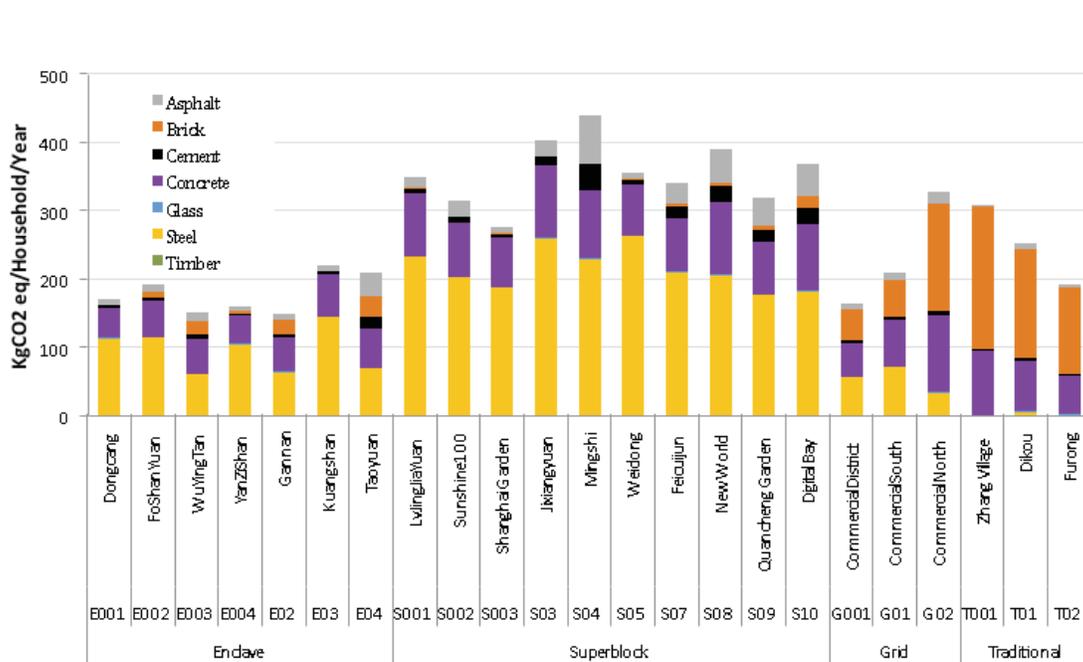
is frequently used in combination with, concrete accounts for a smaller percentage of per household embodied energy consumption and CO<sub>2</sub> emissions. On the contrary, steel and asphalt account for large embodied energy consumption and CO<sub>2</sub> emissions despite the small volume used, as they are energy intensive materials.<sup>3</sup> For example, in Mingshi, asphalt and steel account for only 6% and 16% in terms of material quantity as opposed to concrete (71%); in contrast, they account for 41% and 48% of per household embodied energy consumption, respectively. Brick contributes little to per household embodied energy consumption in the Enclaves and the Superblock neighborhoods but a lot to the Traditional neighborhoods. On average, it contributes to 2% and 0.3% of embodied energy consumption per household of the Enclaves and the Superblocks, respectively. In the Traditional neighborhoods, brick accounts for nearly 55% of the embodied energy consumption per household on average.

<sup>3</sup> The energy intensity of steel is approximately 22.3 MJ/kg. Its carbon intensity is around 0.48KgCO<sub>2</sub>/Kg. The energy intensity of asphalt is approximately 50.7 MJ/kg. Its carbon intensity is around 0.4 KgCO<sub>2</sub>/kg.

**Figure 8-18 Embodied Energy Consumption by Construction Material Type**



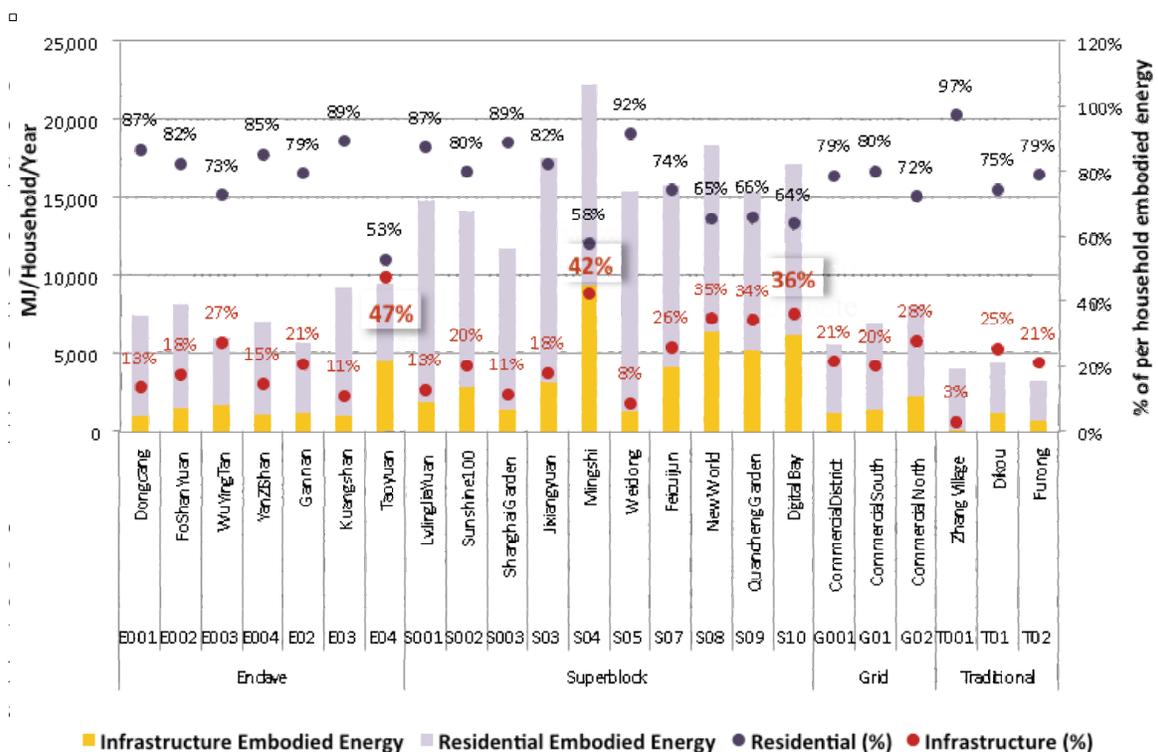
**Figure 8-19. Embodied CO<sup>2</sup> Emissions by Construction Material Type**



Examining the embodied CO<sub>2</sub> emissions by material type, concrete and brick now become significant contributors because of their high carbon intensity (**Figure 8-19**). The carbon intensity of cement, which is used for developing motorways, is approximately 0.84 KgCO<sub>2</sub>eq/kg, twice that of asphalt and steel. Thus, the neighborhoods with large motorways areas are likely to emit large amount of CO<sub>2</sub>. It is also important to note that the construction of the Traditional neighborhoods can be associated with large embodied CO<sub>2</sub> emissions mainly because bricks used for construction are highly carbon intensive. In Traditional cases, brick accounts for 66% of per household CO<sub>2</sub> emissions on average.

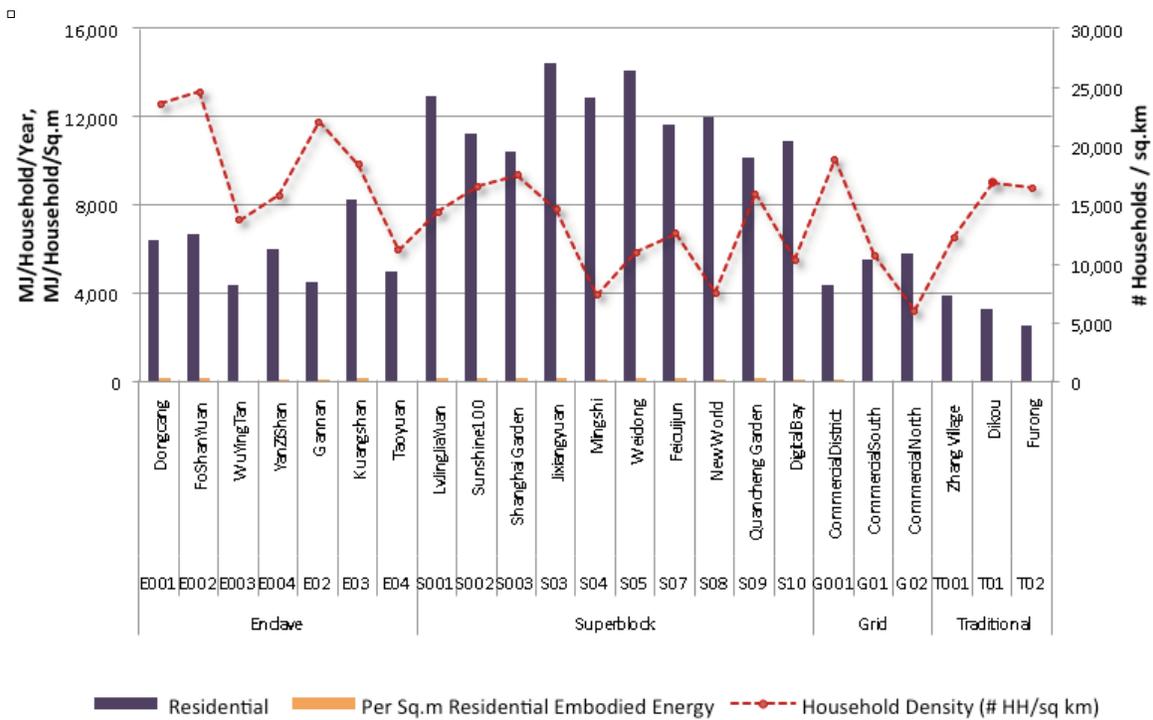
It is important to note that energy consumed in developing neighborhoods' road infrastructure system<sup>4</sup> including parking, particularly underground, is also a significant contributor to a high level of embodied energy consumption. Superblock neighborhoods, which have large paved areas, and low building coverage, require a large amount of embodied energy. For example, in the neighborhoods such as Mingshi and Digital Bay, infrastructure embodied energy consumption account for nearly 40% of the entire per household embodied energy consumption.

**Figure 8-20 Residential and Infrastructure Embodied Energy Consumption**



<sup>4</sup> In the revised embodied energy model, we included energy consumed in building motorways, paved sidewalks, pedestrian pathways, paved surface parking, and underground parking. Asphalt is used for motorways and paving surface parking; brick and concrete are used for sidewalks and underground parking. See assumptions in Table 1.

**Figure 8-21. Embodied Energy Consumption and Household Density**

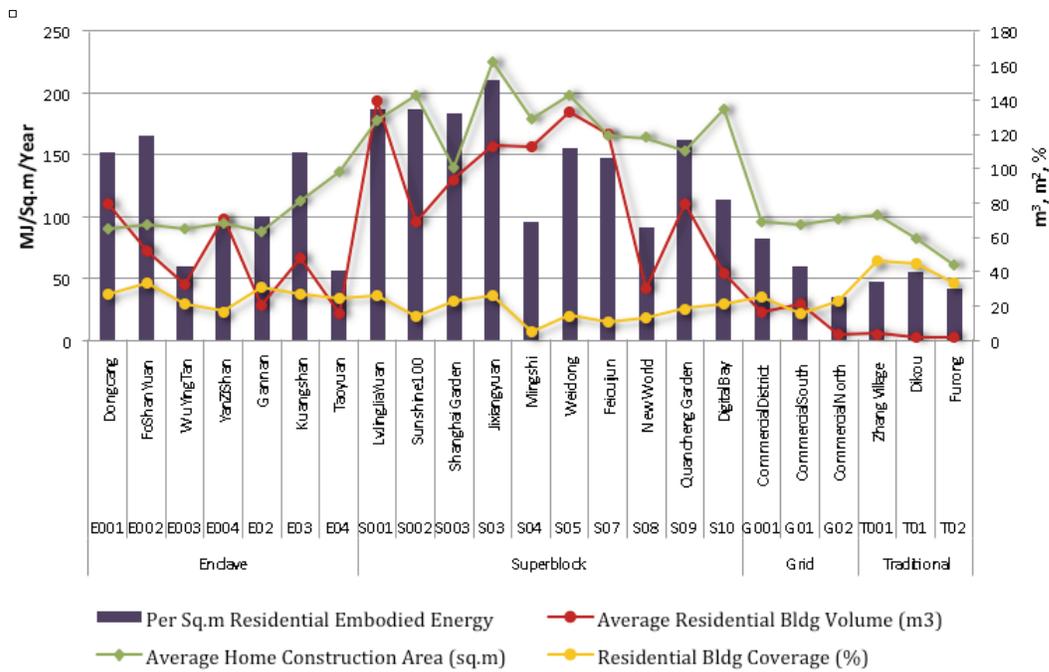


Based on observations from the first year of research, we initially hypothesized that the percentage of high-rise residential buildings or high building coverage<sup>5</sup> would be indicators of large embodied energy use per m<sup>2</sup>.<sup>6</sup> This analysis of 23 sample neighborhoods shows something different. First, it suggests that residential building coverage may not explain the range of per m<sup>2</sup> embodied energy consumption (**Figure 8-22**). For some superblock neighborhoods like Sunshine 100, building coverage is low (14.4%) but the embodied energy consumption is still high, because of their construction and underground parking. Similarly, the Traditional neighborhoods whose building coverage is approximately 47% on average do not have high embodied energy consumption, possibly due to the low building heights. However, the average building height, which is also an important density measure, also does not explain why some typologies may have higher per m<sup>2</sup> embodied energy consumption. For example, Minghi has the highest average building height but its embodied energy consumption is quite low. Our analysis does show however, that the *total building volume* and *average household unit area* may become a good predictor of neighborhood embodied energy consumption (**Figure 8-23**).

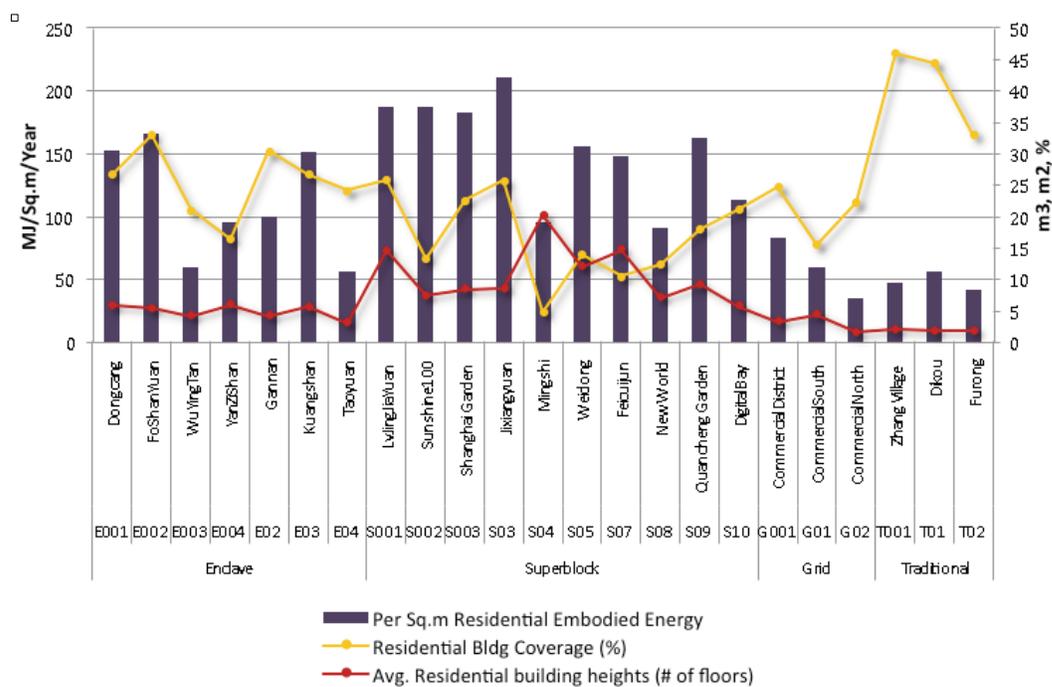
<sup>5</sup> Residential building coverage is the percentage of residential building footprint areas within each neighborhood.

<sup>6</sup> Residential building coverage and the average residential building height are the spatial density measures. Therefore, we examined the relationship between these measures and embodied energy consumption per m<sup>2</sup>.

**Figure 8-22. Embodied Energy Consumption and Neighborhood Density**



**Figure 8-23. Embodied Energy Consumption and Form Characteristics**



### 8.3.2 Conclusion

Our analysis suggest that on a per household basis, Superblock neighborhoods contain higher levels of embodied energy than the other neighborhood typologies; this is most strongly correlated with the large volume of the buildings and large household unit areas. Superblocks also contain the highest levels of embodied energy in their road and parking infrastructure. Nevertheless, when measured by square meter of residential construction area, the results are more variable across all neighborhood typologies, particularly in light of CO<sub>2</sub> emissions associated with the varying material compositions of the neighborhoods. We can see in **Figure 8-17**, that relatively high values of embodied energy emissions can be found in selected Superblock, Enclave, Grid and Traditional neighborhoods – an interesting finding considering that most buildings in the Traditional Zhang Village are low rise. Given this variability, and the potential variability of building designs within individual neighborhood cases, it seems reasonable to suggest that the embodied energy characteristics of a single building does *not* automatically yield low levels of embodied energy at a neighborhood scale. One must look at the total neighborhood composition including infrastructure. Neighborhoods that have consistency of form features across modestly constructed buildings with little common areas, and no underground parking (e.g. mid-rise Enclaves with moderately dense building footprints) do turn out to be relatively efficient in terms of embodied energy.

## 8.4 Renewable Energy Production

To explore the relationship between renewable energy potential and the urban form, we estimated the energy generation potential of rooftop and building façade solar photovoltaic panels (PV) and rooftop microturbines in four representative neighborhoods in Jinan.

As an example, Zhangjia Village is a Traditional low-rise high-density neighborhood. Its building coverage is 54%, the highest among the four neighborhoods. The average surface volume ratio is 0.32. Given such large roof areas, Zhangjia village should have advantage in solar PV energy potential. However, there are many traditional double slope-roof buildings in Zhangjia Village, which are not that ideal for solar PV integration. For these roofs, we can only assume the slopes facing the sun will integrate PV panels.<sup>7</sup>

In terms of the energy potential from the southern façades, buildings in the courtyard are inter-connected or perpendicular to one other, therefore parts of the southern facades are blocked by the connected buildings.<sup>8</sup> The average height of the buildings and the average

---

<sup>7</sup> In the simulation, we roughly assume all the roofs in Zhangjia Village are sloped. Two thirds of the buildings are situated along an east-west orientation, the slope of the roofs are 20 degrees and the vector of the roofs face the true south/north. The rest of the buildings run north-west with the same slope but the projection of the normal facing the true east/west. All the southward, westwards and eastward sides of the roofs could utilize solar PV panels.

<sup>8</sup> The exposed southern façade is estimated to be 20,800 square meters (We assume Zhangjia village are comprised of a) one third of the north-west buildings and b)two thirds of the east-western buildings. We only consider the southern

distance between the buildings are estimated to be six and four meters, respectively – which determines the spacing indicators of the whole neighborhoods and the effective sunlight hours on the solar facade. Because the building heights in Zhangjia Village are low, the wind speed over the roof does not reach the minimum wind speed for wind turbine installation. Therefore wind energy generation capacity is zero.

According to the simulation, Zhangjia Village’s renewable energy potential is 123 MJ/sq. m. All energy is generated from solar PV, where the roof-mounted PV contributes around 90%. The total renewable energy production is about one sixth of the annual total in-home energy demand and one third of the annual electricity demand per square meter. The roof shape decreases the renewable energy potential dramatically (**Table 8-9**). If the roofs were flat and installed with tracking PV panel fully, the renewable energy potential would be doubled to be as high as 250MJ/sqm, one third of home energy demand.

**Table 8-9. Renewable Energy Generation Potential of Four Neighborhoods**

Neighborhood	Renewable Energy Supply Potential	Solar	Wind	Total Electricity Consumption	Total In-Home Energy Consumption
Zhang	123	123	0	351.45	781
Dong Cang	115	115	0.1	376.94	802
Old Commercial	112	117.7	0.3	356.58	849
Sunshine 100	34	33.6	0.4	304.92	693

In comparison, the Dong Cang Enclave neighborhood is comprised of the east-west slab buildings with an average height of 16.4 meters. The north-south distance between two close buildings is 23 meters, determined according to the sunlight spacing regulation in the Chinese residential zoning code. Thus, the southern facades of the buildings in the enclave neighborhood get adequate sunlight throughout the year. In Dong Cang, there is just one tall building of 72-meters. We assume only this building could feasibly install urban wind micro turbines.

According to the estimation, the renewable energy potential for Dong Cang neighborhood in Jinan is estimated to be 115MJ/sq.m. Almost all the energy is from solar PV (**Table 8-9**). Of the solar energy, 80% is captured from the roof-mounted tracking PV systems. The wind energy does contribute to the energy mix, but its weight is very small, less than 1%. Due to the spacing requirement of the wind turbines, low wind speed and micro size of the blades, wind energy potential is low in the Enclave urban environment. Even for the

---

façade integration on the east-west buildings. We assume all east-west buildings are identical. The ratio of the short edge over the long edge is 1/3. The typical building layout plan is 19 meter south-north side by 9 meter east-west side on average. One-third of the southern facades are block by other buildings around. According to the GIS measurement, and the average building height is 6.3 meters, we can roughly estimate the exposed southern façade is about 20800 square meters).

highest building in Dong Cang, it will achieve a higher energy yield if it is integrated with solar PV.

In the old commercial Grid district, there are a variety of building types, as shown in **Chapter 6**, including high-rise towers of over twenty stories, mid-rise slabs and low-rise traditional courtyards. Although the average building height of the old commercial district is almost the same as the Enclave neighborhoods, the variety of the heights is much larger than other neighborhoods. In the old commercial district, there are six buildings that over fifteen stories. We assume these six buildings could install wind turbines.<sup>9</sup> For solar integration, the average building footprint and height derived from the GIS dataset were used to estimate the average dimension of southern façade and the average spacing factor<sup>10</sup>. The average distance between two closest buildings is determined based on the visual analysis on the plan.

**Table 8-9** presents the estimation results of the renewable potential in the Grid. In this analysis, the energy potential in the grid neighborhoods is almost as same as the enclave neighborhoods. This will contain some errors, for the shading effect on the roof of the buildings was neglected in the simulation – the real energy yield from the renewable might be lower. As is shown, the solar PV accounts for over 99% of the renewable energy generation potential of the grid.

Finally, the Sunshine 100 Superblock project is comprised of the towers that are more than 20 stories and some mid-rise slabs. The building coverage is the lowest among the four neighborhoods (14.4%), but the average building height is the highest, which is about 30 meters. In the simulation, we assume the roof of the seven highest towers will be installed with wind turbines, and the rest of the buildings will be integrated with PV panels. For spacing factor, the average height is used, and the north-south distance between two closest buildings is 60 meters, derived from the typical cluster.

The estimation result is shown in **Table 8-9**. The potential renewable energy supply is barely 34MJ/sq m/year, most of which derives from the solar PV generation. Even though 10% of the roof area is installed with wind turbines, their contribution is less than 2%.

#### ***8.4.1 Neighborhood Form and Renewable Energy Potential***

According to the simulation results, solar energy comprises more than 98% of the renewable energy potential in all four neighborhoods. Due to the slow wind speed resulting from the rough urban environment as well as the spacing requirements, wind turbines are less efficient for energy production than solar PV in Jinan.

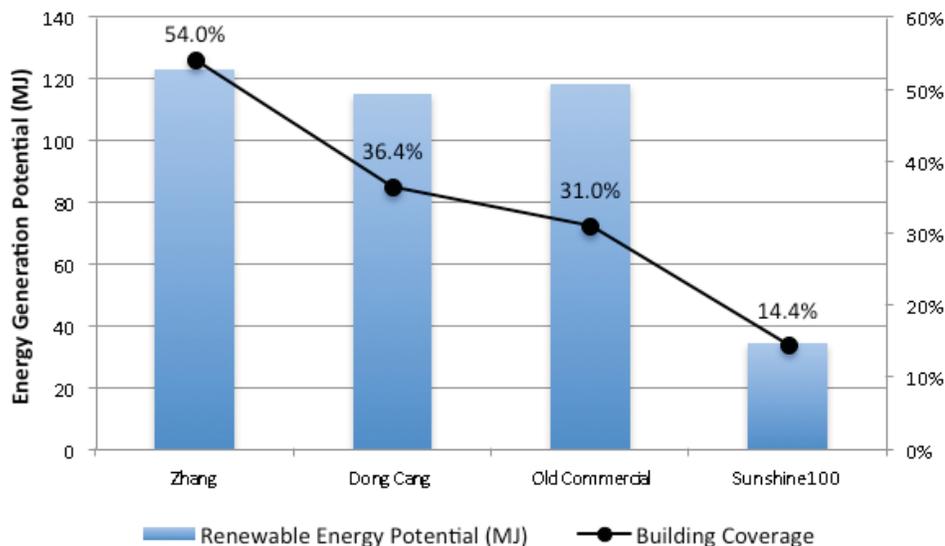
---

<sup>9</sup> In our simulation, we use the average height of 75 meters and the average roof area of the six highest buildings to estimate the wind potential. For the solar potential estimation, we use the average mass dimensions, ignoring the difference between the mid-rise and low-rise building.

<sup>10</sup> We use the average perimeter, height and the area of the building. We assume the ratio of the long edge over the short edge is 3. The average area of the southern façade is then generated.

For solar energy potential, urban form indicators influencing the roof and façade areas and solar potential – e.g. building coverage, surface to volume ratio and orientation – are the deterministic factors. **Figure 8-24** illustrates a positive relationship between renewable potential and building coverage in the Dong Cang Enclave, the old commercial district Grid and Sunshine 100 Superblock; the only outlier here is the Zhangjia Village, which has the highest building coverage, but not as much energy potential as Dong Cang. This is primarily due to the double-slope roofs discussed above.<sup>11</sup> So the shape of the roof also matters in renewable potential estimation.

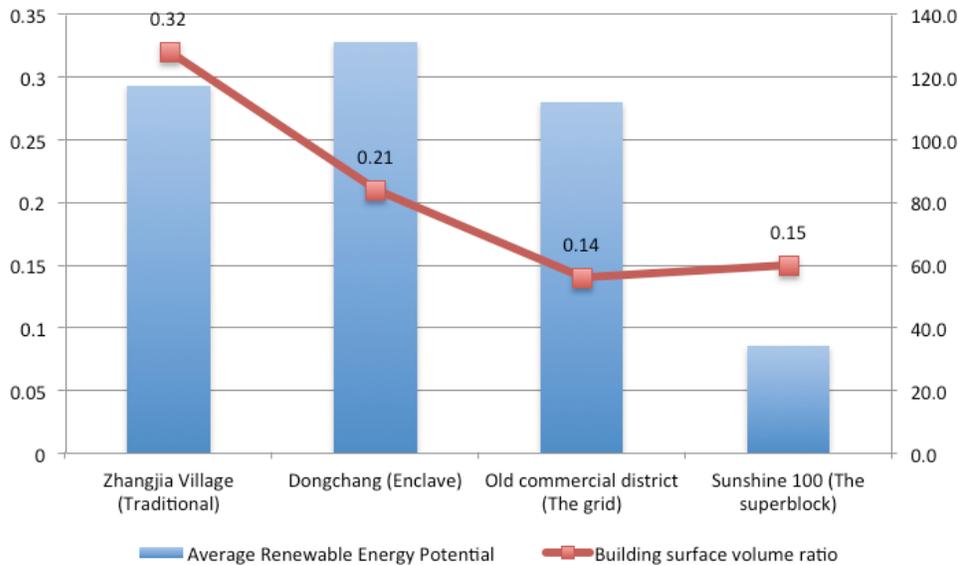
**Figure 8-24. Building Coverage and the Renewable Energy potential**



Building volume ratio matters to some extent. Zheng (2010) finds a positive correlation between the surface volume ratio and the renewable potential. The higher building volume ratio indicates higher renewable energy potential. However, the impact of the roof coverage seems to be more important. Old commercial street Grid and Superblock have almost the same building volume ratio, but old commercial district shows higher renewable energy potential due to more roof area in the total surface area.

<sup>11</sup> The double-slop roof can efficiently capture the solar energy only on the sunward side. The flat roof gives the possibility of installing the high efficient tracking PV system (in our simulation, we assume tracking PV panels are installed with all the flat roofs) with much higher energy yield per area.

**Figure 8-25. Surface to Volume Ratio and Renewable Energy Potential**



For renewable integration in Jinan, the key findings are

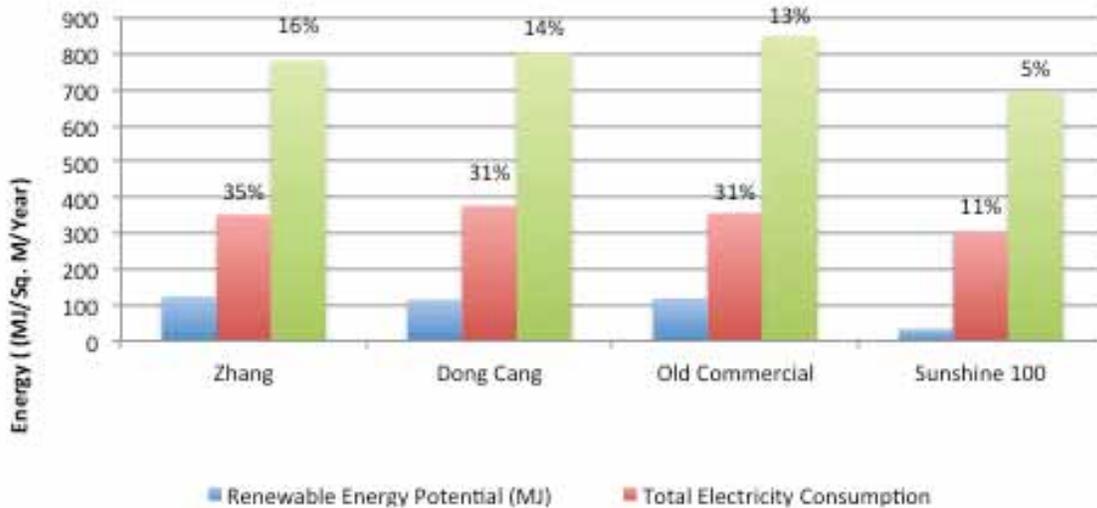
- Solar PV has significantly greater energy generation potential than wind; for renewable electricity generation in Jinan city, solar PV is more efficient per area.
- Higher building coverage provides greater opportunities for PV integration
- Flat roofs gives more potential and flexibility for PV integration
- Higher surface volume ratio allows for greater opportunities for PV integration

#### 8.4.2 Meeting energy demand

On-site energy generation reduces the building energy demand from the grid. Through studying the existing household operational energy consumption from surveys with its the energy potential by building area among the four Jinan neighborhoods, we found Dongchang Enclave and Zhangjia Traditional neighborhood are the most self-sufficient.<sup>12</sup> As it is shown in **Figure 8-26**, in terms of energy produced and/or consumed per unit area, the on-site energy production in both neighborhoods can supply roughly a third of in-home electricity use. Sunshine 100’s performance is the worst – it is renewable energy potential is lowest and it could only contribute 11% of electricity for the neighborhoods.

<sup>12</sup> The household energy consumption data are drawn from Jiyang Zhang’s thesis. The data are the analysis of household energy surveys done by Shandong University, an important partner in Making the Clean energy cities in China project supported by Energy Foundation China, covering 2,700 households in nine neighborhoods representing four neighborhood typologies.

**Figure 8-26. Renewable Energy Potential and In-Home Energy Consumption**



#### **8.4.3 Limitations and future work**

Our renewable estimation only explores the potential supply from solar due to PV and wind. Note that solar hot water follows the same principles as PV and its viability in various neighborhood forms may be inferred from the analysis; use of roof surface for solar hot water as opposed to PV may save even more energy in some cases. In addition, geo-thermal, bio-mass, cogeneration and micro-hydro power should be taken into account in the future.

While our studies show that there is an important relationship between neighborhood form and renewable energy potential, the estimation of the energy potential is based on some rough assumptions. For example, we assume there is no shading on the roof for PV generations and we ignore the shading effects of the PV panels on each other. Finer grain assumption and more precise estimation can be carried out in the future.

## 9 Urban Form and Energy Performance

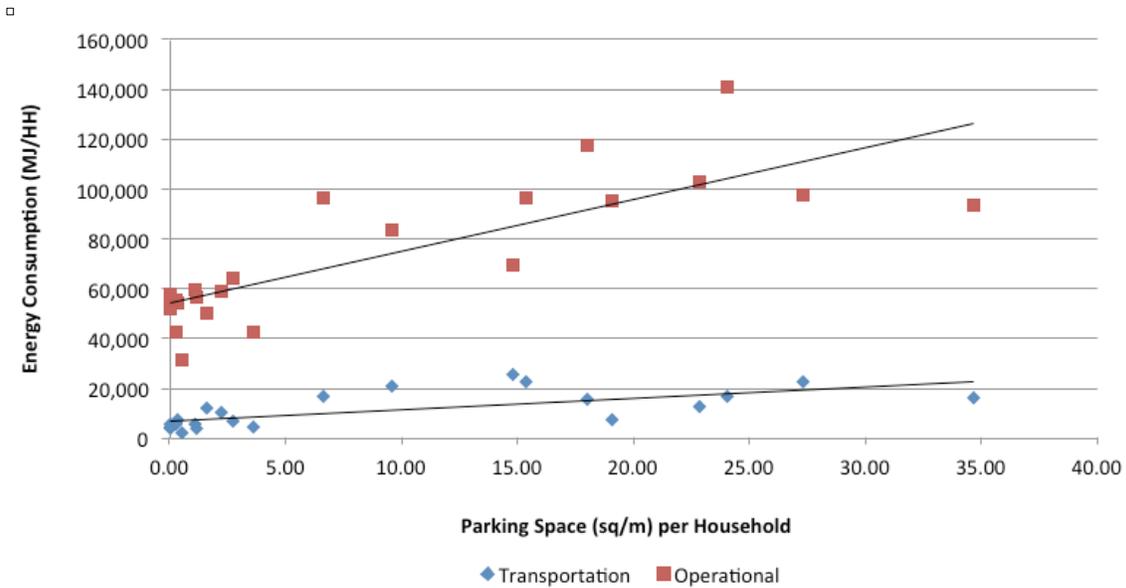
This chapter sums what we have learned from the empirical analysis about the relationships between neighborhood form and energy performance. Our findings are framed by the fact that our data has been drawn Jinan; nevertheless, we feel they have wider implications for neighborhood design in China. And as we will see in the next section, many (but not all) of our findings parallel what can be learned through study of best practice and demonstration cases of low carbon neighborhood design.

### 9.1 Limitations of the Superblock Neighborhood Form

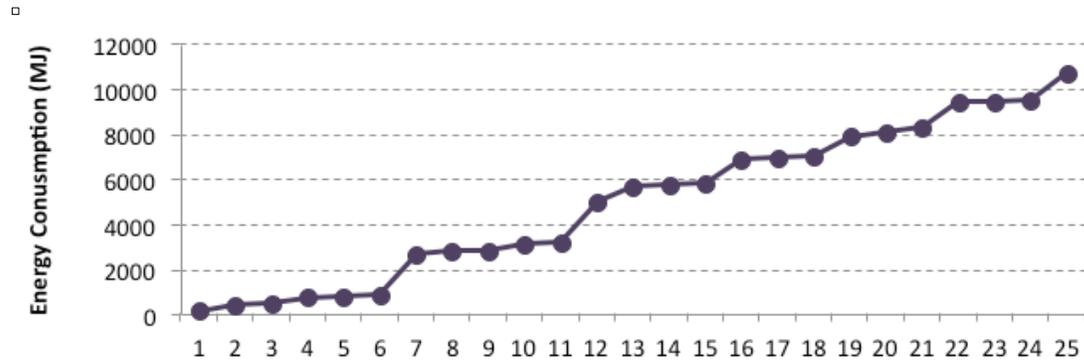
The housing and transportation trends in Jinan described in **Chapter 5** and the analysis of in-home and transportation energy consumption of twenty-three Jinan neighborhoods in **Chapter 8**, illustrate how the gated, Superblock, “tower-in-park” form of development is being offered by the market, shaped by public policies and regulations, as the model neighborhood form for households with increasing income, car ownership, and “modern” lifestyles. These Superblock neighborhoods, incorporate larger units, more parking space, greater amounts of open private green space, and more access control than other neighborhood typologies existing in Jinan (but less access to amenities, shops and services). These characteristics are also the greatest drivers of energy consumption. Larger units (and more income) encourage the purchase and plug-in of a greater number of electric-powered devices, such as air conditioners, drastically increasing in-home operational energy consumption. Higher car ownership, which is the most potent driver of transportation-related energy consumption, is exacerbated by the need to drive to accomplish almost all the daily activities of living – from food to medical services. As well, common-area operational energy consumption is increased, since parking is situated in energy-intensive underground garages. This relationship is illustrated in **Figure 9-1**, which demonstrates the relationship between parking space per household and operational and transportation energy consumption.

Other design characteristics of Superblock neighborhoods also dramatically impact common area energy consumption, as compared to other neighborhood typologies. **Figure 9-2** shows that that common area energy consumption per household increases rapidly as building height increases. For buildings lower than 6 stories, the consumption is very low since elevators are not typically installed. For buildings of 25 stories or higher, pump and elevator energy consumption will exceed 10,000 MJ/yr, nearly 20% of the in-home energy use of an average household (e.g, in the case of Shanghai Garden). The underground garage – a nearly inevitable outcome of the combination of high rise, compact land use in Jinan and increasing vehicle ownership – requires intensive lighting and ventilation. In short, high-rise development increases common area energy consumption.

**Figure 9-1. Total Parking Space per Household (sq.m./HH)**



**Figure 9-2. Relationship Between Building Height and Common Area Consumption**



These findings need to be understood in light of the key finding in **Chapter 6** that the Superblock neighborhoods, despite their tall buildings, do not offer any significant increase in population density compared to other forms of neighborhoods, such as mid-rise slab Enclaves or *hutong* style Traditional villages. This highlights a major liability in the current in the current neighborhood form being promoted by public development policy and regulations across China from an energy perspective, and we would argue from a livability perspective as well. There is no evidence that we can find in Jinan to show that the Superblock form of development is contributing to more efficient land or energy use, or that it is only form of development desired by upwardly mobile Chinese. It is, however the only form of new housing being made available.

## 9.2 Adjusting Urban Form to Improve Energy Performance

There are a number of key, discreet urban design variables that impact energy consumption across neighborhood typologies (beyond income, household composition, unit size and electric-device and car ownership as discussed above).

### 9.2.1 *Operational Energy*

In general, increasing the summer solar gain index or the “porosity” (negative of building volume) of a neighborhood will increase in-home operational energy consumption. A high summer solar gain index means that the solar exposure (taking into account shadows, solar angle, and surface to volume ratio) is intense during the summer months. This will induce heat gain in buildings walls and spaces and subsequently, increase AC use, which as illustrated in **Chapter 3** is one of the largest growth areas in energy consumption in China today. Conversely, solar heat gain can be an asset in winter months; unfortunately many buildings in China are generally hooked into centralized heating systems and households cannot modulate heat delivery to take advantage of this, although this standard is changing to individual thermostats.

Greater porosity means that the total volume of built spaces as compared to the 3-D volume of the neighborhood is less. Greater porosity decreases building-to-building interaction, decreasing shading (increasing solar gain) and, if the average footprint of building in the neighborhood is low (e.g. a ‘tower-in-the-park’ form) may result in greater heat loss in winter.

### 9.2.2 *Transportation Energy*

As illustrated in **Table 8-7**, design variables that increase transportation-related energy consumption are increased parking (both surface and underground), regional accessibility factors, the number of intersections (a measure of accessibility), and green space coverage. While it seems counter-intuitive that increased green coverage would increase transportation energy, it must be thought of in terms of neighborhood form. The presence of large green areas is highly correlated with car ownership, suggesting that this is mostly an indicator of the high level of green space in Superblock neighborhoods, which are highly auto-oriented.

With respect to intersections, we found on a raw level that the greater the number of intersections per unit area, the higher the transportation use and related energy consumption within the district. This is logical (more roads equals more movement) but may seem to contradict the conventional wisdom that more streets and smaller blocks induce greater use of non-motorized transport and less use of cars. In fact, increasing the density of neighborhood grids induces all kinds of trips, including driving as well as walking and biking. The conventional wisdom does hold true if we take into account the design nature of the streets. The more that denser road networks are equipped with pedestrian and streetscape amenities -- like sidewalks, shops, and trees -- the more they

encourage pedestrian use. So on balance travel energy consumption of a dense, pedestrian oriented street grid is less than that consumed by a system of streets that are more widely spaced and less people oriented.

Finally, increased building coverage coupled with smaller building footprints also reduces energy. This suggests that built spaces should cover a significant portion of the neighborhood (as opposed to towers in a park) but that individual buildings should be small, not compressed into monolithic Superblock structures that are not human scale discouraging walkability and multiple use.

### ***9.2.3 Embodied Energy***

The analysis finds that the most important indicators of high embodied energy consumption are neighborhoods with a greater area of road infrastructure and buildings with large volumes. Again, these characteristics typify Superblock neighborhoods, which on a per household basis contain higher levels of embodied energy than the other neighborhood typologies. That said when calculated by square meter of residential construction area, the results are more variable across all neighborhood typologies, particularly in light of CO<sub>2</sub> emissions associated with the varying material compositions of the neighborhoods. Essentially, the embodied energy characteristics of a single building do *not* automatically yield low levels of embodied energy at a neighborhood scale. In general, neighborhoods consisting of mid-rise buildings with moderately dense building footprints turn out to be relatively efficient in terms of embodied energy.

### ***9.2.4 Renewable Energy***

The analysis of renewable energy generation potential finds that the potential of generating energy from solar PV is exponentially greater than generating energy from micro wind turbine technology. To that end, the only design characteristic favoring wind generation is tall buildings, or buildings at the edges of major urban open spaces, as typified by Superblock neighborhoods. Unfortunately, these neighborhoods have the least advantage in capturing solar energy. The urban design characteristics that most improve the renewable energy generation potential from PV integration are increased building coverage, high surface to volume ratio and south-facing orientation. These design factors are intuitive, high building coverage allows for greater roof area and solar orientation increases the efficiency of the PV system.

### ***9.2.5 Conclusion: Moving away from the Superblock***

The results of all four energy component analyses strongly suggest that the Superblock typology is not an energy-efficient urban form. Such projects typically have buildings with small footprints but large volumes and mechanical system requirements, and they are characterized by large open spaces, large blocks with low intersection density, and surrounded by wide streets unfriendly to pedestrians. They are highly porous yet despite

high summer solar gain, cannot take as great an advantage of solar energy generation technology.

While public policy makers have clearly deemed this typology desirable, and developers are providing it, there is a trade off between amenity value – such as elevators, underground parking, and large private green spaces – and neighborhood energy consumption. The analyses suggest that alternative neighborhood typologies can maintain the density and perhaps even unit size of typical Superblocks in a more moderate form that confers greater holistic energy efficiency benefits, not to mention more livable urban design. Grid, Traditional, and Enclave typologies demonstrate different combinations of energy reducing design characteristics, illustrating that there are multiple neighborhood form patterns that can achieve high levels of energy performance.

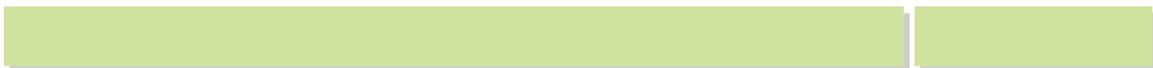
This is even more evident when considering the fact that while several individual urban form variables demonstrate statistically significant impacts on energy consumption, the urban form *typology* variable did not demonstrate consistent results. There are several factors external to urban form, per se, that have shaped energy consumption in the different neighborhood typologies of Jinan, as described in **Chapter 4**. The conditions for modeling empirical data about typologies in Jinan (and China) is limited by the fact that the different typologies were constructed almost wholly at different times in history and therefore were built at different levels of construction sophistication (insulation, central heating) and are supplied by different energy sources. Therefore, energy consumption data is not fully comparable across a level playing field. In another context where different urban form typologies were built contemporaneously using the same level of sophistication, they may very well show marked differences in energy consumption. This is supported by the fact that even in Jinan, *the energy consumed on a per meter basis in new high rise Superblocks is not less than 100 year old Houtongs*. In other words, older neighborhood typologies performed as well as Superblocks, despite the fact that they are built to less efficient construction standards and that their energy is supplied with more carbon-intensive fuel sources. Factoring in adjustments for these deficiencies would almost certainly show the greater urban form benefits of the other neighborhood typologies, even if it were not statically demonstrable given the empirical data we have.

The *Energy Proforma* tool, introduced in Chapter 11, allows users to hold these factors (such as building efficiency, fuel supply and energy use mix) constant and observe solely the impact of urban form changes on energy performance. Observing the relative impacts of these indicators is critical for informing urban designers how design choices lead to tradeoffs in energy consumption. This process is explored at greater length in the following chapters.



## **Section IV**

### **Developing the Clean Energy City – Patterns, Proforma, and Policy Recommendations**





## 10 Developing the Clean Energy City: Patterns and Tools

The overarching goal of the Clean Energy research is to design urban neighborhoods that have high energy performance, that is, which are formed in such a way as to minimize energy consumed in their construction and daily patterns of living, while maximizing the potential for generating renewable energy on-site. This goal raises two sets of questions about design: Firstly, do such neighborhoods currently exist? If so, what are their physical characteristics? In the first year of the research, we focused on answering these questions by scanning best practices in neighborhood design. Case projects drawn from across the world provided a benchmark for our work, while their limitations demonstrated the need for a more comprehensive approach. In the second year, questions have focused more on applying the tools we are developing to advancing the state of the art: If we apply the Energy Proforma to design clean energy neighborhoods, what kinds of neighborhoods would result? How would they compare to, and improve on current practice? This chapter summarizes what we have learned to date from existing projects, as well as our experience in applying the Energy Proforma to design neighborhoods. Gleaning lessons from both exercises, we conclude by defining a taxonomy of clean energy neighborhood design types to inform future practice and policy.

### 10.1 Best Practice Cases in Clean Energy Development

If rating systems reflect the state of the art in clean energy design policy, development projects reveal the state of practice. Over the past two decades, a growing number of projects claiming to be sustainable and energy efficient have been built. Many are model projects sponsored by governments or developers truly interested in innovation. Others are simply schemes to attract attention. What are the most successful cases? How can we compare them? What lessons do they hold for designing clean energy cities in China?

To answer these questions, in the first year of our research on making Clean Energy Cities in China we reviewed the many “sustainable” development projects worldwide to help understand whether and how they are energy efficient and to select and organize cases of best practice. Starting from a candidate list of hundreds of projects that claim to be energy efficient, we worked through several layers of analysis, to identify 25 examples of best practice. Of these, eleven representative projects were selected for study in detail, as shown, for example, in **Figure 10-1**. The collection of representative projects and their key characteristics are summarized in **Figure 10-2**. The entire process of selection and analysis is presented in *Making Clean Energy Cities in China: First Year Report* and accompanying documents.

To characterize the selected projects, they are all at the scale of urban neighborhoods, where complex interrelationships among buildings, spaces and streets shape human activities. They represent a range of types of development. All of the projects have been



### Photos

© 2010 Massachusetts MIT, China

### Three Dimensional Organization

© 2010 Massachusetts MIT, China

### Unit Plan

© 2010 Massachusetts MIT, China

### Energy Summary

**Energy performance**

- **Goal of 200 kWh/m<sup>2</sup>/year**
- **Actual performance is 8.8 gpcdd (100 kWh/m<sup>2</sup>/year) on average (through 8 months from 200 to 200 kWh/m<sup>2</sup>/year)**
- **Average household footprint consumed 200 kWh/m<sup>2</sup>/year**
- **20-50% reduction based on average household footprint**

**Energy sources**

- **Geothermal heat pump: 4 million kWh/year, 30% of total demand**
- **Photovoltaic: 0.2% of total demand**
- **On-site biomass (biogas) heat generation: 2% total demand**
- **Local collection: 10% heat and hot water demand**
- **Local biomass (biogas): 1.5 megawatts, 10.2% total demand**
- **Attribution substantially between providing excess savings for city grid and lowering bills to city electric**

**Insulation**

- **Geothermal heat exchange system for the district is likely the major source of energy cost reduction, providing 30% of heat load in the winter. Grid also contributes to cooling in the summer. Failure to find these underground resources could lead to no net saving for cooling.**
- **Proven solar energy collection contributes a significant amount to total energy consumed for hot water and heating, but not total carbon footprint of the building.**
- **Photovoltaic energy production is a small percentage of total demand due to the relatively small area of the solar collectors for cooling.**
- **Features on a building/neighborhood may also have a significant impact:**
  - **Photovoltaic thermal achievement: 10% on-site heating, biomass for hot water, cogeneration system, and better connections may reduce energy consumption.**
  - **Proving benefit to 0.7 units and households.**
- **Energy use feedback mechanisms can significantly reduce consumption, in one response, one building achieved the goal of being reduced by overall consumption by 40% in two years.**
- **Grids, particularly smart grids response, begin effort to city, when not only the question of sustainability, but also of economic feasibility.**
- **While, critical to realization of energy-saving facilities, they contribute to the target reduction in energy consumption.**
- **Delivered by nature, the nature of individual energy saving features and impact of energy saving.**

© 2010 Massachusetts MIT, China

### Additional Info

#### Energy Consumption by Residential Building

Building name	Area	# Rooms	Year Built	Total Building m <sup>2</sup>	Total Energy m <sup>2</sup>	Average Consumption kWh/m <sup>2</sup>
Residential	24,000	1,000,000	2000	24,000,000	2,400,000	100
Hotel	24,000	1,000,000	2000	24,000,000	2,400,000	100
Office	24,000	1,000,000	2000	24,000,000	2,400,000	100
Shopping	24,000	1,000,000	2000	24,000,000	2,400,000	100
Government	24,000	1,000,000	2000	24,000,000	2,400,000	100
Education	24,000	1,000,000	2000	24,000,000	2,400,000	100
Healthcare	24,000	1,000,000	2000	24,000,000	2,400,000	100
Manufacturing	24,000	1,000,000	2000	24,000,000	2,400,000	100
Transportation	24,000	1,000,000	2000	24,000,000	2,400,000	100
Other	24,000	1,000,000	2000	24,000,000	2,400,000	100

© 2010 Massachusetts MIT, China

Excerpt from Clean Energy Neighborhoods. MIT and Tsinghua University. 1.2010

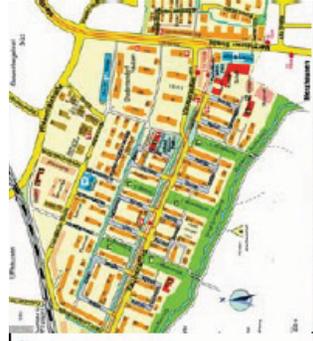
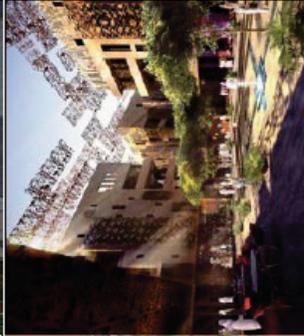
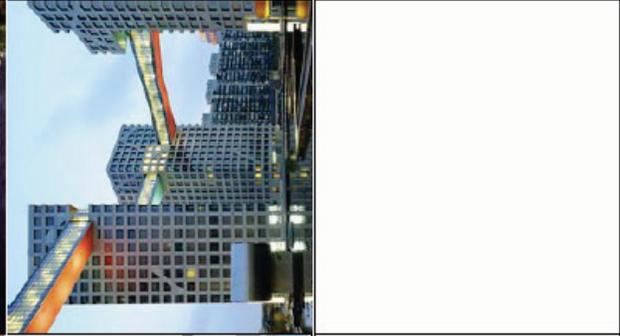
Figure 10-2. Representative Clean Energy Projects

Prototype	Project/context	Form character	Size/dens./program	Transport	Plan	Image	Energy Strategy	Energy Performance
<b>W1 Small Perimeter Block</b> A. Simple	Bo01, Malmo, Sweden Redevelopment of former shipyard in harbor area as demonstration energy efficient/sustainable neighborhood.	High density harbor edge to protect from wind. Small blocks, informally arranged, separated by vehicular/pedestrian oriented streets. Design by multiple architects for diversity.	<ul style="list-style-type: none"> <li>• 25 ha site</li> <li>• 10,000 residents planned (6000 today);</li> <li>• 20,000 workers and students;</li> <li>• 80 companies;</li> <li>• Malmo University.</li> </ul>	<ul style="list-style-type: none"> <li>• Limited parking of .7 cars per household.</li> <li>• Reliance on bus stops within 300 meters of any flat, 7 min intervals.</li> <li>• Extensive bicycle use.</li> </ul>			<ul style="list-style-type: none"> <li>• 105kWh/m<sup>2</sup>/year for res. units goal</li> <li>• 100% locally renewable energy sources.</li> <li>• Heat storage in underground aquifer.</li> <li>• Central wind power plan.</li> <li>• Biogas from waste.</li> <li>• PV + solar collec.</li> </ul>	<ul style="list-style-type: none"> <li>• 120-150 kWh/m<sup>2</sup>/yr for residential units achieved. (did not achieve target)</li> <li>• Shortage of parking.</li> </ul>
<b>W1 Small Perimeter Block</b> B. Complex	Ecolonia, Alphin, Netherlands Reclaimed polder in suburban area, developed as demonstration sustainable neighborhood.	Interlocking block clusters of 2-3 stories, 8-18 units each, demonstrate different designs for sustainable living. Highest density around artificial lake/retention pond. Plan by Lucien Kroll.	<ul style="list-style-type: none"> <li>• 280 housing units</li> </ul>	<ul style="list-style-type: none"> <li>• Center with shops 10 minute walk.</li> <li>• Extensive bicycle paths.</li> <li>• Low speed roads.</li> <li>• No marked parking spaces.</li> </ul>			<ul style="list-style-type: none"> <li>• 85kWh/m<sup>2</sup>/year energy consump. for res. units goal.</li> <li>• Solar orientation; passive sun spaces to south.</li> <li>• Solar thermal HW and PV on 80% homes.</li> </ul>	<ul style="list-style-type: none"> <li>• 40% decrease in gas consumption from average unit.</li> <li>• 10% decrease in electricity consumption.</li> <li>• 25% reduction in household energy use overall (did not meet target)</li> </ul>
<b>W2 High Density Perimeter Block</b> A. Simple	Greenwich Millennium Village, London, UK Former gasworks on urban site, redeveloped for integrate mixed use, sustainable community.	Large blocks with perimeter buildings, up to 13 stories on north edge to block wind, stepping down to 4-6 stories on east and west edges, framing courts. Organized around park. Plan by Ralph Erskine.	<ul style="list-style-type: none"> <li>• 30 ha site</li> <li>• 97 du/ha</li> <li>• 1157 dwelling units</li> <li>• 4,500 m<sup>2</sup> retail + cinema, hotel</li> <li>• primary school</li> <li>• central park</li> </ul>	<ul style="list-style-type: none"> <li>• Car parking restricted and sited away from individual properties.</li> <li>• Excellent bus service to new North Greenwich tube station.</li> <li>• Network of walking and bikeways.</li> </ul>			<ul style="list-style-type: none"> <li>• 80% reduction in primary energy goal.</li> <li>• 50% reduction in embodied energy goal.</li> <li>• High residential density.</li> <li>• Natural day lighting and passive solar gain.</li> <li>• Home office to reduce work trips CDH.</li> </ul>	<ul style="list-style-type: none"> <li>• 67% decrease in primary energy consumption from average.</li> <li>• 25% decrease in embodied energy.</li> <li>• BREEAM Excellent rating.</li> </ul>
<b>W2 High Density Perimeter Block</b> B. With Towers	Symphony Park, Las Vegas, Nevada USA Downtown brownfield switching yard, cleared and being redeveloped for mixed uses and institutions: a new civic heart for the city.	Series of urban blocks with street facing, pedestrian friendly stores and restaurants organized into four districts: civic, hospitality, residential, and medical.	<ul style="list-style-type: none"> <li>• 24.4 ha site</li> <li>• 3094 housing units</li> <li>• 1000 hotel rooms</li> <li>• Performing arts center</li> <li>• Ruvo Center for Brain Health</li> </ul>	<ul style="list-style-type: none"> <li>• Compact, walkable district</li> <li>• Easy access to BRT on Grand Central Avenue</li> </ul>			<ul style="list-style-type: none"> <li>• Walkable streets formed by perimeter shops.</li> <li>• Well connected with rest of downtown.</li> <li>• LEED buildings.</li> <li>• Tower placement to provide shade.</li> <li>• Parking structures with energy efficient roofs reduce heat island and cooling loads.</li> </ul>	<ul style="list-style-type: none"> <li>• 33% fewer car trips than conventional suburban project in city.</li> <li>• Electric and gas energy savings each year enough to power 2100 standard homes.</li> </ul>

Figure 10-2. Representative Clean Energy Projects ( Continued)

Prototype	Project/context	Form character	Size/dens./program	Transport	Plan	Image	Energy Strategy	Energy Performance
<b>W3 Low Rise Slabs</b>  A. Aligned	BedZed, Hackbridge, London, UK  Suburban site surrounded by single family homes and a village center walking distance. Primary school within walking distance.	Low rise repetitive form with linear buildings aligned east-west and fronting south. Unique design places residential spaces on the south side and office and shops on the north sides of buildings.	<ul style="list-style-type: none"> <li>1.6 ha site</li> <li>82 dwelling units</li> <li>50 du/ha</li> <li>Life-work office space incorporated</li> <li>Convenience shops</li> </ul>	<ul style="list-style-type: none"> <li>Car sharing with electric vehicles (charged with PV).</li> <li>5 min walk to transit stop at Hackbridge Village.</li> <li>Shared pedestrian/vehicular site roads.</li> </ul>		<ul style="list-style-type: none"> <li>E-w orientation with south glass; work spaces/retail on north.</li> <li>Roof forms for sun exposure+updraft.</li> <li>Wind cowls for natural ventilation.</li> <li>Roof gardens for insulation.</li> <li>PV's charge cars.</li> <li>CDH plant fired by local wood chips.</li> </ul>	<ul style="list-style-type: none"> <li>48 kWh/m2/yr hot water.</li> <li>34.4kWh/m2/yr electricity.</li> <li>88% less energy on heating than average.</li> <li>57% less energy on hot water.</li> <li>25% less electricity.</li> <li>65% less car mileage on fossil fuel than average.</li> </ul>	
	Geos, Arvada-Denver, Colorado USA  Located in suburban Denver on a former greenfield site surrounded by traditional subdivisions, but adjacent to transit line. (TOD)	Buildings oriented e-w are staggered to provide solar access and semi-private spaces; affects layout of streets, alleys, parcels and trees. Village center has main street, square, services, and retail beneath housing.	<ul style="list-style-type: none"> <li>10 ha</li> <li>282 dwelling units</li> <li>9 du/ha</li> <li>1,200 sm neighborhood services</li> <li>local shopping</li> <li>3.5 ha park</li> </ul>	<ul style="list-style-type: none"> <li>Reduced parking in central garages near "main street".</li> <li>Pedestrian environment with limited car access.</li> <li>Arvada-Denver Fast Tracks transit within walking distance.</li> </ul>		<ul style="list-style-type: none"> <li>Buildings orient e-w for sun exposure.</li> <li>PV on roofs.</li> <li>Geothermal loops beneath "green fingers."</li> <li>Careful placement of deciduous trees for shade in summer and sun in winter.</li> <li>Live-work homes.</li> <li>Social program to "Be the Resource"</li> </ul>	<ul style="list-style-type: none"> <li>0 net fossil fuel energy use.</li> <li>All heat and power is produced on-site by geothermal and PV systems.</li> <li>LEED Silver Certification.</li> </ul>	
<b>W4 Grid</b>  A. Regular	Kronsberg, Hanover, Germany  Model low energy development on the urban edge. Borders countryside at the intersection of tram and commuter rail lines. (TOD)	Rectangular grid creates frame for varied block structures. Density decreases w-e from tram line (retail) to country. Sub-areas of 9 blocks are organized around squares; public space and services at the town center.	<ul style="list-style-type: none"> <li>1200 ha</li> <li>3000 dwelling units; 3000 more planned.</li> <li>15,000 residents.</li> <li>Library, Sr. citizen center, three kindergartens, primary school</li> <li>Nearby commercial and industrial areas: 2750 office jobs across street.</li> </ul>	<ul style="list-style-type: none"> <li>Tram line extended to edge of development with 3 stops in Kronsberg (550 m max. walk to station).</li> <li>Parking .8 cars/unit; 1/3 underground, rest in small clusters.</li> <li>Extensive foot and bike paths.</li> </ul>		<ul style="list-style-type: none"> <li>56kWh/m2/yr heating goal.</li> <li>35kWh/m2/yr elec. goal.</li> <li>PV district with thermal storage tanks to provide 40% of heating.</li> <li>Electricity from two MW turbines in countryside.</li> <li>36 passive solar dwellings.</li> </ul>	<ul style="list-style-type: none"> <li>56kWh/m2/yr heating (42% reduction).</li> <li>50kWh/m2/yr elec. (goal not met).</li> <li>45% less CO2 emissions than conv.: (from PV, solar district heating, wind power, passive houses).</li> <li>15-20kWh/m2/yr heating with passive solar houses.</li> </ul>	
	Civano, Tucson, Arizona USA  Located in suburban Tucson on former desert site surrounded by traditional subdivisions. Major open space reserved to west.	New urbanist block structure with alleys and small lots. Focused on community center with mixed use retail and park. Nearby shopping and jobs. Plan by Stefanos Polyzoides.	<ul style="list-style-type: none"> <li>328 ha</li> <li>200 dwelling units completed; 5000 people at build out.</li> <li>Industry, office, retail cultural activities clustered in village center.</li> </ul>	<ul style="list-style-type: none"> <li>Compact plan encourages walking; shops, services and jobs planned within walking distance.</li> <li>Walking and bike paths.</li> <li>No public transportation.</li> </ul>		<ul style="list-style-type: none"> <li>50% reduction from Tucson model energy code. (= 58kWh/m2 less).</li> <li>PV electric energy</li> <li>Solar hot water heating.</li> <li>High efficiency heat pumps, insulation, windows.</li> </ul>	<ul style="list-style-type: none"> <li>64.5kWh/m2/yr heating and cooling (44% less than av.).</li> <li>13kWh/m2 total energy use (33% less than city average, goal met).</li> </ul>	

Figure 10-2. Representative Clean Energy Projects (Continued)

<p><b>W5 Low-rise Superblock</b></p> <p><b>A. Pedestrian Clusters</b></p>	<p>Vauban, Freiburg, Germany</p> <p>Redevelopment of former army base in urban location 2km from city center. The site is surrounded by neighborhoods, and bounded by a train line, arterial roads and a river park. (TOD)</p>	<p>A variety of building types and densities are clustered in different ways around fingers of green space leading up from the river. With the aim of "car free" and "parking free" living, most ways are mainly for pedestrians or play by Vauban's large school age population.</p>	<ul style="list-style-type: none"> <li>15.2 ha site</li> <li>5000 residents</li> <li>600 jobs</li> <li>Primary school, kindergartens, markets, shopping center, businesses within walking distance.</li> </ul>	<ul style="list-style-type: none"> <li>Tram and bus service down main spine of site.</li> <li>No cars allowed on private property.</li> <li>No car access to central area except for pick-up and delivery;</li> <li>Fee paid parking on periphery near tram.</li> <li>Car sharing.</li> </ul>			<ul style="list-style-type: none"> <li>65kWh/m2/yr heating energy goal.</li> <li>CHP fired by wood chips.</li> <li>PV electricity.</li> <li>Solar collectors for hot water.</li> <li>150 "passive houses."</li> <li>Reduced car travel.</li> <li>Social participation in energy planning and savings.</li> </ul>	<ul style="list-style-type: none"> <li>65kWh/m2/yr average energy use (goal achieved).</li> <li>15kWh/m2/yr energy use for "passive houses".</li> <li>60% CO2 savings through heat supply.</li> <li>40% households do not own a car.</li> </ul>
<p><b>W5 Low-rise Superblock</b></p> <p><b>B. Pedestrian Matrix</b></p>	<p>Masdar, Abu Dhabi, UAE</p> <p>Demonstration 0 carbon city located in open desert landscape near to international airport. Intended to develop the sustainable energy industry in UAE through innovation and new technology.</p>	<p>Plan oriented to prevailing winds that sweep green spines. Tight-knit urban fabric recalls traditional Arab cities, made possible by locating transport below. Small streets and squares shaded by arcades, close buildings and PV roofscape. Plan by Norman Foster.</p>	<ul style="list-style-type: none"> <li>600 ha (6 km2)</li> <li>40,000 residents (planned)</li> <li>135/ha</li> <li>40,000 jobs in 1500 businesses (planned)</li> <li>Integrated residential, offices, shopping, services, institutions.</li> <li>Masdar Institute of Science + Technology.</li> </ul>	<ul style="list-style-type: none"> <li>Automated PRT on lower level, connecting all parts of city; 85 stations.</li> <li>No cars on living surface of city.</li> <li>High capacity overhead train connects to airport and Abu Dhabi.</li> <li>Ubiquitous pedestrian/bicycle network.</li> </ul>			<ul style="list-style-type: none"> <li>0 net fossil fuel energy use (100% renewable sources: 26% solar power; 52% PV, 14% thermal tube; 7% waste to energy).</li> <li>70% reduction in energy usage below average in Abu Dhabi.</li> <li>Exceeds LEED Platinum standards.</li> </ul>	<ul style="list-style-type: none"> <li>30kWh per person/day energy budget to reduce demand.</li> <li>Reduce heat gain by maximizing shade and reflecting sun.</li> <li>Wind towers for natural ventilation.</li> <li>PV on all roofs.</li> <li>Concen. solar power.</li> <li>Geothermal wells for energy storage.</li> </ul>
<p><b>W6 High-rise Superblock</b></p> <p><b>A. Linked towers</b></p>	<p>Linked Hybrid, Beijing, China</p> <p>Located in central Beijing, the project is intended to provide an alternative form for efficient high rise communities by interconnecting the towers with fine grained mixed use.</p>	<p>25 story towers linked at the 18th floors and below grade to form an i-3-D network. Upper level ring includes public programs, galleries, health club and school. Towers frame central space with public amenities and pool used for cooling.</p>	<ul style="list-style-type: none"> <li>6.18 ha</li> <li>750 dwelling units</li> <li>2500 residents.</li> <li>Hotel, schools, conference facilities, offices, restaurants, health, shops and services: a town within the city.</li> <li>Public park and recreation at ground level.</li> </ul>	<ul style="list-style-type: none"> <li>Within walking distance to public transit.</li> <li>Below grade parking.</li> <li>Reduce need for commuting by providing live-work within the complex.</li> </ul>			<ul style="list-style-type: none"> <li>Linked buildings reduce need for vertical transport/ elevator use (47% of high rise energy).</li> <li>600 geothermal wells, circulate water 61-70 degrees F, reducing heat and ac needs.</li> <li>Green roofs and thermal mass retain heat.</li> </ul>	<ul style="list-style-type: none"> <li>Geothermal and linked configuration dramatically reduce energy demands for heat, ac, and elevators.</li> <li>LEED Gold certification.</li> </ul>

## 10.2 Characteristics of the Best Practice Cases

Each of the representative clean energy neighborhoods represents the singular resolution of a complex set of factors within their context, climate and culture. However, looking across them, some general conclusions emerge. First, there is no single, ideal model of clean energy urban form. This is important in the context of China, where simple idealized policies can result in reproduction of one form of urban development across the national landscape. Urban form-energy relationships are so complex that there are many avenues to improving energy performance. Second, while the projects vary in scale and density, they are relatively more compact than their surroundings. This fits well with the Chinese idea of encouraging more compact growth in general, although as we have seen, the quality of the compactness matters a great deal with regard to energy consumption. Some compact forms are more energy efficient than others. Thirdly, they mix uses with the housing to provide convenient shops, services, and employment creating more integrated, pedestrian oriented neighborhoods, and reducing the need for a car. Finally they stand out as examples of livable, high quality design.

The livability aspect was deduced based on the success of the developments in attracting residents and providing environments that facilitated their day-to-day activities and well-being – as evidenced in literature about the projects and prior studies of them. Design quality is to some degree a subjective judgment, however, unless energy efficient neighborhoods are also highly livable they will be less acceptable to the public, in the long run defeating the broader goal. Furthermore, our review of cases indicated that successful clean energy projects foster strong communities that are well liked by their residents who in turn modify their behavior towards the goal of energy efficiency. And so, successful design strategies not only address energy concerns, but also enhance project livability.

While it is difficult to compare across the representative projects, since they use different measures and strategies, they have all produced energy savings within their context and prototype. While high-rise superblock neighborhoods can be highly energy consumptive, the Linked Hybrid model provides an approach that is more efficient than other tower forms. At the other end of the density scale, where suburban sprawl can be equally consumptive, projects like Ecolonia and Civano illustrate the viability of more compact, energy saving forms.

We found it interesting that some strategies traditionally regarded as non-form related actually influence the neighborhood form in significant ways. For example, a carpool program that reduces vehicle miles traveled through shared ridership is usually regarded as a management strategy; however, it can significantly change the neighborhood landscape by reduced parking surfaces. In a similar way, small scale energy saving features at the building level can add up to influence the form of a whole neighborhood. For example, day-lighting requirements can affect the spacing between buildings, rippling through the design of the site. Finally, on-site energy production can have

profound urban form consequences, for example by affecting the pitch of roofs or building orientation for solar collection, or the location and shape of open spaces to accommodate geothermal wells. In sum, we have come to see the concept of clean energy neighborhood form as broader and more intricately intertwined with other scales and factors than we originally imagined, and have striven to incorporate these subtleties into our design tools.

### **10.2.1 Design Features**

A more detailed more detailed review of design features found across the representative clean energy projects is presented in Table 10-1 and lessons are discussed below. Clean energy neighborhoods:

- 1. Conserve infrastructure** – The projects are located on sites that can take advantage of existing infrastructure, reducing the need for new construction such as roads and utilities to service the neighborhood. All of the projects re-use existing sites, including former industrial sites. The suburban projects are located at the edges of urban areas intended to more or less solidify a higher density edge to urban expansion. Kronsberg is particularly interesting in this regard.
- 2. Reduce car travel** – Since auto use is one of the single largest consumers of energy, this category groups the different ways that projects either encourage alternative transport modes or discourage the use of cars in their design. All of the projects are designed to encourage walking and biking with well-developed pathways and pedestrian environments. Many of the projects also strive to integrate shopping, services and employment on-site or nearby to increase convenience and reduce travel. More than half the projects may be considered “transit oriented,” built to accommodate local trams or subway stops on-site or within walking distance. Finally, these same projects take active steps to limit the use of cars on-site, such as Vauban, which has no parking and forbids access by private cars (except in emergencies) within the neighborhood.
- 3. Make use of sun** – Successful projects think about the sun comprehensively as a resource and design determinant, combining both passive and active measures. All of the projects take advantage of the sun in some way. Only half of the projects take advantage of solar orientation to provide passive heat gain in the winter and shade in the summer; an area for improvement. However, most of the projects included active measures, generating electricity through PV panels, or hot water by solar collection, or both. Relatively few projects took advantage of trees to moderate solar heat gain or loss. Geos and Masdar stand out as taking advantage of all these approaches.
- 4. Make use of wind** – In a similar vein, this category encourages designers to think comprehensively about the wind and how project design can maximize its beneficial effects, and reduce liabilities. Wind receives much less attention than the sun in the

projects, perhaps because its effects are highly localized and difficult to model. Two of the projects, Masdar and Bedzed, were designed to actively induce natural ventilation in buildings and public spaces through the use of wind towers or cowls, and two produce electricity by wind power. Wind strongly shaped the design of Bo01 in Sweden and Greenwich in the UK, projects located in colder climates, where taller structures were placed to block cold winter winds coming off the water. Conversely Masdar, located in the desert, incorporated wind swards to induce cooling prevailing wind flow through the project.

5. ***Make use of earth*** – Following on the natural forces of sun and wind, its important to also think comprehensively about the earth as part of an energy form system. Four of the projects have site plans designed to accommodate geothermal thermal wells to contribute to meeting heating and cooling loads. Most notably, green spaces and ways in Bo01, Geos, and Linked Hybrid have been arranged to accommodate the wells and distribution lines. Almost all of the projects make use of green land and roof surfaces to reduce heat absorption and heat island effects.
6. ***Compact height and density*** – These qualities refer to the relative compactness of the prototypical projects within their context, one of the most basic characteristics of clean energy urban form. All of the projects consist of connected multifamily buildings as opposed to detached, single-family homes. Higher density, multifamily construction can reduce heat loss, land consumption, construction materials, and in some cases, travel required by the residents. Almost all the projects cluster buildings into sub-units, creating semi-private space and a hierarchical site organization. This enhances livability and can moderate climatic effects in the winter and summer.
7. ***Community focused structure*** -- One of the surprising findings of the analysis was the degree to which clean energy neighborhoods focused on creating a sense of community in their form. Almost all of the projects created town squares, main streets, or civic centers with important institutions, shops and services as the focus of the design. These are complimented by networks of public green spaces and paths. As revealed in the literature, such design gestures are aimed at building community and public support for the sustainable goals of the project. Community oriented urban forms are complemented in many cases by architecture that highlights energy saving or producing features of the project, giving it a distinctive identity valued by the residents. Finally, almost half of the projects include feedback mechanisms or programs that engage occupants directly in the energy-saving effort. For example, Masdar is incorporating public displays and lighting to signal the energy performance of the development. All of these approaches aim at raising awareness and affecting behavior related to energy use, and in turn affect the urban form.

**Table 10-1. Design Qualities of Clean Energy Neighborhoods**

DESIGN QUALITIES OF CLEAN ENERGY NEIGHBORHOODS Characteristics of International Cases	W1 Small Perimeter Block	W2 Dense Perimeter Block	W3 Low Rise Slab	W4 Grid	W5 Low Rise Superblock	W6 High Rise Superblock				
	Blo01	Ecologia	Greenwich Symphony	BedZed	Gros	Kronenberg	Cleano	Vauban	Mandarin	L-Hybrid
<b>1. LOCATION: CONSERVE INFRASTRUCTURE</b> (services, roads, Infill urban sites, Reuse former industrial sites, Solidify urban edge (suburban infill))										
<b>2. MOBILITY: REDUCE CAR TRAVEL</b> (Walkable/bikeable environments (encourage pedestrians), On-site mixed-use/live-work (reduce commuting), TOD/convenient transit, Restricted (or no) cars and parking)										
<b>3. ENERGY: MAKE USE OF SUN</b> (Solar orient./placement of buildings (passive heat-cool), Solar collectors on roofs (hot water and heating), PV roofs (district electricity system), Deciduous trees and shading (passive heating/cooling))										
<b>4. ENERGY: MAKE USE OF WIND</b> (Natural ventilation: wind towers or cowls, Wind power (district electricity system), Wind protection (reduce heating loads))										
<b>5. ENERGY: MAKE USE OF EARTH</b> (Geothermal energy (and layout), Green roofs (insulate and reduce heat island), Green land and urban agriculture (reduce heat island))										
<b>6. HEIGHT AND DENSITY: COMPACT</b> (Multifamily/attached dwellings (less heat loss), Buildings clustered into-sub units (moderate microclimate))										
<b>7. STRUCTURE: COMMUNITY FOCUSED</b> (Includes civic center, main street or square, Distinctive Identity, with visible energy features, Engages residents/workers in the energy program)										

Dennis Frenchman / MIT / 1.15.10

**10.2.2 Energy Strategies**

The case studies provide a road map of commonly used energy strategies in some of the world’s strongest examples of clean energy neighborhoods. These strategies are discussed below, across the four categories of energy interest introduced in Chapter 3: transportation, operational, embedded/life-cycle, and energy production. Building- level energy strategies are not discussed, as our focus is on urban form. Table 10-2 compares the strategies across the form prototypes and representative projects, presenting a different viewpoint on some of the design issues discussed in the previous section.

**Table 10 2. Energy Strategies in Clean Energy Neighborhoods**

ENERGY STRATEGIES IN CLEAN ENERGY NEIGHBORHOODS Characteristics of International Cases	W1 Small Perimeter Block	W2 Dense Perimeter Block	W3 Low Rise Slab	W4 Grid	W5 Low Rise Superblock	W6 High Rise Superblock						
	Bo01	Ecolonia	Greenwich	Symphony	BerZad	Geos	Kronenberg	Civano	Vauban	Mandarin	L. Hybrid	
<b>1. TRANSPORT ENERGY SAVING STRATEGIES</b>												
Public transit within walking distance (reduce car commute)	■	■	■	■	■	■	■	■	■	■	■	■
Shops, services within walking distance (reduce car commute)	■	■	■	■	■	■	■	■	■	■	■	■
Inclusive housing for diverse incomes (reduce car commute)	■	■	■	■	■	■	■	■	■	■	■	■
Car share program (reduce car commute)	■	■	■	■	■	■	■	■	■	■	■	■
Restricted parking and car access	■	■	■	■	■	■	■	■	■	■	■	■
Compact development relative to context	■	■	■	■	■	■	■	■	■	■	■	■
Walking and biking environment	■	■	■	■	■	■	■	■	■	■	■	■
Local food production	■	■	■	■	■	■	■	■	■	■	■	■
<b>2. OPERATIONAL ENERGY SAVING STRATEGIES</b>												
Solar heat gain; solar orientation and fenestration	■	■	■	■	■	■	■	■	■	■	■	■
Wind blockage to reduce heat loss	■	■	■	■	■	■	■	■	■	■	■	■
Connected, compact buildings to reduce heat loss	■	■	■	■	■	■	■	■	■	■	■	■
Cluster buildings to moderate microclimate	■	■	■	■	■	■	■	■	■	■	■	■
Natural ventilation (indoor and outdoor)	■	■	■	■	■	■	■	■	■	■	■	■
Shading to reduce heat gain	■	■	■	■	■	■	■	■	■	■	■	■
Green roofs, footprint, urban agriculture	■	■	■	■	■	■	■	■	■	■	■	■
District heating/cooling	■	■	■	■	■	■	■	■	■	■	■	■
Energy feedback systems	■	■	■	■	■	■	■	■	■	■	■	■
<b>3. EMBODIED/LIFECYCLE ENERGY SAVING STRATEGIES</b>												
Maximize use of existing infrastructure	■	■	■	■	■	■	■	■	■	■	■	■
Use local materials	■	■	■	■	■	■	■	■	■	■	■	■
Reduce site and building materials	■	■	■	■	■	■	■	■	■	■	■	■
<b>4. RENEWABLE ENERGY PRODUCTION STRATEGIES</b>												
Solar energy (collectors and PV)	■	■	■	■	■	■	■	■	■	■	■	■
Wind power (turbines)	■	■	■	■	■	■	■	■	■	■	■	■
Geothermal heating and cooling	■	■	■	■	■	■	■	■	■	■	■	■

Jue Wang/ MIT / 5.22.10

As a general finding, transportation energy-saving strategies that focus on reduced automobile usage and on-site energy production are the two most common strategies for clean energy. Embodied energy consumed by construction and in materials is a less considered strategy, limited mainly to locating projects on urban infill sites. In terms of saving operational energy, use of passive solar measures are quite popular, however, with geothermal and wind energy less commonly used.

Key energy strategies are reviewed below:

**1. Transportation** – The most common energy-saving strategy of virtually all the representative projects is that they are transit-oriented, compact, mixed-use

developments with good pedestrian networks. All of the projects are served by rail, tram or bus rapid transit within a walking distance of 800 m, or 10-15 minutes (with the exception of Civano, which is located in the suburbs). Most have basic services, shops, and schools within walking distance as well. Six of the projects go further, by restricting car access and four have active car-share programs. Bedzed, for example, has a fleet of shared electric vehicles recharged through photovoltaic cells. Of all the projects, Bedzed, Kronsberg, and Vauban stand out using virtually all available strategies to reduce private car use by as much as 65-70% from the average in their regions (Rosenthal, 2009).

2. **Operational** – In terms of reducing heating, cooling, and other operational energy the most common form strategies are to use compact buildings, to reduce surface area and heat loss, clustered in various ways to moderate microclimates. Beyond this, most of the projects make a serious attempt to maximize passive solar heat gain in cool months through building orientation and fenestration. In the best cases, such as Vauban passive houses, an 80% heating energy savings has been achieved over conventional homes. Less advantage is taken of natural ventilation and shading systems to cool homes in summer. Masdar, Bedzed and Greenwich stand out for using all these strategies to achieve operational energy savings.
3. **Embedded/lifecycle** – Beyond locating on brownfield or urban sites, the projects do little to address the issue of embedded energy over the lifecycle of the neighborhood. The exceptions are Greenwich and Bedzed, which use locally sourced (within 35 miles) and recycled materials (within 35 miles), but there are no estimates of the energy savings achieved.
4. **Energy production** – The most popular form of renewable energy production is the use of photovoltaic panels to produce electricity, incorporated into all but two of the projects. Installed on roofs, facades, or a central location, the orientation, form, and clustering of buildings is critical to maximize sun exposure and reduce shading, which can dramatically affect electricity output. The efficiency and high price of PV's has been an obstacle to widespread use in the past; however, the cases demonstrate its viability to provide, in the case of Masdar for example, up to 52% of the energy needs of a large project. Solar collectors for hot water and heating are often used in parallel with PV's since they require similar geometries to maximize output and are relatively simple to incorporate. Solar collectors cover 40% of heating needs in Vauban, and 30% of the heating and hot water needs in Kronsberg, as part of a district system where the heat is stored in large underground tanks (Fisch, 2008).

Wind power as part of a district electricity system is a less common source of power but can be highly effective. Because of their large size and noise and to maximize wind efficiency without the interference of buildings, turbines are typically placed off-site. Just two turbines cover the electricity needs of 3000 homes in Vauban and a single off-site turbine supplies the electricity needs of 1000 homes in Bo01.

Finally, several projects used geothermal energy extracted from wells to heat or cool buildings. Wells are best placed in open ground for access and district systems must be fairly compact because to lower energy required to pump and heat loss. These limitations can shape the form of a neighborhood as they do in Bo01, Geos, and Linked Hybrid, where well fields lie beneath public open spaces closely integrated with the housing. A field of 550 wells, 100 meters deep, serves much of the heating and cooling needs of Linked Hybrid, making it one of the most extensive geothermal systems in the world.

### **10.3 Envisioning Clean Energy Neighborhoods in Jinan**

Moving beyond existing practice, an important aim of the research is to explore new approaches to clean energy development. To test the Energy Proforma in practice, demonstration clean energy neighborhood designs were prepared for the city of Jinan, China by MIT and Tsinghua University. The two schools have a 25-year history of joint work on complex, large-scale urban design projects, involving graduate students and faculty. The site for the demonstrations, selected by city officials, was a proposed new town being planned adjacent to Jinan's new high-speed rail station on the Jing Hu line, connecting the city directly with Beijing and Shanghai.

The conceptual master plan for Jinan West is illustrated in the accompanying diagram. Designed to accommodate one million people, it is a typical 20th century Euclidean layout with separated land uses organized around a central axis, running east-west perpendicular to the station entrance. The axis contains enormous public spaces, high-rise office buildings, and cultural center. To the north and south are residential areas composed of high-rise superblocks that decrease in density moving away from the axis. Similar plans for new towns can be found all over China.

#### ***10.3.1 Design process***

Demonstration clean energy neighborhood designs for Jinan West, were developed in studios held during the summer of 2010 and the winter of 2011, involving teams of graduate students working with faculty. Each team focused on an area along a cross section extending north-south through the center of the site plan. This ensured that all neighborhood conditions within the proposed new town were considered, from the dense commercial center to less dense residential areas on the edges of the town. In all, over 50 students and faculty were involved in these demonstration projects.

In developing their designs, each team began by analyzing the international cases as well as neighborhoods in Jinan representing prototypical urban forms. These were among the same neighborhoods that had been studied in the empirical research so their energy performances were known. With these as benchmarks, the teams then developed proposals for new clean energy neighborhoods on the train station site using the Energy

Proforma as a design and decision-making tool. The Proforma provided feedback on the energy performance of the projects as they evolved. This differed dramatically from the conventional urban design process where energy consumption at the neighborhood scale cannot easily be assessed and therefore is not a prime consideration of design. Our hypothesis was that continuous testing, adjustments, and feedback during the complex process of moving from concept to developed proposal, made possible by the Proforma, would lead to more refined products in which all elements of the designs reinforce each other, yielding optimal form-energy systems.

The resulting projects, summarized in **Figure 10-3**, confirm the value of the methodology. All represent innovative, systemic approaches to clean energy urban form. They exceed the energy performance of even the most efficient neighborhoods now in Jinan, and many of the international cases, while creating high quality, livable neighborhoods. Overall, we concluded that the ability to understand energy consequences during the design process led to more creative and technically competent solutions. The projects from summer 2010 are described in detail in the report, *Designing Clean Energy Cities: New Approaches to Urban Design and Energy Performance*. (Frenchman, Wampler, Zegras, 2011)

### ***10.3.2 Characteristics of the Demonstration Designs***

Looking across the projects in Table 10-4, we see design strategies to improve energy performance that echo themes found among the examples of best practice. Beyond these, however, some entirely new strategies are proposed which have little precedent. This confirms our hypothesis that use of the Proforma will nudge designers towards more energy efficient forms, while at the same time facilitating innovation by confirming that a particular direction is, indeed, energy efficient even if unconventional. Some key characteristics and lessons that can be drawn from the demonstration neighborhood designs are discussed below.

- 1. High density** – All the designs are relatively high density, most achieving greater densities than Sunshine 100 in Jinan (FAR 2.15), for example, which was studied in the research. They are all therefore particularly applicable to China, as opposed to some of the lower density best practice examples. Significantly, one of the demonstration designs – 3-D Grid – achieves a relatively high density using 3-4 story buildings, belying the common wisdom in China that high density requires high rise construction. (In fact, day-lighting requirements in China, cause high-rise residential towers to be widely spaced, limiting the overall density that can be achieved by this form.) Several of the schemes combine towers with low-rise structures, raising the density beyond what could be achieved by either form alone. Using this strategy, the Integrated Tower design achieves the greatest density of all at 5.98 FAR. (For comparison, this is less dense than mid-town Manhattan where 10 FAR is common.)

**Figure 10-3. Demonstration Clean Energy Neighborhood Designs**

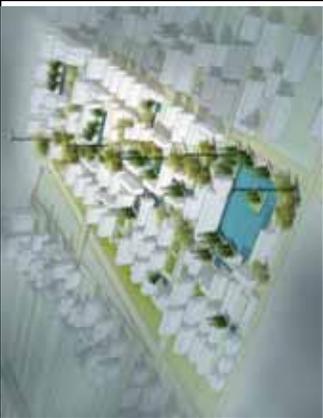
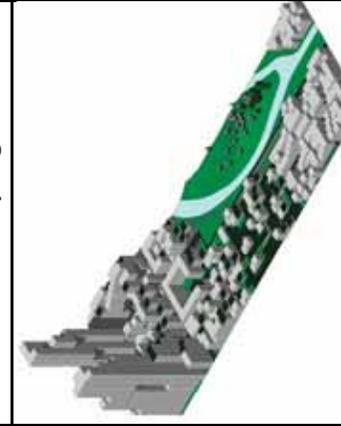
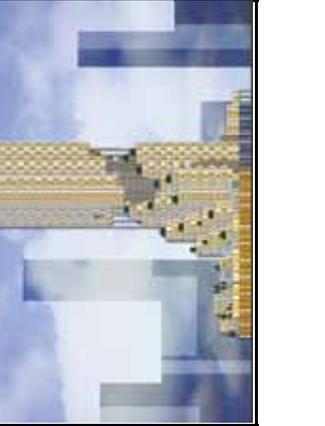
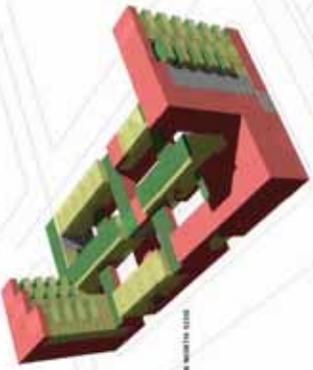
Reinvented Enclave	Description	Form-Energy Strategies	Performance <sup>1</sup>
	<ul style="list-style-type: none"> <li>◆ Semi-grid of blocks with southern facing slabs</li> <li>◆ Major wind corridor and water cooling features</li> <li>◆ Village centers around landscape features</li> <li>◆ Clustered services and activities</li> </ul>	<ul style="list-style-type: none"> <li>◆ Improve on existing energy efficient enclave form.</li> <li>◆ Cluster mixed-use and amenities</li> <li>◆ Reuse rubble onsite to creating topography</li> <li>◆ Use wind for cooling and natural ventilation</li> <li>◆ Generate electricity from wind</li> <li>◆ Orient single-loaded residential buildings toward sun</li> <li>◆ Limit auto circulation; extensive bike and pedestrian system.</li> </ul>	<ul style="list-style-type: none"> <li>◆ FAR = 2.10</li> <li>◆ 57,363 mj/hh</li> <li>◆ 114 kwh/m2</li> </ul>
<p><b>High Low Rise</b></p> 	<ul style="list-style-type: none"> <li>◆ Perimeter of low-rise structures forming courtyards with high-rise residential towers above</li> <li>◆ Dense mixed-use on ground floor Office, shopping, services and schools, and recreation onsite</li> <li>◆ System of courtyards (semi-private open space) and public streets</li> </ul>	<ul style="list-style-type: none"> <li>◆ Integration of high and low-rise forms creates human-scaled, high-density neighborhood</li> <li>◆ Strategic tower placement limits casting shadows on adjacent structures</li> <li>◆ Use of residential towers as wind towers for cooling and ventilation of low-rise perimeter buildings</li> <li>◆ Use of courtyards to provide pleasant microclimate</li> <li>◆ Clearly defined public realm to induce outdoor activity</li> <li>◆ Ground fl. mixed-use provides easy service access.</li> </ul>	<ul style="list-style-type: none"> <li>◆ FAR = 2.52</li> <li>◆ 76,830 mj/hh</li> <li>◆ 73 kwh/m2</li> </ul>
<p><b>Criss-Cross</b></p> 	<ul style="list-style-type: none"> <li>◆ Alternative design for a CBD</li> <li>◆ Hybrid of east-west residential on upper floors, and north-south business and commercial on lower floors</li> <li>◆ Civic and cultural nodes at intersection of buildings</li> <li>◆ Organized around major transit node</li> </ul>	<ul style="list-style-type: none"> <li>◆ East-west residential structures maximize sunlight while integrating directly with commercial uses, creating a 24 hour urban environment</li> <li>◆ North-south orientation of commercial structures blocks winter wind from residential structures but allows summer wind to penetrate.</li> <li>◆ Nodes of activity connected with bike, pedestrian, and canal network.</li> <li>◆ Parking only accessible from perimeter roads</li> <li>◆ Green roofs planted on ground level parking garages</li> </ul>	<ul style="list-style-type: none"> <li>◆ FAR = 3.62</li> <li>◆ 86,690 mj/hh</li> <li>◆ 230 kwh/m2</li> </ul>

Figure 10-3. Demonstration Clean Energy Neighborhood Designs

	Description	Form-Energy Strategies	Performance
<p><b>3-D Grid</b></p> 	<ul style="list-style-type: none"> <li>◆ Reinterpretation of Traditional village prototype in a 3-D form</li> <li>◆ Fine grained urban fabric with mix of uses</li> <li>◆ 2-4 story buildings linked on all levels</li> <li>◆ Walkable environment</li> <li>◆ Highly flexible design; interior and exterior spaces and adapt to season</li> <li>◆ Highly vegetated surfaces.</li> </ul>	<ul style="list-style-type: none"> <li>◆ Integration of mixed-use and high density; include live-work lofts.</li> <li>◆ Canal system used for microclimate, transportation, and grey-water filtration</li> <li>◆ Reduced embodied energy use through low-rise structures and minimal excavation</li> <li>◆ Lower operational energy via fewer elevators, pumps</li> <li>◆ Controlled vehicular access to maximize livability and pedestrian circulation</li> <li>◆ On-site energy generation</li> </ul>	<ul style="list-style-type: none"> <li>◆ FAR = 2.2</li> <li>◆ 67,600 mj/hh</li> <li>◆ 107 kwh/m2</li> </ul>
<p><b>Urban Sponge</b></p> 	<ul style="list-style-type: none"> <li>◆ Eco-city interpretation of high density living</li> <li>◆ Integrated commercial and residential uses</li> <li>◆ Building orientation and composition arranged to take advantage of solar exposure at micro scale</li> <li>◆ Urban park/waterfront for climate mitigation</li> <li>◆ Network of activity nodes and squares around transit stations.</li> </ul>	<ul style="list-style-type: none"> <li>◆ Building height gradient calculated to maximize solar access for residential units</li> <li>◆ High density towers free space for large open spaces, plazas, geothermal wells and bioswales</li> <li>◆ System of greenways and pedestrian/bike paths around activity nodes and transit stations</li> <li>◆ Passive solar heating and daylighting achieved through trombe walls and southern orientation.</li> <li>◆ Efficient household unit size decreases operational energy use.</li> </ul>	<ul style="list-style-type: none"> <li>◆ FAR = 2.7</li> <li>◆ 60,140 mj/hh</li> <li>◆ 69 kwh/m2</li> </ul>
<p><b>Integrated High-rise</b></p> 	<ul style="list-style-type: none"> <li>◆ Low rise buildings terrace upwards in a south to north orientation to high density towers.</li> <li>◆ Residential condominiums stack on the southern facing roofs of commercial, office and parking structures</li> <li>◆ Perforated towers allow light to pass through and provide platforms for terraced gardens.</li> </ul>	<ul style="list-style-type: none"> <li>◆ Vertical integration of uses minimizes trip distance</li> <li>◆ High vertical density allows for maximization of open space, inducing people to spend time out of doors.</li> <li>◆ Large south facing windows max solar heat and light</li> <li>◆ Roof gardens mitigate storm water runoff and provide small private open spaces.</li> <li>◆ Strategic placement of towers leaves large public spaces unshaded during the day.</li> <li>◆ Multi-tiered pedestrian network improves walkability within 3-D environment.</li> </ul>	<ul style="list-style-type: none"> <li>◆ FAR = 5.98</li> <li>◆ 51,428 mj/hh</li> <li>◆ 89 kwh/m2</li> </ul>

**Figure 10-3. Demonstration Clean Energy Neighborhood Designs**

Image	Description	Form-Energy Strategies	Performance
	<ul style="list-style-type: none"> <li>♦ Towers rise above small, low-density perimeter blocks</li> <li>♦ Residential towers wrapped with commercial towers; shared elevators and common area facilities</li> <li>♦ Interconnected system of canals and courtyard ponds</li> <li>♦ Multiple levels of circulation</li> </ul>	<ul style="list-style-type: none"> <li>♦ Smaller blocks increase intersections, enabling pedestrian movement and limiting traffic.</li> <li>♦ Integrated building uses reduce common area energy consumption by sharing building operation systems and VMT by bringing offices and amenities close to residential areas.</li> <li>♦ Courtyards and ponds create microclimate through shading and evaporation</li> <li>♦ Multi-tiered circulation improves walkability</li> <li>♦ Perforated buildings reduce embodied energy and increase ventilation.</li> </ul>	<ul style="list-style-type: none"> <li>♦ FAR = 2.51</li> <li>♦ 66,885 mj/hh</li> <li>♦ 204 kwh/m2</li> </ul>
	<ul style="list-style-type: none"> <li>♦ Small 'L' shaped modular apartment buildings are arranged to create a low-rise, fine-grained pedestrian-only urban village.</li> <li>♦ Mid-rise slabs incorporate parking and commercial on lower floors, with residential towers above.</li> <li>♦ Southern orientation and wave-like form maximizes sun exposure while blocking winter winds from the village.</li> </ul>	<ul style="list-style-type: none"> <li>♦ Integration of mid and low-rise forms creates a human-scaled environment.</li> <li>♦ System of paths along a rainwater collection and greywater filtration systems that follow the path of summer winds creates a vegetated, cool walking experience.</li> <li>♦ Southern orientation and wave-like form maximizes solar exposure for passive heating, daylighting, solar electricity/hot water product.</li> <li>♦ Mid-rise buildings block winter winds.</li> <li>♦ Vehicular access is limited to perimeter roads and commercial streets.</li> </ul>	<ul style="list-style-type: none"> <li>♦ FAR = 1.46</li> <li>♦ 41,126 mj/hh</li> <li>♦ 94 kwh/m2</li> </ul>

<sup>1</sup>Note: Comparable figures for the Sunshine 100 project in Jinan are: FAR = 2.15; 132,357 mj/hh; 133 kwh/m2

2. **Mixed use, 3-D lower levels** – All the schemes incorporate a street level mix of shops, services, civic amenities and schools integrated with the housing (low or high rise). Several of the schemes extend these mixed uses up to 3-4 stories interconnected across blocks, creating a dense mix of activities highly accessible to pedestrians; reducing the need for cars and energy consumed in traffic, while increasing the day to day convenience of living in the city. Still others – 3-D Grid and Wrapped Towers, for example – include office and productive spaces in the mix as well, a growing trend in cities worldwide. In China, these forms represent a significant departure from the typical single-use housing estates, which have now become standard.
3. **Street grids** – The demonstration designs adopt a variety of access strategies, however all are well integrated with the city street fabric. The predominant form is a variation on the traditional city grid as shown in High-low Rise and Wrapped Towers, where public streets provide both pedestrian and vehicular access to most buildings. While an ancient method of city making, grids provide highly efficient access minimizing travel distances between any two points. This too is at odds with current policies of urbanization in China, which encourage gated communities on large superblocks, regulating public streets to the periphery, where they become arterials highways too wide and busy to support pedestrian use.
4. **Courtyard variations** – Five of the schemes may be seen as variations on the traditional courtyard typology at one scale or another. By this we mean that multiple units are organized around enclosed semi-private spaces on the interior of blocks. Such configurations mitigate the microclimate, offering shade and ventilation in the summer, while blocking wind and retaining heat in cooler months. The addition of vegetation and water can add to the effect. The High-low Rise scheme takes maximum advantage of this arrangement. Blocks are organized around courtyards on the ground (surrounded by low-rise housing and mixed uses) but so are the towers, where upper level courts provide natural daylight and ventilation, cooled by vegetation.
5. **Multi-function towers** – Most of the designs include high-rise elements, but they incorporate multiple functions that result in energy savings beyond typical single-use residential towers. For example, Wrapped Towers combines commercial and productive space with housing on each floor to enable living and working within the same building. Criss-cross achieves the same mix vertically, placing commercial uses and services on lower floors (oriented east-west) and residential units on upper floor (oriented south) while sharing the same vertical circulation. Towers may also serve to ventilate lower level spaces by incorporating chimneys within their form.
6. **Integrated blocks** – Among the more innovative concepts explored in the schemes is the interconnection of environmental systems on the scale of the block, as opposed to

the more common practice of designing each building as a free standing element with its own passive and active heating and cooling regime. The best example is High-low Rise, where the towers are located to provide shade or sun when appropriate on the courtyards below. Equipped with vertical chimneys, the towers also act to ventilate lower level structures and spaces on the entire block through natural convection in the summer, and to collect heat for recirculation in the winter. The block scale is also lends itself to cogeneration of heat, hot water and electricity, as well as to renewable energy generation, integrating PV on low-rise roofs with wind turbines on the high rise elements.

- 7. *Complex forms*** – The advent of digital modeling of urban form has opened the door to a more detailed understanding of how built spaces intersect with urban systems and the natural forces of sun and wind and water. Coupled with the energy Proforma, this can enable more finely tuned designs that respond to local conditions rather than simplistic models of form. This enables us to move away from repetitive slab and tower patterns of development, which emerged in response to sunlight requirements in China. In contrast, the Urban Sponge scheme, for example, meets all residential sunlight requirements in a highly individualized, humanely scaled urban design with multiple unit types, building shapes, private outdoor spaces, courtyards, high and low structures adding up to more livable and energy efficient projects. Such finely crafted forms can be easily achieved by Computer Aided Design applications, which calculate individual unit exposures, sunlight and shadow in the process of design.

Some of the characteristics of the demonstration neighborhood designs echo qualities found in the examples of best practice. Others, such as multifunction towers, integrated blocks, and individualized forms represent somewhat new approaches.

#### **10.4 Projects to Prototypes: A Taxonomy of Clean Energy Neighborhood Design**

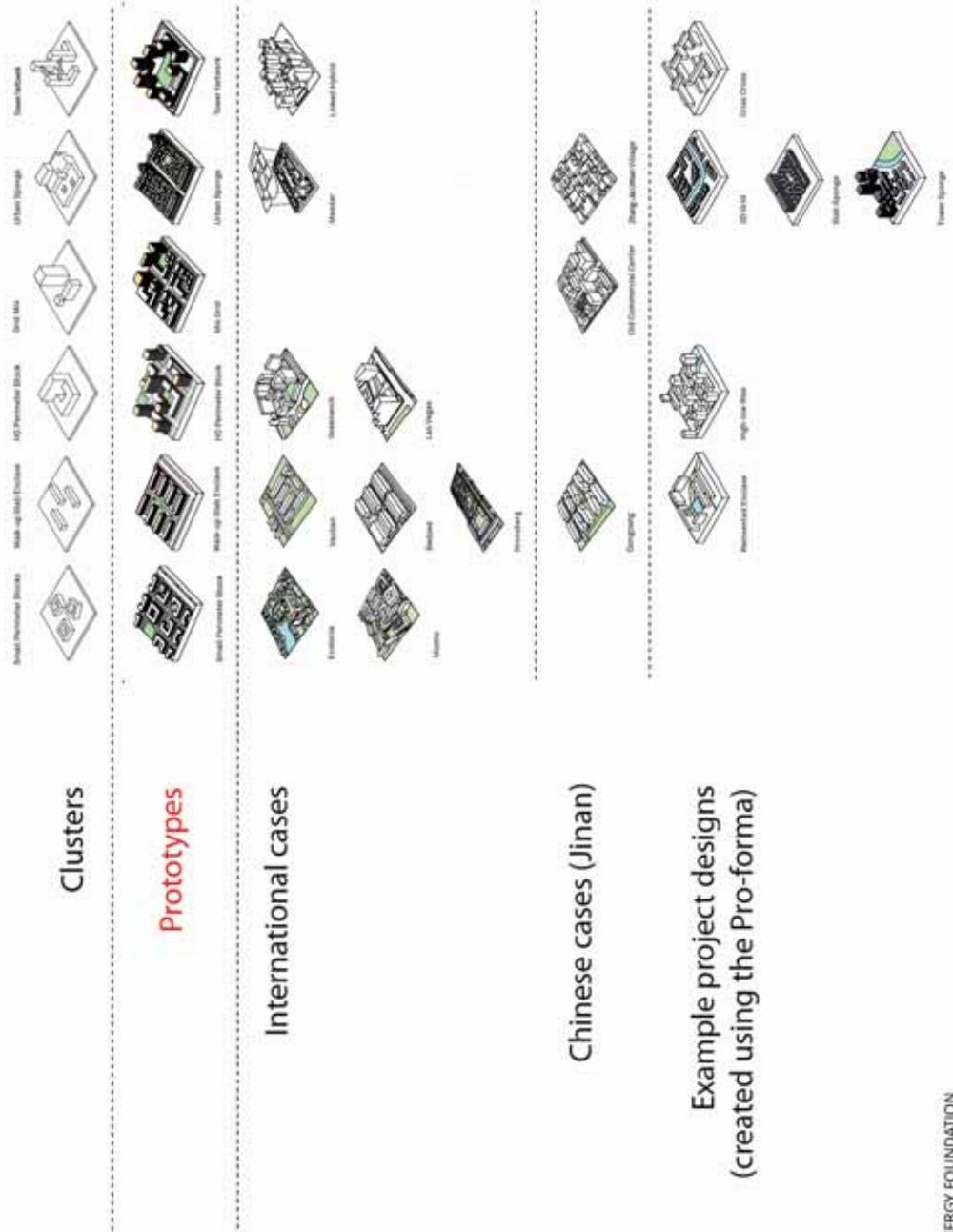
Very few, if any, places in the physical fabric of a city or neighborhood are unique. Rather, the form is composed of a collage of prototypical patterns. One of the most provocative findings of our analysis is that the examples of clean energy design, both from best practice and from the student studies, fell into repetitive categories of urban form (though the student examples tended to be more robust and inventive, we think because the Proforma enabled refinements of energy performance and physical form during the process of design). And so, we hypothesized that these types might represent a basic taxonomy of approaches to clean energy design based on existing practice.

Part of our study of relationships between energy and urban form has been a search for the basic prototypical units that underlie these patterns. Clearly, key components of what we call the “form-energy system” extend beyond the building. As we have seen in examining different neighborhoods and their energy performance, the organization of buildings can profoundly affect operational consumption by casting shadows on one

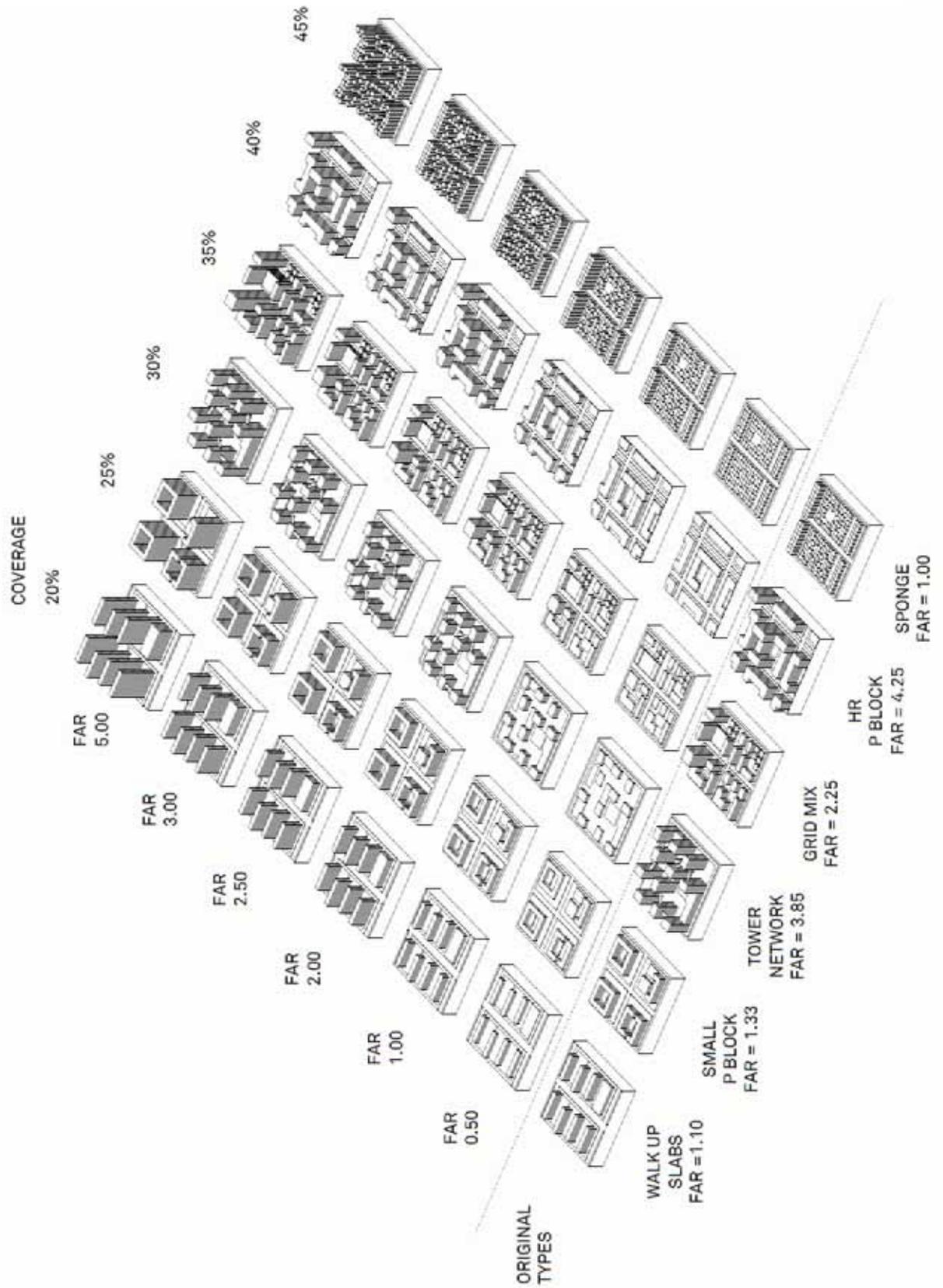
**Figure 10-4. Taxonomy of Clean Energy Neighborhoods**

**CLEAN ENERGY CITIES: ENERGY PROFORMA®**  
 A tool for evaluating the energy performance of neighborhood designs

# TAXONOMY OF CLEAN ENERGY NEIGHBORHOODS



**Figure 10-5. Variations in Clean Energy Neighborhood Designs**



another or blocking wind, or reducing surface area. Building and street patterns affect travel behavior, facilitating pedestrian movement or requiring elevators, or the car. And finally site characteristics affect the potential for on-site renewable energy generation. To bring clarity to these complex interrelationships, this section defines a set of prototypical clean energy neighborhood forms that has emerged from the research to date.

#### *10.4.1 Clean Energy Neighborhood Prototypes*

The collection of (1) demonstration projects, (2) examples of best practice, and (3) urban forms that we found to be energy efficient in Jinan, represent a universe of livable, clean energy urban designs. Clearly there are many avenues to achieving this goal, but the variety is not infinite. Upon analysis, the designs can be seen to represent variations on just six basic prototypes. Each prototype represents a different “form-energy system”, a term which encompasses both the physical and energy characteristics of an environment. The prototypes capture the essence of urban form including relationships among buildings, sites, routes of access, and the surrounding city. They also capture activities and patterns of behavior engendered by the form, and finally, strategies for saving and producing energy.

Taken with their variations, the prototypes provide a taxonomy of clean energy neighborhood design. The taxonomy is presented in **Figure 10 4**, and variations are illustrated in **Figure 10-5**. The taxonomy is important for several reasons. First, the prototypes can be used to easily understand and compare how different form-energy systems operate, and to ultimately measure them using the Energy Proforma (see Chapter 12). Secondly they can provide a shortcut to quickly test the suitability of complex form-energy systems to particular sites. We are currently developing a web-based tool to do this linked to the Energy Proforma. Designers will be able to adjust any of the six prototypes to the parameters of a particular site across dimensions such as density, coverage, and use mix, and get a read on expected energy performance. Lastly, the prototypes can be used as language of design, providing the basic elements to assemble unique variations and approaches to clean energy neighborhoods.

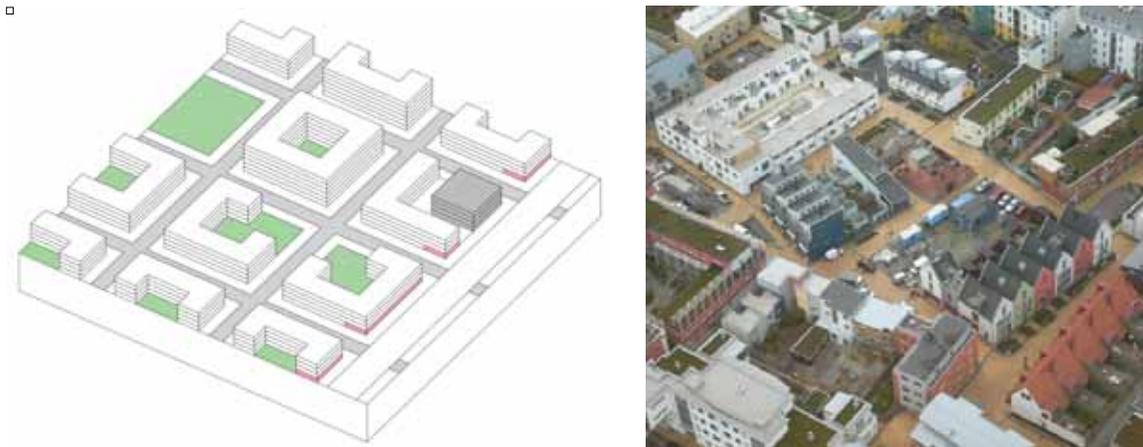
The taxonomy of prototypes includes the “clusters” associated with each of the prototypes, representing the most basic unit of the form-energy system. Defined in the Year 1 Report, clusters capture relationships between buildings, spaces, movement systems, and activities that underlie patterns of energy use (of course, they have profound social implications for the people living within them, as well). They are the DNA of the prototypes. The figure also includes some of the cases of best practice, Jinan neighborhoods, and demonstration designs which represent variations on the prototypes we discovered through the research.

The prototypes are discussed below:

### ***Small Perimeter Block***

This prototype, illustrated in Figure 10-6, dense packs the environment with clusters of small-scale connected buildings of 3-4 stories arranged around the edges of small blocks (70m square), leaving a court in the middle. Such arrangements can comfortably accommodate densities up to FAR 2.0.

**Figure 10-6. Small Perimeter Block prototype. Malmo, Sweden**



- ***Operations*** – If properly oriented, the cluster allows sun to penetrate to all units, retains heat in the winter, and can mitigate the effects of wind in cold climates. Energy is conserved by moderation of the microclimate and the reduced need for elevators in low rise structures. It also allows for individual front doors on the perimeter and semiprivate space inside the block, a highly livable arrangement.
- ***Travel*** -- The collection of small blocks creates a highly permeable (accessible), pedestrian dominated environment that can easily accommodate a mix of shops, services, and schools where convenient and feasible. This reduces the need for a car, which may still access any unit through shared streets, although parking would ideally be located at the periphery of the neighborhood.
- ***Renewable energy*** -- large roof surfaces provide ample space for PV and solar hot water (and the court yields space for geothermal wells, if desired).
- ***Embodied energy*** – Low rise allows for lighter weight construction and reduced embodied energy.

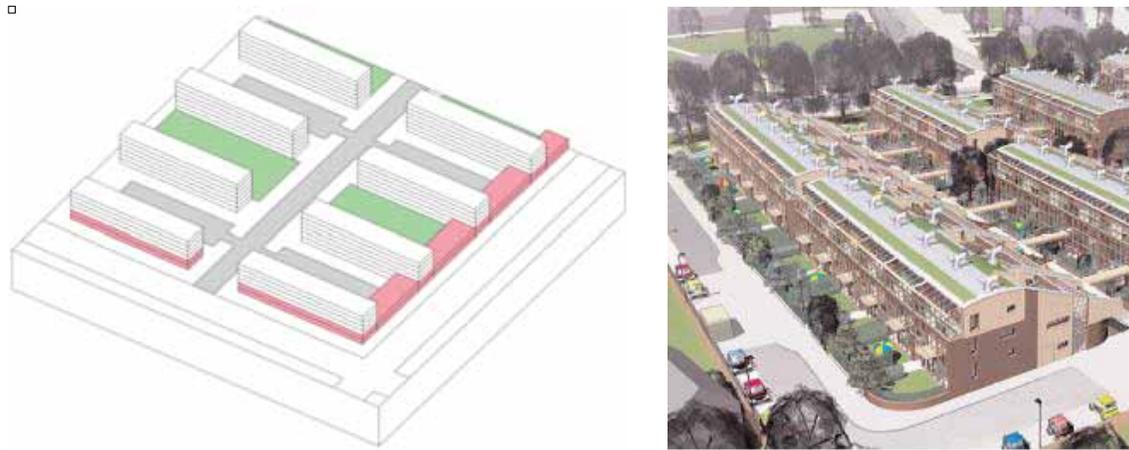
The clearest example of this prototype is the sustainable community of BO01 in Malmo Sweden, pictured in Figure 10.6, although there are many variations, including those

found in planned cities such as Barcelona, where the Cerda grid at FAR 3.0 represents a higher density version of the prototype.

### ***Slab Enclave***

These forms consist of stacked flats arranged in linear 4-6 story buildings grouped into more or less private enclaves surrounded by city streets lined with shops and services, as illustrated in **Figure 10-7**. Spaces between buildings are used for auto access and parking alternating with “backyard” common space for the residents. Such arrangements can comfortably accommodate densities of up to 3.0 FAR.

**Figure 10-7. Slab Enclave prototype. Bedzed, London, UK**



- ***Operations*** -- These forms are typical in many clean energy projects because, when aligned east-west with proper shading devices, they can maximize solar gain in the winter and reduce it in the summer, lowering heat and cooling energy demands. In China, units are typically arranged off common stairwells serving 3-4 units per landing with no elevator. (Elsewhere units are accessed off single-loaded corridors.) This efficient plan enables cross ventilation in each unit, reducing demands for cooling, and minimizes energy use in common space and elevators.
- ***Travel*** – Shops, restaurants and services on surrounding streets are accessible on foot from within the enclave. Larger scale enclaves should be well connected to surrounding public streets to enable direct access (as opposed to a single gated entry, which increases travel distances and energy use by cars).
- ***Renewable energy*** – Sloped roof surfaces can provide ideally oriented space for PV and solar hot water, however, the amount of roof surface per unit is less than the small perimeter block, and becomes even lower as the height of the slabs increases.

- **Embodied energy** – Low rise allows for lighter weight construction and efficient floor plates with minimal common space reduces embodied energy.

This prototype is typical of the thousands of projects constructed in Chinese cities through the 1990's, like Dongcang in Jinan, which follow a rigorous east-west arrangement maximizing southern exposure. But it is also found in many of the iconic best practice cases like Bedzed, Kronsberg, and Vauban. In China, the slab enclaves were originally constructed with no accommodation for local conditions or mixed uses, and criticized for their standardization. However the simple forms are also easily adapted, and over time community facilities, services, recreation, restaurants and retail have been added around and inside the enclaves, and the buildings themselves have been altered, enhancing their livability and energy efficiency. The demonstration design “Reinvented Enclave” illustrated in **Figure 10-8**, shows how the energy saving and place-making potentials of this prototype could be maximized in a highly livable, low-carbon neighborhood.

**Figure 10-8. Reinvented Enclave**



### ***High Density Perimeter Block***

This prototype has many of the advantages of its smaller, low-rise cousin, but involves integrated blocks that are bigger in scale and density. Typical projects may include 8-10 story or even taller buildings grouped with lower scale structures around the edges of moderately scaled urban blocks (120 m square) leaving a space in the middle. Building entrances, local shops and services face public streets and sidewalks surrounding the blocks, creating a highly walkable environment, while interior spaces may accommodate semi-private residential entrances, amenities or other activities shielded from the bustle of the city. Depending on the size of the blocks, livable densities up to FAR 4.25 can be achieved.

**Figure 10-9. High Density Perimeter Block prototype. Millennium Village, UK.**



- ***Operations*** – If the clusters are properly oriented, and taller elements carefully located, sunlight to units may be maximized, and wind minimized, during winter months, reducing heat demands. During the summer, taller elements may shade the units and court spaces below, reducing cooling demands. Furthermore, by integrating the energy systems of high and low rise structures, chimneys or vertical spaces within taller elements can provide natural ventilation for the entire block, as well as recover and re-circulate heat in cooler months.
- ***Travel*** – Conventionally scaled (2 lanes with parking) city streets surrounding the blocks maximize opportunities for shops, restaurants, services, schools and parking structures to be integrated in the fabric, all conveniently accessible because of the grid. Animated public streets encourage walking and use of the public realm, tending to reduce auto usage and time spend by people in their apartments, reducing energy consumption.

- Renewable energy – The roofs of low rise elements provide good locations for photovoltaics and solar hot water. Taller structures are less efficient solar collectors, because roof surfaces are small in comparison to the volume of the building, however, depending on height they could offer sites for wind power. Court spaces provide locations for geothermal wells.
- Embodied energy – Taller structures require heavier construction, more steel and therefore have more embodied energy. Lower structures may be of lighter construction, yielding moderate embodied overall.

The “High-low Rise” demonstration design, illustrated in **Figure 10-10**, shows the potentials of this highly versatile prototype offering: a humanly scaled, mixed use grid of streets at the lower level, semiprivate spaces for residents within blocks, coupled with taller elements that provide density. The totality acts as a highly efficient and livable form energy system. Variations on the prototype can be seen at Millenium Village, in Greenwich, UK, where taller buildings are located to the north to allow sun penetration and to deflect wind off the Thames. Another example is Symphony Park in Las Vegas, where 30 story buildings on the perimeter of blocks are located to shade streets and courtyards below. Variations on the high density perimeter block prototype have been used extensively in Vancouver, one of the world’s most livable, high density cities.

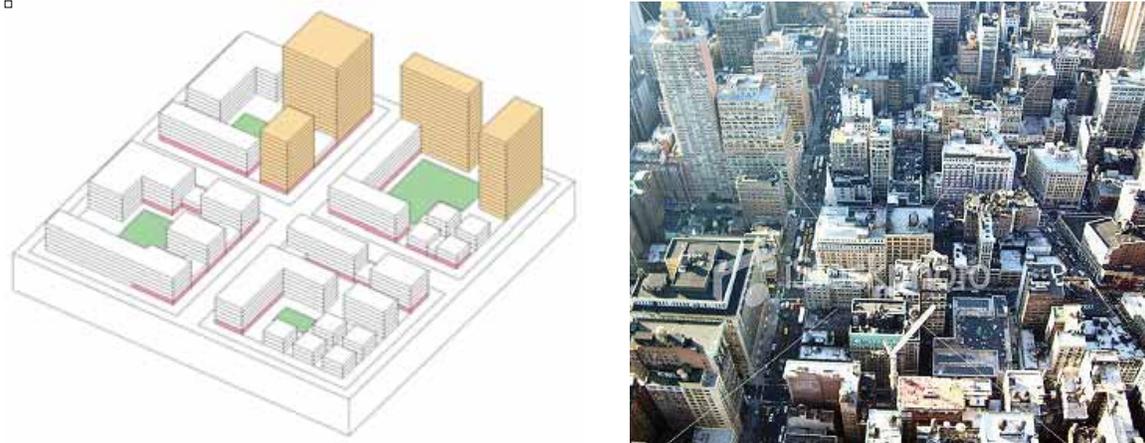
**Figure 10-10. High-low Rise**



### *Mixed Grid*

This prototype represents the traditional urban pattern of rectilinear public streets and private blocks (70 x 250m), illustrated in **Figure 10-11**. A wide variety of low and high rise housing types and other uses may be built within the blocks, with shops and services on first and second floors, all unified by the system of streets. There is no regular pattern of form or spaces within the blocks except as may be given by the geometry of parcels and zoning restrictions on lot coverage and density. The totality enables high density, accessibility, and walkability within a diverse, mixed use environment that has been shown by our research and others to be energy efficient. Overall density can go quite high – up to FAR 6.0 or more – depending on the size of the blocks.

**Figure 10-11. Mixed grid prototype. New York City.**



- **Operations** – This prototype is less able to take advantage of energy savings to be found by integrating high and low rise building systems because there is no regular pattern of form. Of course, individual structures may be oriented and designed to take advantage of passive solar heat gain and loss, however the overall potential to save energy is less than would be found in a more integrated system. The major energy savings of this prototype emerge from its ability to achieve relatively high densities within a very accessible, livable environment.
- **Travel** – As with the perimeter block prototype, city streets surrounding the blocks maximize opportunities for shops, restaurants, services, schools and parking structures to be integrated in the fabric, all conveniently accessible because of the grid. Animated public streets encourage walking and use of the public realm, tending to reduce auto usage and time spent by people in their apartments, reducing energy consumption. The densities that may be achieved by this prototype makes mass transit more feasible.

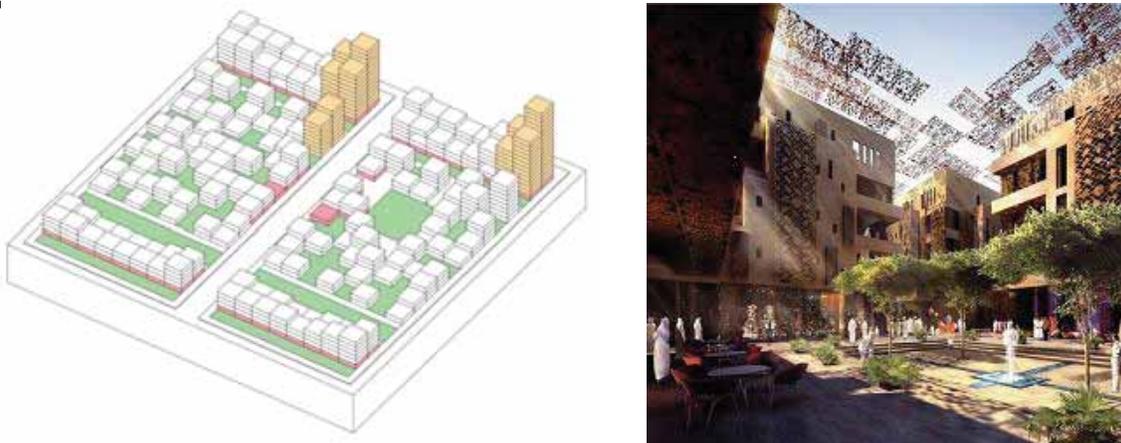
- **Renewable energy** – As with passive measures, the Mixed Grid has less potential of incorporating renewable energy systems than a more organized form, notwithstanding individual opportunities on a building by building basis.
- **Embodied energy** – Taller structures enabled by this prototype require heavier construction, more steel and therefore have more embodied energy.

The Old Commercial center of Jinan is example of the Mixed Grid prototype, offering a wide diversity housing types, commerce, and jobs within a compact, energy efficient grid of streets and blocks, where walking is encouraged and transit is easily accessible. The most iconic example of this prototype is probably Manhattan, New York City, albeit at an extreme density of approximately FAR 9.0. Many studies have shown that the higher density, accessibility and mix of uses on Manhattan, make it the most energy efficient city in the US. (New Yorker 10.18.04)

### *Urban Sponge*

This prototype of development has deep roots, but is being updated for the 21<sup>st</sup> century, as illustrated in **Figure 10-12**. The roots can be found in traditional patterns of settlement like Zheng Jia Village in Jinan, a pedestrian environment that mixes living with working, production, and commerce in a complex but highly permeable urban form of built and open spaces – like a sponge -- that we found to be quite energy efficient. 21<sup>st</sup> century variations, extend this idea into the 3-D realm, enabling the same advantages at a much higher density. Density can range from very low up to FAR 6.0 or more.

**Figure 10-12: Urban Sponge prototype. Masdar, Abu Dhabi.**



- **Operations** – Traditional variations of the Urban Sponge cluster type are organized around spaces and courtyards of various sizes which allow sunlight to enter but mitigate the microclimate, protecting from cold winds in the winter and providing shade and natural ventilation in the summer. Through computer aided design

applications, and contemporary construction techniques, it is possible to extend these benefits into three dimensions including even high rise structures with upper level “court” spaces that provide daylight or shade as appropriate, natural ventilation, and places for cooling vegetation, saving energy in surrounding units on all four, even six sides. Given the inherent integrated nature of environmental systems in this prototype, taller elements may naturally ventilate and recapture heat from lower elements as with the High Density Perimeter Block prototype.

- **Travel** -- The Urban Sponge is a pedestrian environment, where cars and parking structures are relegated to the periphery of large scaled blocks (150 x 300-600m). However, vehicular access to service and vertical circulation must be maintained on the ground level. This saves energy by reducing car travel, and potentially elevator use to the degree that mixed uses – schools, services, even shops and restaurants -- can be located on routes of movement at or above ground level.
- **Renewable energy** – The same sensitivity to design for passive heating and cooling within a permeable 3-D form, can be given to the location of photovoltaic and solar heating elements, which theoretically should maximize their energy capture.
- **Embodied energy** – Embodied energy consumed per unit would depend upon density and height. Taller structures enabled by this prototype require heavier construction, more steel and therefore have more embodied energy.

Several of the demonstration designs represent variations on this prototype at different densities, highlighting its versatility and potential for increased application in the future. “3-D” Grid, for example, expands the traditional village structure to a four story matrix,

**Figure 10-13. Urban Sponge.**



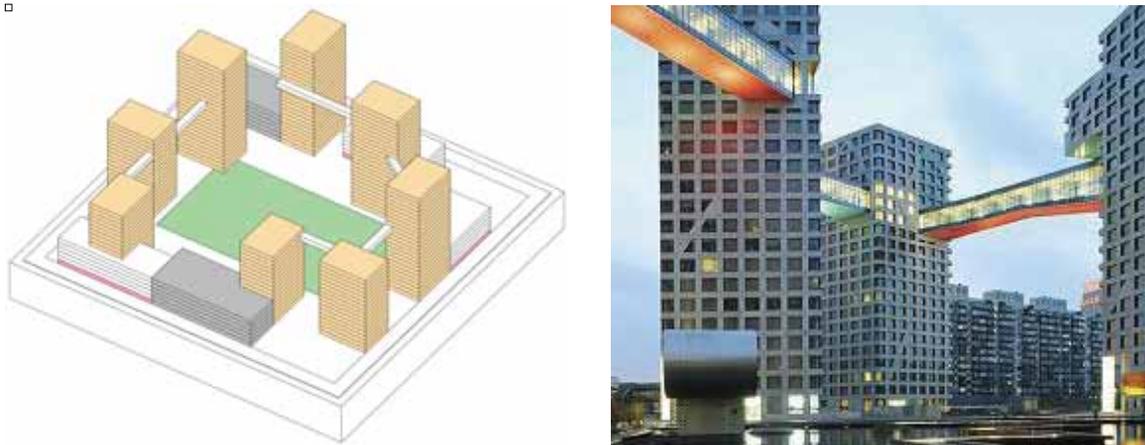
where pedestrian paths, shops and services are location along upper level pedestrian routes as well as on the ground, and courtyards may be multistoried or spring from upper levels. “Urban Sponge” and “Wrapped Towers” adopt the same strategy moving the permeable matrix up to 8-10 story or even taller structures, incorporating high-rise towers into the mix, illustrated in **Figure 10-13**. In these cases, lower volumes on the north side, which receive less direct sunlight, tend to be the locus for commercial and production space.

Similar approaches are used in the best-known case of this prototype, Masdar, under construction in Abu Dhabi which will have no cars, allowing pedestrian movement to be tightly interwoven with the buildings and mixed uses on several levels. Photovoltaic panels are strategically situated to generate power while also shading public spaces below. Tightly spaced buildings also shield pedestrians from the sun while wind towers provide natural ventilation.

### ***Tower Network***

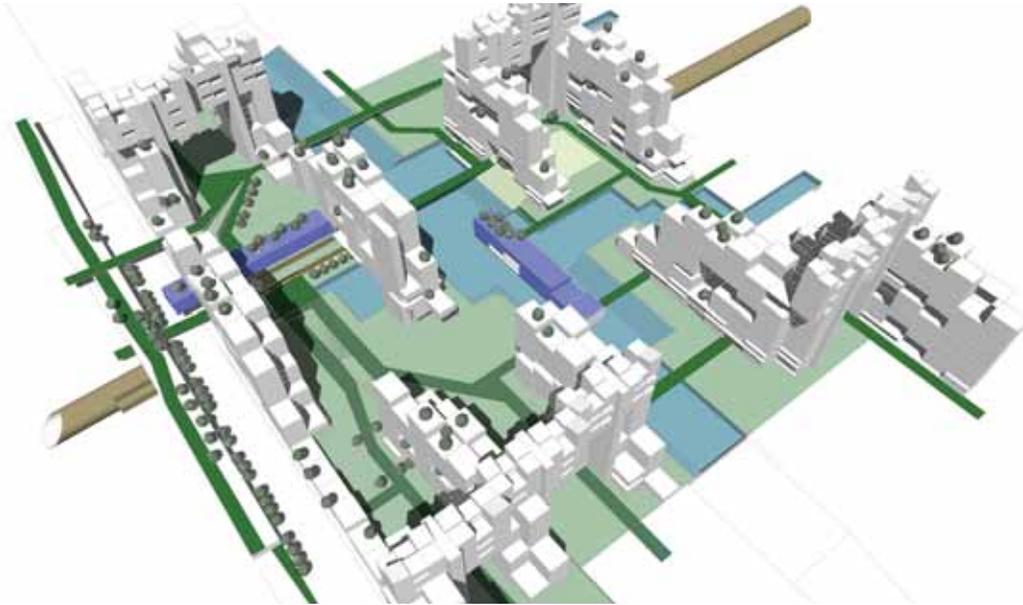
This prototype is a newly emerging high-rise form in which the tower elements are not freestanding, but connected to one another at the lower levels and high in the air, forming a network, as illustrated in **Figure 10-14**. As a network they offer multiple paths of movement horizontally and vertically, overcoming the energy consuming characteristic of separated towers which require descending to the ground by elevator to accomplish any task outside of the apartments. Connecting the towers at their bases, also provides opportunities for integrated parking, shops, services, schools, meeting and hotel spaces, for example in these lower structures. This prototype is most appropriate to highly developed downtown locations where the towers could be a mix of residences, offices, and hotels, reaching densities from FAR 4.0 to 9.0.

**Figure 10-14. Tower Network prototype. Linked Hybrid, Beijing.**



- **Operations** – To maximize solar gain, and beneficial shade, towers need to be carefully located so as not to interfere with each other or activities on the ground. This will inevitably be more difficult than high-low schemes given the number of towers and suggests that office and hotel uses, which require less direct sunlight, be concentrated more in the northern sections of a district or on the lower levels of the towers.
- **Travel** – Connecting upper levels, provides the opportunity to establish a secondary public realm of shops, services, educational, and social activities in the air, as well as convenient access between living and working -- between apartment and office buildings. This makes the most sense where the density is sufficient to also support activity on the ground and the two realms can be effectively linked. This networked, mixed use environment can reduce the need for vertical trips as well as car trips on the ground, saving energy.
- **Renewable energy** -- This predominantly high-rise cluster provides less roof space than alternatives and therefore has less potential for photovoltaic or solar hot water generation. Depending on height and spacing, the towers do offer opportunities for wind power generation. By using towers to achieve density, more ground space can theoretically be made available for geothermal wells, if appropriate.
- **Embodied energy** -- Embodied energy consumed per unit would depend upon density and height. Taller structures enabled by this prototype require heavier construction, more steel and therefore have more embodied energy.

The most well-known of the Tower Network projects is Linked Hybrid in Beijing. The project creates a public realm of restaurants, social and civic uses at the 18th floor by linking residential and office towers with bridges. The towers, arranged to form an inner court space, are also connected at the lower levels by structures containing a mix of uses which face surrounding public streets. The addition of green roofs and 600 geothermal wells beneath the central court and pool, make this a very energy efficient project. The concept is carried further in “Criss-cross”, a demonstration design in which linear buildings that run north-south on the lower levels -- serving office, commercial, and production activities – are connected on the upper levels by building elements which run east-west, containing housing (orienting south in typical fashion), shown in **Figure 10-15**. Common elevators are used to access all uses, facilitating living and working within the same complex. This arrangement defines large scale spaces on the ground devoted to recreation, cultural, and community use, and parking.

**Figure 10-15. Criss-cross.**

The prototypes define a range of clean energy neighborhood design approaches at different ideal densities, all of which have potential to save significant energy over conventional forms of urbanization in China. Equally significant are form types that were not included in the collection. Most notable are “Tower-in-Park projects composed of single use, widely separated, high rise, residential buildings in gated enclaves, which our studies in Jinan demonstrated to consume almost twice as much energy as any other form of development. Also not included is low rise single family villa type projects – typically found in suburbs – that are equally inefficient. While we feel these represent the universe of approaches now on the table, of course others may emerge in the future.

#### ***10.4.2 From Prototypes to Guidelines***

Design studies over the course of Phase 2 have laid the groundwork for understanding the characteristics of clean energy neighborhood design. We now have a strong sense of the factors which do, and do not, contribute to energy efficiency and potential for renewable energy generation at the neighborhoods scale. This knowledge will be essential to creating guidelines for clean energy development in China. To date, our knowledge is largely qualitative, however. Based in our empirical findings in Jinan, the Energy Proforma provides a tool to help dimension the prototypes and their constituent characteristics. We pursue this goal in Chapter 12.



## 11 Measuring Neighborhood Energy Performance: Energy Proforma<sup>©</sup> Version 2.0<sup>1</sup>

Designers, developers and decision makers at national, state and city levels have become increasingly aware of the role of the built environment in determining energy consumption, greenhouse gas emissions, and climate change (McGlade 2009).<sup>2</sup> However, systematic tools that can assess and/or predict the energy performance of urban development at the neighborhood scale are unavailable. This has hindered research, design, and ultimately policy for clean energy urban development. The *Energy Proforma*<sup>©</sup> is being developed by MIT to address this gap.

### 11.1 Concept

The Energy Proforma is modeled after concept of a real-estate financial pro-forma, which provides a standardized method to assess the financial performance of a proposed development project. In a similar vein, the Energy Proforma provides a standardized method to assess the *energy performance* of a development project. The user inputs variables based on a neighborhood's design, location, and socio-economic characteristics; the Energy Proforma then calculates the "net present energy value" of the project, expressed in terms of mj/household or mj/square meter of built area. This standardized value allows designers to approximate the energy performance of projects as they are being designed and make adjustments in process. As well, researchers and policy-makers may understand and compare the energy performance of proposed or built projects.

The Energy Proforma is a comprehensive tool that assesses the energy performance of a proposed neighborhood design, or existing neighborhood form, across four dimensions, which are the same as those considered in the empirical studies, including:

- ***Embodied energy*** – consumed in the building and site construction (earth moving) of the neighborhood;
- ***Operational energy*** – consumed in private residential units and in the use and maintenance of common facilities and spaces of the neighborhood;

---

<sup>1</sup> © MIT, 2010. Recommended platform for viewing Proforma as web tool: Internet Explorer 8 or later. Requirements for creating .gml files to upload into webtool: Google SketchUp with CityGML Plugin. Requirements for viewing Pro-forma as spreadsheet: MS Excel 2002 or higher on MS Windows, or MS Excel 2004 for Macintosh on Mac OS X (The Tool will not work with MS Excel 2008 for Macintosh)

<sup>2</sup> As C40Cities Climate Leadership Group notes, cities and states try to reduce GHG by: increasing the energy efficiency of buildings, outdoor lighting, and transport; using energy intensive resources more effectively; and producing clean energy at the district-level as well as sourcing clean energy from large-scale suppliers. However, none these efforts take into account the underlying energy impacts of urban form, which affects all other variables.

- **Transport energy** – that must be consumed by those who live, work, and visit the site to undertake their daily activities of living;
- **Renewable energy** – production potential of the neighborhood from solar (hot water and electricity) and wind sources.

The Proforma assesses overall energy performance by aggregating estimates of the energy consumed across the embodied, operational, and transport dimensions -- over time, then subtracting the potential for renewable energy production resulting in a measure of the net present energy value for the neighborhood.

The specific input variables to the Proforma are derived from the same parameters used in the empirical analysis discussed in Chapter 8 (listed in detail in **Table 11-1**). The input variables and calculations of energy consumption were developed not only based on scientific methods but also through extensive communication among urban design researchers and energy modeling researchers. As a result, the input variables of the Energy Proforma reflect the kind of information that would be readily produced by designers and developers in the process of conceiving their projects. The Proforma holistically considers and quantifies material intensity, energy consumption, and GHG emissions, enabling designers to explore the comprehensive energy consumption of relatively large-scale, complex development projects rather than being limited to the energy efficiency of individual buildings.

To calculate predicted energy consumption, Energy Proforma version 2.0 utilizes findings from life cycle analysis of prototypical urban neighborhoods in Jinan, China. These findings were derived through statistical analysis of survey data provided by close to seven thousand residents in 23 neighborhoods and detailed GIS data on the physical form of the neighborhoods, as discussed in **Chapters 7-9**. Of course, as a standard tool the Energy Proforma can be employed in any location where sufficient data is available. In other contexts outside of China much of the required data may be available through publically available sources, minimizing the need for special purpose surveys. In the near future, digital data on human activities, movement, energy utilization, and all aspects of the built environment will become more and more available; facilitating the usability and accuracy of the Proforma.

Energy Proforma version 2.0 represents a significant advancement over version 1.0. Version 1.0, developed in year 1 of the research, was tested in two practical applications in China and at MIT. In all, the two applications involved 45 Tsinghua and MIT professional masters and PhD students, who produced a dozen clean energy neighborhood designs using the Proforma. The results of these exercises provided rich feedback on the value and functionality of the tool, which, along with other technical inputs, provided the basis to revise the Proforma in Year 2. Key advancements, which have now been incorporated in Version 2.0 include:

**Table 11.1. Project design data and Proforma variables**

Nominal project design data	Input variables Energy Proforma v 2.0
<ul style="list-style-type: none"> <li>• Land use</li> <li>• Green land area</li> <li>• Vehicular roads</li> <li>• Shared roads</li> <li>• Pedestrian ways</li> <li>• Residential land area</li> <li>• Commercial land area</li> <li>• Parking land area</li> <li>• Public transport</li> <li>• Water</li> <li>• Civic land area</li> <li>• # Residential floors</li> <li>• # Commercial floors</li> <li>• Building footprints</li> <li>• Total built residential floor space</li> <li>• Total built commercial floor space</li> <li>• Total built civic floor space</li> <li>• Total construction area</li> <li>• Cluster dimensions</li> <li>• Average household size</li> <li>• Household Density</li> <li>• Southern exposure</li> </ul>	<p><i>General Neighborhood Attributes</i></p> <ul style="list-style-type: none"> <li>• Average HH Demographics (size, income, mode pref, etc)</li> <li>• # of households (units)</li> <li>• Neighborhood area (sq. m)</li> <li>• Distance to CBD</li> <li>• BRT Corridor (Y/N)</li> <li>• # Transit stops w/in 500m</li> <li>• Usable Built Area of Total (%)</li> <li>• Insulation condition</li> <li>• Elevator intensity</li> <li>• Water use intensity</li> <li>• Parking Ratio</li> <li>• Parking Type</li> </ul> <p><i>Form conditions</i></p> <ul style="list-style-type: none"> <li>• Building Footprint</li> <li>• Average building heights (# of floors)</li> <li>• Height of Floors</li> <li>• Length of Walls (N,S,E,W)</li> <li>• Normal Vectors Walls</li> <li>• Window-to-wall ratio</li> <li>• Building Use Ratios</li> <li>• Street-Level Use Ratios</li> <li>• Roof Type</li> <li>• PV Panel Condition</li> <li>• Green space coverage</li> <li>• Road types lengths, areas</li> <li>• Tree coverage</li> </ul>

1. **Methodology** -- More refined methodologies for predicting operational, travel, and embodied energy, drawn from more extensive and detailed empirical work;
2. **Sun and wind** -- An approach to accounting for the effects of sun and wind on project operational energy use, (although we are studying alternative methodologies);
3. **Renewable energy generation** -- A measure of the potential of a design to take advantage of renewable energy generation from photovoltaic or wind power. Contrary to measurements of embodied, operational, and transportation energy

*consumption*, the renewable energy portion of the Proforma assesses the amount of energy that a development can potentially *produce* through the use of renewable energy technologies. This being the case, renewable energy offsets are *subtracted* from the net present energy value of a development.

4. **Web based user interface** -- A more refined and intuitive interface for Energy Proforma users has been developed. The interface became an issue as more variables were included in the Proforma requiring ever more inputs. Consequently, Proforma version 2.0 has been converted from a spreadsheet into a *web-based* application, which allows detailed as well as short-cut analyses of potential designs. In addition, many variables may now be taken directly from 3-D modeling software commonly used by designers and planners, making the tool more practical as a tool for design.

The Energy Pro-forma is being developed at MIT with inputs from allied researchers, designers and city government officials. Contributors to date have included: Tsinghua University Schools of Architecture and Environmental Science, Shandong University Transportation Planning and Design Research Center, and Beijing Normal University. More importantly, urban designers who are potential users of this model have also participated as the “co-developers” so that their interests and design languages are directly incorporated into the integrative energy-modeling tool.

## 11.2 Operation of the Energy Proforma

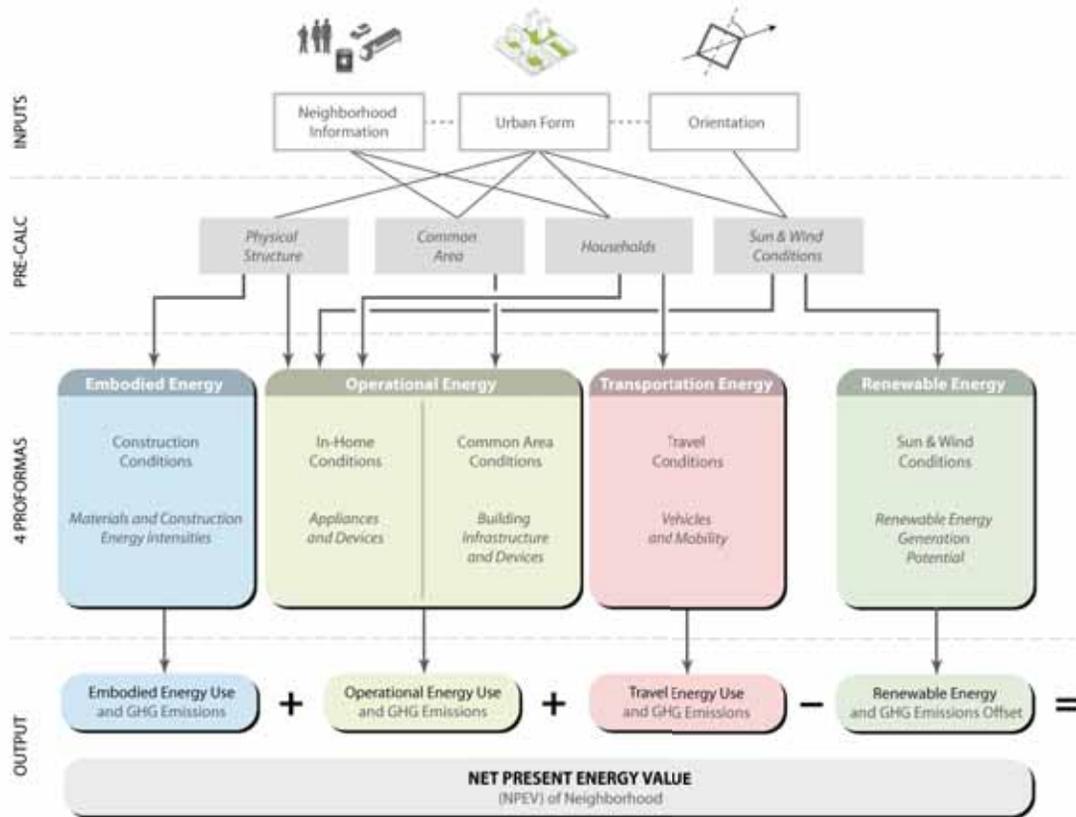
The conceptual operation of the Energy Proforma is illustrated in **Figure 11-1**. The operation of the tool involves four key steps described below:

### 11.2.1 Inputs

These are the raw quantities and characteristics of a neighborhood in the language and measurements commonly used by planners and designers. Inputs are of three types: 1) Neighborhood attributes including socio-economic data about the residents, and contextual information such as distance from the center of town, surrounding land uses, parking, and the availability of public transportation; 2) Urban form elements such as building footprints, heights, façade characteristics, unit sizes, ground floor uses, and road characteristics; and 3) aspects of the neighborhood relating to sun and wind, such as orientation.

As shown in **Figure 11-2** neighborhood attributes such as demographic and context information are entered using an on-line input sheet. Data related to urban form and orientation, rather than being entered by hand, may be extracted directly from a simple .gml file exported from Google Sketchup. This is a common design and 3-D visualization program used by designers.

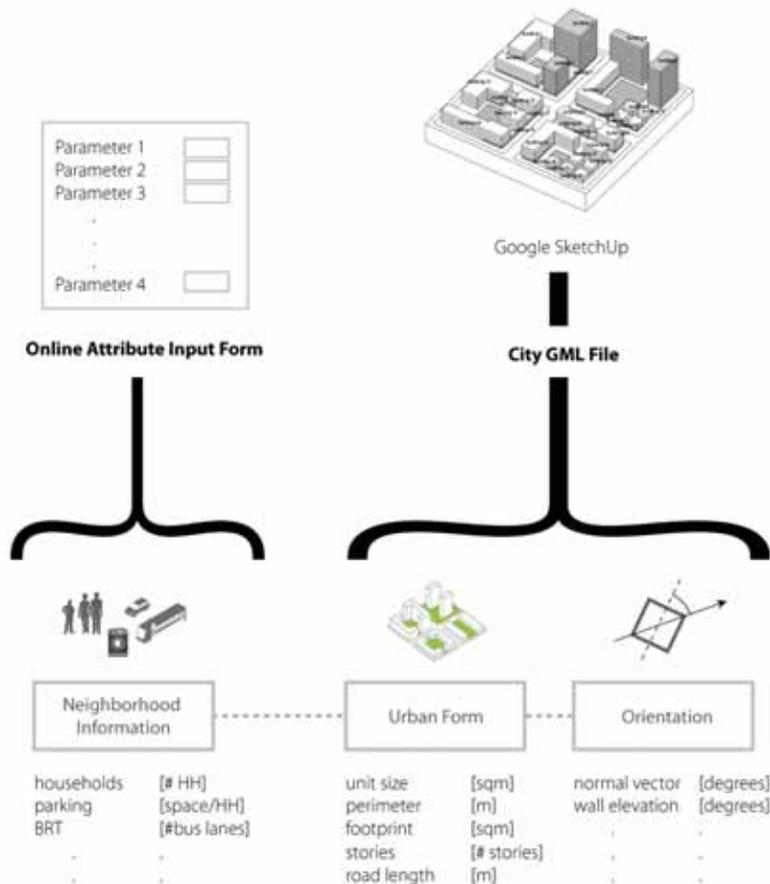
**Figure 11.1. Conceptual operation of the Energy Proforma**



**11.2.2 Pre-calculation**

Given the raw inputs, the Energy Proforma then performs a series of internal calculations to convert this information into a form the program can use. As illustrated in **Figure 11.1**, it dimensions parameters related to 1) the physical structure of the built project, such as surface-to-volume ratio; 2) the nature of common areas, such as use mix; 3) household characteristics; and 4) sun and wind relationships. These parameters are then utilized in the various elements of the Energy Proforma to model energy use. For example parameters related to the composition of households, the physical form and location of buildings, and sun and wind conditions affecting the units, and other parameters, are employed to predict in home, operational energy consumption.

Figure 11-2. Input Methodology and Sample Input Variables

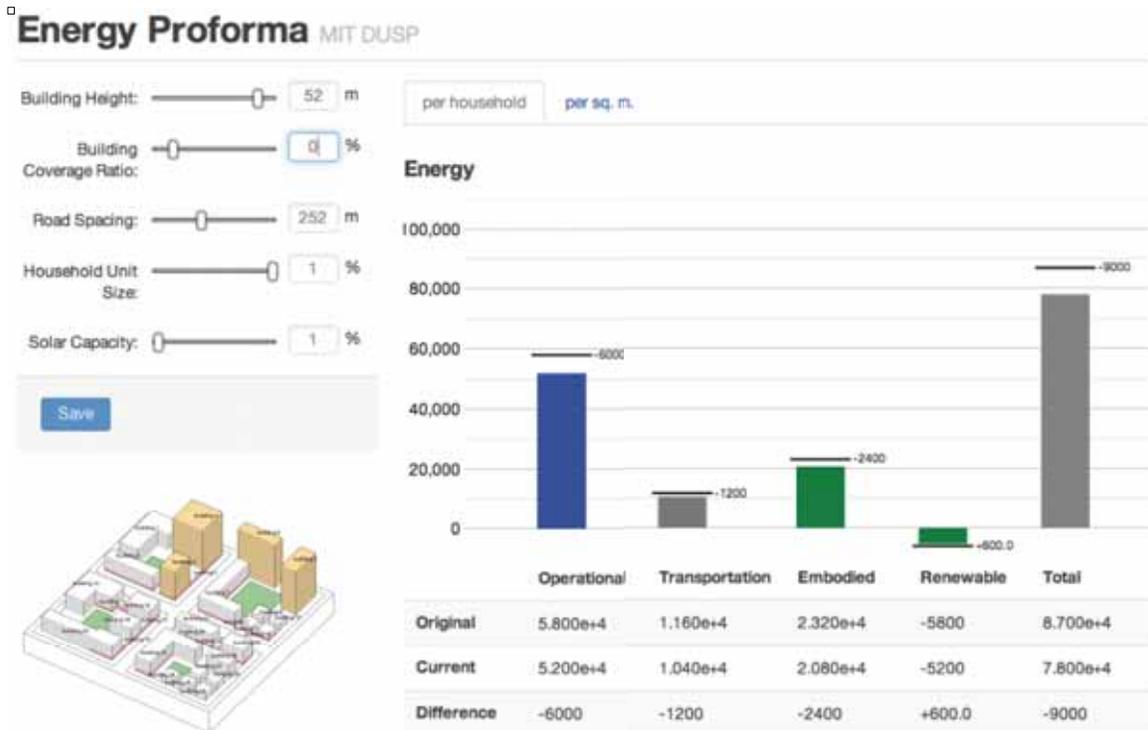


### 11.2.3 Proforma models

Using the parameters, the Energy Proforma, calculates 1) energy use embodied in the project, 2) energy consumed by operation of the units and common facilities, 3) energy required to transport residents to and from their daily activities of living, and 4) renewable energy generation potential of the project form. These calculations draw on known significant relationships between specific aspects of urban form and energy consumption derived from the empirical work in Jinan, as well as other studies carried out as part of the research: on the impact of sun and wind, for example.

The four energy dimensions are then combined to derive a “Net Present Energy Value,” representing a per annum energy cost accounting for the lifespan of the neighborhood. its own consumption. Note that the value for renewable energy potential is *subtracted*, since this Proforma value represents the amount of energy that a neighborhood design may generate to offset

Figure 11-3. Screenshot of a section of the Energy Proforma output sheet



### 11.2.4 Outputs

The final output is presented in a single display, as shown in **Figure 11-3**. The total annual energy performance *per household* is presented by default, along with constituent elements including embodied, operational, and transport energy consumption, and renewable energy generation potential. The user may change the output to instead display units of energy per square meter of residential construction, or tons of CO<sub>2</sub> emitted.

The output sheet not only displays an estimate of energy consumption given a *static* set of input variables. It also enables the user to manually adjust the input parameters of their neighborhood, within reasonable limits, to see what effect these changes might have on energy performance. Changes are made through the use of integrated sliders. The output graphs, though dynamic, still retain a marker for the original values for comparison against the initial input. Finally, in use as a design tool, the user may save various design schemes on a separate output sheet to compare multiple iterations of one or more input geometries in the process of developing an optimal design.

### 11.3 Use of the Energy Proforma

Formatted as an online web tool, the Energy Proforma version 2.0 is intended to be a companion to design. There are two ways that the Energy Proforma may be employed:

- **Custom design** -- The user uploads an emerging urban design scheme of any form at any point during the design process to get a read on its energy performance. Furthermore, adjustments to key design parameters such as average building height, units size and density, road spacing, and use mix so they can learn which parameters will have the most effect on reducing energy consumption, and adjust their design or program accordingly.
- **Shortcut analysis** -- At the predesign stage, the Energy Proforma may be used to assess the potentials of a site or find a fruitful design direction for low-carbon development. For this purpose, each of the six prototypical forms of clean energy neighborhood defined in **Chapter 10** have been preloaded into the program. The designer enters neighborhood context information, then selects one of the prototypes which is applied to the site, and a reading given on the energy performance that may be expected from that type of development. As with the custom design, the user may adjust key parameters to understand how to improve performance. and compare the results of several different prototype designs developed on the same site.

For each scheme, the Energy Proforma outputs an estimate of the energy consumed and CO<sub>2</sub> produced by such an urban form on either a per household or per square meter basis. The user may save the results of different schemes to compare them in the process of homing in on the best approach. It is this functionality that makes the web tool especially important in an iterative design process.

For more detail on how to set up and employ the Energy Proforma, a copy of the **Energy Proforma User Manual** is included in **Appendix [X]**.

### 11.4 Testing the Energy Proforma

To demonstrate the value of the Energy Proforma version 2.0 and to understand how well it operates in practice, we tested the tool on a series of neighborhoods drawn from those we have studied and designed in the research to date. The neighborhoods included:

- Four neighborhoods in Jinan representing each of the basic types studied in the empirical research: urban village, slab enclave, grid, and high-rise superblock. The energy performance of these neighborhoods is known through the research, presented in **Chapter 9**. They served as a way to test and potentially calibrate the Energy Proforma.
- Two neighborhoods drawn from the international cases of best practice, known for their clean energy design and high performance: Vauban, in Germany and Bedzed, near London, discussed in **Chapter 10**. The operational energy performance of these demonstration projects is known because they are compiled and reported annually.

They also served to test the Proforma, and its value in comparing projects located in a different context than Jinan.

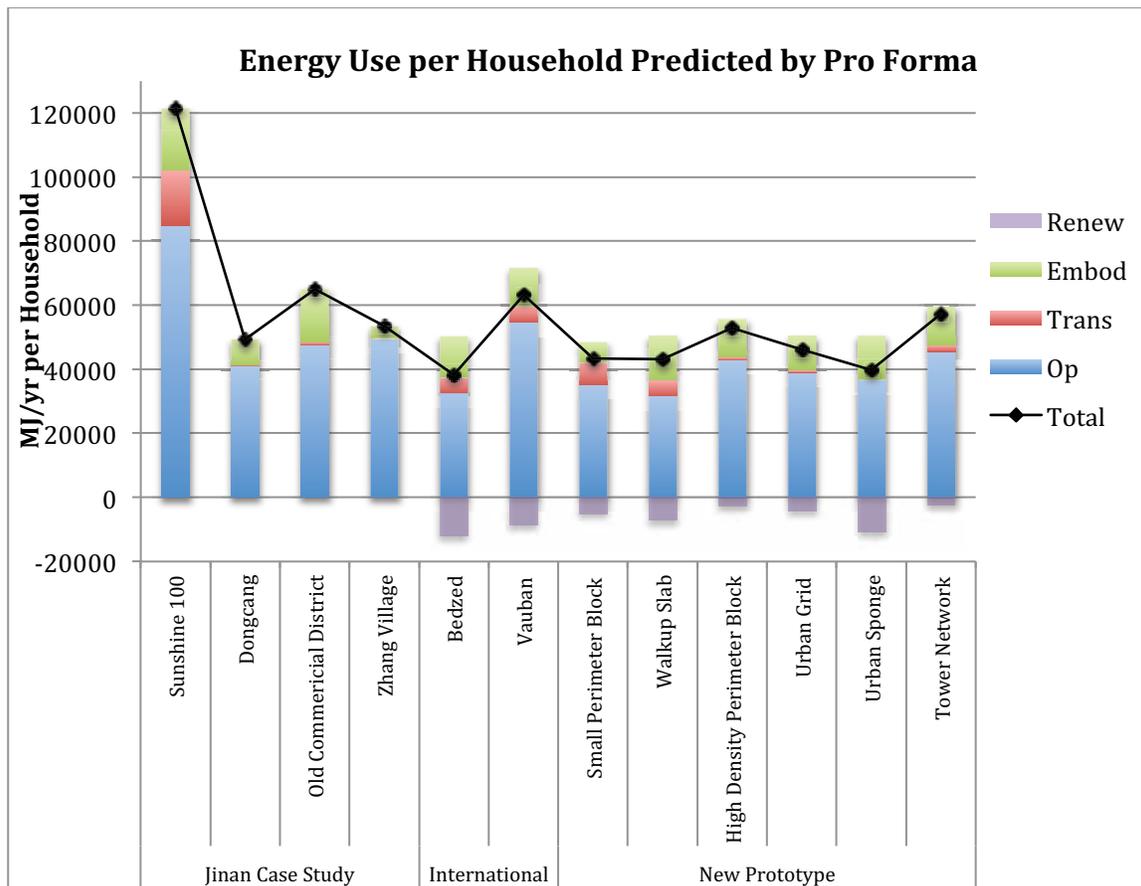
- The six prototypical clean energy neighborhood forms identified through the research, also presented in **Chapter 10**. These prototypes emerged out of all the work on clean energy design done to date. The Proforma served to confirm that these prototypes were indeed energy efficient, and how they compared with other cases.

For all neighborhoods tested, we held the demographic profile constant, to represent a typical upper middle-income household in Jinan.

### 11.4.1 Comparison of Neighborhoods

A key value of the Energy Proforma is that it enables comparison of energy performance across different neighborhood forms. **Figure 11-4** displays results for all twelve neighborhoods, including yearly embodied, operational, and transportation energy consumption, and renewable energy potential (not calculated for Jinan neighborhoods).

**Figure 11-4. Energy Proforma Results for 12 neighborhoods**



For the twelve urban forms, the Proforma predicts a range of values between 38,251 MJ/HH/yr at Bedzed, a demonstration clean energy project, and 121,414MJ/HH/yr at Sunshine 100, a high-rise superblock project in Jinan, a difference of 217%. Sunshine 100 also consumes the most energy on a per square meter basis, 778 MJ/m<sup>2</sup>/yr, versus the Urban Grid neighborhood in Jinan which consumes the least, 550 MJ/m<sup>2</sup>/yr. These results parallel the empirical data, which confirm that high-rise super-block, tower-in-park projects consume almost twice as much energy as any other form of development.

Some additional conclusions and directions that may be drawn from these initial studies are discussed below.

#### ***11.4.2 Transportation Energy***

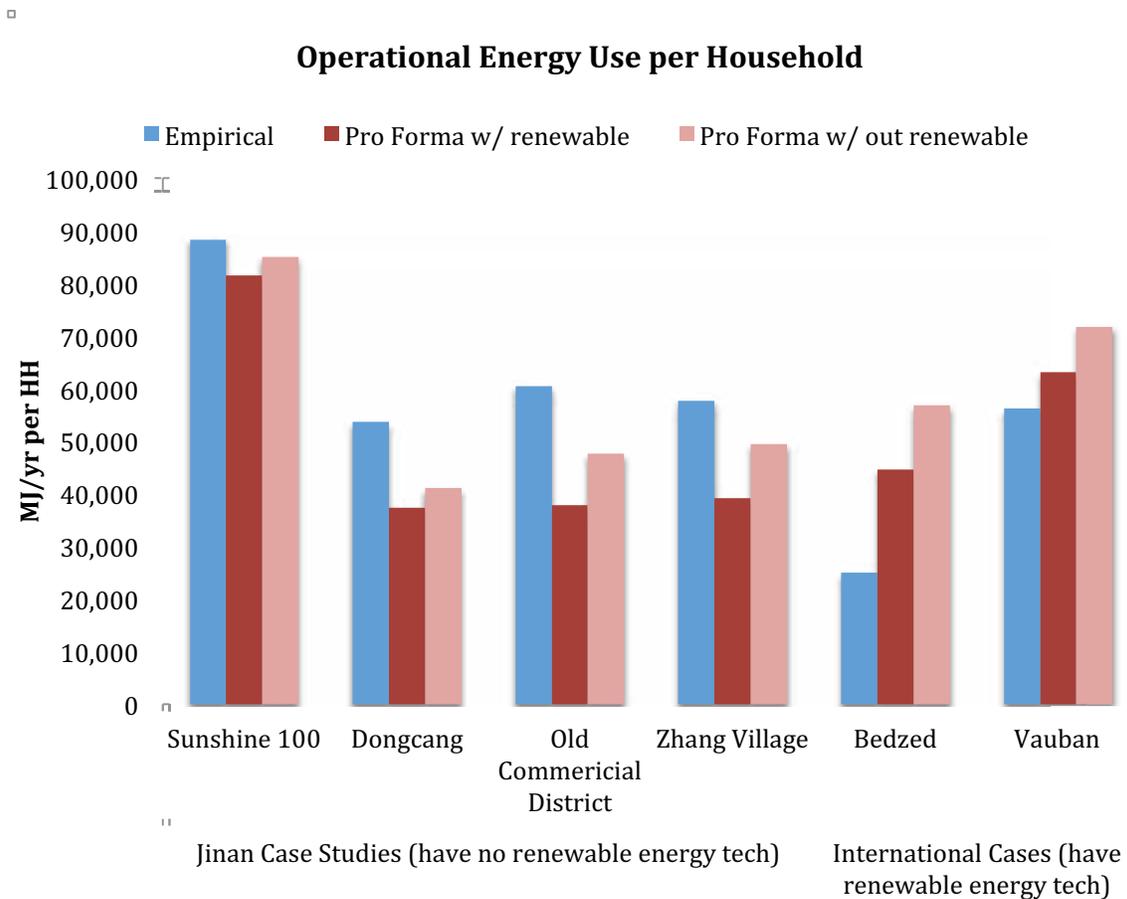
With regard to transport energy consumed by living in these neighborhood forms, again we see that there is a significant variation, with Sunshine 100, the high-rise tower-in-park form, being the most consumptive due to its auto dependence. The Proforma prediction of energy consumption of around 18,000 MJ/HH/yr compares roughly with the empirical results of 23,000 MJ/HH/yr, also the highest of the neighborhoods studied. Since we are aiming at understanding relative energy consumption of neighborhood forms, the absolute difference between these figures is less important and may be an issue of calibration. The international communities of Bedzed and Vauban also register higher on this scale. Although these are demonstration clean energy communities, they are located in Europe, where car ownership is higher. Transport energy consumption associated with these projects is not measured so a comparison is impossible.

Looking at the low end of the scale, several of the Jinan neighborhoods register very low with regard to transport energy consumption. In Zhang Village, for example, this is to be expected since it is a totally pedestrian environment and car ownership is quite low; it is also next to a bus rapid transit line. However, the empirical studies indicate a transport energy consumption of nearly 5000 MJ/HH/yr. The results were similar for the other two existing Jinan neighborhoods, although the differences were less between what the Energy Proforma predicts and what was observed empirically. These results may indicate that Energy Proforma is undercounting transport energy somewhat, by not taking into account informal parking areas, for example, or over-counting the importance of pedestrian streets that may still be serving cars. Despite these absolute differences, overall the Energy Proforma does do a reasonable job of predicting the relative transport energy of different urban forms. Further refinements will enhance the sensitivity of the tool to specific conditions.

#### ***11.4.3 Operational and Renewable Energy***

In all of the neighborhoods studied, the Proforma predicts operational energy to be the largest contributor to overall energy use, paralleling what was observed empirically. **Figure 11.5** compares operational energy results of the Energy Proforma to operational

**Figure 11-5. Energy Proforma operational and renewable energy results**



energy determined from empirical study of the four Jinan neighborhoods, and as reported by the two international cases of best practice. The chart shows operational energy reported by the Energy Proforma both with and without renewable energy offsets. The red bar indicates the predicted energy consumption of the neighborhood without renewable energy; the pink bar illustrates what the energy consumption would be if the potential of the form to incorporate renewable energy generation were fully exploited.

In the case of the Jinan neighborhoods, which do not incorporate renewable energy, the Energy Proforma and empirical values are relatively closely aligned. In both cases, Sunshine 100 consumes the most energy per household, while Dongcang consumes the least, although the Proforma does seem to slightly under-predict energy consumption of the Chinese neighborhoods across the board. The international cases are a different story. Both incorporate renewable energy technology. In the case of Vauban, the Energy Proforma predicts operational energy consumption with renewable offsets of 57,000

MJ/HH/yr, very close to the 62,000 MJ/HH/yr that has been measured at the project. In the case of Bedzed, however, the Energy Proforma predicts operational energy consumption much greater than that measured at the project. This can be explained by the fact that Bedzed has been designed to be one of the world's most energy efficient developments incorporating extreme passive solar, natural ventilation, and renewable energy features. With further development, future versions of the Proforma should be sensitive enough to account for such features. It should also be noted that the coefficients in Energy Proforma version 2.0 are based on data from Jinan, where climate conditions and lifestyles differ markedly from Europe. Locally derived data would provide a better assessment of Proforma results.

**Figure 11.5** reveals the marginal benefit of developing the potential for renewable energy generation in each of the neighborhoods. In all of the cases, we assumed that 50% of roofs and 20% of south-facing walls were covered in PV, and 20% of roofs were planted (green roofs). The renewable energy generation potential per household is then a function of the geometry and arrangement of units in the form. It is no surprise (but comforting) that the Energy Proforma indicates Bedzed as having best potential for marginal gain from renewable energy with a benefit of 12,053 MJ/HH/yr, since Bedzed was designed specifically to achieve such results. Conversely, we find that the Sunshine 100 has the least potential to generate renewable energy, with a benefit of only 3,422 MJ/HH/yr. This makes sense, since Sunshine 100's tower design offers little surface area for roof-mounted PV panels.

#### **11.4.4 Orientation**

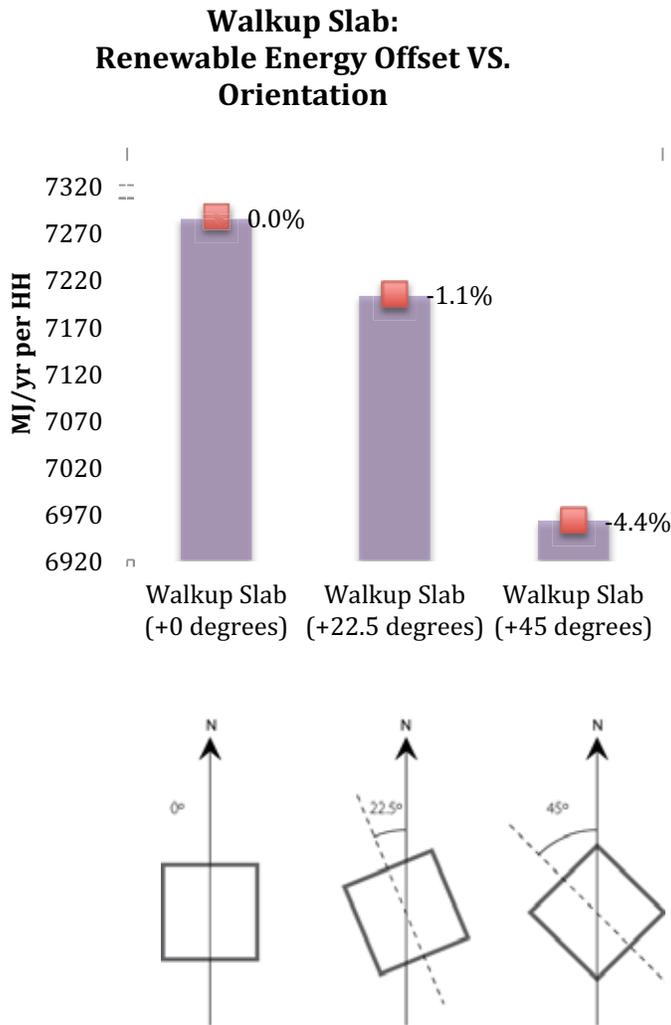
The sensitivity of Energy Proforma version 2.0 to urban form characteristics has been tested in a number of dimensions beyond those mentioned above. As one example, the tool can demonstrate the effects of changing the orientation of a neighborhood design. Using the Walkup Slab prototype as an example, **Figure 11.6** illustrates the effects of rotating the orientation while holding all other parameters constant. According to our Pro-forma, renewable energy potential can be effected by up to 4.4 percent by simply rotating the orientation of the project.

### **11.5 Performance of Clean Energy Neighborhood Prototypes**

A taxonomy of Clean Energy Neighborhoods was proposed in **Chapter 10**, including six prototypes of clean energy neighborhood form. Each prototype represents a different "form-energy system", encompassing both the physical and energy characteristics of an environment. The prototypes capture the essence of urban form including relationships among buildings, sites, routes of access, and the surrounding city. They also capture activities and patterns of behavior engendered by the form, and finally, strategies for saving and producing energy.

**Figure 11-6. Orientation study comparing how renewable energy potential is affected by changing orientation of form relative to North.**

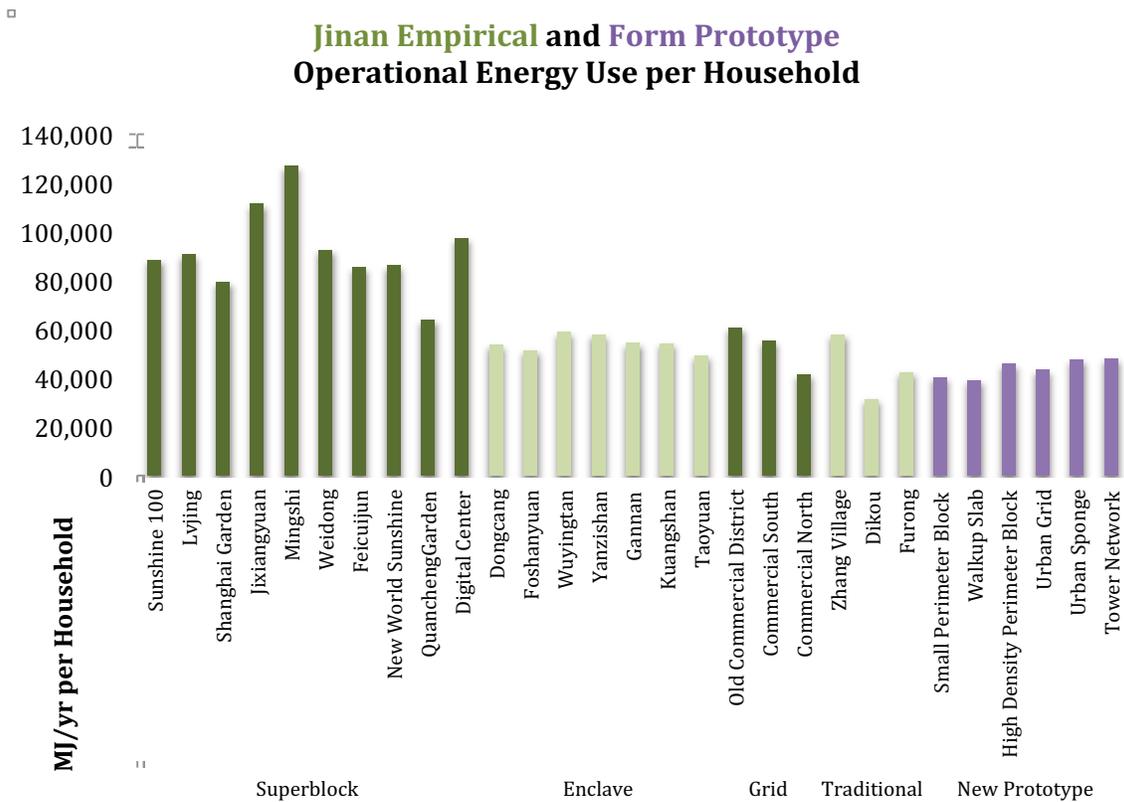
□



To demonstrate the use of the Energy Proforma in a research context, the energy performance of the six prototype neighborhood forms was assessed, and then compared to the household energy consumption of 23 neighborhoods in Jinan, China, as determined through our empirical analysis. The results are presented in **Figure 11-7**. The model predicts that, if a neighborhood were designed using one of these prototypes and built in Jinan, its total energy consumption would be less than all existing patterns of neighborhood development, with the exception perhaps of the traditional houtong. The prototype forms offer substantial energy savings over the high-rise superblock neighborhoods, at the same or greater density of development.

Compared among themselves, the six prototype clean energy neighborhoods produce similar low energy results, even though they represent fundamentally different urban forms. The Pro-forma predicts energy consumption within the relatively narrow range of 40,000 and 60,000 MJ/yr per HH. This confirms what we expected, since these specific form topologies were derived from our study of best practices, empirical evidence in Jinan, and demonstration designs.

**Figure 11-7. Comparison of Clean Energy Neighborhood Prototypes with Jinan Cases**



### 11.6 Conclusion

Energy Proforma version 2.0, developed over the course of the research to date, has been shown to be a valuable tool in predicting and comparing the relative net present energy value of proposed designs and existing neighborhoods. It is currently a dynamically evolving platform for discussing, demonstrating, and measuring energy-related aspects of urban form. However, the Energy Proforma needs further testing and development before it can become the standard tool we envision. This is the goal of the research team

for the coming year, beginning with another practical demonstration of its use for neighborhood design (and retrofit) in Jinan by MIT and Tsinghua University in the summer of 2012. As we move forward, the Energy Proforma will become more and more accessible to planners, designers, and policy-makers alike through the use of an intuitive web platform. Furthermore, the transparency of model will become ever-more important so that it is both easily understood and improved.



## 12 Policy Recommendations

Reflecting on what we have learned in the research to date, this final chapter considers policy directions that may be taken to enhance the energy performance of neighborhood development in China. Further development of these recommendations will be an important theme in the final year of the project.

As discussed in **Chapter 2**, the current energy and urban development policy spheres in China do not directly or adequately address energy consumption at the neighborhood scale. Nevertheless, new carbon intensity targets and policy directives for ‘EcoCities’ set by the central government provide both a mandate and a critical opportunity to affect the *design and development process* for new and growing cities. In the absence of clear national policies or practices that define a ‘Low Carbon City’ or ‘Clean Energy Neighborhood,’ a data-driven, China-tested, neighborhood-level energy modeling tool is essential to benchmark, measure, and compare the energy performance of urban neighborhoods across China. The Energy Proforma is such a tool that can act as a keystone for a suite of policy options that will support the development of clean energy neighborhoods from the perspective of both public and private stakeholders.

This **Chapter 12** puts forward recommendations that employ the Energy Proforma, empirical and design-based analyses of this research to guide urban planning policies both for the near and long-term and at both local and national levels. **Section 12.1** outlines a suite of recommendations: 1) Conducting *Energy-Efficient Neighborhood Pilot Projects*, in which policy-makers, real estate development and urban design professionals can build experience designing and implementing clean energy neighborhoods through the use of 2) *Neighborhood Energy Guidelines* and 3) a *Neighborhood Energy Performance Standard* (NEPS). In **Section 12.2**, we consider the implications of these recommendations and the Energy Proforma tool for the national Low Carbon City initiative and policy development.

### 12.1 Neighborhood Design Policy

In this section, we describe a three-phase policy formulation process for incorporating the study’s neighborhood-scale findings into planning codes and practices at multiple urban scales. Some recommendations will be applicable to initial planning phases (comprehensive and regulatory plans) and some to residential development phases (neighborhood and building plans) outlined in **Section 2.3** of the report.

First, local pilot projects can directly apply energy-based design modifications using inspiration from best practice neighborhood patterns and prototypes (Chapter 10) and design guidelines informed by the Energy Proforma. The Jinan city government and planning bureau can incorporate these energy-based guidelines for neighborhood design

into the residential planning code, by following the example of other Chinese cities that have revised planning guideline documents (**Section 2.3**). MOHURD can then coordinate with local administrations to develop a national NEPS, which acts as a benchmark for attainable clean energy neighborhood design. At each phase, the Energy Proforma can be an important tool for city planners, developers, and neighborhood designers, in the development and refinement of pilot designs, the comparison of energy savings due to changing neighborhood planning guidelines, and overall tradeoffs between different design and planning decisions in order to achieve a statutory NEPS.

### ***12.1.1 Energy-Efficient Neighborhood Pilot Projects***

The *Energy Conservation Law* states the central government's expectation that local administrations will support pilot project development. Pilot projects usually precede the widespread implementation of new guidelines or standards, so identifying development partners who can follow through with implementation and post-occupancy monitoring of neighborhood developments is the first step. During the pilot project development, each of the following stakeholders should be included, in order to determine the appropriate distribution of responsibilities, risks, and investments for effective implementation of the standards and guidelines: city administration, urban planning bureau, construction bureau, land developers, planning and design institutes, utilities, and homebuyers.

In this initial stage of learning energy-based design, if the intent of the guidelines is directly communicated to a small group of designers and developers, the designers will be more likely to interpret the guidelines effectively and to communicate the importance of modifying conventional neighborhood designs to all stakeholders. This pilot group of development professionals can also demonstrate the usability of the Energy Proforma tool in practice.

### ***12.1.2 Neighborhood Energy Guidelines***

We suggest a series of modifications to current neighborhood design codes and practices to improve energy performance of neighborhood design within the reality of current policy regimes. These empirically based guidelines operate both as a short-term step in the process of transforming neighborhood development practices and as design criteria that support a future NEPS. In order to integrate the guidelines more directly into the planning review and code enforcement process, the guidelines should align the interpretation of current residential planning codes with more energy-efficient outcomes. For example, if the Jinan residential parking code requirement of 1.5 to 2 underground parking spaces per household were limited to 1.2 spaces per household to promote less car use (in coordination with local land use and public transportation improvements), transportation energy savings could be achieved. The guidelines may also introduce new requirements into the land development and neighborhood planning processes, if current codes do not address key energy efficiency criteria, such as building massing based on improving natural ventilation and reducing localized heat island effects. Additionally, qualitative design guidelines can be extracted from the key energy strategies and urban

form characteristics of best practice energy-efficient neighborhood prototypes described in **Chapter 10**.

To associate these guidelines with the empirical analysis of Jinan and the Energy Proforma tool, the potential average energy savings due to implementing each guideline is approximated according to its impact on operational, transportation, and embodied energy. These percentage reductions in energy use are based on the average energy use among the sample superblock neighborhoods in Jinan (16,000 MJ/HH embodied, 95,000 MJ/HH operational, 17,000 MJ/HH transportation, and 128,000 MJ/HH total energy use), because this residential form and population are the most likely target of energy-based design for new developments.

**Table 12-1. Guidelines based on Jinan energy use analysis**

<i>Energy Efficiency Guideline</i>	<i>Example Value Change</i>	<i>Commentary</i>	<i>Potential Average Energy Savings due to Example Change</i>
<b>Neighborhood Density and Massing</b>			
Decrease average building footprint	100 sq.m. decrease	In conjunction with greater density, smaller building footprints are associated with lower transportation energy use (Transportation Energy section, Chapter 8).	12% of HH transportation energy use (1.5% of total)
Increase the neighborhood density, to reduce the porosity ratio	6 percentage point reduction (1 standard deviation for superblocks)	A greater building volume across the neighborhood may reduce operational energy consumption due to winter wind cooling effects (Operational Energy section) and is associated with lower car ownership (Transportation Energy section, Chapter 8).	7.5% of HH operational energy use (5.5% of total) 7% of HH transportation energy use (1% of total)
<b>Neighborhood Passive Systems (Surfaces of Building and Site)</b>			
Reduce summer solar gain index	7 percentage point reduction (0.5 standard deviations for superblocks)	By reducing the south-facing façade area to achieve a 7 percentage point reduction in the summer solar gain index, summer cooling loads may be reduced (Operational Energy section, Chapter 8).	4% of HH operational energy use (3% of total)
<b>Building Active Systems</b>			
Implement heat metering, heating control, and insulation upgrades for all new	Minimum 65% improvement over 1980, per Design for EE Buildings;	Heating takes up 30-50% of each household’s operational energy use across all typologies (Operational Energy section, Chapter 8). The central government’s	Some operational energy reduction. (Savings is most likely included in

and existing residential construction	should follow Beijing's 75% improvement	building retrofit program has improved the efficiency of centralized heating by 40% in pilot projects (Yan, 2011), and these efficiency measures may have the single largest impact of all building energy-related guidelines. Flexible heating should also enable residents to conserve energy (Operational Energy section, Chapter 8).	Jinan sample of newer neighborhoods.)
Improve air conditioner efficiency or explore alternative cooling methods, while maintaining flexibility of air cooling systems.	-	According to empirical evidence, AC cooling accounts for about 25% of household electricity use, a large fraction that suggests energy savings potential in improving cooling systems.	Some operational energy reduction
Promote energy-efficient and smart elevator systems, or limit building heights	-	Although elevators consume a maximum of 3.5% of a household's share of operational energy in superblocs (Operational Energy section of Chapter 8), elevator efficiency and maintenance provides a margin for improvement.	< 2% of HH operational energy use (1.5% of total)

**Function Mix and Land Use**

Increase amount of storefronts along streets	20 percentage point increase in storefront length along streets	Improving walkability and services in the neighborhood can reduce travel energy consumption (Transportation energy section, Chapter 8)	17% of HH transportation energy use (2% of total)
--	---	--	---

**Housing Choice**

Limit area of apartment unit floor plans, and incentivize selection of smaller apartments	10sq.m. smaller apartment floor area compared to average of 123sq.m.	Floor area per household is an important determinant of both household operational energy consumption (Operational Energy section, Chapter 8) and the share of embodied energy (Embodied Energy section). Real estate development policies have limited apartment sizes in the past, and stronger control of housing floor area should be linked to energy use reduction targets.	3.5% of HH operational energy use (2.5% of total) 8% of HH embodied energy use (1% of total)
Inclusionary zoning incentive for developers	10% or more low-income apartments	Mixed-income housing provisions may improve energy efficiency on several levels: a more diverse workforce can hold service jobs nearer to the housing; the workers can support mixed-use neighborhood services; and lower-income households can moderate the overall neighborhood energy demand.	Some impact on operational energy use; Some impact on transportation energy use

**Pedestrian and Road Network**

Decrease underground parking spaces per household	0.3 spaces/HH decrease	By limiting underground parking, households appear to own fewer cars (Transportation Energy section, Chapter 8)	28% of HH transportation energy use (3.5% of total)
Increase % of roads with sidewalks and “walkable” streets	20 percentage point increase	(See Transportation Energy section, Chapter 8)	10% of HH transportation energy use (1.5% of total)
Add bus route with stops near neighborhood	1 bus route	(See Transportation Energy section, Chapter 8)	5% of HH transportation energy use (1% of total)

**Building Structure and Materials**

Require structural design calculations based on structural analysis, including reducing building height and increasing building coverage.	-	Both the embodied energy analysis and the design of concrete structures in China are generally based on conservative, prescriptive codes. Structural efficiency can be improved significantly by analyzing actual loading and capacity requirements. Shorter buildings may require less steel, which is a major contributor to GHG emissions related to embodied energy (Embodied Energy section, Chapter 8).	10% or more of embodied energy (1% of total)
---	---	---	--

**Renewable Energy**

Design neighborhood to improve rooftop solar access and incorporate neighborhood-wide solar water heater system. Reduce building height to improve system performance.	100% hot water supply in summer	Buildings under 12 stories may be more likely to install solar water heaters (Operational energy, Chapter 8), that save both electricity and gas. Yuan (2011) suggests that newer high-rise buildings are more likely to accommodate SWH, and building heights should be controlled to balance between water pressure requirements and the amount of cooled water that will be wasted in long supply pipes.	5% of HH operational energy use (4% of total)
Design neighborhood to improve rooftop solar access and incorporate solar PV.	PV roof coverage to achieve 10% of electricity use per HH	In high-rise tower construction, building coverage and surface-to-volume ratio should be revised to accommodate greater PV surface areas. Current superblock designs may only support 10% of a household’s electricity needs with 90% PV roof coverage, but other neighborhood forms may support over 35% of HH electricity. Using roof space for wind energy generation is not as effective as installing PV (Renewable Energy, Chap 8).	5% of HH operational energy use (4% of total)

Combining the findings of the empirical analysis with our findings from practice and research into low-carbon neighborhood design (**Chapter 10**), we have deduced a preliminary set of qualitative design and programmatic guidelines for low-carbon neighborhood development. The guidelines qualify in narrative terms the implications of the research to date for neighborhood form, but at this point mainly define key topics to be considered by designers. These will be further developed and specified in the final phase of the project, beginning with their application in Jinan on a demonstration basis by MIT and Tsinghua University in the summer of 2012. Guidelines include:

- ***Neighborhood density and height*** – One of the important findings of the study has been that “tower-in-park” forms made up of widely separated high-rise buildings are generally not significantly higher in density (households per hectare) than more energy efficient low-rise neighborhoods with higher ground coverage. We recommend a mix of low and high-rise structures, enabling a higher density than either of the above forms, in the average range of 2.5-5 FAR depending on context (Barcelona = 3.5; Washington DC = 6). This should enhance energy performance overall, while providing the framework for incorporating multiple uses at the ground level, which is important to other guidelines. In general, smaller, more densely packed units (implying shared amenities and services) result in greater energy efficiency.
- ***Road network and pedestrian connectivity*** – Higher road density within and among neighborhoods minimizes vehicular travel distances from home to work, social life, shopping, and services, and facilitates lower-energy forms of travel such as walking or bicycles. It also enables smaller street widths, encouraging walkability and integration of land uses. Conversely low road density results in fewer, wider streets that create barriers to pedestrian movement and urban integration. We recommend road spacing of 80 to 240 maximum meters within neighborhoods, and multiple connections to surrounding urban fabric. We recommend against gated forms of development that restrict access and add to travel distances. Roads should incorporate sidewalks, pedestrian amenities, and multiple activities to the degree possible to facilitate walking and discourage use of the car. A network of pedestrian and bikeways should be available to provide non-motorized access to the daily activities of living.
- ***Neighborhood use mix*** – The presence of integrated shops, services, and work places within neighborhoods has been shown to reduce travel energy consumption, as opposed to separated land uses that require vehicular access generating unnecessary movement across the city (adding to traffic congestion). We recommend including multiple uses within neighborhoods sufficient to provide for the daily activities of living (food, drugs, hard goods, social life, learning, medical and dental services, etc.), as well as opportunities for employment within walking distance, averaging 500 meters.

- **Renewable energy potential** -- Orientation and design of buildings and their facades to achieve maximum passive solar gain in the winter and minimum in the summer (depending on site characteristics and location) is a baseline requirement for energy performance. Note that this may not coincide with minimum day-lighting requirements in the current code, or the convention that all residential buildings face directly south. We recommend more complex forms that include a greater variety of exposures to balance summer and winter conditions (although southern exposure may predominate). Also, forms that provide sufficient roof surfaces to accommodate PV electricity and solar hot water systems that supply 10% and 100% of these needs respectively (implying a higher site coverage than found in “tower-in-park” housing, for example). Finally, integration of indoor and outdoor space, with natural vegetation and water, such as through the use of courtyard forms, can moderate the microclimate of residential units, reducing heat gain in summer and loss in winter.
- **Quality of form** – On balance, our studies have shown that the use of diverse forms (as opposed to large simplified masses), particularly at the ground level, result in less energy consumption within neighborhoods. This is due to a variety of factors, which involve all of the above issues, from enabling higher density to facilitating walkability, mixed use, and passive energy savings.

### 12.1.3 The Neighborhood Energy Performance Standard (NEPS)

Similar to minimum fuel efficiency standards for motor vehicle design, establishing a Neighborhood Energy Performance Standard (NEPS) would set maximum energy consumption and carbon emissions values per square meter or per household, calibrated to an expected energy use reduction from a baseline neighborhood development in a specific locality. With such a standard, developers and designers can demonstrate conformance with the NEPS by providing calculations from the Energy Proforma tool, which supports an integrated approach to designing energy-efficient neighborhoods.

Precedents for the proposed NEPS already exist in China’s codes and standards for buildings. The *Design Standard for Energy Efficiency in Residential Buildings*, described in **Section 2.3**, establishes a maximum building energy consumption value and requires either a prescriptive application of insulation and other energy conservation measures, or a performance-based simulation of the building’s thermal efficiency. The city of Malmö is in the process of formulating a similar building energy performance standard. In major cities in China, transportation analyses are often conducted as well, which could be leveraged for evaluating transportation energy efficiency.

To attain approval under the NEPS, most development projects will need to fulfill performance improvements on both planning and architectural levels. In fact, coordination across adjacent real estate development projects may be necessary for modifying neighborhood massing and ensuring viable streetscapes. Trade-offs between operational, embodied, transportation, and renewable energy improvements will need to

be negotiated within the project design team as well as between investors and planners. Instead of becoming an additional impediment to the design process, the NEPS can present an opportunity to bring multiple stakeholders to the table to identify possible design innovations, reconsider development priorities, and balance between public interests, private real estate objectives, and consumer advocacy. A new, less energy consumptive urban form will be the result.

#### ***12.1.4 Additional policy instruments and strategies***

Policies and informational programs should be designed to enhance a city's capacity to implement public pilot projects, as well as the capacity of urban resource end-users to improve their energy efficiency. Potential areas for intervention include:

- City financing and guidelines for energy-efficient social housing. The city can most directly enforce guidelines in publicly-financed housing projects.
- Guidelines for urban village upgrade projects.
- Guidelines for upgrading and retrofitting older “enclave” walk-up slab projects, and for “tower-in-park” neighborhood forms that are highly energy consumptive.
- Guidelines for transportation, streetscape, and public space upgrade projects.
- Integration of Energy Proforma calculations with software packages used by design institutes. Design institutes currently use CAD software that can check for urban planning code conformance. The Web Proforma is an initial step towards wider application of the neighborhood energy guidelines and performance standards.
- Incentives for developers. Tax credits that are mentioned in the *Energy Conservation Law*, parcel selection, and FAR allowances can all support development agreements that include energy-efficient planning.
- Educational initiatives by professional associations, such as the real estate association or local design institute groups, targeting developers and design professionals.
- Homeowner educational programs, apartment and equipment purchasing guides, neighborhood handbooks, and neighborhood informatics for new and existing developments. Ongoing educational initiatives may enable residents to utilize the neighborhood resources in the energy-efficient ways that planners intended. The *Energy Conservation Law* requires real estate developers to provide buyers with information on energy-saving measures and insulation warranties; however, this requirement should be enforced and expanded to cover the range of criteria for neighborhood energy efficiency.
- Systematic data collection and sharing is needed to more rapidly develop the energy calculation tools. Publicly-available energy consumption databases can then allow stakeholder groups to share energy-efficiency strategies on a wider scale, in addition to enabling competition between cities and developers, greater consumer awareness, and better national policymaking.
- Neighborhood energy performance compliance can be counted towards carbon reduction targets at the city level, and city administrators can demonstrate the

effectiveness of local energy efficiency initiatives to the provincial and central governments, after the energy evaluation system is tested and considered reliable.

## 12.2 National Policymaking Recommendations

The 12<sup>th</sup> FYP period is a critical point in China's energy and climate policymaking. China faces a greater set of challenges than before, such as how to mobilize regional players in achieving the new carbon intensity reduction goals and how to measure the outcomes not just for policy evaluation purposes but also to improve international climate negotiations. We observed in our evaluations of energy programs undertaken for the 11<sup>th</sup> FYP (**Chapter 2**) that China's central planning was hampered during the process of regional implementation due to 1) lack of system for defining goals in measurable form during pre-execution planning phase; 2) lack of system for collecting and analyzing data during program operation to monitor progress; 3) lack of a system for encouraging post-implementation public feedback to improve future programming.

China holds a great opportunity to address these challenges through the scores of low carbon pilot projects being deployed across the country. These pilot localities, now elevated to positions of responsibility, create ideal self-contained and well-regulated testing grounds for the implementation of new policy measures. A data-driven, China-tested tool for neighborhood-level energy modeling such as the Energy Proforma can fit naturally within these pilot activities to facilitate the development of the pilot cities themselves, and for future scale-up into policy tools such as the NEPS that incentivize the nation-wide deployment of energy- and carbon-saving urban forms.

*We recommend that the low carbon pilots deployed under the 12<sup>th</sup> FYP adopt three policy directives to address the measurement, monitoring, and evaluation challenges of the 11<sup>th</sup> FYP: define goals, manage data, and solicit feedback. We further recommend that these pilot cities tailor the aforementioned suite of neighborhood energy policies and the Energy Proforma to their own location as a means of achieving these policy directives.*

### 12.2.1 Recommendation I: Define

We recommend that China's central planners create a low carbon urban development checklist detailing what the low carbon pilots must achieve in 1) physical features of the urban form; 2) legal requirements for management and measurement; 3) provisions for public engagement and feedback. This checklist must be distributed to the governing body of each low carbon pilot locality upon induction into the national low carbon pilots program. Urban form directives in the checklist may be achieved through design guidelines as described in Section 12.1.

### 12.2.2 Recommendation II: Manage

We recommend that China's central planners require the low carbon pilots to report primary, secondary, and economic household information to a central database. Primary

information is defined as data on household utility use, particularly water, electricity, and central heating. Secondary information is defined as data on household access to low carbon services and features like building retrofit services and/or public transportation. Economic information is defined as data on quality of life valuation like household income and home resale prices. This information must be made available to the Chinese Academies and other research institutions for expert evaluation of the low carbon pilot program's activities, impacts, lessons, and opportunities. This data may also be utilized to retool the Energy Proforma to respond to local conditions in different pilot cities.

### ***12.2.3 Recommendation III: Engage***

We recommend that China's central planners train and leverage government, enterprise, and civil society leaders in the low carbon pilot localities to generate policy feedbacks that inform future program improvements. A nationally uniform and continuous low carbon program management-training curriculum must be developed for pilot administrators to ensure that all pilots are successfully implementing and sharing best practices. A nationally uniform and continuous low carbon enterprise operations-training curriculum must be developed for manufacturers in pilot zones to ensure adherence to low carbon production practices. Environmental protection bureaus in low carbon pilots must encourage environmental NGO registration so that civil society can rise to serve its natural role as supporter of low carbon government initiatives and compliance watchdog of the private sector.

### ***12.2.4 Next Steps: The Role of MIT's Energy Proforma Research***

Thus far our team has developed a robust database of energy use and carbon emissions influencers at the neighborhood level in the case city of Jinan, China. The Energy Proforma tool we developed through this exercise models how the independent actions of policy makers, real estate developers, and residential consumers combine at the urban level into neighborhood forms that influence and perpetuate specific energy use patterns. Iterated across China's vast landscape of rapid urbanization, the implications of our findings are immense: to properly manage the contribution of urbanization to China's low carbon development, we must conceive of each neighborhood as an energy system and interact not just with individual buildings but with the built ecosystem as a whole.

Moving forward, we will continue to build on this research, specifically within the context of managing existing and proposed low carbon pilots under the 12<sup>th</sup> FYP. Drawing from the lessons we learned from the 11<sup>th</sup> FYP programs, we will expand our work in each of the three recommended areas (define, manage, engage), providing research support to key policymakers around each: 1) we will continue to explore the physical features as well as management mechanisms required for definition as a low carbon urban system; 2) we will continue to collect empirical data and improve the underlying models to fine-tune the Energy Proforma and determine how data collection and analysis is best pursued; 3) we will expand our research to determine how urban level stakeholders are best engaged to bring about low carbon development.

## Works Cited

### Chapter 1

1. IEA. (2009). International Energy Outlook. IEA Report#:DOE/EIA-0484.  
<http://www.eia.doe.gov/oiaf/ieo/index.html>
2. Mckinsey & Company. (2009). China's green revolution: Prioritizing technologies to achieve energy and environmental sustainability.
3. Meinshausen, M., Meinshausen, N., Hare, W., Raper, S. C. B., Frieler, K., Knutti, R., Frame, D. J. & Allen, M. (2009). Greenhouse gas emission targets for limiting global warming to 2°C. *Nature*. Vol 458, No.7274: 1117-1118
4. Research Centre for Sustainable Development (RCSD). (2007). Chinese Academy of Social Sciences. Understanding China's Energy Policy. [http://www.hm-treasury.gov.uk/d/Climate\\_Change\\_CASS\\_final\\_report.pdf](http://www.hm-treasury.gov.uk/d/Climate_Change_CASS_final_report.pdf). 2007
5. U.S. Energy Information Administration. (2010). Annual Energy Review 2009.  
[www.eia.gov/aer](http://www.eia.gov/aer)

### Chapter 2

1. Economist. (2011). Wind from the East.  
[http://www.economist.com/blogs/dailychart/2011/02/alternative\\_energy](http://www.economist.com/blogs/dailychart/2011/02/alternative_energy)
2. Finamore, Barbara, Lin, A., & Davidson, M. (2011) China Puts Forth Energy Intensity, Carbon Intensity, and Total Energy Consumption Targets in Twelfth Five Year Plan in Effort to Tackle "Unsustainable Economic Growth".  
[http://switchboard.nrdc.org/blogs/bfinamore/china\\_puts\\_forth\\_energy\\_intens.html](http://switchboard.nrdc.org/blogs/bfinamore/china_puts_forth_energy_intens.html)
3. He, Na. (2010). Residents Struggle as Cold Weather Heads South.  
[http://www.chinadaily.com.cn/cndy/2010-02/09/content\\_9447442.htm](http://www.chinadaily.com.cn/cndy/2010-02/09/content_9447442.htm)
4. Hsu, Angel, & Zhao, Y. (2011). China Dialogue.  
<http://www.chinadialogue.net/article/show/single/en/4076>
5. Huang, Joe, & Deringer, J. (2007). Status of Energy Efficient Building Codes in Asia. *Review, Hong Kong SAR: Asia Business Council*.
6. Jin, Ruidong, & Alyas, S. (2010). China Building Green Practice. *2010 ACEEE Summer Study on Energy Efficiency in Buildings*. 4.125-4.137.
7. Levine, Mark D. (2010). Energy Efficiency in China: Glorious History, Uncertain Future. <http://www.aps.org/units/maspg/meetings/upload/levine.pdf>
8. Liu, Jianqiang. (2010). From Sham to Reality.  
<http://www.chinadialogue.net/article/show/single/en/3916>
9. Ma, Haibing, & Fu, L. (2011). Revolt. <http://blogs.worldwatch.org/revolt/beyond-the-numbers-a-closer-look-at-china's-wind-power-success/>
10. Price, Lynn, Wang, X., & Yun, J. (2010). The Challenge of Reducing Energy Consumption of the Top-1000 Largest Industrial Enterprises in China. *Energy Policy*. Vol. 38, No. 11:6 485-6498.

11. Sathaye, Jayant, & Tyler, S. (1991). Transitions in Household Energy Use in Urban China, India, the Philippines, Thailand, and Hong Kong. *Annual Review Energy Environment*. Vol 16: 295-335.
12. Wang, Ke. (2011). The Role of Cities in Meeting China's Carbon Intensity Goal. <http://insights.wri.org/open-climate-network/2011/09/role-cities-meeting-chinas-carbon-intensity-goal>
13. Xinhua. (2011) *China Daily*. [http://www.chinadaily.com.cn/china/2011-11/28/content\\_14176208.htm](http://www.chinadaily.com.cn/china/2011-11/28/content_14176208.htm)
14. Hui, L. (editor). (2011). China Pledges its Urbanization Drive to be Low Carbon. [http://news.xinhuanet.com/english2010/china/2011-06/21/c\\_13942037.htm](http://news.xinhuanet.com/english2010/china/2011-06/21/c_13942037.htm)
15. Zhangjin (editor). (2011). CRI English. <http://english.cri.cn/6909/2011/11/22/1461s668304.htm>
16. Zhang, Ming'ai. <http://www.china.org.cn/english/environment/231086.htm>
17. Zhu, Zhe. (2005). Welfare Heating to be Stopped in 2007. [http://www.chinadaily.com.cn/english/doc/2005-12/19/content\\_504441.htm](http://www.chinadaily.com.cn/english/doc/2005-12/19/content_504441.htm)

### Chapter 3

1. Adalberth, K. (1997). Energy Use during the Life Cycle of Buildings: A Method. *Building and Environment*. Vol. 32, No. 4: 317–329.
2. Ashie Y., V. Thanh Ca, & Asaeda, T. (1999). Building canopy model for the analysis of urban climate. *Journal of Wind Engineering and Industrial Aerodynamics*, Vol. 81, Issues 1-3: 237-248
3. Baker, N, & Steemers, K. (2000). Energy And Environment In Architecture: a Technical Design Guide. London, *E & FN Spon*.
4. Ballinger, J. Prasad, D., Lawson B., Samuels, R., & Lyons, P. (1995) R&D of current environmental technologies in Australia. *Proceedings in Pan Pacific Symposium on Building and Urban Environmental Conditioning in Asia*.
5. Blanchard, S., & Reppe, P. (1998). Life Cycle Analysis of a Residential Home in Michigan. *University of Michigan*.
6. Buchanan, A. & Honey, B. Energy and carbon dioxide implications of building construction. *Energy and Buildings* Vol. 20, No. 3: 205-217
7. Chandler, T.J. (1976). Urban climatology and its relevance to urban design, *Geneva: Secretariat of the World Meteorological Organization*.
8. Chang, Y., Ries, R. J., and Wang, Y. (2011). The quantification of the embodied impacts of construction projects on energy, environment, and society based on I-O LCA. *Energy Policy*. Vol. 39, No. 10: 6321-6330.
9. Chen, T., Burnett, J., and Chau, C. (2009). Analysis of embodied energy use in the residential building of Hong Kong. *Energy* Vol. 26: 323-340
10. Deqi, Han. (2010). Building Energy Consumption will be the major driver in the future energy consumption growth. [http://www.eeo.com.cn/Politics/by\\_region/2010/02/30/166471.shtml](http://www.eeo.com.cn/Politics/by_region/2010/02/30/166471.shtml)
11. Duffy. A. (2009). Land use planning in Ireland- a life cycle energy analysis of recent residential development in the greater Dublin area. *Int. Journal of Life Cycle Assessment*. Vol. 14: 268-277.

12. Ewing, R., & Rong, F. (2008). The Impact of Urban Form on U.S. Residential Energy Use. *HOUSING POLICY DEBATE*. Vol. 19, Issue 1: 1-27
13. Fay, R., Treloar, G. and Iyer-Raniga, U. (2000). Life-cycle energy analysis of buildings: a case study. *Building Research & Information*. Vol. 28, No. 1: 31-41
14. Givoni, B. (1998). *Climate Considerations In Building And Urban Design*, New York: Van Nostrand Reinhold.
15. Givoni, B. (1994). *Passive And Low Energy Cooling of Buildings*. New York: Van Nostrand Reinhold.
16. Huang, S. and Hsu, W. (2003). Materials flow analysis and energy evaluation of Taipei's urban construction. *Landscape and Urban Planning*. Vol. 63, No. 2: 61- 74
17. International Standardization Organization (ISO). (2006). Environmental management: life cycle assessment: principles and framework. ISO 14040.
18. Lawrence Berkeley Laboratory – China Energy Group (LBL-CEG). (2010). Cement. <http://china.lbl.gov/research/industry/cement>
19. Martilli, A., Clappier, A., & Rotach, M. An Urban Surface Exchange Parameterisation for Mesoscale Models, *Boundary-Layer Meteorology*, Vol.104, No. 2: 261-304
20. McKinsey & Company. (2009). China's green revolution: Prioritizing technologies to achieve energy and environmental sustainability
21. Peters, G., Weber, C., Guan, D. & Hubacek, K. (2007). China's Growing CO2 Emissions- A Race between Increasing Consumption and Efficiency Gains. *Environmental Science & Technology* Vol. 41, No. 17: 5939-5944.
22. Maat, K., van Wee, B., & Stead, D. (2005). Land use and travel behaviour: expected effects from the perspective of utility theory and activity-based theories. *Environment and Planning B: Planning and Design*, Vol. 32, No 1: 33-46.
23. Norman, M., H. Asce, M., and Kennedy, C. (2006). Comparing high and low residential density: life-cycle analysis of energy use and greenhouse gas emissions. *Journal of Urban Planning and Development*. Vol. 132, No. 1: 10-21.
24. Oke, T. (1998). Street design and urban canopy layer climate. *Energy and buildings*. Vol. 11, No. 1-3: 103-113.
25. Olgyay, V. & Olgyay, A. (1963). *Design With Climate: Bioclimatic Approach to Architectural Regionalism*. Princeton, N.J.: Princeton University Press.
26. Ortiz, O., Castells, F., and Sonneman, G. (2009). Sustainability in the construction industry: A review of recent developments based on LCA. *Consumption and Building Materials*. Vol. 23, No. 1: 28-39.
27. Ratti C., Baker, N., & Steemers, K. (2005). Energy consumption and urban texture. *Energy and Buildings*. Vol. 37, No. 7: 762-776.
28. Research Centre for Sustainable Development (RCSD). (2007). Chinese Academy of Social Sciences. Understanding China's Energy Policy. [http://www.hm-treasury.gov.uk/d/Climate\\_Change\\_CASS\\_final\\_report.pdf](http://www.hm-treasury.gov.uk/d/Climate_Change_CASS_final_report.pdf).
29. Stone, Brian, & Rogers, M. (2001). Urban Form and Thermo Efficiency-How the Design of Cities Influences the Urban Heat Island Effect. *Journal of the American Planning Association*. Spring, Vol. 67, No. 2: 186-198.
30. Treloar, G. (1996). The environmental impact of construction: A case study, Australia and New Zealand Architectural Science Association, Sydney, Australia.
31. Wang, Songqing. (2007). Life Cycle Assessment of Residential building Energy Consumption in Severe Cold Region, Master Thesis, Harbin Institute of Technology:

32. Zhou, Nan, McNeil, M. & Levine, M. (2009) Energy for 500 million Homes: Drivers and Outlook for Residential Energy Consumption in China. *Lawrence Berkeley National Laboratory*.

#### Chapter 4

1. China Academy of Urban Planning & Design (CAUPD). (2002). Master and Strategy planning of Jinan 2002.
2. Fengyun, Mu, Zhang, Z., Lu, B., & Wang, C. (2008). Remote Sensed Monitoring of Jinan City in 25 Years and Driving Forces analysis. *Journal of Shandong Agricultural University (Natural Science)*. Vol. 39, No. 1: 73-79.
3. Kang, Honggang, Sun, X. (2009). Research on the Urban Expansion and Drive Mechanism Based on RS and GIS: A Case Study of Jinan City. *Areal Research and Development*. Vol 28, No. 3.
4. Jinan Statistical Yearbook. (2011).
5. Jinan planning agency. (2007) Specifications on Master planning of Jinan (1996-2010).
6. Wang, Jianqiang. (2004). A Study on the Morphological Development of Modern Jinan City Since 1840. Master thesis at Architecture College of Tsinghua University.
7. Wang, Xibo. (2003). Study on Urban Planning of Jinan in Modern Age. Master thesis of engineering in Wuhan Technology University.
8. Yuan, Zhaohua. (2008). The Study on Development Model of the living Space in Jinan under the view of suburbanization. Master thesis in Urban Planning at Xi'an University of Architecture and Technology.

#### Chapter 5

1. Beijing Statistical Yearbook. (2011).
2. Jinan Statistical Yearbook. (2001 - 2011).
3. Yuan, Zhaohua. (2008). The Study on Development Model of the living Space in Jinan under the view of suburbanization. Master thesis in Urban Planning at Xi'an University of Architecture and Technology.

#### Chapter 6

1. Cervero, R., Day, J., (2008). Residential Relocation and Commuting Behavior in Shanghai, China: The Case for Transit Oriented Development. Working Paper UCB-ITS-VWP-2008-4, UC Berkeley Center for Future Urban Transport.  
<<http://www.its.berkeley.edu.libproxy.mit.edu/publications/UCB/2008/vwp/UCB-ITS-vwp-2008-4.pdf>>.
2. Ewing, R. and Cervero, R. (2010). Travel and the Built Environment. *Journal of the American Planning Association*. Vol. 76, No. 3: 265-294.
3. Ewing, R., Bartholomew, K., Winkelmann, S., Walters, J. & Chen, D. (2008). *Growing Cooler: The Evidence on Urban Development and Climate Change*. Urban Land Institute.

4. Monson, K. (2008). String Block vs Superblock Patterns of Dispersal in China. *Architectural Design*. Vol. 78, No. 1: 46-53.  
<http://onlinelibrary.wiley.com/doi/10.1002/ad.608/abstract>

### Chapter 7

1. Ministry of Construction (MOC). (2005). National Standard of the People's Republic of China, GB 50352-2005: Code for Design of Civil Buildings. Jointly issued by Ministry of Construction (MOC) and General Administration of Quality Supervision, Inspection and Quarantine (GAQSIQ).

### Chapter 8

1. U.S. Energy Information Administration. (2005). Residential Energy Consumption Survey - Detailed Tables. [www.eia.gov](http://www.eia.gov)
2. Office of Energy Efficiency, Natural Resources Canada. (2007). Survey of Household Energy Use.
3. Zhang, Qingyuan. (2004). Residential energy consumption in China and its comparison with Japan, Canada, and USA. *Energy and Buildings*. Vol. 36: 1217– 1225.
4. Zeng, Heshuang. (2011). Integration of renewable energy with urban design. Masters Thesis in City Planning at the Massachusetts Institute of Technology.

### Chapter 11

1. Fisch, M. N. (2008). Hannover/Kronsber Solar District Heating. *IGS Projects*. German Ministry of Economics and Labor, Institute of Buildings Services and Energy Design.
2. Frenchman, D., Wampler, J., & Zegras, C. (2011). *Designing Clean Energy Cities: New Approaches to Urban Design and Energy Performance*. MIT.
3. Owen, David. (2004). Green Manhattan. *The New Yorker*.  
[http://www.newyorker.com/archive/2004/10/18/041018fa\\_fact\\_owen](http://www.newyorker.com/archive/2004/10/18/041018fa_fact_owen).
4. Rosenthal, E. (2009). In German Suburb, Life Goes on without Cars. *The New York Times*.  
[http://www.nytimes.com/2009/05/12/science/earth/12suburb.html?\\_r=2&pagewanted=1](http://www.nytimes.com/2009/05/12/science/earth/12suburb.html?_r=2&pagewanted=1)



## **Appendices**



## Appendix A: Travel Energy Consumption

### *Travel Energy and Emission Calculation from Household Survey Data*

In the household survey, there is a travel diary table that collects the travel activities each household does for a typical week, including trip purpose, frequency, mode, trip length, and time taken (destinations are recorded for some of the trips to estimate the trip length if one is not available). Table A-1 shows the major difference in recording trips between

	2009 survey	2010 survey
Distinguish weekday and weekend	Yes	No
Distinguish commuting and non-commuting trips	No	Yes
Unit of Trip-maker	Each household member	Commuting: each household member Non-commuting: household
Trip purpose, frequency, mode, trip length (required)	Yes	Yes
Trip destination, time taken (optional)	Yes	Yes
Occupancy (optional)	No	Yes
BRT treated as a separate mode from buses	No	Yes

the two years' surveys. The travel energy calculation methods therefore differ accordingly.

**Table A-1. Major Difference in trip recording between 2009 and 2010 surveys**

#### *a) Travel Energy Consumption calculation:*

$$EN_i = \sum_m EN_i^m * 52/10^3, \quad m \in \{auto, taxi, bus, motor, ebike\}$$

$$EN_i^m = \sum_j \sum_k \left( FR_{i,j,k}^m * \frac{TD_{i,j,k}^m}{OC_{i,j,k}^m} \right) * EI^m$$

*Where:*

$EN_i$ : Annual transport-related energy consumption (GJ) by household  $i$

$EN_i^m$ : Weekly transport-related energy consumption (MJ) by household  $i$  for trips with mode  $m$

$FR_{i,j,k}^m$ :  $TD_{i,j,k}^m$ ,  $OC_{i,j,k}^m$ : same as above

$EI^m$ : Energy Intensity factor per kilometer (MJ/km) of mode  $m$

$$E_i = \sum_m E_i^m * 52/10^3, \quad m \in \{car, taxi, bus, motor, ebike\}$$

**b) Travel CO2 Emission calculation:**

$$E_i^m = \sum_j \sum_k \left( FR_{i,j,k}^m * \frac{TD_{i,j,k}^m}{OC_{i,j,k}^m} \right) * EF^m$$

Where:

$E_i$ : Annual transport-related CO2 emissions (tCO2) by household  $i$

$E_i^m$ : Weekly transport-related CO2 emissions (kgCO2) by household  $i$  for trips with mode  $m$

$FR_{i,j,k}^m$ : Frequency of trips, with the mode  $m$  and purpose  $k$ , made by person  $j$  in household  $i$  per week (including weekends)

$TD_{i,j,k}^m$ : Travel distance (km) of trips, with the mode  $m$  and purpose  $k$ , made by person  $j$  in household  $i$  per week

$OC_{i,j,k}^m$ : Occupancy of trips, with the mode  $m$  and purpose  $k$ , made by person  $j$  in household  $i$

$EF^m$ : CO2 emission factor per kilometer (kgCO2/km) of mode  $m$

**c) Related Factors:**

Occupancy Rate

Occupancy rates of car, taxi, motorcycle and e-bike are associated with each trip, and are reported in the 2010 survey data. The 2009 survey does not include the occupancy rate question therefore those are estimated under some assumptions. Specifically, person trips with the same reported purpose, length and time among two or more household members are treated as one trip. For buses and BRT's, the system-wide occupancy rate is estimated using empirical operation performance data in Jinan (Table A-2).

**Table A-2. Jinan Transit Operation Statistics**

Year	Annual Operating Distance (10,000 km/year)	Daily Passenger Volume (10,000 passenger-trips/year)	Average Trip Length (km/passenger-trip)
------	---	---	--

	Total Transit	BRT	Total Transit	BRT	Total Transit	BRT
2008	18207		74566		4.04	
2009	19059		80393	7592		4.892
2010	18800		84500			

Source: Jinan Public Transit Development Report 2010, Jinan Public Facility Development Report 2009

Therefore, the bus occupancy rate in Jinan for 2009 survey household is:  $74566 \times 4.04 / 18207 = 16.55$ ; and the bus occupancy rate in Jinan for 2010 survey household is  $80393 \times 4.04 / 19059 = 17.04$ . The BRT occupancy rate for 2010 survey is:  $11000 \times 4.892 / 1420 = 37.9^1$

### (1) Energy Intensity Factor

$$EI^m = FU^m * EC^m$$

Where:

$FU^m$ : Fuel economy factor (L/km; kwh/km) associated with mode  $m$

$EC^m$ : Energy Content of each fuel type (MJ/L) of the fuel consumed in mode  $m$

**Table A-3 Energy Intensity Factors for Different Modes**

Mode ( $m$ )	Vehicle Fuel Economy <sup>a</sup> ( $FU^m$ )	Fuel Energy Content <sup>2</sup> ( $EC^m$ )	= Energy Intensity factor ( $EI^m$ )
Automobile	0.092L/km	32.2 MJ/L	2.962 MJ/km
Taxi	0.083L/km	32.2 MJ/L	2.673 MJ/km
Bus	0.266L/km <sup>3</sup>	35.6 MJ/L	9.470 MJ/km
BRT	0.5L/km <sup>4</sup>	35.6 MJ/L	17.80MJ/km
Motorcycle	0.019L/km	32.2 MJ/L	0.612 MJ/km
E-bike	0.021kwh/km <sup>c</sup>		0.076 MJ/km

a. Assume that all automobiles/taxis/motorcycles use gasoline, bus and BRT fleet uses diesel.

b. Cherry, C. R., J. X. Weinert, et al. (2009). "Comparative environmental impacts of electric bikes in China." Transportation Research Part D 14: 281-290.

### (2) CO2 Emission Factor

$$EF^m = FU^m * CC^m$$

<sup>1</sup>To-date (1,000 days from opening in 2008 to Jan. 2011) operating distance and passenger volume data from Jinan Public Transit Cooperation, [http://www.sd.xinhuanet.com/wq/2011-01/25/content\\_21950800.htm](http://www.sd.xinhuanet.com/wq/2011-01/25/content_21950800.htm)

<sup>2</sup>Energy content factors from MIT Energy Club (2007). Units & Conversions Fact Sheet. [http://web.mit.edu/mit\\_energy/resources/factsheets/Units&ConvFactors.MIT%20EnergyClub%20Factsheet.v8.pdf](http://web.mit.edu/mit_energy/resources/factsheets/Units&ConvFactors.MIT%20EnergyClub%20Factsheet.v8.pdf)

<sup>3</sup> <http://www.jnjtj.gov.cn/info/display.jsp?ID=BF01L0DK50H>

<sup>4</sup> BRT bus fuel economy figure (50L/100km) taking model Zhongtong LCK6180G

Where:

$FU^m$ : Fuel economy factor (L/km; kwh/km) associated with mode  $m$

$CC^m$ : CO2 content factor (kgCO2/L; kgCO2/kwh) of the fuel consumed in mode  $m$

**Table A-4. CO2 Emission Factors for different modes**

Mode ( $m$ )	Vehicle Fuel Economy ( $FU^m$ )	× CO2 Content Factor ( $CC^m$ )	= CO2 emission factor ( $EF^m$ )
Automobile	0.092L/km <sup>a</sup>	2.165 kgCO2/L <sup>b</sup>	0.199 kgCO2/km
Taxi	0.083L/km <sup>c</sup>	2.165 kgCO2/L <sup>b</sup>	0.180 kgCO2/km
Bus	0.266L/km <sup>d</sup>	2.470 kgCO2/L <sup>b</sup>	0.657 kgCO2/km
BRT	0.5L/km	2.470 kgCO2/L <sup>b</sup>	1.235 kgCO2/km
Motorcycle	0.019L/km <sup>e</sup>	2.165 kgCO2/L <sup>b</sup>	0.041 kgCO2/km
E-bike			0.026 kgCO2/km <sup>f</sup>

a. Estimated from fuel economies of automobiles in China and weighted by vehicle fleet composition. The market shares of automobiles with fuel consumption rates of 6.5L/100km, 8.3L/100km, 10.2L/100km, 11.9L/100km, 13.9L/100km are 4.96%, 53.69%, 32.09%, 8.65%, 0.62%, respectively. China National Transportation Statistics. 2008

b. Assuming all automobiles/taxis/motorcycles use gasoline, and all buses use diesel. Energy content factors from MIT Energy Club (2007). Units & Conversions Fact Sheet.  
[http://web.mit.edu/mit\\_energy/resources/factsheets/Units&ConvFactors.MIT%20EnergyClub%20Factsheet.v8.pdf](http://web.mit.edu/mit_energy/resources/factsheets/Units&ConvFactors.MIT%20EnergyClub%20Factsheet.v8.pdf)

c. Estimated from fuel economies of 7 taxi types in Jinan, including JETTA (6.7L/100km), SANTANA (7L/100km), SANTANA2000 (8L/100km), FUKANG (8.3L/100km), PASSAT(9L/100km), BUICK(11L/100km).

d. 0.3L/km is from Zheng, Chen (2008). "Simulation Calculation of Bus Fuel Economy under City Traffic Environment". Tractor and Farm Transporter. 35(4): 44-45

e. Estimated from fuel economies of motorcycles in China and weighted by vehicle fleet composition. The market shares of motorcycles with fuel consumption rates of 0.8L/100km (special light duty type), 1.3L/100km (light duty type), 2.2L/100km (engine-90 type), 3.3L/100km (engine-125 type) are 15%, 30%, 40%, 15%, respectively. China National Transportation Statistics. 2008

f. Cherry, C. R., J. X. Weinert, et al. (2009). "Comparative environmental impacts of electric bikes in China." Transportation Research Part D 14: 281-290.

*Two-Step Model Results*

*Step-1: Vehicle Ownership Model (MNL with robust standard error)*

- Alternatives: 0: no vehicle owned (Base outcome)  
 1: own e-bikes only  
 2: own motorcycles (only or plus e-bikes)  
 3: own cars only  
 4: own cars and other vehicles (motorcycles or e-bikes or both)

**Table A-5. Step-1 Vehicle Ownership Model Estimation Result**

Vehicle Portfolio Ownership (no vehicle owned as base)		Own E-bikes only		Own Motorcycles (only or plus ebikes)		Own Cars only		Own Cars and Other Vehicles	
		Coef.	Robust z	Coef.	Robust z	Coef.	Robust z	Coef.	Robust z
Multinomial Logistic Regression									
				Number of obs = 3955					
				Wald chi2(80) = 1144.67					
				Prob > chi2 = 0					
Log pseudo-likelihood = -4970.4258									
<b>Constant</b>									
		-2.12	-2.29	-1.12	-1.19	-7.36	-7.30	-7.89	-6.57
<i>Household Characteristics</i>									
	ln(household annual income in 1,000 rmb)	0.12	1.73	0.22	1.93	0.98	10.86	1.03	9.52
	no household member is currently employed	-0.79	-5.25	-0.94	-3.46	-1.64	-5.81	-0.99	-2.69
	2 household members are currently employed	-	-	-	-	0.14	1.30	0.45	2.54
	3 or more household members are currently employed	-	-	-	-	-	-	0.85	3.83
	having children (<20 years old) in the family	0.27	2.81	0.40	2.74	0.43	4.00	0.75	5.73
	having seniors (>=60 years old) in the family	-0.30	-2.51	-0.53	-2.66	-0.42	-2.90	-0.78	-4.62
	renting	-0.28	-2.38	-	-	-0.99	-5.71	-1.01	-4.64
	single	-0.95	-4.84	-0.82	-2.80	-	-	-0.54	-1.25
	having 4+ household members	0.26	2.11	0.23	1.22	0.17	1.22	0.43	2.75
	having access to a company/business car	-0.84	-2.70	-0.69	-1.43	-	-	-0.63	-1.85
<i>Attitude</i>									
	driving is a sign of prestige	0.17	2.10	-	-	-	-	-0.23	-2.12
	taking bus is convenient	-0.29	-2.61	-0.24	-1.40	-0.54	-4.46	-0.66	-4.83
	I like biking	-	-	-0.17	-1.14	-0.25	-2.55	-	-
	time spent on travel is a waste to me	-	-	0.20	1.47	-	-	0.26	2.26
<i>Neighborhood Attributes</i>									
	F.A.R.	-0.25	-2.47	-0.35	-2.05	0.54	4.20	-	-
	average distance between neighborhood entries (m)	0.00	4.03	-	-	0.00	3.27	0.00	4.92
	intersection density (# of intersections per km)	0.08	5.56	-	-	0.11	5.75	0.12	5.90
	building coverage	-	-	3.19	4.16	-3.82	-5.41	-	-
	percentage of road with trees	-0.59	-3.81	-	-	-	-	-0.60	-3.17
	percentage of road with street-level shops	-1.20	-2.76	-	-	-1.83	-3.79	-1.71	-2.88
	percentage of road with walking facilities	-0.41	-2.33	0.37	1.37	-0.78	-3.50	-1.20	-5.15
	land use mix within 500m catchment area	2.18	1.9	-2.74	-2.34	3.98	3.05	2.67	1.85

Step-2(a): Travel Energy Consumption Model (OLS regression with robust standard error)

**Table A-6. Step-2(a) Travel Energy Consumption Model Estimation Result**

Regression with robust standard errors	Number of obs	3955
	F( 10, 3943)	157.68
	Prob > F	0
	R-squared	0.3191
	Root MSE	3.0573

*ln\_t\_mj\_year (treating zero values in t\_mj\_year as zero, ln\_t\_mj\_year=ln(t\_mj\_year + 1)*

	robust				VIF
	Coef.	Std. Err.	t	P>t	
<b>Constant</b>	<b>1.77</b>	<b>0.78</b>	<b>2.27</b>	<b>0.02</b>	
<i>Household Characteristics</i>					
<b>ln(household annual income in 1,000 rmb)</b>	<b>0.45</b>	<b>0.12</b>	<b>3.84</b>	<b>0.00</b>	2.75
<b>no household member is currently employed</b>	<b>-1.61</b>	<b>0.27</b>	<b>-6.05</b>	<b>0.00</b>	2.60
<b>senior household: household head is over 60 years old</b>	<b>-0.85</b>	<b>0.24</b>	<b>-3.46</b>	<b>0.00</b>	1.73
<b>having access to a company/business car</b>	<b>1.74</b>	<b>0.33</b>	<b>5.32</b>	<b>0.00</b>	1.10
<i>Instrument Variables (Vehicle Ownership Portfolio)</i>					
<b>probability of owning ebikes only</b>	<b>2.85</b>	<b>0.86</b>	<b>3.33</b>	<b>0.00</b>	2.10
<b>probability of owning motorcycle</b>	<b>6.92</b>	<b>2.22</b>	<b>3.11</b>	<b>0.00</b>	4.95
<b>probability of owning cars only</b>	<b>2.36</b>	<b>0.68</b>	<b>3.47</b>	<b>0.00</b>	6.18
<b>probability of cars and other vehicle (motorcycle or ebike</b>	<b>6.32</b>	<b>0.73</b>	<b>8.63</b>	<b>0.00</b>	2.84
<i>Neighborhood Attributes</i>					
<b>parking provision (sq.m. parking space per household)</b>	<b>0.13</b>	<b>0.02</b>	<b>7.76</b>	<b>0.00</b>	1.40
<b>building coverage</b>	<b>-5.17</b>	<b>0.85</b>	<b>-6.08</b>	<b>0.00</b>	3.81
<b>percentage of cul-de-sacs</b>	<b>1.21</b>	<b>0.33</b>	<b>3.64</b>	<b>0.00</b>	1.60
<b>average building footprint (sq.m)</b>	<b>0.00</b>	<b>0.00</b>	<b>5.42</b>	<b>0.00</b>	1.90
<b>land use mix within 500m catchment area</b>	<b>2.24</b>	<b>0.91</b>	<b>2.45</b>	<b>0.01</b>	2.06

Step-2(b): Travel CO2 Emission Model (OLS regression with robust standard error)

**Table A-7. Step-2(b) Travel CO2 Emission Model Estimation Result**

Number of obs	3955
F( 13, 3941)	192.07
Prob > F	0
R-squared	0.3454
Root MSE	2.2236

*ln\_t\_kgCO2\_year (treating zero values in t\_kgCO2\_year as zero, ln\_t\_mj\_year=ln(t\_kgCO2\_year + 1)*

	robust				VIF
	Coef.	Std. Err.	t	P>t	
<b>Constant</b>	<b>2.14</b>	<b>0.42</b>	<b>5.14</b>	<b>0.00</b>	
<i>Household Characteristics</i>					
<b>ln(household annual income in 1,000 rmb)</b>	<b>0.32</b>	<b>0.08</b>	<b>3.96</b>	<b>0.00</b>	2.53
<b>no household member is currently employed</b>	<b>-1.22</b>	<b>0.18</b>	<b>-6.68</b>	<b>0.00</b>	2.45
<b>senior household: household head is over 60 years old</b>	<b>-0.68</b>	<b>0.17</b>	<b>-3.97</b>	<b>0.00</b>	1.73
<b>having access to a company/business car</b>	<b>1.42</b>	<b>0.25</b>	<b>5.73</b>	<b>0.00</b>	1.09
<i>Instrument Variables (Vehicle Ownership Portfolio)</i>					
<b>probability of owning ebikes only</b>	<b>2.07</b>	<b>0.62</b>	<b>3.36</b>	<b>0.00</b>	2.09
<b>probability of owning motorcycle</b>	<b>5.07</b>	<b>1.49</b>	<b>3.41</b>	<b>0.00</b>	4.28
<b>probability of owning cars only</b>	<b>1.87</b>	<b>0.49</b>	<b>3.80</b>	<b>0.00</b>	5.84
<b>probability of cars and other vehicle (motorcycle or ebike)</b>	<b>4.93</b>	<b>0.49</b>	<b>10.14</b>	<b>0.00</b>	2.50
<i>Neighborhood Attributes</i>					
<b>parking provision (sq.m. parking space per household)</b>	<b>0.11</b>	<b>0.01</b>	<b>8.56</b>	<b>0.00</b>	1.41
<b>building coverage</b>	<b>-2.95</b>	<b>0.54</b>	<b>-5.51</b>	<b>0.00</b>	3.22
<b>percentage of cul-de-sacs</b>	<b>0.63</b>	<b>0.28</b>	<b>2.26</b>	<b>0.02</b>	2.19
<b>average building footprint (sq.m)</b>	<b>0.00</b>	<b>0.00</b>	<b>4.41</b>	<b>0.00</b>	1.98
<b>number of bus routes with stops within 500m radius</b>	<b>-0.01</b>	<b>0.01</b>	<b>-1.57</b>	<b>0.12</b>	1.93

Marginal Effect

Table A-8 Marginal Effect of Attributes

	Step-1: Vehicle Ownership				Step-2 (a)	Step-2 (b)	Energy Consumption		Emission	
	E-bike	Motorcycle	Cars Only	Car Plus	energy	emission	d(ln_t_MJ)	% change	d(ln_t_kgCO2)	% change
ln(household annual income in 1,000 rmb)	(0.05)	-	0.11	0.07	<b>0.45</b>	<b>0.32</b>	0.976	<b>165.3%</b>	0.743	<b>110.2%</b>
no household member is currently employed	(0.07)	-	(0.12)	-	<b>-1.61</b>	<b>-1.22</b>	(2.090)	<b>-87.6%</b>	(1.59)	<b>-79.6%</b>
2 household members are currently employed	(0.02)	(0.00)	-	0.04	-	-	0.140	<b>15.0%</b>	0.11	<b>12.0%</b>
3 or more household members are currently employed	(0.03)	(0.01)	(0.02)	0.09	-	-	0.418	<b>51.9%</b>	0.33	<b>39.5%</b>
having children (<20 years old) in the family	-	-	0.03	0.05	-	-	0.370	<b>44.8%</b>	0.29	<b>33.6%</b>
having seniors (>=60 years old) in the family	-	-	-	(0.04)	-	-	(0.279)	<b>-24.3%</b>	(0.22)	<b>-19.6%</b>
renting	-	0.02	(0.09)	(0.05)	-	-	(0.402)	<b>-33.1%</b>	(0.32)	<b>-27.6%</b>
single	(0.14)	(0.03)	0.06	-	-	-	(0.478)	<b>-38.0%</b>	(0.34)	<b>-28.8%</b>
having 4+ household members	-	-	-	0.03	-	-	0.169	<b>18.4%</b>	0.13	<b>14.1%</b>
having access to a company/business car	(0.13)	-	0.05	-	<b>1.74</b>	<b>1.42</b>	1.501	<b>348.5%</b>	1.25	<b>249.7%</b>
senior household: household head is over 60 years old					<b>-0.85</b>	<b>-0.68</b>	(0.846)	<b>-57.1%</b>	(0.68)	<b>-49.2%</b>
driving is a sign of prestige	0.04	-	-	(0.02)	-	-	(0.036)	<b>-3.5%</b>	(0.03)	<b>-3.3%</b>
taking bus is convenient	-	-	(0.05)	(0.04)	-	-	(0.371)	<b>-31.0%</b>	(0.29)	<b>-25.2%</b>
I like biking	0.02	-	(0.03)	0.00	-	-	(0.002)	<b>-0.2%</b>	(0.00)	<b>-0.5%</b>
time spent on travel is a waste to me	(0.01)	-	(0.01)	0.02	-	-	0.082	<b>8.6%</b>	0.07	<b>6.8%</b>
F.A.R.	(0.07)	(0.02)	0.09	-	-	-	(0.154)	<b>-14.3%</b>	(0.10)	<b>-9.5%</b>
average distance between neighborhood entries (m)	0.00	(0.00)	-	0.00	-	-	0.001	<b>0.1%</b>	0.00	<b>0.1%</b>
intersection density (# of intersections per km)	0.01	(0.00)	0.01	0.01	-	-	0.059	<b>6.1%</b>	0.05	<b>4.7%</b>
building coverage	0.11	0.25	(0.54)	0.04	<b>-5.17</b>	<b>-2.95</b>	(4.179)	<b>-98.5%</b>	(2.29)	<b>-89.9%</b>
percentage of road with trees	(0.10)	0.02	0.04	(0.04)	-	-	(0.325)	<b>-27.7%</b>	(0.24)	<b>-21.5%</b>
percentage of road with street-level shops	-	0.06	(0.16)	-	-	-	0.002	<b>0.2%</b>	(0.02)	<b>-2.1%</b>
percentage of road with walking facilities	-	0.05	(0.07)	(0.08)	-	-	(0.341)	<b>-28.9%</b>	(0.28)	<b>-24.7%</b>
land use mix within 500m catchment area	-	(0.29)	0.42	-	<b>2.24</b>	-	1.262	<b>253.2%</b>	(0.66)	<b>-48.3%</b>
parking provision (sq.m. parking space per household)	-	-	-	-	<b>0.13</b>	<b>0.11</b>	0.128	<b>13.6%</b>	0.11	<b>11.2%</b>
percentage of cul-de-sacs	-	-	-	-	<b>1.21</b>	<b>0.63</b>	1.214	<b>236.8%</b>	0.63	<b>88.0%</b>
average building footprint (sq.m)	-	-	-	-	<b>0.00</b>	<b>0.00</b>	0.001	<b>0.1%</b>	0.00	<b>0.1%</b>
number of bus routes with stops within 500m radius	-	-	-	-	-	<b>-0.01</b>	-	<b>0.0%</b>	(0.01)	<b>-1.2%</b>

## Appendix B: Embodied Energy Consumption

Before we introduce the details of our embodied energy model, it is important to first identify the functional units of our LCA approach. Two functional units have been selected for this study: per m<sup>2</sup> basis and per household basis. The use of living area as a functional unit allows the comparison of multifunctional residential development projects on a homogeneous basis. However, value judgments about an individual's living space are implicit to this functional unit assumption. As such, per household basis is also included in the analysis to assess the relative importance of living space considerations when comparing urban density impacts.

### *The limitation of previous neighborhood embodied energy model*

The embodied energy consumption model developed last year had basically three major limitations. First, the previous residential embodied energy model included energy consumed in producing materials used for all buildings within each neighborhood. The quantities of all building materials were summed up, multiplied by the energy intensity of each material, and then divided by the total number of households. However, to be more precise, “residential embodied energy” should be calculated by summing up the energy consumed for producing construction materials that are used *only* for residential and mixed-use residential buildings.

Second, in the previous model, we assumed that all buildings would be constructed using the same construction methodologies and materials regardless of neighborhood typologies in which they are located. However, this assumption is far from reality considering the history of housing policy, construction methods, and the development of construction materials in China over the past half century. The materials used for housing construction vary depending on the levels of technological improvements<sup>1</sup> in the construction industry sector during a particular period of time. For example, Traditional neighborhoods were mostly built before 1930s when brick panels and wood beams were largely used. The buildings located in the Superblock neighborhoods, however, were built during the 2000s when brick became less popular as construction materials due to the

---

<sup>1</sup> During the 1960s, industrialized methods of construction were introduced in China (Junhua et al. 2001). After the 1960s, important components of buildings such as structures and building envelopes including floors, staircases, large concrete panels, concrete frames were assembled and pre-fabricated by construction material industries. The industrialization of construction methods implies that large-scale housing development projects are implemented based on the standardized modules of construction materials.

changes of building structures and technologies. Thus, it is unrealistic to assume that all the buildings are constructed with the same materials regardless of typologies.

Third, we presented our results in only one functional unit: embodied energy consumption *per household*. The energy consumption analysis presented in a single functional unit does not fully capture the diverse aspects of relationship between urban forms and the neighborhood embodied energy consumption. Furthermore, it is limited in offering a useful framework to compare different energy consumption levels across various neighborhood typologies. The study of Norman and his colleagues (2006) which investigated the relationship between urban forms and energy consumption using LCA approach provides a useful solution to this problem. They compared high and low residential complexes located in Canada using two different types of functional units: *per household* and *per m<sup>2</sup>*.

#### *Revised neighborhood embodied energy consumption model*

The initial embodied energy model was revised so as to improve aforementioned limitations. It consists of three major parts. First, the quantities of construction materials used in each neighborhood typology are estimated based on the new assumptions about the use of construction materials. Second, the energy intensity of each material type is multiplied by the quantities of each material. We can then yield total energy consumption of each typology ( $E_m$ ).  $E_m$ , or the energy consumed in manufacturing construction materials, is calculated as follows:

$$E_m = \sum_{i=1}^n q_i e_i$$

Where  $n$  is the total number of building materials and elements;  
 $q_i$  is the amount of construction materials  $i$  (kg),  
 $e_i$  is the energy intensity of material  $i$ , or the energy required for manufacturing the building materials  $i$  (MJ/kg);

Third, we normalize the total energy consumption by both the number of households and the size of each neighborhood. In the following sub-section, we describe in details how we calculated the quantities of each construction material type.

#### *1.1 Estimation of material quantities*

The information about the quantities of construction materials is critical in our model. It is also important for understanding the relationship between urban development patterns

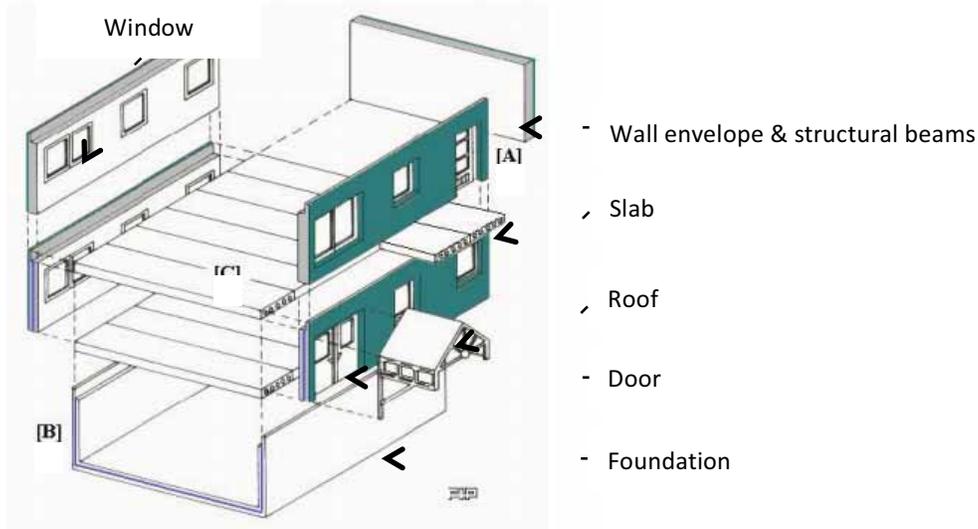
and the embodied energy consumption. However, the detailed information about the types of building materials and their quantities is not available. In order to fill the data gap, we need assumptions and judgments that are credible. The revised version of embodied energy model thus develops its assumption not only by using the GIS data we collected but also by considering the history of technological improvements in construction material sectors.

The calculation of material quantities consists of two sub-categories: materials consumed for residential buildings and those for infrastructure. For both categories, the volumes of construction materials were first calculated using GIS data and assumptions about design dimensions. Then these values were multiplied by the density of each material. In order to estimate the quantities of materials used for constructing residential buildings, we assumed that all residential buildings consist of seven major components as illustrated in Figure 1: wall envelope, slabs, window areas, doors, roof, structural beams, and foundation. These building components are built with six major construction materials as follows: asphalt, brick, concrete, glass, steel, and timber<sup>2</sup> (Table B-1). We also assumed that the neighborhood infrastructure system consists of motorways, sidewalk areas, pedestrian pathways, and underground and surface parking spaces (Figure B-2). Asphalt, brick, concrete, and cement are used for the infrastructure system (Table B-1).

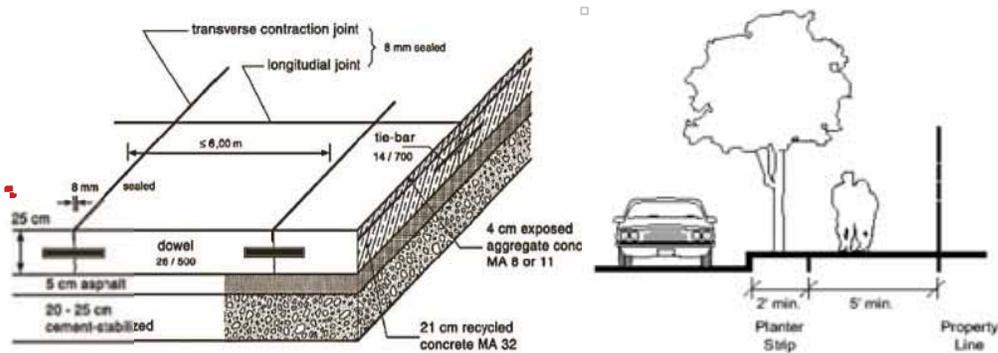
---

<sup>2</sup> Chen et al. (2001) argued that not all construction materials should be considered in detail in the embodied energy analysis. They found that where the quantity of material (in terms of mass) was calculated to be less than 0.0001kg, their overall impact was found to be too insignificant. They hence selected concrete,

**Figure B-1. Basic structure of residential buildings: Envelope and slabs**



**Figure B-1. Basic structure of infrastructure system**



**Table B-1. Construction materials and the structure of buildings and infrastructure systems**

Material Type	Buildings	Detailed usage	Infrastructure	Detailed usage
Asphalt	O	Roof shingles	O	Pavement of motorways and surface parking space
Brick	O	Structure (Envelope + Slab)	O	Tiles for sidewalk areas
Cement	X	-	O	Pavement of motorway areas, pedestrian ways, and surface parking space

Concrete	O	Structure (Envelope + Slab), foundations	O	Pavement of motorway areas, pedestrian ways, and constructing underground parking space
Glass	O	Window	X	-
Steel	O	Structure (Envelope + Slab)	X	-
Timber	O	Structure (Envelope + Slab), Window frames, Doors	X	-

### 1.2 Assumptions about the use of materials in different neighborhood typologies

The structures of buildings are considered important in terms of the choice of the material types and building technologies. High-rise structures require construction materials that are much more durable than the ones used for low-rise buildings. In this light, we first categorized residential buildings into two groups: those *above 4 stories* and those *under 4 stories*. We assumed that the former are constructed with masonry concrete panels with steel beams regardless of neighborhood typologies. In particular, 65% of the quantities of residential building structures are reinforced concrete, and 35% are steel (Fernandez et al. 2007). It is assumed that no bricks and wood materials are used for the structural purposes for those above 4 stories. For the buildings under 4 stories, it is assumed that wood, brick, and concrete are used but no steel structures are required. We further assumed that the four neighborhood typologies are built with a different composition of construction materials as they have been developed at various time periods (Table 2). Based on the literature review on the history of urban design and building technologies, following assumptions were made.

**Table B-2 Chronological order of urban typology developments in Jinan**

<b>Traditional</b>	<b>Grid</b>	<b>Enclave</b>	<b>Superblock</b>
<b>~ 1930</b>	<b>1930-1960</b>	<b>1980-2000</b>	<b>2000-</b>

#### **Traditional (~1930)**

According to our GIS surveys, 99% of residential buildings in the Traditional neighborhoods are less than 4 stories. Structurally, low rise buildings whose heights are mostly less than 4 stories do not require steel. Literature confirms that in China, brick and wood were used frequently for construction before 1950s (Junhua et al.2001). Photographs of the old neighborhoods that were built during this period and are being demolished these days also support this evidence (Figure 1). Based on this evidence, we

assumed that, in Traditional neighborhoods, 20% of residential buildings whose heights are less than 4 stories are built with wood, 60% built with brick and 20% with concrete.

**Figure B-2. Traditional neighborhoods being demolished**



© James Weir<sup>3</sup>

### **Grid (1930-1960)**

Standardized housing designs of the Soviet Union were introduced in China in the 1950s. The residential buildings developed during this period of time were mostly less than 4 stories and each floor was about 2.8 meters high. Their basic structures were constructed with the *combination of brick and concrete*: in particular, and the exterior walls were constructed with two layers of bricks with one layer of concrete beam above (Junhua et al. 2001:135). In the Grids, it is thus assumed that 40% of residential buildings were built with brick and the rest 60% is built with concrete. No residential buildings under 4 stories were built with wood in Grid neighborhoods.

### **Enclave (1980-2000)**

Industrialized methods of construction were first introduced in the 1960s and were commonly used throughout following a few decades. During the past two decades, the precast concrete production was popular in China as it serves the government policies to provide low-income housing on a massive scale for the growing urban population. As a result, the nation's annual production capacity of concrete blocks reached one million cubic meters by the end of 1970s. And, by the mid-1980s, over 6 million square meters of housing had been completed using precast concrete building technologies (Junhua et al. 2001: 184-185). Therefore, it can be argued that the major construction material type of the Enclave neighborhoods is concrete. Between 1980s and 2000s, alternative building materials were increasingly more used in addition to large concrete panels. In particular,

---

<sup>3</sup> Retrieved from: <http://blog.chinatravel.net/activities-tours/shanghai-traditional-chinese-homes-demolished-for-development.html>

wood and industrial wastes such as slag, and stove ash were used to produce various types of wall panels and floors. It can be assumed that, in the Enclaves, 20% of residential buildings were built with wood, 20% with brick, and 60% built with concrete.

### Superblock (2000- )

The Superblock neighborhoods have been constructed quite recently. Residential buildings of the Superblocks are mostly above 4 stories. Only 7% of residential buildings are under 4 stories on average. Recently, in developing countries like China, reinforced concrete is used extensively particularly for multi-family housing due to its relatively low cost (Yakut 2004). We thus assume that, in the Superblock, 80% of residential buildings are constructed with concrete and only 20% are built with brick. No residential buildings are built with wood in the Superblock neighborhoods. The assumptions made about the choice of construction materials are summarized in Table 2.

**Table B-3. Summary of assumptions about the construction material usage**

	Neighborhood Typologies			
	Enclave	Superblock	Grid	Traditional
<u>High rise bldgs. (Floors &gt; 4 stories)</u>				
Concrete	65%	65%	65%	65%
Steel*	35%	35%	35%	35%
<u>Low rise bldgs. (Floors ≤ 4 stories)</u>				
Wood structure	20%	0%	0%	20%
Brick panels	20%	20%	40%	60%
Concrete	60%	80%	60%	20%

\* Steel is used only in buildings above 4 stories. Steel is not used in the buildings under 4 stories.

### 1.3 Assumptions about design dimensions

The design dimensions of buildings and neighborhood infrastructure is critical for estimating the quantities of construction materials, but these details are not available. We thus made assumptions based on Chinese buildings codes and literature (Table B-4).

**Table B-4. Assumptions of residential buildings and infrastructure dimensions**

Buildings	Dimension	Unit	Source
Height per floor (layer)	3	m	Junhua et al. 2001, Chinese building code
Thickness of slab	0.15	m	

Thickness of wall envelope	0.3	m	Chinese building code; Lee and Chen 2008 <sup>4</sup>
-- Concrete portion of the wall	0.65		Fernandez 2006
Thickness of glass	0.003	m	Lee and Chen 2008
Roof (material use %)			
--- Concrete roof	50%	%	-
----- Thickness of concrete roof tiles	0.007	m	
--- Asphalt (bitumen) roof	50%	%	-
----- Thickness of asphalt roof shingles	0.002	m	
% of window area (window-to-wall ratio)	30%	%	Yu et al. 2008
Width of window frame	0.05		
Thickness of window frame	0.05	m	
Dimensions of steel beams			
-- steel beam (radius=0.015m, length= 3m))	0.1413	m <sup>3</sup>	
Dimensions of wood beams	0.02100	m <sup>3</sup>	
-- wood beam (w=0.1m, l=0.07m, h=3m)	1.92	m <sup>2</sup>	
-- Doors (w=0.96m, l=2m)			
-- Thickness of standardized doors	0.07	m	
<b>Infrastructure</b>			
Thickness of concrete pavement for motorways	0.02	m	
Thickness of cement pavement	0.02	m	
Thickness of asphalt pavement	0.05	m	
Thickness of sidewalk areas	0.125	m	-
Width of sidewalk areas	2	m	-
Thickness of concrete pavement for pedestrian pathways	0.2	m	
Thickness of envelope of underground parking space	0.3	m	
Thickness of foundation	0.2	m	
Height of floor of the underground parking space	2.7	m	

#### 1.4 Calculation of material quantities

Before calculating the quantities of each material, we first need to introduce the ways we calculated the number of wood and steel beams as they are often used in the form of structural beams. To simplify and facilitate the calculation, we assumed that all the residential buildings are built in a square shape.

<sup>4</sup> The observed thickness of the exterior wall in Chinese residential buildings ranges from 0.23 m to 0.38m (Yu et al 2008; Fernandez 2007; Lang and Huang 1992). However, we assume that the building structure complied with the national building codes.

The number of steel / wood beams used for slabs per floor =  $\left(\frac{\sqrt{\alpha}}{2} - 1\right) \times \left(\frac{\sqrt{\alpha}}{3} \times 2\right) \dots \ominus$

The number of steel / wood beams used for wall envelope per floor =  $\left(\frac{\sqrt{\alpha}}{2} - 1\right) \times 4 \dots \ominus$

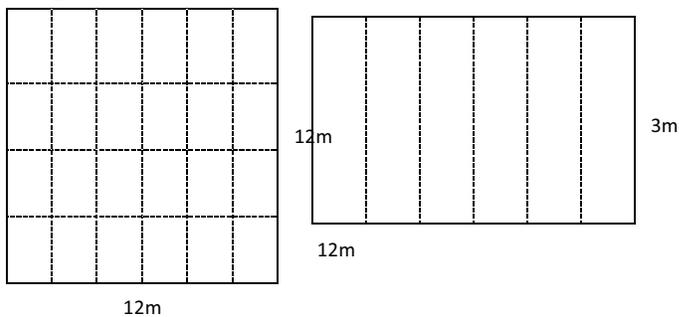
$$\therefore N_{\text{wood\_beams}} = \ominus + \ominus$$

Where,  $\alpha$  = Average residential building footprint area

$N_{\text{wood\_beams}}$  = Number of wood beams used per 1 residential building

The rationale for these formulae is as follows. First, as we assumed that each residential building is square-shaped, the length of each building's segment equals to  $\sqrt{\alpha}$ . We assumed that the distance between the beams used for slabs is 2m and the length of each steel or wood beam is 3m (Figure B-4). Let's assume that the average residential floor area equals to 144 as illustrated in Figure B-4. Based on our assumption, approximately 40 wood/ steel beams are required for each slab. For the wall envelope, a total of 20 beams will be required.

**Figure B-3. Calculation of wood / steel beams**



**Slab**

Interval: 2m with 3 m  
long steel / wood beams  
Total # of beams: 40

**Wall Panel**

Interval: 2m  
# of beams per one side  
of bldg. envelope:5  
Total # of beams used for envelope: 20

Second, we also need to introduce the ways in which we calculated the percentage of each construction material used for building structures which differ by neighborhood typologies.

The percentage of residential buildings structured in wood = (% of residential buildings above 4 stories) \* (% of wood-structured residential buildings above 4 stories) + (% of res bldgs. Under 4 stories) \* (% of wood-structured res bldgs. Under 4 stories)

The percentage of wood-structured residential buildings above 4 stories and the percentage of wood-structured residential buildings under 4 stories are available from our assumptions described in Table 3. The percentages of residential buildings structured in brick and concrete are estimated using the same method. For steel, only the percentage of residential buildings above 4 stories is considered. These percentages are multiplied by the total number of residential buildings in each typology to estimate the actual number of buildings that use certain construction materials.

The following equations are the calculation methods estimating the quantities of each construction material.

○ *Asphalt*

- Residential building usage

For residential buildings, asphalt is used in manufacturing roof tiles.

$$V_{A\_residential} = a_{Roof} * P_{roof\_asphalt} * T_{roof\_asphalt}$$

Where  $V_{A\_residential}$  = the total volumes of asphalt used for residential buildings,

$P_{roof\_asphalt}$  = the percentage of roof areas made of asphalt,

$T_{roof\_asphalt}$  = the thickness of asphalt shingles

- Infrastructure usage

For neighborhood infrastructure system, asphalt is used for paving motorway areas and surface parking spaces. Therefore,

$$V_{A\_infrastructure} = a_{motorway} * 0.05$$

Where  $V_{A\_infrastructure}$  = the total volumes of asphalt used for constructing infrastructure,

$a_{\text{motorway}}$  = motorway areas (calculated by multiplying average motorway width by total length of motorways),

0.05 = thickness of the pavement of motorways using asphalt (m)

○ *Brick*

▪ Residential usage

$$V_{B\_residential} = P_{residential\_brick} * [\{\beta * 3.0 * N_{floor} * (1 - \omega) * N_{residential} * 0.3\} + \alpha * (N_{floor} + 1) * N_{residential} * 0.15]$$

Where  $V_B$  = the total volumes of brick used for structures of residential buildings,

$P_{residential\_brick}$  = Percentage of residential buildings built in brick

$\beta$  = Average perimeter of residential building,

3.0 = Height per floor (in our model, the height per floor is 3 m),

$N_{floor}$  = Average number of floors,

$\omega$  = window-to-wall ratio,

$N_{residential}$  = Number of residential buildings in a neighborhood,

0.3 = Thickness of envelope (m)

0.15 = Thickness of slab (m)

▪ Infrastructure usage

$$V_{B\_infrastructure} = a_{sidewalk} * T_{sidewalk\_brick} * P_{sidewalk\_brick}$$

Where  $V_{B\_infrastructure}$  = the total volumes of brick tiles used for paving sidewalk areas,

$a_{sidewalk}$  = total sidewalk areas,

$T_{sidewalk\_brick}$  = the thickness of brick tiles used for paving sidewalk areas,

$P_{sidewalk\_brick}$  = the percentage of sidewalk areas built with brick

○ *Cement*

▪ *Infrastructure usage*

$$V_{CE\_infrastructure} = a_{motorway} * 0.02$$

Where  $V_{CE\_infrastructure}$  = Volumes of cement used for infrastructure system  
0.02 = thickness of cement pavement (m)

○ *Concrete*

▪ *Residential usage*

$$V_{CO\_residential} = P_{residential\_concrete} * [\{\beta * \gamma * N_{floor} * (1 - \omega) * N_{residential} * 0.3\} + \alpha (N_{floor} + 1) * N_{residential} * 0.15] + (a_{Roof} * P_{roof\_concrete} * 0.007)$$

Where  $V_{CO\_residential}$  = the total volumes of concrete used for the structures of residential buildings,

$P_{residential\_concrete}$  = Percentage of residential buildings built in concrete,

$P_{roof\_concrete}$  = the percentage of roof areas made of concrete tiles,

0.007 = the thickness of concrete roof tiles (m)

▪ *Infrastructure usage*

$$V_{CO\_infrastructure} = (a_{motorway} * 0.02) + (a_{sidewalk} * 0.125 * P_{sidewalk\_concrete}) + (a_{pedestrian} * T_{CO\_pedestrian}) + (\beta_{underground} * 2.7 * N_{floor\_underground} * T_{envelope\_underground}) + (\alpha_{underground} * T_{foundation} * N_{floor\_underground})$$

Where  $V_{CO\_infrastructure}$  = the total volumes of concrete used for neighborhood infrastructure system,

$P_{sidewalk\_concrete}$  = the percentage of sidewalk areas built with concrete,

$a_{pedestrian}$  = areas of pedestrian pathways,

$T_{CO\_pedestrian}$  = the thickness of concrete pavement of pedestrian pathways (= 0.2m),

$\beta_{underground}$  = Average perimeter of underground parking space,

$N_{floor\_underground}$  = Number of layers of underground parking space,

$T_{envelope\_underground}$  = Thickness of envelope of underground parking space (= 0.3m),

$\alpha_{underground}$  = Areas of underground parking space,

$T_{foundation}$  = Thickness of foundation (= 0.2m),

0.02 = thickness of concrete pavement,

2.7 = Height of floor for underground parking space,

0.125 = thickness of sidewalks

○ *Glass*\*

$$a_{window} = \beta * 3.0 * N_{floor} * \omega * N_{residential}$$

\* The material density of glass is measured in terms of Kg/m<sup>2</sup>. Therefore, we only estimated window areas.

○ *Steel*

$$V_{steel} = [N_{floor} * \left\{ \left( \frac{\sqrt{\alpha}}{2} - 1 \right) \times \left( \frac{\sqrt{\alpha}}{3} \times 2 \right) + \left( \frac{\sqrt{\alpha}}{2} - 1 \right) \times 4 \right\} *] N_{Residential\_steel} * 0.1413$$

Where  $V_{steel}$  = total volume of steel beams used for residential buildings over 4 stories,

$$N_{Residential\_steel} = \text{Number of residential buildings over 4 stories,}$$

0.1413 = dimension of steel means (m<sup>3</sup>)

○ Timber (Wood)

$$V_{\text{timber}} = \{ (U_{\text{size}} + 1) * N_{\text{households}} * 1.92 * 0.07 \} + (\beta * 3.0 * N_{\text{floor}} * N_{\text{residential}} * \omega * 0.05) + (N_{\text{floor\_under 4 stories}} * N_{\text{wood\_beams}} * N_{\text{residential\_wood}} * 0.012)$$

Where  $V_{\text{timber}}$  = Total volume of timber used for residential buildings,

$U_{\text{size}}$  = Average number of persons per household,

$N_{\text{floor\_under 4 stories}}$  = number of floors of residential buildings under 4 stories,

$N_{\text{residential\_wood}}$  = Number of wood-structured residential buildings,

1.92 = Dimension of standardized doors (m),

0.07 = the thickness of standardized doors (m)

0.05 = the thickness of window frame

0.012 = Volume per standardized wood beam (m<sup>3</sup>)

The volumes of each material are multiplied by its density so as to estimate the amount of each material on a kg basis. The construction material quantities of each neighborhood were then multiplied by the coefficients of energy intensities and carbon intensities drawn from both literature and data available in SimaPro.

**Table B-5. Material Energy and Carbon Intensities**

Material Type	Type & Usage	Energy Intensity		Carbon Intensity	
		Coefficient	Unit	Coefficient	Unit
Asphalt (bitumen)	-- Roof tiles	50.7	MJ/kg	0.4	
	-- Infrastructure				
Brick	-- Brick tiles for building infrastructure system	3.8	MJ/kg	0.213	KgCO2/kg
	-- Brick blocks for structural use (building wall envelope)	2.7			

<b>Concrete</b>	- Reinforced concrete (for structural use)	1.1	MJ/kg	0.043	KgCO2/kg
	-- Concrete roof tile	1.7			
<b>Portland Cement</b>	Infrastructure	2.7	MJ/kg	0.839	KgCO2/kg
<b>Glass</b>	Window	29.8	MJ/kg	0.232	KgCO2/kg
<b>Steel (steel beam)</b>	Structural purpose	22.3	MJ/kg	0.482	KgCO2/kg
<b>Timber</b>	-- Doors	1,735	MJ/m2	0.125	KgCO2/kg
	-- Window frame	4,518.0	MJ/m2		
	-- Structure	32,023.3	MJ/m3		

**Table B-6. Material Density**

<b>Materials</b>		<b>Coefficient</b>	<b>Unit</b>
<b>Portland Cement</b>	<b>Types</b>	1500	kg/m3
<b>Concrete</b>	-- Concrete, normal (for structural use_	2400	kg/m3
	-- Concrete roof tile	49	kg/m2
		1522	kg/m3
<b>Steel (steel beam)</b>		7850	kg/m3
<b>Timber</b>	-- Timber for doors -- Timber for window frame -- Timber for structural use (wood beam)	16.0	kg/m3
<b>Glass</b>	Glass windows	9.9	kg/m2
<b>Asphalt (bitumen)</b>		14.6	kg/m2
		2400	kg/m3
<b>Brick</b>	Brick tiles (for infrastructure construction)	40	kg/m2
	Brick blocks (for structural use)	1850	kg/m3



## Appendix C: Sun-and-Wind-Related Urban Form Indices

To compare the geometrical properties of a neighborhood/cluster typology over another, and measure the relation of these properties to buildings operational energy use, it is essential to translate these properties to quantifiable – comparable and measurable – indices. Accordingly, the geometric properties, which are hypothetically influential on operational energy use, Porosity, Orientation, Height Irregularity and Surface to Volume Ratio, are defined as quantifiable indices. Calculating these indices for case studies in Jinan, and based on the surveyed data on the energy consumption of these neighborhoods, it would be possible to statically analyze the mentioned geometric properties of clusters to their operational energy use.

### Wind Related Indices

#### *Porosity*

For porous media, porosity is defined as the fraction of the volume of pores (void spaces) over total volume. Several studies on the permeability/hydraulic conductivity of porous media have revealed that materials with higher porosity are more permeable: i.e. the higher rate of fluid movement through the material (Darcy's Law). By assimilating a neighborhood to a porous medium – open spaces to a pores, and buildings to the solid skeleton – it can be argued that the more porous a neighborhoods is, the more permeable to wind flow it is; that is, there is a higher capacity for natural ventilation and cooling convection in these neighborhood in summer. On the other hand, in very porous neighborhoods, buildings would be exposed to cold winter winds. Thus, it can be hypothesized that the more porous a neighborhood, the higher its heating energy load, and the lower its cooling energy load.

For a cluster/neighborhood porosity is defined as the ratio of the total volume of open spaces to the total volume where the total volume of open spaces is equal to the area of open spaces multiplied by the average height of buildings, and the total volume is equal to the summation of the volume of open spaces and total volume of buildings.

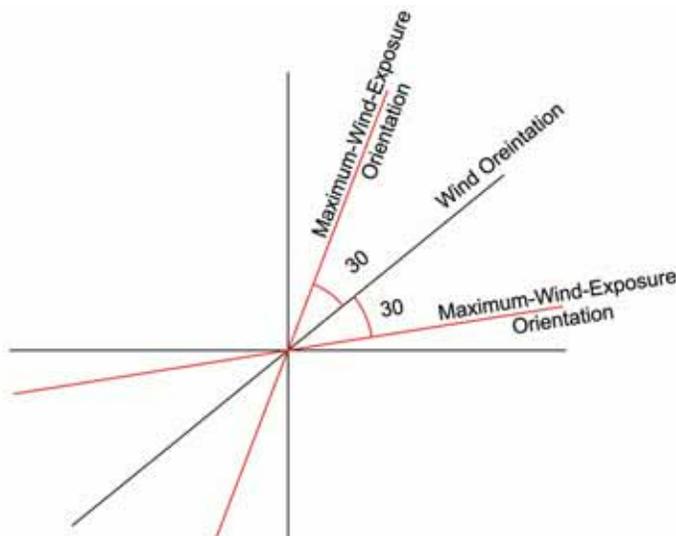
#### *Buildings-Wind Orientation Index*

In a single-standing building the exposure to the wind flow would be maximized if its longest facade is perpendicular to the wind direction. However, in a cluster of buildings, this form of orientation – perpendicular to the prevailing wind – doesn't allow the wind to penetrate into the entire fabric. Studies (e.g. Givoni, 1994) have revealed the optimal orientation in a cluster for increasing natural convection is a 30-degree angle between the longest face of buildings and the wind direction, either clockwise or counter-clockwise (Figure C-1). This angled form of orientation helps natural ventilation in buildings, and decreases the cooling energy load in summer, in contrast, this can increase the air leakage

through windows and decrease the R-value of façades, and consequently increases heating energy load in winter.

As the prevailing wind direction can be different in summer and winter (as it is Jinan) two different orientation indices have to be defined. These two indices measure how much of facades of buildings are parallel to the angle in which buildings' exposure to the

**Figure C-1. Orientation in which buildings' exposure to the wind is maximized is a 30-degree angle between the longest face of buildings and the wind direction, either clockwise or counter-clockwise**



wind is maximized – 30° angled from the wind. While a higher summer buildings-wind orientation value hypothetically means a lower cooling energy load, a high winter building-wind orientation value may result in a high heating energy load.

#### *Height Irregularity Index*

Irregularity in the height of buildings increase downwash vortex. When a building is taller than its surrounding buildings, the bottom of building is blocked to the wind flow, while the top of building is exposed to the wind flow. This creates pressure difference between the top and bottom of the tall building, and a wind up-to-down wind vortex on the facade of the tall building. As this vortex is parallel to the façade, its ventilation and air leakage impact are less than horizontal wind vortices.

Thus, it can be expected that height irregularity can increase the cooling energy load in summer by decreasing natural cooling convection, and decrease heating energy load in winter by decreasing through-windows air leakage.

## Solar-Related Indices

### *Shadow Ratio Index*

In an urban fabric, shadows on façades or roofs can be casted by other buildings or other facades of the same building. Façade can also be in their own shadow. While the latter is only dependent on the position of the sun in the sky and the orientation of facades, the first one, besides the position of the sun in the sky, is depend on the configuration of buildings in the site. In this research, in order to measure the total area of shadows, these two groups of shadows are calculated separately. The solar energy that a surface receives is proportional to area of the surface that is not in shadow.

Two different shadow ratio indices (the percentage of in-shadow areas of surface) for roofs and facades are defined.

### *Winter/Summer Solar Gain Index*

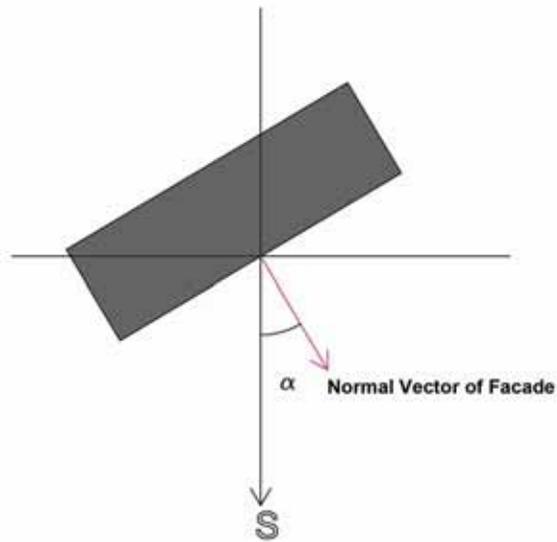
The solar gain index is defined based on shading condition (shadow ratio) and the angle between solar beam and façade. At a certain time, the amount of solar energy that a surface receives is directly related – is proportional to the sin of this angle – to the angle between this surface and the solar beam. For example, in installation of photovoltaic panels the altitude of panels is taken into account, as it determines the angel between the surface of panel and the solar radiation. On the other hand, the amount of gained solar energy is also proportional to the area of the surface that is not in shadow. As the solar gain has different impact in summer and winter, two separate indices have to be defined for summer and winter. These indices make possible the comparison of different neighborhoods in terms of solar gain.

For this purpose these two parameters (beam-façade angle and shading condition) should be measured in different times as sample indicators. By measuring the in-shadow area of facades, we can estimate the percentage of facades and roofs that receive solar radiation at any of these times of the year. The solar value of any surface at a certain time is defined as  $A_S * \sin(w)$ , where  $A_S$  is the area of a surface that is not in shadow and  $w$  is the angle between the façade and solar beam.

### *South Orientation Index*

In the Northern Hemisphere, spaces with windows to the south receive natural light for a longer period of time during the day than spaces with windows to the east or west. Thus, orienting the long façade to the south can decrease the lighting energy use. For each individual façade the south orientation value is defined as the area of the projection of the façade onto the south plane and is equal to  $\cos(\varnothing) \times A$ , where  $\varnothing$  is the angle between the normal vector of the wall and the south vector, and  $A$  is the area of wall (Figure C-2)

**Figure C-2. Surface to Volume Ratio**



Buildings receive natural light through their surfaces. In large buildings such as hospitals, large malls, schools, universities and other types of institutional buildings that have low surface to volume ratio, a large fraction of interior spaces, such as corridors, staircases and even rooms don't receive enough (or at all) natural light and require electrical lighting. In other words, the surface to volume ratio is an indicator of the fraction of spaces that have the capacity to receive natural light; i.e. a high surface to volume ratio can decrease lighting energy use.

In addition, as the buildings lose energy through the surface, the surface to volume ratio can also impact the rate of heat transfer, and consequently

## Appendix D: The Renewable Energy Potential Estimation and its Form implications

A clean energy urban form could be more than energy-efficient – but also provides large possibility for renewable energy production. The total energy demand of the neighborhood in our energy pro-forma is the sum of transportation, operational and embodied energy subtracting the renewable energy potential. As the fourth component in the energy pro-forma, the renewable energy potential module is an estimation based on Jinan climate conditions and given form indicators. It aims to show designers the benefit of onsite clean energy supply and carbon emissions reduction of renewable energy technology integration.

The renewable energy estimation includes two parts, solar energy estimation and wind energy estimation. Based on our studies on the related art and practices, we assume one unit of onsite renewable electricity will substitute one unit of grid electricity. The solar energy is the electricity produced from the grid-connected solar PV system installed on the roofs or/and southern facades of buildings, and wind energy comes from micro urban wind turbines mounted on the top of the tallest buildings. The installations of the PV panels and wind turbines are incompatible in our pro-forma – for the same roof, only one renewable energy technology can be applied.

For both types of renewable energy generation, the determinants can be categorized into three classes: the local climate information, the urban form indicators and the technical factors (such as energy efficiency) in the system.

### The Estimation Methodology

#### *Solar Energy*

Since photovoltaic is the most fast-developing and promising solar energy technology, it is selected as the referring technology in the pro-forma for solar energy potential estimation. Photovoltaic converts the sunlight into electricity through semi-conductive materials. The energy generation is related to the solar irradiation intensity on the panels, the total area of the PV panels, the effective solar duration and the efficiency of PV system. The formula for solar electricity estimation is

$$E_{pv} = \sum_{i=1}^n G_{hy\_i} * A_i * H * \gamma_i * \eta \quad (1)$$

$E_{pv}$  - the estimated annual electricity generation form solar PV ( kwh).

$G_i$  - the global average hourly irradiation falls on the surface  $i$  over the year (kwh);

$H$  - the Annual sunshine duration. The solar duration is the length of time in which the solar radiation falling on a plane perpendicular to the direction of the Sun is greater or equal to 120 W/m<sup>2</sup>. According to China Meteorological Administration, Jinan's annual sunshine hour is 2546.8<sup>1</sup>;

$\gamma_i$  - the unshaded percentage % on the surface  $i$ , which is the ratio of the actual unshaded sunlight duration to the possible sunlight hours within the same period.

$A_i$  - the total area on the PV surface;

$\eta$  - the efficiency of PV system. The system efficiency is the product of the module efficiency and the system de-rating rate.

To simply the estimation, our proforma only considers the PV installed on the roof and on the southern facades. For the roof integration, we assume the tracking system is deployed in all the flat roofs and the area of the PV installed is equal to the roof area. For the slope roof, the PV is installed in parallel to the sunside. The shading on panels on the roofs casted by other buildings and other PV panels are ignored in our estimation.

#### *Wind Energy*

The energy pro-forma estimates the renewable wind energy potential by calculating the annual electricity energy production from the roof-mounted wind turbines on the tallest buildings in the neighborhoods. Wind turbines capture the wind energy when the wind flow turning the blades of the turbines, and the wind turbines transfer the kinetic energy to the electricity. The average power of the wind turbines is highly dependent on the wind condition of the local physical environment. The average power of the wind turbine can be estimated via function (2)

$$P_w = C_p \frac{1}{2} \rho A v^3 \quad (2)$$

$P_w$  – the power of the wind turbine

$C_p$  - is the coefficient of performance; It changes with the specific turbines and local wind resources.

$\rho$  - is the air density. Air density will change with the pressure and the temperature. According to ISA (International Standard Atmosphere), at sea level and at 15°C, the air density is approximately 1.225 kg/m<sup>3</sup>. To simply the calculation, our energy proforma keeps the air density constant as 1.225 kg/m<sup>3</sup> for all estimations.

$A$  - is the swept area of the wind turbine, it can be calculated as  $A = \pi \times \text{Radius}^2$ . The radius of the wind turbines are calculated by assuming the diameter of the wind turbine is 0.1 of the building dimension character. BAWT diameter is often around 0.1 of building

---

<sup>1</sup> China Meteorological Data Sharing System

[http://cdc.cma.gov.cn/shuju/search1.jsp?dsid=SURF\\_CLI\\_CHN\\_MUL\\_MYER\\_19712000\\_CES&tpcat=SURF&type=table&pageid=3](http://cdc.cma.gov.cn/shuju/search1.jsp?dsid=SURF_CLI_CHN_MUL_MYER_19712000_CES&tpcat=SURF&type=table&pageid=3)

characteristic dimension to achieve higher efficiency from the wind-accelerated effect close to the structure (A.R. Jha, 2011).

V - the wind speed, the deterministic factor in (26). Our energy pro-forma uses the estimated annual mean wind speed for power estimation. Here, v is re-adjusted according to its location and form characteristic of the local neighborhood based the recorded annual mean wind speed in Jinan (3m/s)<sup>2</sup>. The estimation of V is the most complicated part in wind energy output estimation, and the detail description will be presented in the later section.

In terms of calculating the annual energy output, equation (3) is applied in the pro-forma

$$E_w = 1.91 \times P_w \times T \times N = 1.91 \times 8760 \times P \times N \quad (3)$$

E<sub>w</sub> is the total annual energy output from wind. N is the number of the installed wind turbines, which will be affected by the roof area as well as the spacing requirement of wind turbines. 8760 is the time length of the year – 365\*24 hours. 1.91 is the adjusted factor when adopting mean wind speed in energy output calculation. (Stankovic, 2007)

---

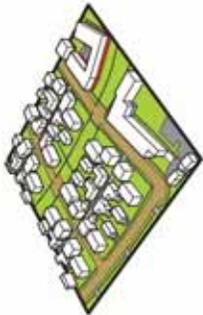
<sup>2</sup> This annual mean wind speed is draw from China Metrological Administration recorded climate data between 1971 and 2000.  
[http://cdc.cma.gov.cn/shuju/search1.jsp?dsid=SURF\\_CLI\\_CHN\\_MUL\\_MMON\\_19712000\\_CES&tpcat=SURF&type=table&pageid=3](http://cdc.cma.gov.cn/shuju/search1.jsp?dsid=SURF_CLI_CHN_MUL_MMON_19712000_CES&tpcat=SURF&type=table&pageid=3)



## **Appendix E: Cluster Analysis of Clean Energy Urban Design**



**W3B**  
Low-rise Slabs,  
Staggered  
based on Genos  
Denver, CO, USA



FAR  
LAND COVERAGE  
UNITS/HECTARE

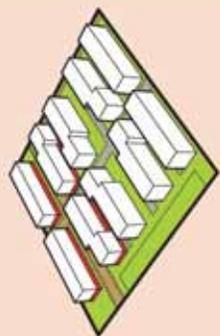
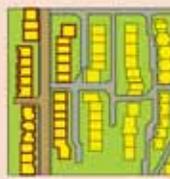
0.73  
24.5%  
44

Southern Sun Exposure

0-13°	21%
13-90°	21%
90°	42%



**W3C**  
Low-rise Slabs,  
Enclave  
based on DongCang  
Jinan, China



FAR  
LAND COVERAGE  
UNITS/HECTARE

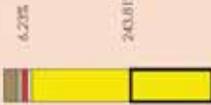
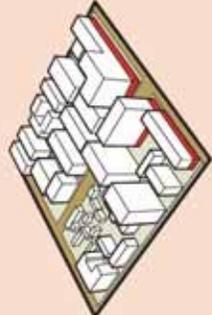
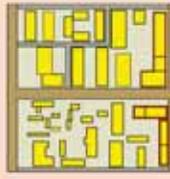
1.82  
33.5%  
257

Southern Sun Exposure

0-13°	38%
13-90°	0%
90°	38%



**W4A**  
The Grid,  
Regular  
based on Old Comm. Ctr  
Jinan, China



FAR  
LAND COVERAGE  
UNITS/HECTARE

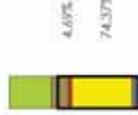
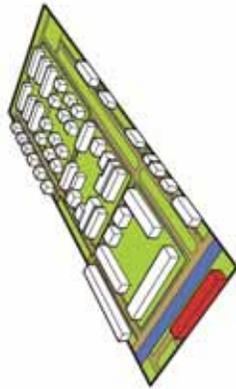
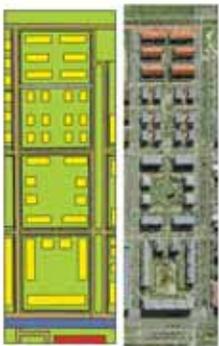
2.45  
35.0%  
345

Southern Sun Exposure

0-13°	0%
13-90°	49%
90°	49%



**W4A**  
The Grid,  
Regular  
based on Kronsberg  
Hanover, Germany



FAR  
LAND COVERAGE  
UNITS/HECTARE

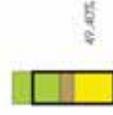
0.75  
18.0%  
105

Southern Sun Exposure

0-13°	0%
13-90°	50%
90°	50%



**W4B**  
The Grid,  
New Urbanist  
based on Civoano  
Arizona, NV, USA



FAR  
LAND COVERAGE  
UNITS/HECTARE

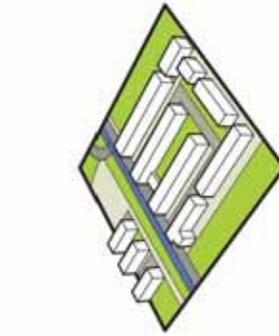
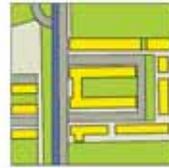
0.6  
30.0%  
40

Southern Sun Exposure

0-13°	19%
13-90°	10.0%
90°	30%



**W5A**  
Low-rise Superblock,  
Pedestrian Cluster  
based on Vauban  
Freiburg, Germany

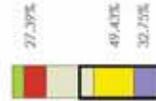
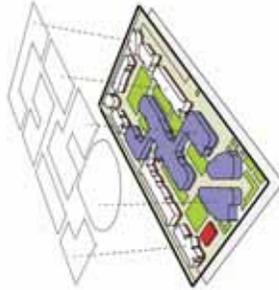


FAR 1.97  
LAND COVERAGE 49.0%  
UNITS/HECTARE 256

Southern Sun Exposure  
0°-13° 0%  
13°-90° 51%  
0°-90° 51%



**W5B**  
Low-rise Superblock,  
Pedestrian Matrix  
based on Masdar  
Abu Dhabi, UAE

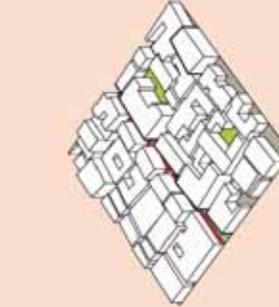


FAR 1.1  
LAND COVERAGE 27.5%  
UNITS/HECTARE 47

Southern Sun Exposure  
0°-13° 4%  
13°-90° 41%  
0°-90° 45%



**W5C**  
Low-rise Superblock,  
Traditional Form  
based on Zhang-Jia Village  
Jinan, China

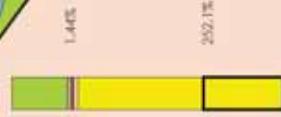
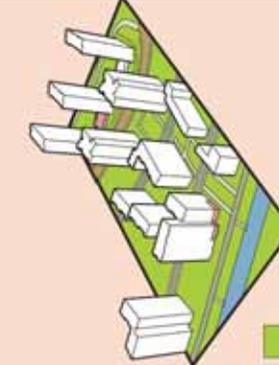


FAR 0.75  
LAND COVERAGE 75.0%  
UNITS/HECTARE 120

Southern Sun Exposure  
0°-13° 0%  
13°-90° 50%  
0°-90° 50%



**W6A**  
High-rise Superblock,  
Towers in Park  
based on Sunrise 100  
Jinan, China

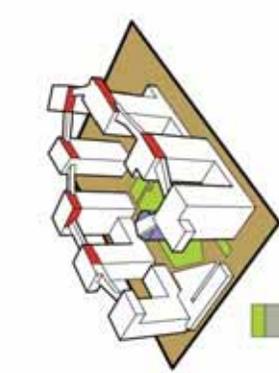


FAR 2.37  
LAND COVERAGE 15.4%  
UNITS/HECTARE 220

Southern Sun Exposure  
0°-13° 15%  
13°-90° 25%  
0°-90° 45%

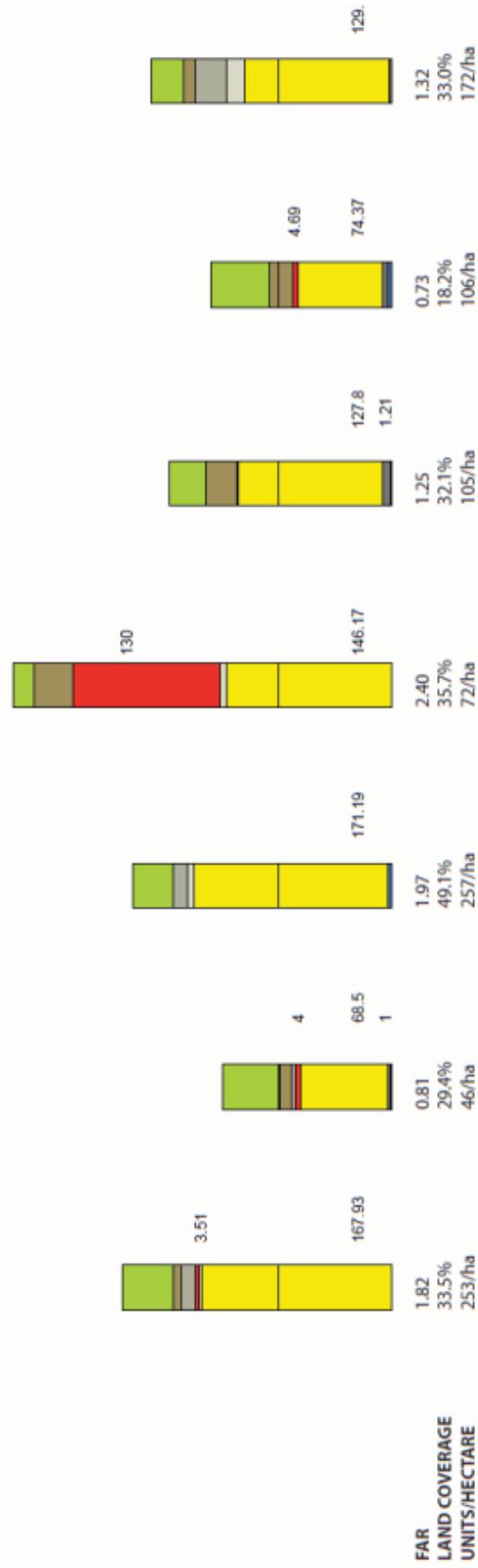
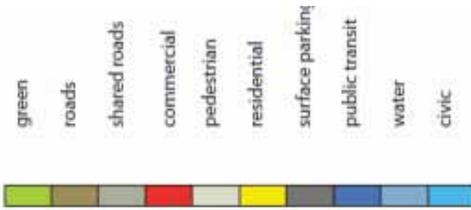


**W6B**  
High Density Perimeter Block,  
Linked Towers  
based on Linked Hybrid  
Beijing, China



FAR 3  
LAND COVERAGE 18.0%  
UNITS/HECTARE 230

Southern Sun Exposure  
0°-13° 22%  
13°-90° 9%  
0°-90° 31%



FAR	LAND COVERAGE UNITS/HECTARE	percentage	net area										
1.82	253/ha	33.5%	167.93	0.81	29.4%	46/ha	3.51	1.82	33.5%	167.93	0.81	29.4%	46/ha
1.82	253/ha	35.7%	171.19	1.97	49.1%	257/ha	130	2.40	35.7%	146.17	1.25	32.1%	105/ha
1.82	253/ha	32.1%	127.8	1.25	32.1%	105/ha	4.69	1.25	32.1%	127.8	0.73	18.2%	106/ha
1.82	253/ha	33.0%	129	1.32	33.0%	172/ha	129	1.32	33.0%	129	0.73	18.2%	106/ha

use	donggang net area	geos denver net area	vauban net area	las vegas net area	greenwich net area	kronsberg net area	bo01 malmo net area
green	16373	15779	13186	8202	10250	45816	9515
roads	2067	4377	0	14493	8571	18568	3156
shared roads	4632	1114	5035	0	0	0	9160
commercial	1209	1284	0	4043	0	1046	0
pedestrian	503	865	1976	2277	147	0	0
residential	9632	7887	15917	13301	10032	16605	10676
parking	0	0	0	0	2018	643	533
public transport	0	0	1070	0	0	2699	0
water	0	0	0	0	0	0	0
civic	0	351	0	0	381	121	0
TOTAL	34416	32525	37184	42316	31399	89305	33040
residential floors	6	3	4	20.3	4	4	4
commercial floors	1	1	0	20.3	0	4	0
footprint	10941	9522	15917	17344	10413	17651	10676
built residential	57794	24594	63668	62005	40127	66420	42705
built commercial	1209	1284	0	54788	0	4185	0
built civic	0	351	0	0	381	121	0
total built	59003	26228	63668	116793	40508	70605	42705
cluster dimensions	180*180	180*180	180*180	180*270	180*180	180*540	180*180
cluster area	32400	32400	32400	48600	32400	97200	32400
multiplier	1.82	0.81	1.97	2.40	1.25	0.73	1.32
coverage	33.46	29.39	49.13	35.69	32.14	18.16	32.95
average unit size	60	140	65	150	100	55	65
units per cluster	819	149	833	351	341	1026	558
clusters per hectare	0.31	0.31	0.31	0.21	0.31	0.10	0.31
units per hectare	253	46	257	72	105	106	172





## **Appendix F: Energy Sources in the Residential Sector of Jinan**

The residential sector in Jinan currently consumes four types of energy: electricity, gas, coal, and municipal centralized heating, as discussed below.

### **Electricity**

The electricity coverage of Jinan urban area reached 100% in the 1990s. Jinan Electricity Supply Company (JESC), a state-owned enterprise, is the city's only electricity provider, offering identical electricity price for residential users city-wide. Residential electricity consumption in Jinan peaks during the summer season due to cooling loads, but in recent years the winter consumption has increased significantly, reflecting the trend towards increased household ownership of electric heating appliances as a complement (or substitute) to traditional heating approaches (JESC, 2010).

With regard to both electricity generation (287,000 GWH) and installed generating capacity (61 million KW), Shandong Province ranks second among all provinces in China. Coal is the dominant energy source for electricity generation in Shandong – 99% of electricity is generated by coal power plants (JESC, 2010).

### **Gas**

Gas in Jinan is mainly consumed for cooking, water heating and a very limited proportion of space heating. Three types of gas, namely natural gas, liquefied petroleum gas and coal gas, are consumed in the residential sector, covering 97.8% of urban households (Jinan Government Annual Work Report, 2010). Residential neighborhoods constructed after 1995 normally have gas pipelines installed, through which either natural gas or coal gas can be directly transferred to households. Steel-bottled liquefied petroleum gas is available for households which cannot access piped gas.

### **Coal**

Coal has been used in Jinan's urban households for decades, serving space heating, water heating and cooking purposes, but its use is fading rapidly due to the expansion of gas and centralized heating coverage, which offer increased safety, convenience, and cleanliness. New residential neighborhoods in Jinan normally have access to municipal centralized heating, so coal is only consumed in older neighborhoods and the "urban villages", which have been enfolded into the city through rapid urbanization. Coal for household use takes the form of honeycomb briquettes, the purity, heat value and smoke impact of which vary according to the quality. Households use coal stoves with chimneys to burn coal for space heating. For cooking purpose, small movable stoves are also used.

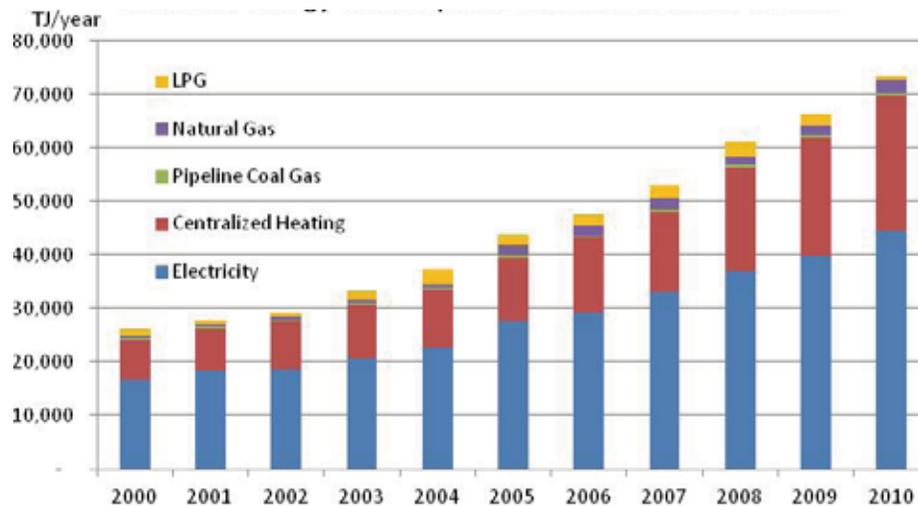
## Centralized Heating

The household centralized heating coverage in Jinan has reached 49% (Jinan Government Annual Work Report 2010), and the renewal of old residential neighborhoods to install centralized heating pipelines has been taking place city wide. Centralized heating delivery takes the form of hot water or steam, with coal as the primary energy source for generation. The centralized heating system does not meter individual household heating consumption; instead, the heating fee is calculated based on the constructed area of the home. Households cannot adjust the in-home temperature. The heating period lasts from Nov. 5 to March 15, 140 days in total.

## Trends

From **Error! Reference source not found.**, we can see that the city has made steady progress in building infrastructure for neighborhoods so that electricity, centralized heating, and natural gas are available, replacing coal and liquefied petroleum gas (LPG).

**Figure F-1. Citywide Residents' Energy Consumption in Jinan**



Source: Jinan Statistical Yearbooks 2001 to 2011, all original consumption data are converted to TJ.

## Appendix G: Energy Proforma User Guide

### *Neighborhoods & Energy*

It is intuitive that neighborhood form – the design and composition of buildings, streets, and open spaces – is linked to energy consumption. Neighborhoods with ‘walkable’ streetscape design are touted as more sustainable for getting residents out of cars. Other neighborhoods claim their residents conserve energy through employing green building technologies and materials. While neighborhoods may improve upon others with respect to discrete energy consumption reduction strategies, how does one compare how different urban form strategies impact the comprehensive energy performance of one neighborhood over another?

Are all urban forms equal in their energy performance or is there a difference among them? What is the source of the differences? How can designers and developers choose among a vast array of variables to design more energy efficient scenarios in particular circumstances? How can they assess the energy consumption of their project or alternatives? And finally, how can they do this in a way that is comparable to other projects to provide a basis for some kind of energy policy about the built environment?

These questions have yet to be answered and they form the foundation of this studio. The goal is both to expand our understanding of clean energy cities from evaluating them holistically – that is with a focus on all the kinds of energy consumption that occur in a neighborhood – as well as develop tools to compare their energy performance.

In order to approach this task, we focus on the scale of the neighborhood. Neighborhoods, commercial districts, and real estate projects are the fundamental building blocks of urban growth. How can we hope to make a meaningful impact on reducing energy consumption in cities without addressing the issue of how energy is consumed at the scale at which the city is actually being built? Furthermore, while we may know how individual buildings and cars consume energy, it is less clear how they consume energy based on the daily choices, patterns and behaviors of the individuals that use them within the geographical scope of their daily requirements – the neighborhood.

### *Existing Policy for Energy and Urban Development in China*

The questions we pose in this studio are particularly germane to urban development in China. With its rapid social and economic transition, China has now become the world’s largest emitter of greenhouse gases. Urbanization is both the manifestation and driver of economic growth and development. Over the past two decades, the percentage of the population living in cities has grown from 26% to 47%, and this growth is projected to continue (McKinsey, 2009).

Nevertheless, urbanization is also a key driver of China’s carbon emissions because it is an extremely energy intensive activity that is dominating China’s economy. Energy consumption stemming from economic sectors involved in urbanization is increasing faster than other sectors of the economy. The

residential sector alone is now the second largest energy-consuming sector following industry (RCSD, 2007) due to improving living standards reflected in the way cities are built and used by residents, such as increased numbers of appliances and private cars. The building and appliances and transportation sectors are projected to have the fastest carbon emission growth in the next twenty years – quadrupling by 2030, while the total emissions will only double (U.S. EIA, 2010, McKinsey 2009).

Existing energy policy and urban development processes in China are ill equipped to engage with the complexity or magnitude of this challenge. Energy policy is focused primarily on reducing emissions from industry while the energy performance of cities is regulated only at the individual building level; there has been little at the scale of neighborhood energy efficiency. Meanwhile, urban development policy governs planning processes at the municipal, sub-district, and neighborhood level. Nevertheless, none of these statutory planning processes or design guidelines specifically target energy efficiency in neighborhood-scale urban form and in fact, generally discourage it.

Regulatory plans for neighborhoods establish a set of boundary lines for road, infrastructure, green space, public facility, water, and historical conservation zones. The planning parameters for each of the resulting land parcels (land use, constructed floor area, FAR, building density, coverage, height, and some public amenities) are also listed on the regulatory plan. These planning codes effectively create car-oriented neighborhood designs. The codes do not emphasize the importance of pedestrian street life, and tend to encourage the use of cars in large-scale residential developments. At the real estate parcel level, regulations such as daylight access requirements; security guidelines that limit access points into a neighborhood; and allocation of parking spaces; all affect the interrelationship of buildings within a neighborhood, which in turn impact the quality of outdoor space, solar gains, ventilation, and the travel decisions and modes of residents due to the placement and functionality of public facilities.

Additionally, the regulatory plan often incorporates a preliminary urban design, to coordinate and evaluate the plan's proposed zoning, overall building massing, and public space. In general, neighborhood-planning codes are not spatially oriented, and a developer can satisfy the code requirements with a poorly arranged spatial plan that, for example, separates uses and access to alternative transportation. Moreover, the modernist, towers-in-the-park model that is the *de facto* residential real estate standard, promoted by developers and generally supported by planning bureaus, will usually be approved under the current planning regulations. Certain planning code parameters, especially the regulations for building spacing and sunlight access, have consistently resulted in south-facing rows of slab or tower buildings and have limited the potential for more compact and innovative neighborhood layouts.

Going forward into its 12<sup>th</sup> five-year plan, China has for the first time adopted a national carbon intensity target of 17 percent reduction in carbon output per unit of GDP on 2010 levels by 2015. In order to meet this goal China's policies are trending toward more holistic approaches, such as a new pilot program for location-based energy and carbon management experiments – the "EcoCity." Unfortunately, the principles and procedures guiding the first pilots suggest that the existing regulatory framework for urban planning and neighborhood design will clash with the EcoCity's clean energy goals. Each pilot EcoCity is governed by guiding principles that articulate environmental goals as well as metrics. Unfortunately, these principles are only advisory, while the planning parameters in the control plan are mandatory. Furthermore, out of the 26 EcoCity indicators established for one pilot, only two pertain to energy and at the building, rather than the neighborhood, scale.

### *The Need for Patterns & Tools to Design Clean Energy Cities*

It is clear that while the EcoCity concept is a step in the direction toward designing clean energy cities in China, the current planning process lacks strong guidelines about what constitutes low-carbon

neighborhood design as well as methods for managing low carbon development. Therefore, neighborhood planning and design procedures need to break new ground in *defining and measuring* clean energy cities in China.

### Patterns: Defining Clean Energy

The Energy Research Institute has raised numerous warnings that China still does not have a good grasp of what low carbon development entails. Provincial governments mistakenly believe that the trappings of American-style modernity – like wide roads, tall buildings, and golf courses – indicate progress and pursue these urban forms in the name of low carbon development. In reality they are perpetuating environmentally unsound practices while failing to develop real low carbon indicators like energy and carbon monitoring.

One major purpose of this studio then, is to develop high quality examples of clean energy urban form. Through our research on global clean energy neighborhoods and assessment methods, as well as previous studios, the ‘Designing the Clean Energy City’ project has identified and analyzed best-practice clean energy neighborhood forms. These prototypes – distilled into the “pattern books” listed in your additional readings – provide for the first time: a) a common language of clean energy development, b) examples and inspiration as a starting point for designers; and c) a comparable database on the energy performance of different design approaches. A synthesis of these prototypes suggests a taxonomy of neighborhood design typologies that display high energy performance. New designs developed in this studio will expand and enrich our understanding these and potentially new clean energy forms.

### Tools: Validating and Improving Clean Energy Design

In order to restructure their urban planning processes and codes in a way that complies with some ‘clean energy’ standard, cities in China would need tools that can evaluate and validate the potential energy consumption of clean energy neighborhood *designs*. Without access to such tools, cities cannot conduct their own place-specific analysis, or compare their strategies to others in a systematic way, and will struggle to improve upon their plans. The second goal of this studio then, is to test and improve a tool the ‘Designing the Clean Energy City’ research team is developing to assess of energy performance at the neighborhood scale.

While energy consumption is currently possible to estimate at the building design scale through physical modeling software, the challenge at the neighborhood scale is more complex. First, the scale of neighborhood development introduces new interrelationships of urban form, embodied in tradeoffs such as the solar gain verses shading that results from spacing, height, and massing of multiple buildings. More importantly however, the behavioral component of neighborhood energy consumption – how individuals *choose* to use energy in, outside, and between buildings – adds new layers of complexity toward estimating the holistic, life-cycle energy consumption of a neighborhood, regardless of how building and transportation systems are designed to be energy efficient.

Unlike individual building energy rating systems or engineering-based simulation tools for building energy performance, designers of *neighborhoods* have no comprehensive measurement tool to quantify or visualize the energy consequences or trade-offs of their decisions or to give feedback during the design process at this time. The existing state of practice globally to address this issue is increasingly through using a clean energy design assessment and rating systems (such as LEED Neighborhood Development) that espouse clean energy principles. Rating systems however, are highly limited as a design or policy tool for neighborhood energy, because they are prescriptive yet based on subjective criteria. In other words, they are not based in empirical measurements of energy consumption. They draw primarily from the general thinking of experts and practitioners about the characteristics of sustainable design, rather than

systematic research; criteria for clean energy design are generally stated as design features or principles, rather than clear metrics with measurable units. Furthermore, their validation rely heavily on the judgment of certified assessors and the evaluation process is therefore a black box for designers and developers. Ratings only reveal a project's performance against the rating system itself, but do not provide much information regarding the project's actual energy performance relative to other projects.

A commonly accepted energy measurement tool could be utilized by a wide range of stakeholders. Designers need practical tools to provide feedback on the performance of alternative development schemes, enabling them to make optimal choices among a huge set of design variables affecting energy use. Policymakers, with a commonly accepted protocol for measuring energy at the neighborhood scale, could understand norms across many projects and set targets without prescribing solutions. Developers could use such a tool to meet policy targets, while still maximizing value. The role of the assessment tool we envision parallels the universally accepted role of a *financial proforma* in real estate development. The financial proforma collapses a wide array of factors – market demand, construction systems, costs, sources of capital, mix of activities, and effects over time – into a single number: the net present value or rate of return on the project. Similarly, our Energy Proforma collapses transport, operational, and embodied energy use of a neighborhood, along with its potential for energy production over time, to a single number: its *net present energy value*.

If such a tool can be successfully applied in China, we believe it will have wide applicability for urban design and development practice as well as policy-making around urban development and energy. The aim is to produce a Chinese model for assessing and encouraging clean energy urban form that can become the common practice for development worldwide.

# Introduction to the Energy Proforma

## *What is the Energy Pro-forma<sup>1</sup>?*

In the most simple of terms, the Energy Pro-forma (<http://energyproforma.mit.edu/>) is a simulation tool that allows one to predict the energy characteristics of a neighborhood development based upon a set of input variables derived from a neighborhood's parameters. The input variables are derived from the same parameters used in the empirical analysis, detailed in Chapter 8 of *Making the Clean Energy City in China: Year 2 Report: 2010-2011* (listed here in Table 1). The input variables and calculations of energy consumption were developed not only based on scientific methods but also through extensive communication among urban design researchers and energy modeling researchers. As a result, the input variables of the Energy Pro-forma reflect the kind of data that would be readily produced by designers and developers in the process of conceiving their projects.

The beta version of the Pro-forma has been developed based on the life cycle analysis of typical urban neighborhoods in Jinan, China. It measures four types of energy: embodied energy use, operational energy use, transportation energy use, and renewable energy generation potential. It holistically considers and quantifies the material energy intensity, energy consumption, and the GHG emissions associated with development projects. It also enables designers to explore the comprehensive energy consumption of relatively large-scale, complex projects rather than being limited to the energy efficiency of individual buildings.

## Development of the Energy Pro-forma

The Energy Pro-forma was developed at MIT with inputs from a number of researchers, designers and city government officials with different tasks. Contributors included: School of Architecture, Tsinghua University, Transportation Planning and Design Research Center of Shandong University, Beijing Normal University, School of Environmental Science, Tsinghua University, and Lawrence Berkeley National Laboratory. More importantly, urban designers (design studio students and faculties at MIT and Tsinghua University) who are potential users of this model have also participated as the “co-developers” so that their interests and design languages are directly incorporated into the integrative energy modeling tool.

Initial preparation of the Pro-forma and its parameters was completed in Microsoft Excel. However, the conversion of the Pro-forma into a webtool made the input of geometric information less arduous, as dimensions are extracted from a simplified Google Sketchup file of the given neighborhood development rather than input by hand.

## *General concept and features*

**Figure G-1** shows the conceptual framework of inputs and outputs the Energy Pro-forma. The webtool includes four calculation steps: (1)Input, (2)Pre-calculation, (3)Pro-forma, and (4)Output. Inputs variables are the quantities and characteristics of a neighborhood that can most easily be measured by planners and

---

<sup>1</sup> © MIT, 2010. Recommended platform for viewing Pro-forma as web tool: Internet Explorer 8 or later.

Requirements for creating .gml files to upload into webtool: Google SketchUp with CityGML Plugin. Requirements for viewing Pro-forma as spreadsheet: MS Excel 2002 or higher on MS Windows, or MS Excel 2004 for Macintosh on Mac OS X (The Tool will not work with MS Excel 2008 for Macintosh)

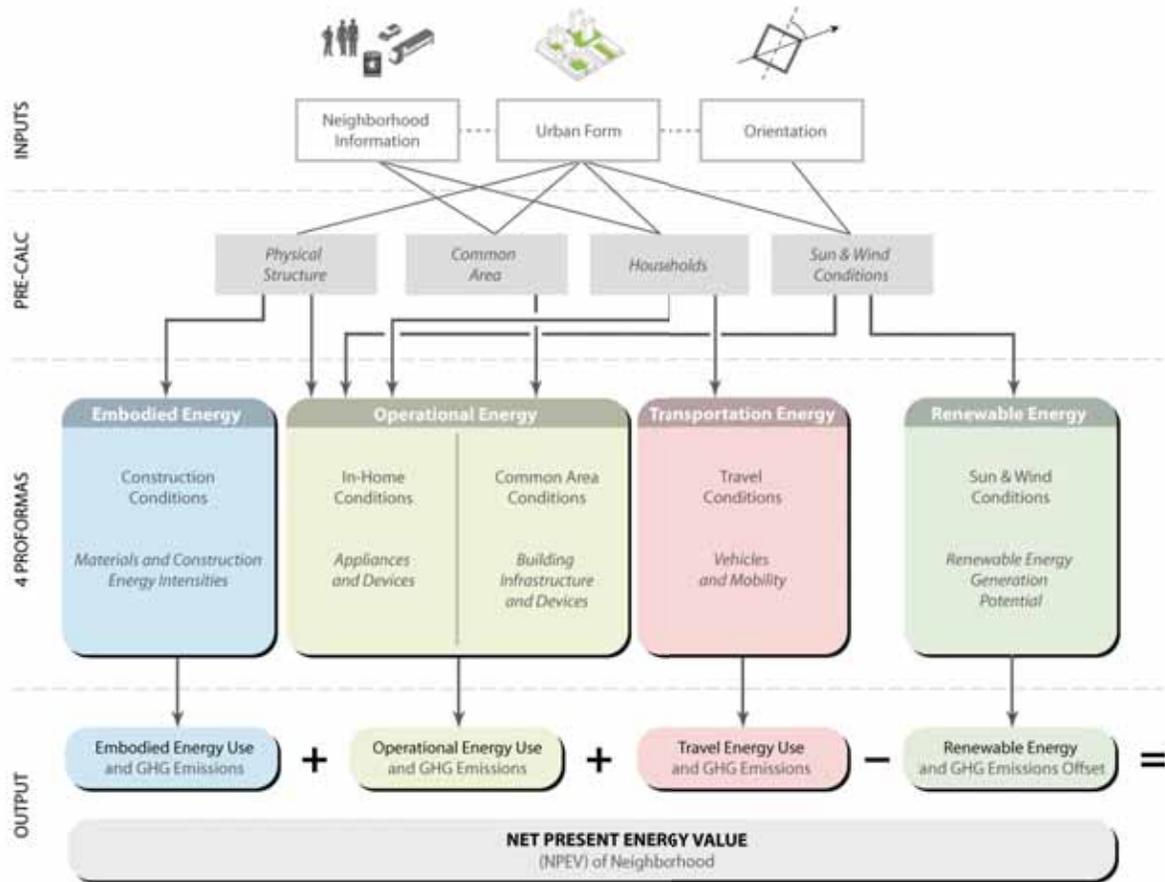
designers. Note that most if not all of the input variables in the Energy Pro-forma are in metric units. A sample of input variables are listed in below in Table 1 and described at greater length in the Glossary at the end of this booklet. Examples of input variables include building height and building footprint area, and these are embedded in project design data. However, other parameters such as surface-to-volume ratio require a second step, which we call pre-calculation. Lastly, project attribute data such as household income and local climate are included.

**Table G-1. List of Input variables**

Nominal Project design data	Pre-calculated and Neighborhood Attribute Variables
<ul style="list-style-type: none"> <li>• Land use</li> <li>• Green land area</li> <li>• Vehicular roads</li> <li>• Shared roads</li> <li>• Pedestrian ways</li> <li>• Residential land area</li> <li>• Commercial land area</li> <li>• Parking land area</li> <li>• Public transport</li> <li>• Water</li> <li>• Civic land area</li> <li>• # Residential floors</li> <li>• # Commercial floors</li> <li>• Building footprints</li> <li>• Total built residential floor space</li> <li>• Total built commercial floor space</li> <li>• Total built civic floor space</li> <li>• Total construction area</li> <li>• Cluster dimensions</li> <li>• Average household size</li> <li>• Household Density</li> <li>• Southern exposure</li> </ul>	<ul style="list-style-type: none"> <li>• Neighborhood area (sq. m)</li> <li>• Distance to CBD</li> <li>• BRT Corridor (Y/N)</li> <li>• # Transit stops w/in 500m</li> <li>• Usable Built Area of Total (%)</li> <li>• Parking Ratio</li> <li>• Parking Type</li> <li>• Building Footprint</li> <li>• Average building heights (# of floors)</li> <li>• Height of Floors</li> <li>• Length of Walls (N,S,E,W)</li> <li>• Normal Vectors Walls</li> <li>• Window-to-wall ratio</li> <li>• Building Use Ratios</li> <li>• Street-Level Use Ratios</li> <li>• Roof Type</li> <li>• PV Panel Condition</li> <li>• Green space coverage</li> <li>• Road types lengths, areas</li> <li>• Tree coverage</li> <li>• # of households (units)</li> <li>• Average HH Demographics (size, income, mode pref, etc)</li> </ul>

The inputs, pre-calculated parameters, and neighborhood attributes are then fed into four distinct Pro-forma model, which measure: embodied energy use, operational energy use, transportation energy use, and renewable energy generation potential. After each of the four energy elements are calculated, they are then combined to derive a “Net Present Energy Value,” a per annum energy cost accounting for the lifespan of the neighborhood. Note that the value for renewable energy is subtracted, since this Pro-forma value represents the amount of energy that a neighborhood generates to offset its own consumption. This value is calculated as a total energy consumption value and a total carbon emissions value, and expressed in both per household and per square meter of construction area.

**Figure G-1. The conceptual framework of the Energy Pro-forma**

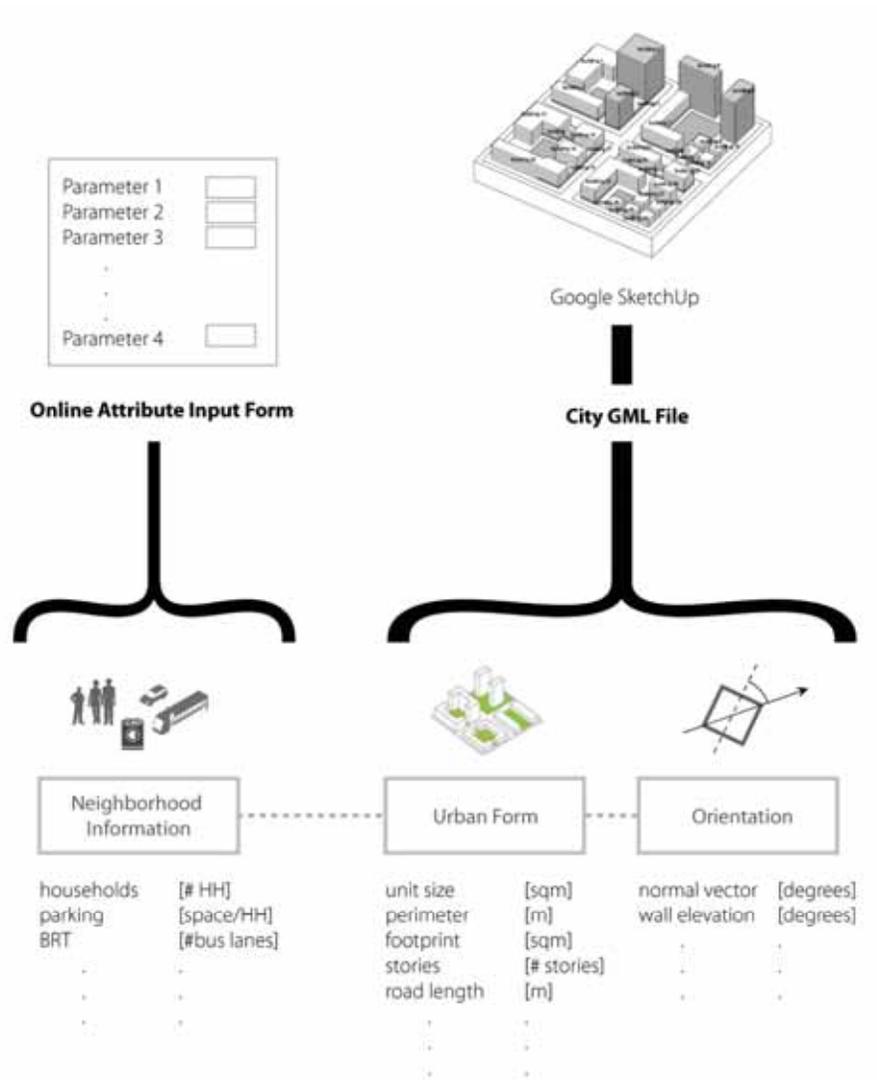


*How is Energy Pro-forma used?*

The Pro-forma is ultimately formatted as an online web tool. The user is able to manually upload urban geometries and their attributes, or otherwise choose from preloaded urban forms and attributes. The Pro-forma then outputs an estimate of the energy consumed and CO2 produced by such an urban form on either a per household or per square meter basis. Furthermore, the user is able to adjust some basic parameters of their design (such as average building height, average unit size, etc) within the Pro-forma so that they can learn which parameters will have the most effect on reducing energy consumption. It is this functionality that makes the webtool especially important in an iterative design process.

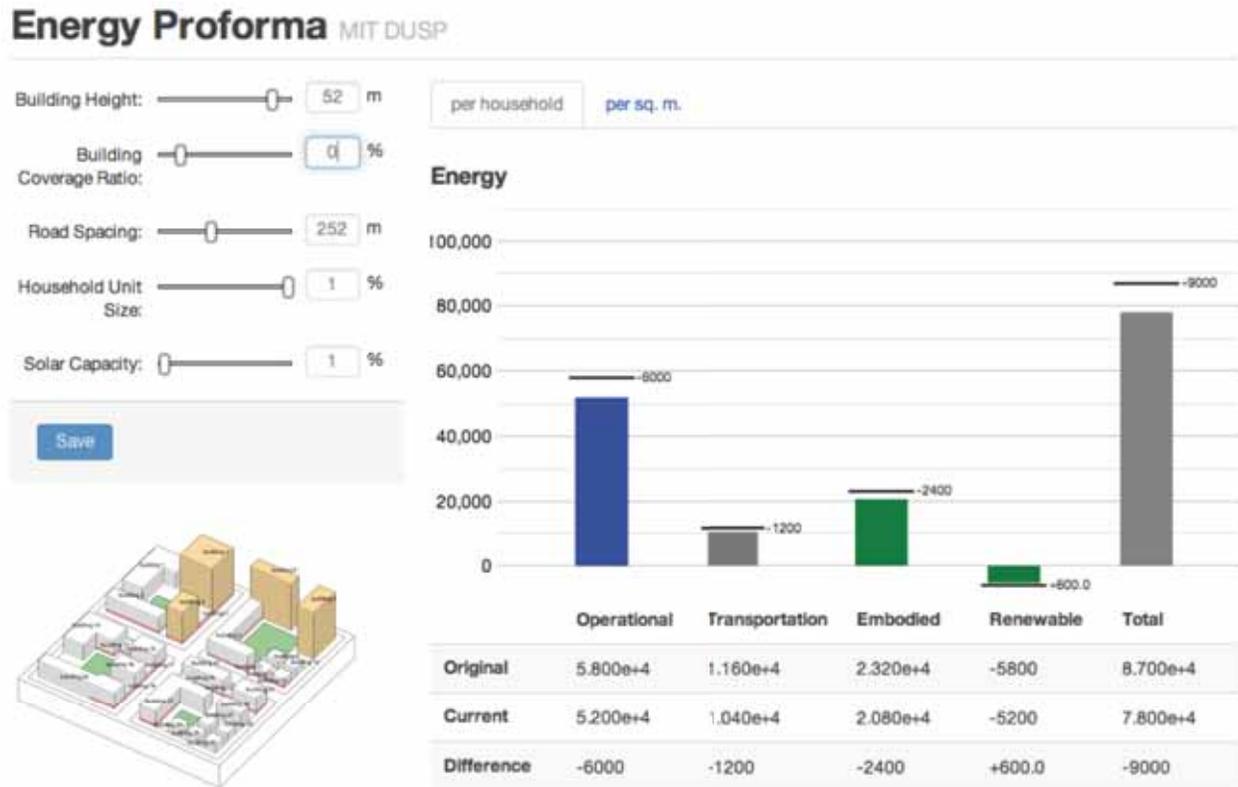
Some inputs related to urban form, rather than being entered by hand, are extracted from a simple .gml file exported from Sketchup. Other attributes such as neighborhood information, demographics, and local sun and wind conditions are entered using an online input sheet (**Figure G-2**). The webtool then uses the initial set of input data to precalculate additional inputs as needed for the Pro-forma.

**Figure G-2. Input Methodology and Sample Input Variables**



The final output is presented in a single display (**Figure G-3**). The annual operational, transportation, embodied, renewable energy consumption per household is presented by default. The user may change the output to instead display tons of CO2 instead of energy, or units per square meter of residential housing instead of units per household. The output sheet does not only give an estimate of energy consumption given a static set of input variables. Rather, the user is also able to manually adjust parameters of their neighborhood, within reason, to see what effect changes might have on energy consumption. Changes are made through the use of integrated sliders. The output graphs, though dynamic, still retain a marker for the original values for comparison against the initial input. The user may also compare multiple iterations using one or more input geometries.

Figure G-3. Screenshot of Part of the Energy Pro-forma Output Sheet



## USER MANUAL

### **Build SketchUp - CityGML Models and Get Outputs for Web Energy ProForma**

The Web Energy ProForma: <http://energyproforma.mit.edu/>, is an interface that connects neighborhood design models with calculations of their energy performance. To realize this connection, the users are asked to upload an .XML file that contains the database of a certain design model. CityGML plugin for Google SketchUp is an easy linkage between 3D models and .XML files.

The CityGML is a collection of tools for the preparation, distribution and visualization of 3D city models. The CityGML plugin for Google SketchUp expands the capability of recognizing and editing CityGML models. It links the SketchUp models with the functions of CityGML tools.

This manual will give you instructions on how to link your design models to .XML files that can be directly imported into the Web Energy Proforma, to test the energy performance of your neighborhood design.

Here are six major steps:

- I. Simplify the Design
- II. Draw a Plan
- III. Define the Types of Buildings and Roads
- IV. Build SketchUp Models and Make Components
- V. Input CityGML Attributes
- VI. Check and Export .XML files

The instructions below will guide you through the process step by step☺

## I. Simplify the Design

Web Energy ProForma is a quick tool to test the energy consumption of your design. It is a simplified version of Energy ProForma. To know more about the complete spreadsheet, please refer to Energy ProForma.

There are two major reasons to simplify your models for Web Energy ProForma. Firstly, as you may want to test the energy consumption to assist your design process and decision making, the test model should be simple so you can easily adjust the model and test it back and forth. Secondly, Web Energy ProForma is a new tool. The currently version contains only the basic and most significant variables, which limit the diversity of the input model.

Starting from sketch, you can simplify your design from the following three aspects:

1. Select **typical clusters** as samples rather than building the whole neighborhood model. Your neighborhood design may be based on the same design principles or logics. To build a test model, you can choose only one or several typical clusters that can represent all your design principles and the most important considerations. Usually the typical cluster should be at least **180m \* 180m**.
2. Leave **only buildings and roads** in the model. The current Web Energy ProForma can calculate only building and road attributes. Other urban design features, such as open space, parks, parking lots, water body, railways, etc, are out of the scope of web tool calculation. Other urban design elements will be added as the web tool develops.
3. Simplify your building forms to basic **blocks**, rather than building complex forms.

For example, one typical cluster from the Vauban low-carbon city in Germany can be selected and simplified as:



Fig. The plan of Vauban neighborhood and the simplified model of the typical cluster

Buildings of Bedzed low-carbon neighborhood in England that have solar houses can be simplified as a series of blocks with varied building heights:

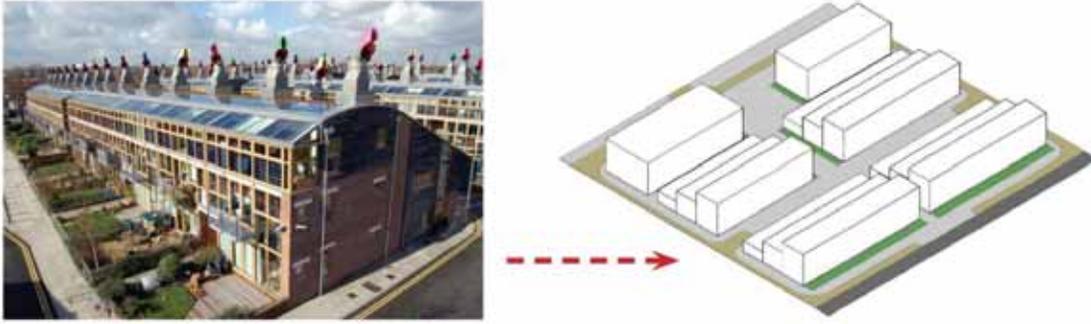


Fig. The Bedzed building and its simplified model

## II. Draw a Plan

You can draw the plan for the simplified model with any software (such as AutoCAD, Rhino, SketchUp) that can eventually be imported into SketchUp. Please note that you need to be consistent in using **METER as unit** for all plans and models.

Draw the boundary of the site, the roads and buildings in the plan.

For the **site**, make it as simple as you can. Draw its boundary in a polyline.

For **buildings**, draw each of them as quadrilateral in polylines. Deconstruct the complex forms, such as an “L” shaped building or a building with parts of different heights, into separate enclosed quadrilateral. Remember that you only want enclosed quadrilateral polylings.

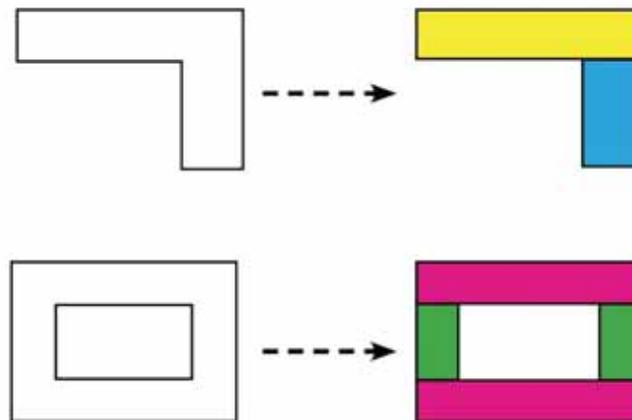


Fig. Examples of redrawing buildings into squares

For **roads**, you also need to redraw them into separate quadrilateral polylines. For those vehicular roads with sidewalks, draw only the parts where vehicles can use, and leave the sidewalks blank.

Here is an example of the plan of a simplified neighborhood:

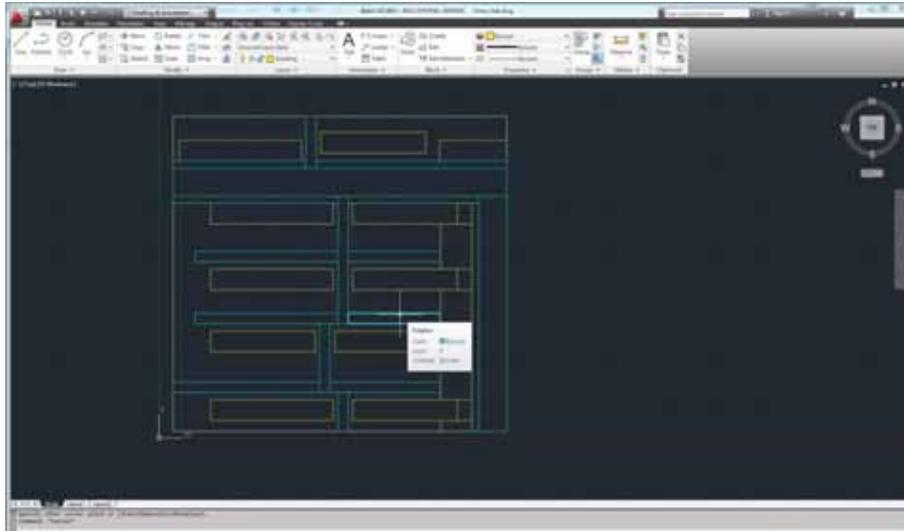


Fig. The simplified plan of the slab residential community

### III. Define the Types of Buildings and Roads

Define building and road types according to the following guides. Please write down the information (the following bullets) of each type you have defined.

#### A. Building Types:

Each building has one attribute in CityGML – “**class**”.

Buildings with significant different values of the following attributes should be assigned to varied building types, which should be given different numbers in “class” under CityGML:

- Floor to floor heights
- Roof types
- Window-to-wall ratios
- Shared wall ratios (e.g. 50% shared east walls, 100% shared south walls, etc)
- Building uses mix (or ratio of mixed use)

\* Buildings with different orientations, depth, total heights, or total widths can be part of a single building type.

#### B. Road Types:

Each road has two attributes in CityGML – “**usage**” and “**class**”.

For road “usage”, there are two types:

- ‘**motor**’ for vehicular roads. Any road used by vehicles should be considered as ‘motor’ in usage. Those vehicular roads with sidewalks are also considered as ‘motor’.
- ‘**ped**’ for pedestrian-only roads.

For road “class”, roads with different values of the following attributes should be assigned to varied road types, which should be given different numbers in “class” under CityGML:

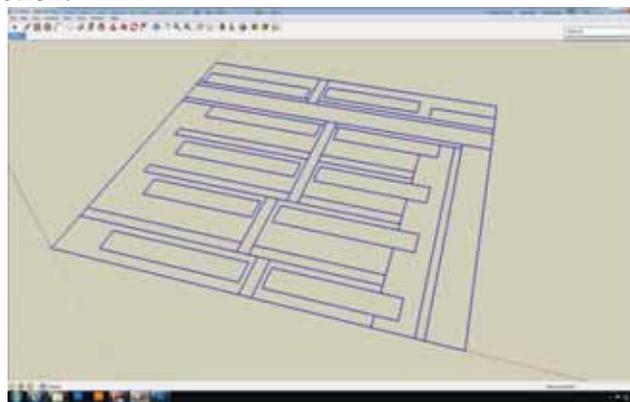
- Material of the roads
- Width of the roads
- Percentage of sidewalks
- Coverage of street trees

After you have written down the building types and road types, please check if the types are categorized appropriately as above. **Please try to summarize and avoid too many building types or road types.**

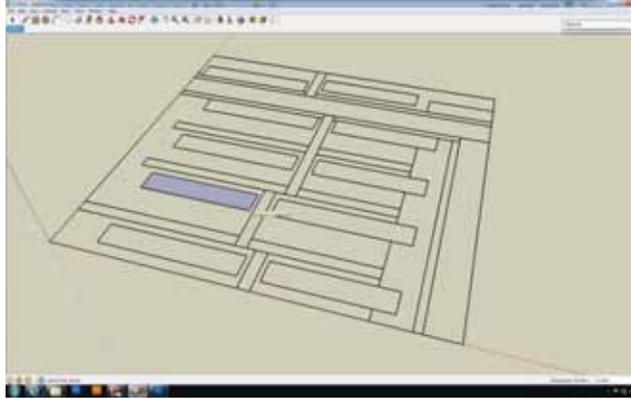
#### IV. Build SketchUp Models and Make Components

Here are steps of building SketchUp models and making components. In this part the layers of models are not important. Please note the key is to **make every part of the model a separate component**.

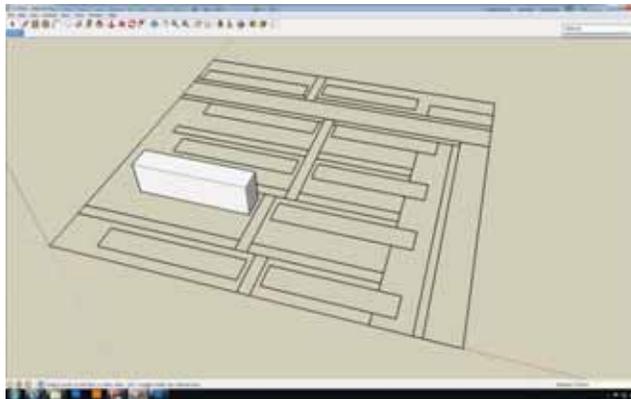
1. Delete the default “person” component at the origin of coordinate of the SketchUp interface.
2. Import the simplified plan into SketchUp. You can import from your .dwg, .dxf, .3dm files into SketchUp. Please use the “tape measure” tool to check if the scale of the plan is the same as your plan in the unit of meter. Otherwise you need to scale the plan back into the original figures.
3. Make sure that the southwest corner of the plan is on origin of coordinate. Re-align the plan into the correct direction.



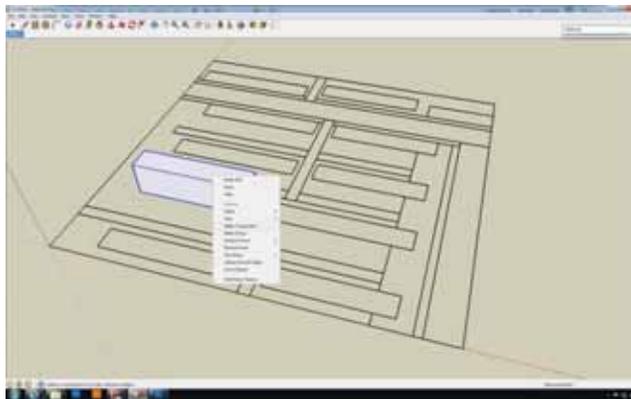
4. Redraw the site. Use “line” tool in SketchUp to draw the boundary of the site. Make sure a surface is formed once the lines are enclosed.
5. Make the site a component. Double-click the surface as selecting the surface and the lines of the site boundary to make a component.
6. Redraw building footprints. Use “line” tool to draw the boundary of each building. Make sure a surface is formed once the lines are enclosed.



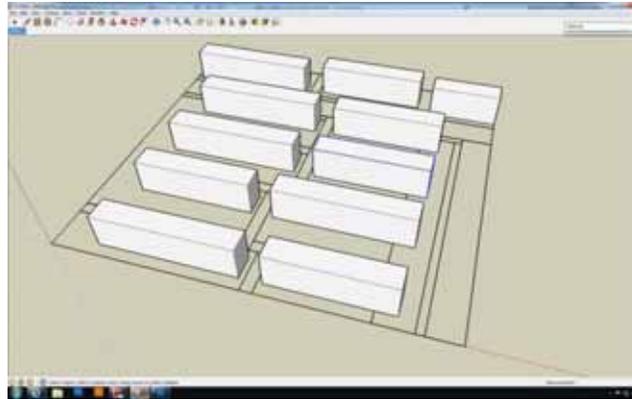
7. Extrude building footprints. Use “push/pull” tool in SketchUp to extrude the building to the correct height.



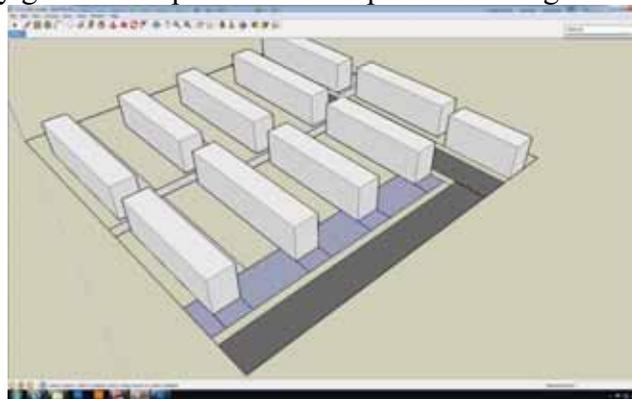
8. Make each building a component. Triple-click the volume of the building as selecting the whole volume. Then right click and select “Make Component” to make the volume a component.



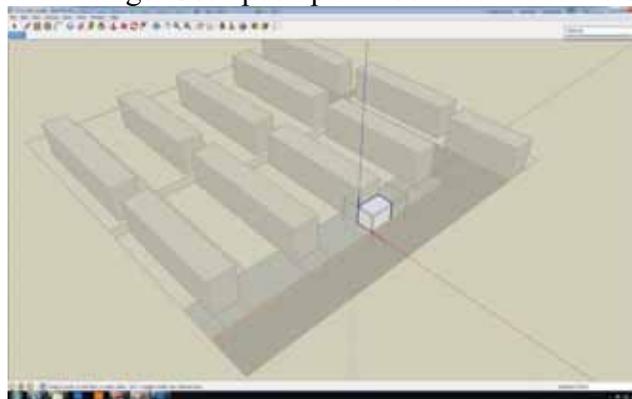
9. Repeat Step 4 to 6 to make every free-standing building a separate component.



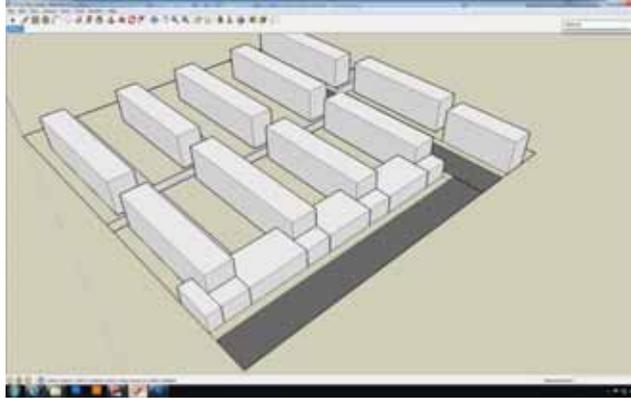
10. Redraw the building footprints that are partially attached to other buildings. Draw the rest building plans only after the attached buildings have been created as components. Otherwise the components may get mixed up rather than separate buildings.



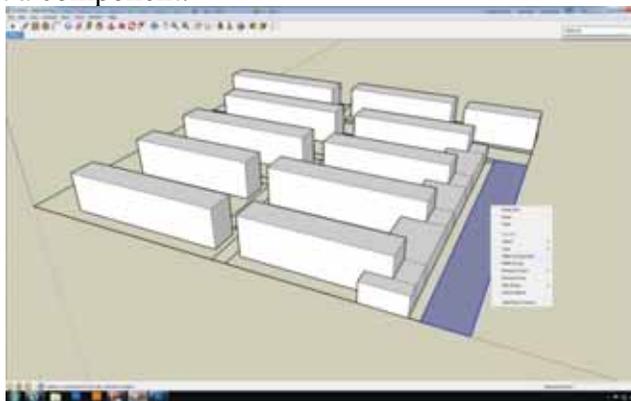
11. Extruded the attached buildings. Use “push/pull” tool to extrude the building to its height.



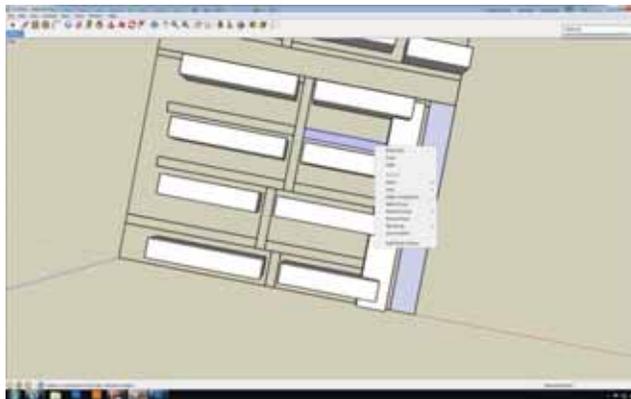
12. Make each attached building a component. After creating components please check if the whole block is selected once you single-click any part of the building.

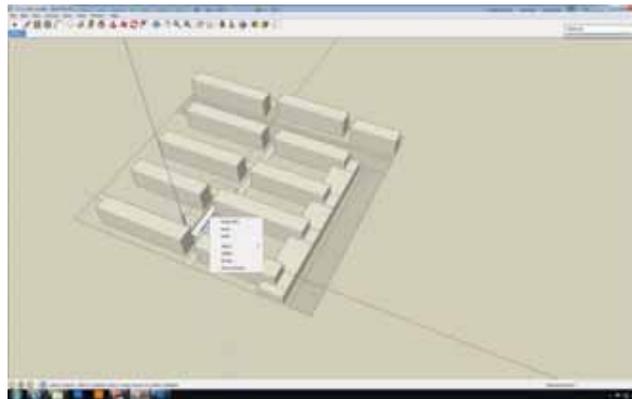
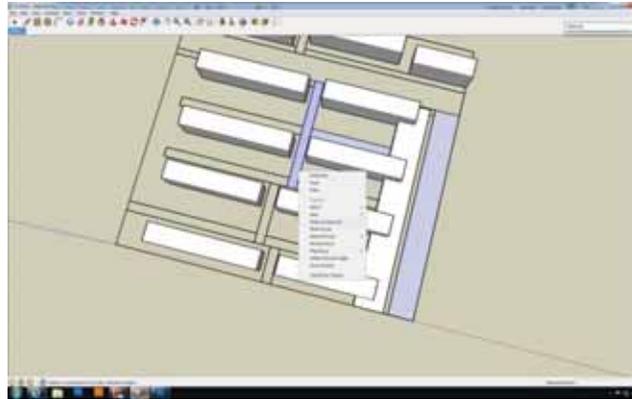


13. Redraw the road and make it a component. You need to redraw the boundary of one road and immediately make it a component.

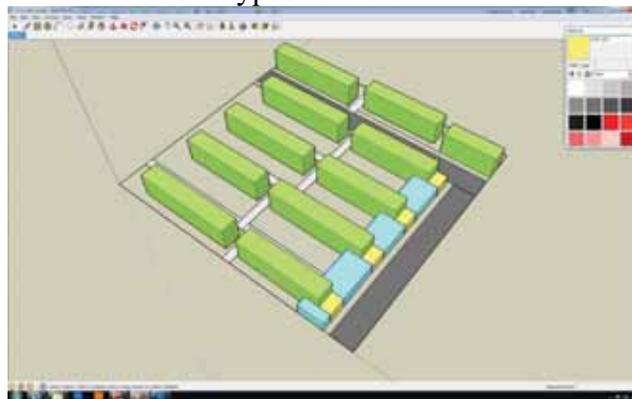


14. Repeat Step 11 to each segment of road. After making the first road segment a component, you can draw the next one and make it another component, and so on. Otherwise the components may get mixed up. Make sure each quadrilateral segment of the road is a separate component.





15. Color the buildings and roads to mark different building types and road types. To help yourself to differentiate building types, especially when there are several building types, you can give the same color to buildings of the same type that you have defined in Step III. Do the similar thing to differentiate road types as well.



16. Group the buildings and roads of the same types. For the buildings of the same type that you have defined in Step III (the same color that you have given in Step 14), you can select those building components, right-click and select "Make Group". You can do the same thing with the roads.

## V. Input CityGML Attributes

In this part you will use SketchUp CityGML plugin to input the attributes of the types you have defined in Step III.

### Site Information:

- a. Select the site component, right-click on it and select “attribute->edit”.
- b. In the STANDARD ATTRIBUTE tab, click “Add Attribute”.
- c. In Name field, select “usage”.
- d. In Value field, type “site”.
- a. Click “Accept” in dialog box.
- e. Click “Accept” in Attribute Edit window.

### Building Information:

- b. For each building component, right-click on one of the building instances and select “attribute->edit”.
- c. In the STANDARD ATTRIBUTE tab, click “Add Attribute”.
- d. In Name field, select “class”.
- e. In Value field, type a number (integer value) of the building type, as you defined in Step III.
- f. Click “Accept” in dialog box.
- g. Click “Accept” in Attribute Edit window.

### Road Information:

- a. For each road segment, right-click on shape and select “attribute->edit”.
- b. In the STANDARD ATTRIBUTE tab, click “Add Attribute”.
- c. In Name field, select “usage”.
- d. In Value field, type “motor” if the road is for vehicles or “ped” if the road is for pedestrians. For the vehicular roads with sidewalks, only give the “motor” value in usage.
- e. Click “Accept” in dialog box.
- f. In the STANDARD ATTRIBUTE tab, click “Add Attribute”.
- g. In Name field, select “class”.
- h. In Value field, type a number (integer value) for each of the vehicular road types or pedestrian path types as you have defined in Step III.
- i. Click “Accept” in dialog box.
- j. Click “Accept” in Attribute Edit window.

## VI. Check and Export .XML files

Before exporting model, you need to check if

- a. The model has been assigned to origin of coordinate, and towards the correct direction. Most part of the model should be in Quadrant 1.
- b. Every single part of the model is a component. Nothing else is left in the model.
- c. Every component has been given appropriate CityGML attributes as Step V.

Revise the errors if there are any. Then you can export the model as CityGML file.

- a. Select menu Plugins->CityGML->Export
- b. Type a descriptive name in the Save dialog box. Use underscores ( \_ ) instead of spaces. Click "Save".
- c. In the export dialog box, select LOD2.
- d. Select additional layers to export, if necessary.
- e. All other default values on all tabs should not be changed.
- f. Click "Start Export".
- g. Close Ruby console.



