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Towards Low-Carbon Urban Forms: A Comparative Study on Energy Efficiencies of Residential Neighborhoods in Chongming Eco-Island

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Abstract

The hyper-fast urbanization process in China has led to the mixes of traditional and contemporary neighborhoods, especially in the aspects of residential districts. The aim of this paper is to explore the interrelationship between urban form and energy efficiency of the residential neighborhoods on Chongming Eco-Island, which is a leading example in China's urbanization towards low-carbon and sustainability. By the empirical study and simulation on six most dominant neighborhood typologies, it is found that the annual building energy consumption of them vary significantly largely due to the various occupant behaviors. Moreover, the calculation of solar potential and energy trade-offs between production and consumption indicates that the nucleated villages and slab buildings have the greatest retrofitting potentials, which lead to the policy implications for Chongming' s low energy and low carbon urban management.

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Keywords: urban form; energy efficiency; solar potential; residential neighborhoods.

1. Introduction

The hyper-fast urbanization process has led to the mega-scaled development in a vast majority of Chinese cites. Chongming eco-island, as the mere habitat located in northeastern Shanghai, is faced with inevitable urbanization process accompanied with the construction of China's coastal highway (newly-connected bridge and tunnel). It is foreseeable that the real estate boom will bring huge changes to the island which was used as an agricultural production site for Shanghai since 1950s. The mixes of traditional and contemporary residential neighborhoods in Chongming is becoming a microcosm of Chinese urbanization. This paper aims to better understand the impact of different residential urban forms

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on their energy consumptions and further analyzes the potential renewable supply and retrofitting potential in correlation with these dominant urban morphologies, leading to a comprehensive result of Chongming' s low energy and low carbon urban policy.

Pérez-Lombard et al. [1] has concluded that approximately 40 per cent of energy end-use in the developed world and 20 per cent in the developing world takes place in buildings. Major factors influencing levels of energy consumption in buildings include climate, urban context (or morphology), building design, system efficiency and occupant behavior [2]. At the neighborhood scale, higher density residential areas were found to have higher energy efficiency than discontinuous or sparse settlements [3-4]. In terms of energy gains, Takebayashi et al. [5] found building coverage ratio and building height have great influence in solar radiation. However, most of the research is based on energy gains and losses simulation of built environment, with little consideration of the trade-offs between energy efficiency and solar potentials, especially in both urban and rural areas. It is obvious that the context-specific factors are powerful levers with which to optimize the energy efficiencies of buildings and neighborhoods. In this paper, the research gap in this field is filled up by exploring the complex trade-offs and relationship between the renewable energy gain and the energy uses of different urban forms.

2. Research method

For the empirical basis of investigation, six typical cases, i.e., Farmhouse, Linear-Village (L-Village), Nucleated Village (N-Village), Townhouse, Slab, and High-rise, have been selected from Chongming Island in Google satellite maps after an on-site visit to Chongming. The samples range from rural area to urban district, from low-density village to compact blocks, and from low-rise buildings to high-rise buildings. The categories for each type vary according to density, height, context-specific and architectural style. For each of the types, a 300-by-300-meters sample was chosen to represent the urban fabric as homogenously as possible. Each of the neighborhood typology was represented by a three-dimensional digital model for which the basic information of footprint, floor-to-area ratio, window-to-wall ratio, and building height was concluded, as preparation for energy simulation as well as visualization.

Based on the preliminary understanding of the physical environment, on-site interviews were carried out to find out energy behaviors of the residents in each types. In addition to the electricity bills in spring/autumn, summer and winter, other aspects such as household characteristics (dwelling area, family population, water heater type and number air-conditioning), and occupant behavior (air-conditioning set-point and daily number of hours using air-conditioning) are also included in the survey. The capacity to fully utilize the solar potential was simulated and calculated by Ecotect, utilizing the 3D urban model as input.

3. Evaluations of energy trade-offs

3.1. Energy consumption

Energy use intensity (EUI) is calculated in the same indoor comfortable conditions for the six neighborhoods by using Energy Plus. The simulation EUI follows the previous implication that higher density leads to higher energy performance. However, with the introduction of surveyed EUI, great differences between simulation and survey have been discovered. Although farmhouse, L-village and N-village share the same building types, the residents' behaviors have great impact in energy consumption patterns. Most of the residents in farmhouse and L-village are local landlords living with a humble life, while the residents in N-village are mostly young tenants, who prefer a more comfortable lifestyle.

Residents in townhouse tend to be rich and choose Chongming as their second house, which leads to the extremely high EUI pattern.

3.2. Solar potential

The new urban pattern and built environment largely depend on the spatial factors such as streets orientation, parcel shape, ratio between building heights and distance considering the solar access as a structural design parameter, where the photovoltaic systems integration and the achievement of an efficient solar energy production could be reached by an optimized urban context. We proposed the minimum scenario of annual solar power generation as full coverage ratio of rooftop photovoltaic panels on residential buildings, while the maximum refers to the additional 50 percent utilization of the rest of building rooftops, including buildings for services, commercial and warehouses.

3.3. Trade-offs

The difference between energy consumption and solar potential has been analyzed in Table 1, referring as energy gain (mWh). Concerning the unique EUI pattern in Chongming neighborhoods, survey data were adopted instead of the simulated results of energy consumption. Neighborhood typologies as farmhouse, L-village, N-village, and slab can achieve a positive energy gain with the installation of photovoltaic panels on the rooftop. L-village and slab buildings have the greatest potential because of their well-organized layouts and moderate residents' behaviors. In comparison, constrained by the high-level EUI, the neighborhoods of townhouse typology cannot achieve a positive trade-off even with the highest coverage ratio scenario of photovoltaic panels. High-rise neighborhood, though get negative results in its trade-off between energy consumption and solar potential, can still achieve a near-zero energy scenario in its energy gain per capita.

Table 1. Trade-off by neighborhood typology

Type	Surveyed Energy Consumption (mWh)	Min. Solar Potential (mWh)	Energy Gain (mWh)	Energy Gain (mWh/person)
Farmhouse	79.0	142.2	63.2	12.6
L-Village	542.2	1422.0	879.8	4.4
N-Village	4152.3	4408.2	255.9	0.6
Townhouse	7188.1	2844.0	-4344.1	-29.0
Slab	1346.0	2559.6	1213.6	0.4
High-rise	4544.7	2133.0	-2411.7	-0.6

4. Conclusions

The initial urban form analysis featured some of the fundamental relationships between the six typologies. The variables such as the building heights and density change greatly in different neighborhood types, resulting in various possibilities for energy consumption pattern, photovoltaic system integration and achievement of efficient solar energy production.

Energy consumption induced by urban form is significant, while residents' behavior is another deciding factor in energy consumption. In simulation level, Annual building energy consumption per unit is much higher in rural area due to the poor retaining structure performance and low air-conditioner efficiency. Higher density residential areas tend to have higher energy efficiency than discontinuous or sparse settlements. In reality, great differences among residents' behaviors and user schedules lead to enormous changes in energy use intensity, in which neighborhoods with mostly local landlords tend to consume much less energy than any other ones with tenants. Taking renewable energy potential into consideration, the solar potential is highly correlated with building coverage ratio which is still the determinant aspect of the photovoltaic installations, though mutual shading also has the impact on the solar generation. N-village, with the highest residential building coverage ratio, can generates the solar power up to approximately 4408 mWh a year within a 300-by-300-meter neighborhood.

The obtained results confirm that by applying the proposed methodology to urban interventions is possible achieve better energy performance. The complex trade-offs between the renewable energy gain and the energy consumption have been quantified and explained. With the introduction of photovoltaic system, neighborhoods of farmhouse and L-village can achieve a self-sustained growth in the aspect of energy use, while N-village and slab can even generate more solar power due to their higher coverage ratio and lower energy consumption in the user end.

The research offers the policy implications as simple tools for illustrative studies of future urban renewal or development. Although the creative nature of building or community design is hard to quantify, the analysis indicates that the very basic building features could be incorporated into the energy optimization of residential neighborhoods in Chongming Eco-Island, which can help urban planners and policy makers to come up with reasonable and sound design solutions with the existing retrofitting and construction technologies, as well as the requirement of Chongming's low energy and low carbon urban policy.

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Biography

Tianren Yang is a graduate student in College of Architecture and Urban Planning, Tongji University. He received his Bachelor of Engineering degree from Tongji University and Master of Science in Urban Design from Georgia Institute of Technology. He is also a graduate research assistant in Sino-U.S. Eco Urban Lab.