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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.