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Urban Form and Building Energy Performance in Shanghai Neighborhoods

Steven Jige Quan[a b], Jiang Wu[b], Yi Wang[b], Zhongming Shi[b], Tianren Yang[b], Perry Pei-Ju Yang[a b*]

[a]*Eco Urban Lab, College of Architecture, Georgia Institute of Technology, Atlanta, USA*
[b]*Sino-U.S. Eco Urban Lab, College of Architecture and Urban Planning, Tongji University, Shanghai, China*

Abstract

Urban form is considered as two different concepts here: one as geometry and the other as a complex system. This paper uses simulation experiments to test the density and energy performance relationship in nine Shanghai neighborhoods, with the urban form defined as a complex system. The results show a complex pattern. When density is only related to geometry, the density seems to negatively impact building energy use intensity, following the widely perceived conclusion from previously studies. But when density is related to neighborhood typology, which determines many energy-related parameters, the relationship may be totally different. The study suggests that energy performance research of urban form at the neighborhood scale has to consider the historical, social and cultural contexts, which could lead to more comprehensive low energy and low carbon urban policies for Shanghai.

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Keywords: Shanghai neighborhoods; urban form; building energy performance; FAR; microclimate

1. Introduction

The relationship between urban form and building energy performance draws more and more attentions nowadays as building energy use has a significant share in the total energy use [1]. Many scholars have tried to identify this relationship using different definitions of urban form. Some scholars have focused on the geometry of urban form. For example, Pisello, Wong, Giridharan, Ratti and Rode examined how

* Corresponding author. Tel.: +1-404- 894-2076; fax: +1-404-894-1628.
E-mail address: perry.yang@coa.gatech.edu.

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different geometries of urban form influence building energy performance through the building typology, urban heat island effect, daylight and mutual shading [2-6]. Another group, including Wang and Ye [7, 8], and Salat [9], began to test the idea of urban form as a complex system including geometry and other factors such as material types, characteristics of residents, housing units and neighborhoods, and construction years. However, most of the studies from this group examined only certain factors. But urban form is a multi-level concept, and the complex causal relationship relies on cross-disciplinary methods, and few studies have probed into it [10].

In this paper, we see urban form as much more than simply geometry, since it develops with many engineering constraints such as structure, HVAC system, material, users' behavior, etc.[9] and in different historical and cultural contexts. But different from traditional building energy simulation studies, the energy performance analysis of urban form needs to define the system boundary first, as urban form involves several spatial levels, including building, parcel, island (block), fabric (neighborhood) and district [11]. Because of its relative independence and autonomy in the development of its urban form, neighborhood is often chosen as the system boundary of the urban form for energy studies [6, 9, 12]. However, as discussed above, the relationship between neighborhood, as a complex system, and building energy performance has received relatively little attention in current studies.

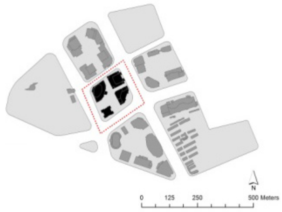
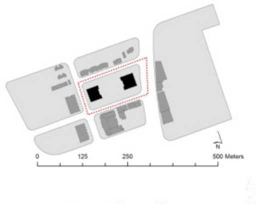
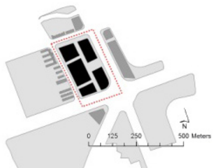
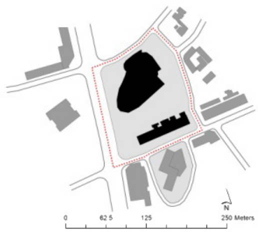
This paper attempts to address this oversight by exploring the relationship between the complex system of urban form at the neighborhood level and building energy use through case studies of nine Shanghai neighborhoods. The urban forms of these neighborhoods were measured using the building density indicator of FAR (Floor Area Ratio). Thus how neighborhoods with different density measures perform in building energy use becomes the key research question of this paper. In previous planning studies, it was commonly recognized that density is generally negatively correlated with energy use [13, 14]. But with the understanding of a urban form as complex system, that viewpoint needs further examinations.

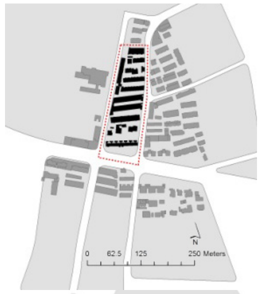
2. Study Areas And Datasets

This study selected nine Shanghai neighborhoods as research areas. Three neighborhood typologies were identified along with the historical development of Shanghai based on the study of Sha, et al, including historical patterns, workers' communities, and contemporary urban patterns [15]. Each typology has its unique fabric pattern and characteristics, which are distinctly shaped by the historical and social conditions. The first typology, the historical pattern, refers to the most prevalent neighborhood typology from the 1860s to the 1940s, known as Shanghai Lilong. This typology of neighborhood was originally built for the middle class and consisted of two to three-story dwellings constructed using brick, however nowadays its residence is mainly low to middle income people because the outdated building material and construction make this typology of neighborhood less appealing comparing to other neighborhood typologies. The second typology, called the "workers' community" encompasses the special districts designated as workers' housing when Shanghai mainly functioned as a manufacturing center. Buildings within this typology are typically slab block buildings of up to six stories. The third typology is the contemporary urban pattern, which features the large-scale real estate boom of the 1990s, characterized by clusters of large public building mass and towers [15]. The nine Shanghai neighborhoods selected to represent the three typologies with commercial, residential and mixed uses are shown in Table 1.

The spatial data, including the building footprints and building heights, were organized in ArcGIS, while the façade and roof materials and the window-wall ratio as the input for energy simulation were measured and determined based on field survey and Baidu Streetview, an online street view tool similar to Google Streetview but with more abundant data for Chinese cities. The measures of FAR and total floor area of all buildings were calculated in ArcGIS for each neighborhood.

Table 1. Shanghai neighborhood cases

ID	Neighborhood	Function	Typology	Layout
C1	Lujiazui	Commercial	contemporary	
C2	Wujiaochang-Fengda	Commercial	contemporary	
C3	Wujiaochang-Wanda	Commercial	contemporary	
C4	Shenhong	Mixed	Mixed	
R1	Zhongkai	Residential	contemporary	
R2	Huiyuanfang	Residential	contemporary	

R3	Pingdeli	Residential	historical	
R4	Jishanli	Residential	historical	
R5	Anshanxincun	Residential	workers' community	

Legend for the layouts: black – focus building; dark grey – surrounding building; light grey – urban block; red dotted line – research area boundary

3. Methodology

Based on the building physics and urban planning studies [10, 16-18], the mechanism of how urban form influences building energy use is summarized in Fig. 1.

This diagram shows that urban physical form and other factors such as material, system, schedule and land cover jointly determine the building energy use through several urban physics processes. Therefore it is critical to define the system boundary of "urban form" before the study on the relationship between urban form and its energy performance. In order to capture the comprehensive effects of the real settings, in this study urban form is defined as a complex system which integrates geometry, material, system, occupants and land cover in the simulation of building energy use.

To take into account the complex processes shown in Fig. 1., traditional building energy modeling is not capable because of lacking the consideration of those indirect impacts of urban form on the energy performance, including the microclimate and mutual shading [18]. Instead a loosely-coupled toolset was used to simulate all the processes in this study. Such toolset includes UWG (Urban Weather Generator) and UMI (Urban Modeling Interface), both of which were developed by the Sustainable Design

Laboratory at the Massachusetts Institute of Technology (MIT). UWG is a computational tool for generating microclimate data with the input of geometric measures, albedo and emissivity of materials of buildings and roads, tree and vegetation covers, HVAC systems and occupant densities and schedules based on the TEB (Town Energy Budget) modeling [16]. UMI is a building energy simulation plugin for Rhino based on the EnergyPlus engine that takes the mutual shading into account [19]. In order to simulate the building energy use for each of the nine neighborhoods, microclimate weather files were generated by the UWG for each neighborhood first with parameters measured in the GIS dataset, and then those weather files were used as weather condition inputs with all the other required information in UMI to simulate the total annual building energy use in each neighborhood.

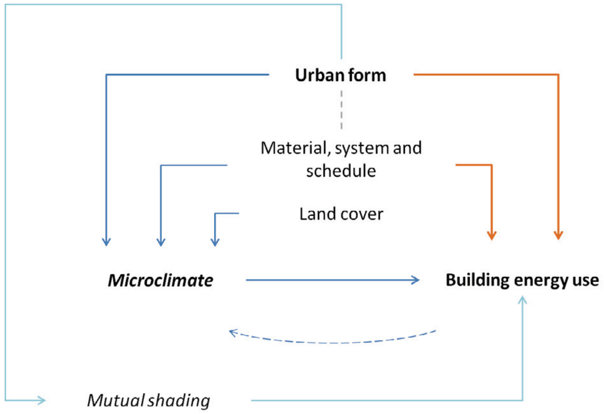


Fig. 1. Diagram of the causal relationship between urban form and building energy use (orange: direct impact; blue: indirect impact)

4. Results

The results for each neighborhood were plotted against the FAR to show the relationship between building energy performance, measured with EUI (energy use intensity, calculated as building energy / total floor area) and density measured as FAR, shown in Fig. 2.

An initial examination of Fig. 2. may lead to a seemingly very different conclusion than previous studies, with higher density leading to higher energy use intensity. However, when different building functions are accounted for, commercial neighborhoods adhere to the expected relationship found in previous studies (higher density leads to lower energy use intensity). Residential neighborhoods, though, show a distinct pattern. It seems that density is related to the geometry of the neighborhood as well as the neighborhood typology, or the function of buildings, which relates to many factors such as material, HVAC systems, user behavior, etc. In the residential neighborhoods, greater density suggests more recent neighborhood, which may have more HVAC systems installed and whose residents may have more income and tend to consume more energy, and thus these factors may outweigh the impacts of geometry itself and lead to the greater energy use intensity. On the contrary, since the four commercial neighborhoods were developed during the same period, their differences are mainly geometry and therefore their density-energy relationship is in line with previous findings. The contrast of findings in residential and commercial neighborhoods demonstrates that different ways of defining urban form affects the results of neighborhood energy use. The density-energy relationship may differ between the consideration of singular factor of geometry and multiple factors of a complex system that include geometry, materials, HVAC systems and users' behavior according the function of buildings.

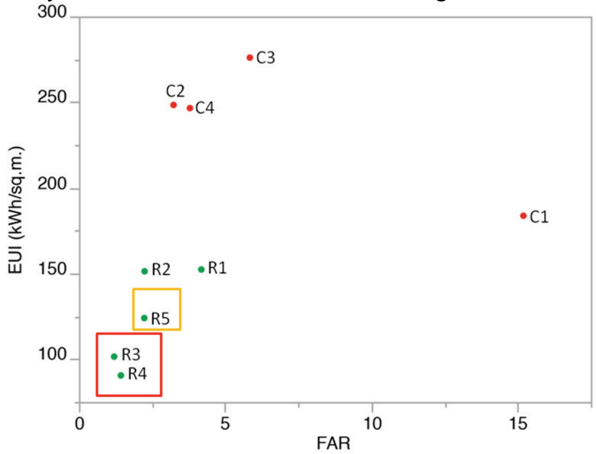


Fig. 2. Relationship between FAR and building energy performance of neighborhoods

5. Conclusions

This study examines the relationship between urban form and building energy performance based on the case study of nine Shanghai neighborhoods. In previous studies, urban form is considered as only geometry, though in very few researches it began to be considered as a complex system. This paper tries to examine the elements in the urban form as a complex system and their relationship with energy performance. In the case study of Shanghai neighborhoods, the density-energy relationship was explored with the urban form defined as a complex system, using a loosely coupled simulation toolset that takes into account the elements and interactions identified. The results suggest that the density-form-energy relationship may change when the system boundary of urban form is defined differently from geometry only to a complex system including multiple factors. Urban energy research at the neighborhood level has to consider not only the geometry, but also the engineering system in buildings, as well as the historical, social and cultural contexts. Further studies on Shanghai neighborhoods will include more empirical data to support the suggestions.

References

[1] Perez-Lombard L, Ortiz J, Pout C. A review on buildings energy consumption information. *Energ Buildings* 2008;**40**:394-8.

[2] Pisello AL, Taylor JE, Xu XQ, Cotana F. Inter-building effect: Simulating the impact of a network of buildings on the accuracy of building energy performance predictions. *Build Environ* 2012;**58**:37-45.

[3] Wong NH, Jusuf SK, Syafii NI, Chen YX, Hajadi N, Sathyanarayanan H, et al. Evaluation of the impact of the surrounding urban morphology on building energy consumption. *Sol Energy* 2011;**85**:57-71.

[4] Giridharan R, Lau S, Ganesan S, Givoni B. Urban design factors influencing heat island intensity in high-rise high-density environments of Hong Kong. *Build Environ* 2007;**42**:3669-84.

[5] Ratti C, Richens P. Raster analysis of urban form. *Environ Plann B* 2004;**31**:297-309.

[6] Rode P, Keim C, Robazza G, Viejo P, Schofield J. Cities and energy: urban morphology and residential heat-energy demand. *Environ Plann B* 2013;**41**(1):138-62.

[7] Wang D. *Household operational energy consumption in urban China: a multilevel analysis on Jinan*: Massachusetts Institute of Technology; 2012.

[8] Ye H, Wang K, Zhao XF, Chen F, Li XQ, Pan LY. Relationship between construction characteristics and carbon emissions from urban household operational energy usage. *Energ Buildings* 2011;**43**:147-52.

[9] Salat S. Energy and the form of urban fabric: the example of Paris. *Central Europe towards Sustainable Building*. Prague, Czech Republic; 2013.

[10] Ratti C, Baker N, Steemers K. Energy consumption and urban texture. *Energ Buildings* 2005;**37**:762-76.

[11] Berghauser Pont M, Haupt P. *Spacematrix: Space, density and urban form*. Rotterdam: Nai Publishers; 2010.

[12] Salat S. Energy loads, CO2 emissions and building stocks: morphologies, typologies, energy systems and behaviour. *Build Res Inf* 2009;**37**:598-609.

[13] Newman PW, Kenworthy JR. Gasoline consumption and cities: a comparison of US cities with a global survey. *J Am Plann Assoc* 1989;**55**:24-37.

[14] Holden E, Norland IT. Three challenges for the compact city as a sustainable urban form: Household consumption of energy and transport in eight residential areas in the greater Oslo region. *Urban Studies* 2005;**42**:2145-66.

[15] Sha Y, Wu J, Ji Y, Chan SLT, Lim WQ. *Shanghai Urbanism at the Medium Scale.* Springer; 2014.

[16] Bueno B, Norford L, Hidalgo J, Pigeon G. The urban weather generator. *Journal of Building Performance Simulation* 2013;**6**:269-81.

[17] Al-Homoud MS. Computer-aided building energy analysis techniques. *Build Environ* 2001;**36**:421-33.

[18] Quan SJ, Li Q, Augenbroe G, Brown J, Yang PP-J. Urban Data and Building Energy Modeling: A GIS-based Urban Building Energy Modeling System Using the Urban-EPC Engine. In: Geertman S, Ferreira J, Goodspeed R, Stillwell J, editors. *Planning Support Systems and Smart Cities*, Boston: Springer; 2015, p. 447-69

[19] Reinhart C, Dogan T, Jakubiec JA, Rakha T, Sang A. Umi-an urban simulation environment for building energy use, daylighting and walkability. *Building simulation 2013: Proceedings of BS2013: 13th conference of IBPSA (International Building Performance Association);* 2013, p. 476-83.