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Council on Tall Buildings and Urban Habitat

Future Cities 未来城市

Towards **Sustainable Vertical Urbanism**

迈向可持续的垂直城市主义

A collection of state-of-the-art, multi-disciplinary papers on tall buildings and sustainable cities

多学科背景下的高层建筑与可持续城市发展最新成果汇总

Editors (编者): Antony Wood, Shiling Zheng (郑时龄) & Timothy Johnson

Sustainability & Environment

可持续发展与环境

CTBUH Research Project: The Sustainability Implications of Urban + Suburban Locations – Initial Report

CTBUH对城市与郊区不同地点的可持续发展影响研究——初期报告

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Peng Du is currently a PhD candidate and teaching assistant in the College of Architecture at Illinois Institute of Technology, focusing on sustainable vertical urbanism. Peng also works at the CTBUH, assisting with proposed and on-going research projects and tall building design studios, as well as coordinating China operations. He was awarded the 2013-14 ARCC/King Student Medal for Excellence in Architectural + Environmental Research. Prior to studying and working in Chicago, he received his Master of Architecture degree from Tongji University in 2011.

杜鹏现在是美国伊利诺伊理工大学建筑学院的博士候选人、助教，主要研究领域是可持续的垂直城市发展。他同时也在世界高层建筑与都市人居学会 (CTBUH) 工作，协助申请和参与研究课题，指导高层建筑设计课程，以及协调学会在中国的运营工作。他获得了北美建筑研究中心协会 (ARCC) 颁发的2013-14年度学生荣誉勋章，以表彰他在建筑与环境研究中的杰出表现。他在去芝加哥学习工作以前，于2011年获得同济大学建筑学硕士学位。

Dr. Antony Wood has been Executive Director of the CTBUH since 2006, responsible for the day-to-day running of the Council. Based at the Illinois Institute of Technology Chicago, Antony is also a Research Professor in the College of Architecture there and a visiting professor of tall buildings at Tongji University Shanghai. His field of speciality is the design, and in particular the sustainable design, of tall buildings. Prior to moving to Chicago, he worked as an architect in Hong Kong, Bangkok, Jakarta, Kuala Lumpur and London. His PhD explored the multi-disciplinary aspects of skybridge connections between tall buildings.

安东尼•伍德 博士，自2006年起担任CTBUH执行理事，负责学会的日常运作。他同时也是芝加哥伊利诺理工大学建筑学院研究副教授和上海同济大学的客座教授，其专业领域是高层建筑设计，尤精于可持续设计。到芝加哥工作前，他曾在香港、曼谷、雅加达、吉隆坡及伦敦等地任建筑师，他的博士论文从多个学科的角度探讨了摩天大楼之间的空中桥廊连接问题。

Abstract

It is widely accepted that the concentration of people in denser cities – sharing space, infrastructure, and facilities – offers much greater energy efficiency than the expanded horizontal city, which requires more land usage as well as higher energy expenditure in infrastructure and mobility. But the principal has never actually been examined at a detailed level. Most research in this area to date has focused on the large scale-energy consumption and populations of cities, rather than communities. The Council on Tall Buildings and Urban Habitat (CTBUH), in an attempt to investigate this, embarked on a research project in early 2014, in conjunction with the Illinois Institute of Technology (IIT), entitled "A Study of the Sustainability Implications of Differing Urban + Suburban Locations in Chicago," which is focused on demystifying the myths on both sides of the density vs. sprawl debate. The fundamental objectives of this research project are two-fold; (i) to investigate the true sustainability aspects of people's lifestyle through a comparison of Chicago downtown high-rise and suburban low-rise living, and (ii) to develop a methodology for this evaluation for the benefit of other cities globally. This paper gives a summary of progress to date.

Keywords: Tall Buildings, Sustainability, Infrastructure, LCA, Embodied Energy, Quality of Life

摘要

将人口集中在密度更大的城市 (共享空间和基础设施) 会比水平蔓延的城市 (需要更多土地，并在基础设施和交通上消耗大量能源) 对能源的利用效率更高——尽管这一观点已经达成了广泛共识，但其中的关键影响因素还从未在细节层面上被研究过。迄今为止，大多数在这一领域的研究都集中在解决城市大尺度范围下的能耗和人口问题，而非在社区这一更小的尺度范围下。为此，世界高层建筑与都市人居学会 (CTBUH) 与伊利诺伊理工大学 (IIT) 在2014年初联合开展了一项主题为"芝加哥城市与郊区不同地点的可持续发展影响研究"的课题，分别对"密度与扩张"这两个问题进行深入地比较和论证。此项研究的主要目标有两个: (1) 通过比较芝加哥市区高层建筑与郊区低层建筑的居住来研究真正与居民生活方式相关的可持续发展因素; (2) 开发出一套研究方法用于评估全球其它城市的可持续发展。本文总结了此课题截止到目前的最新进展。

关键词: 高层建筑，可持续发展，基础设施，全生命周期评估、自含能量、生活质量

Background

The U.S. population has continued to urbanize. As a share of total population, the metropolitan population has increased from 69 percent in 1970 to 80 percent in 2000 (Hobbs & Stoops, 2002). Within metropolitan areas, however, the population has continued to suburbanize. From 1970 to 2000, the suburban population slightly more than doubled, from 52.7 million to 113 million.[1] This phenomenon is especially highlighted in Chicago, where there has been a huge population shift from city to suburbs over the last half of 20th century. The population of the City of Chicago peaked at 3.6 million in 1950, containing 70 percent of the wider metropolitan area residents. By 2000, 2.9 million Chicagoans made up only 36 percent of the wider metropolitan population.[2]

研究背景

美国人口的发展一直在经历着城市化进程。居住在大都市的人口占总人口的比例从1970年的69%增长至2000年的80% (Hobbs & Stoops, 2002) 。而在大都市区域内，其人口却一直在向郊区转移。郊区人口在1970年至2000年间增长了两倍还多，数量从5270万增长至11300万[1]。这一现象在芝加哥尤为明显: 芝加哥在20世纪后半叶经历了人口从城市向郊区的大规模转移，

1: Source: U.S. Census Bureau. Actually, U.S. Bureau of the Census does not identify a location as "suburban." Metropolitan areas are divided into two classifications: (a) inside central city and (b) outside central city. Many researchers treat the latter areas as suburban, and they are so treated in this paper (see Giuliano et al. 2008, Appendix B).
1: 资料来源: 美国人口调查局. 事实上，美国人口调查局并没有定义过"郊区"。大都市地区被划分为两类: (a)城市中心以内区域和(b)城市中心以外区域。很多研究者都将后者所指的区域看作是"郊区"，本文对此也持同样的观点 (详见Giuliano et al. 2008, Appendix B) 。

2: Source: Metropolitan Decentralization of Chicago. College of Urban Planning and Public Affairs, University of Illinois at Chicago. July 2001.
2: 资料来源: 芝加哥大都市区的郊区化发展。伊利诺伊大学芝加哥分校城市规划与公共事务学院. 2001年7月。

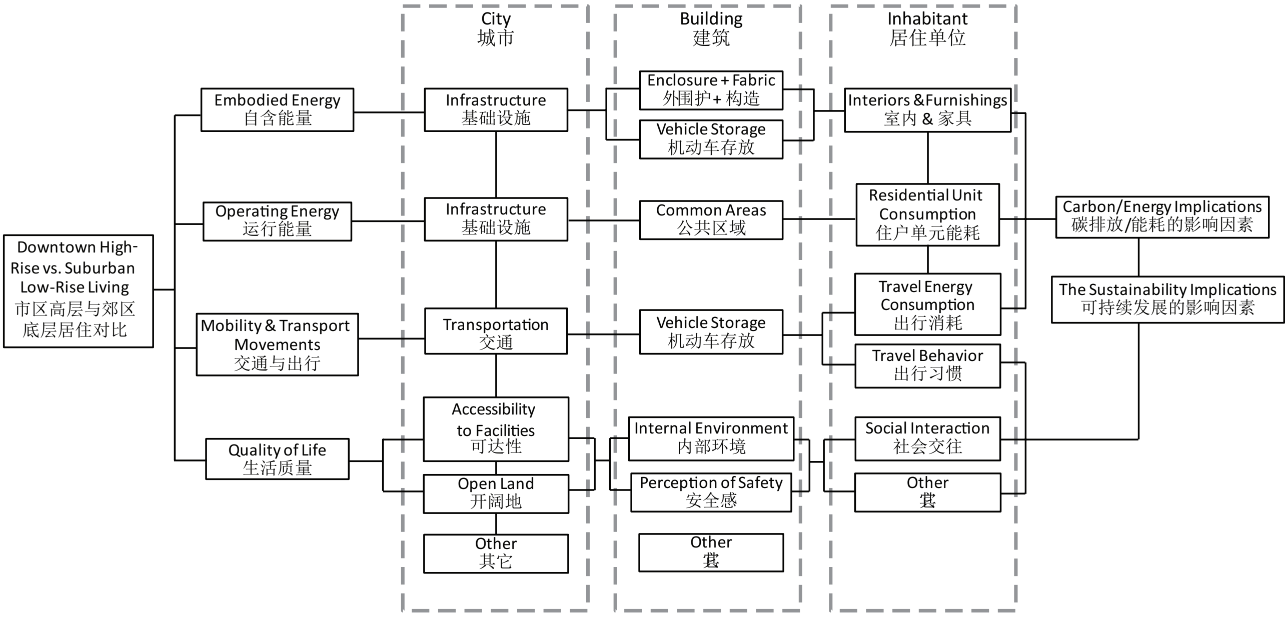

Figure 1. Conceptual diagram of research methodology. Source: created by authors.
图1. 研究方法的概念图示。来源: 作者自绘。

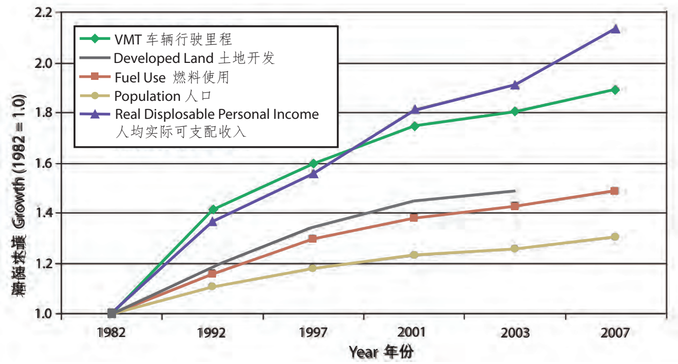

Figure 2. Growth in U.S. highway passenger VMT, population, developed land, real disposable personal income, and energy consumption, indexed to 1982. Source: Transportation Research Board. 2009. Driving and the Built Environment: The Effects of Compact Development on Motorized Travel, Energy Use, and CO_2 Emissions. Special Report 298.
图2. 美国高速公路车辆行驶里程、人口、土地开发、人均实际可支配收入和能耗的增长比较图。来源: 交通运输研究委员会。2009. 驾驶与建成环境: 紧凑型发展对小汽车出行、能耗和CO_2排放的影响. 特别报告298。

These dispersed, automobile-oriented, suburbanized patterns have resulted in the consumption of vast quantities of undeveloped land, the necessity for large horizontal infrastructure networks to support, and the undertaking of increasing vehicle miles traveled (VMT), which contribute to increasing energy usage and greenhouse gas (GHG) emissions. Specifically, vehicle travel on U.S. highways has been increasing at a much faster rate than either population or developed land for several decades (see Figure 2).

Methodology

The multidisciplinary research project which forms the basis of this report embraces factors such as the embodied energy of the materials in the inhabitation; the actual monthly energy consumption of the home (and the implications of differing power sources – electric, gas, bio-fuel, district heating, etc.); mobility movements through all modes of transport – walking, bicycling, automobile, bus, CTA train, Metra, etc.; the embodied and operating energy of the infrastructure to support inhabitation; and the other direct energy-carbon implications of each lifestyle. In addition, the research project engages with the single people, couples and families in the households that will inform this study to determine issues on the quality of life between dense high-rise and suburban low-rise living. The general analytical framework and data analysis methods are summarized in Figure 1.

All the data is being collected primarily through surveys and questionnaires direct with residents of the households. Specifically, the questions in the survey include the following sections: demographics (each household member's age, gender, race, employment status, etc.), household information (income, ownership status, time of residence, etc.), residential building and unit information (type, year, material, floor #, GFA, etc.), owned vehicle/bicycle information (type, year and mileage traveled tracking), travel behavior during a typical week (destination locations, frequency, travel time, modes of travel, etc.), monthly utility usage (electric, gas and water including provision of utility bias for a 12-month period), land use characteristics, satisfaction with residential life, sustainable living behavior investigation, etc. The data set we have collected so far is approximately 200 households in both high-rise and low rise-scenarios.

其中城市人口在1950年达到历史最高的360万，占其所在范围更大的大都市区域总人口的70%; 而到了2000年，城市人口降至290万，却只占其范围更大的区域总人口的36%[2]。

这些分散的、以汽车为导向的郊区化的城市形态就导致对大量未开发的土地、更大的水平向发展的基础设施网络，以及更多的车辆行驶里程 (VMT) 的需求。其中，VMT的增长会带来能耗的增加，并排放更多的温室气体 (GHG) 。而特别需要关注的是: 在最近的几十年间，美国高速公路车辆行驶里程的增长速度远比人口或土地开发的增长速度要快 (见图2) 。

研究方法

本报告的主体部分将介绍这一多学科交叉的研究项目所涵盖的内容，其中包括居住单位所需建材的自含能量、家庭每月实际所消耗的能量 (以及分析使用不同能源所带来的影响，其中包括电、天然气、生物燃料、集中供热等) 、使用各种交通方式的出行 (包括步行、自行车、汽车、公交汽车、CTA地铁、Metra火车等) 、居住生活所需基础设施的自含能量与运营耗能，以及其它因生活方式不同所直接带来的能源和碳排放影响。另外，此项研究项目还分别考量在高密度的高层居住和郊区低层居住生活中，因住户人口模式的不同 (单身、夫妻和家庭) 对于其各自生活质量的影响。图1总结了此项研究的整体分析框架和数据分析方法。

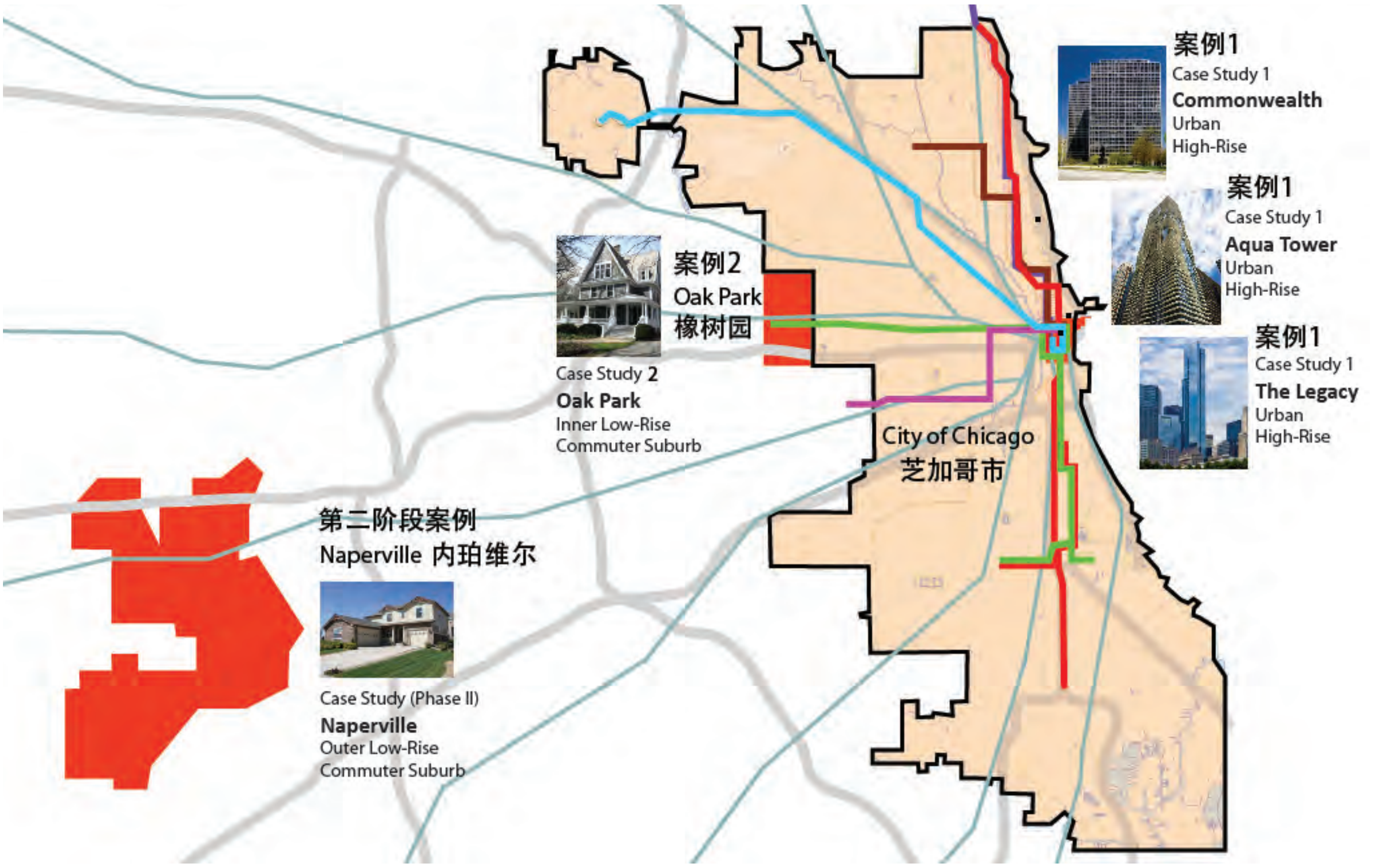

Figure 3. Site location of the 3 case studies
图3. 三个研究案例的地理位置以及交通体系图

Case Studies

The initial phase of this study is being undertaken based on two case studies: a series of residential towers in the City of Chicago as the urban high-rise case studies, and Oak Park as the suburban low-rise case studies. Their geographic locations and connected transportation systems are shown in Figure 3. A phase II of the project will take place in other outer commuter suburban areas, such as Naperville, IL.

The three urban high-rise cases include The Legacy at Millennium Park (250-meter tall, 73-story condominium tower accommodating 357 units), The Aqua Tower (262-meter tall, 86-story mixed-use tower accommodating 447 apartments, 264 condos and 334 hotel units) and Commonwealth Plaza (two 77-meter tall, 27-story condominiums accommodating about 390 units). The research project already benefits from the solid support of the owners of all these buildings, who will encourage the maximum involvement of residents. All of the three urban case studies are located in areas of high density and various types of public transport.

Oak Park, a district accommodating 51,878[3] inhabitants located 7 miles from Chicago city center will form the inner low-rise commuter suburb case study. Oak Park is considered quite sustainable in many aspects – constituting a relatively dense mix of single-family homes and apartment blocks, has a very walkable environment, is plugged into much of public transport system (especially the mass transit CTA green and blue lines) that service Chicago, etc.[4] Since the USA is one of the most energy-profligate nations when it comes to residential energy consumption, it is believed that Oak Park as a case study may be more akin, in agglomerated terms, to European or Asian situations, where there is good suburban access to public transport, and local amenities.

此研究项目的所有数据是通过调研和对居民所完成的调查问卷直接获得的。其中，调查问卷的问题包含了以下几个部分: 人口特征 (包括住户中每个人的年龄、性别、种族、就业状态等信息) 、家庭信息 (包括家庭收入、居住所有权、居住时间等) 、住宅和住户信息 (包括类型、建成时间、材料、楼层、居住面积等) 、家庭所拥有的汽车/自行车 (包括类型、年份、行驶里程记录等信息) 、典型一周的交通行为 (包括目标地点、出行频率、出行时间、使用的交通方式等信息) 、每月的能耗 (包括12个月周期下的电、天然气和水) 、土地使用特征、居住生活满意度以及可持续的生活方式调查等。

案例研究

此研究项目的第一个阶段是建立在对两个案例研究的基础上: 分别为芝加哥市区的若干高层住宅 (城市高层居住案例) 和橡树园 (郊区低层居住案例) 。图3显示了不同案例的地理位置以及与之相关联的交通体系。研究的第二个阶段则会扩展至其它更加远离市区的郊区案例，例如伊利诺伊州内珀维尔。

城市高层的三个案例包括千禧公园的Legacy大厦 (一座高250米的73层高层住宅，可容纳357个家庭住户单元) 、Aqua大厦 (一座高262米的86层高层综合体，可容纳447个租赁公寓单元、264个家庭住户单元以及334个酒店套房) 以及Commonwealth Plaza (两座高均为77米的27层高层住宅，共可容纳约390个住户单元) 。此项研究已经受益于这些项目业主的大力支持，他们在积极地鼓励尽可能多的居住者参与到此项研究中。所有三个城市高层案例所在的高密度地区都有发达的公共交通体系。

3: Data from U.S. Census Bureau. Last updated: Jan 3, 2013
3: 数据来源: 美国人口调查局。最后更新: 2013年1月3日

4: Actually, Oak Park was named the third best neighborhood to live in in the United States by the American Planning Association in 2010.
4: 事实上，橡树园在2010年被美国规划协会评为全美最好社区的第三名。

Table 1 summarizes the basic characteristics across these different case studies.

Research Fields and Initial Findings

Field 1: Embodied Energy

The embodied energy of a building is the energy consumed during the manufacturing and construction phases of the building. It comprises all the energy inputs that are needed to manufacture the material elements of a building, such as enclosure, flooring, glazing, roofing, fittings, and fixtures. Embodied energy is divided in two parts: initial embodied energy, which is utilized in the initial construction of the building, and recurring embodied energy, which is utilized in the replacement and maintenance in materials' life spans.

The research has done an extensive literature review in embodied energy of high-rise and low-rise buildings. Past research includes numerous studies on the embodied energy of low-rise buildings based on a Life Cycle Assessment (LCA). Calculated by different researchers across real case studies and digital models, the embodied energy varies with research scope, research methodology, and the case study itself (e.g., different buildings use, different structure & exterior walls). Yet, all the studies approve that the embodied energy accounts for typically a very small portion, approximately 10%-15%, of the total life-cycle energy consumption over a 50-year home life (Keoleian, 2001). Actually this figure is even less if the energy consumption in transportation in terms of people's life style is considered. Based on the literature review conducted, the average value of the embodied energy of low-rise buildings (1-2 stories) is 750 MJ/sf^2.

Compared to low-rise buildings, few published studies determine the embodied energy of tall buildings due to the projects' complexity and limited data availability. One of the many criticisms leveled at tall buildings

橡树园离芝加哥市中心7英里，拥有人口51,878[3]，将在此研究中作为离市区较近的郊区低层研究案例。橡树园在很多方面都被看作是一个相当"可持续"的区域——例如，拥有独栋住宅和多层公寓构成的密度相对较高的混合社区、非常适宜步行的环境、发达的公共交通系统 (特别是有芝加哥地铁的绿线的蓝线经过) 等[4]。由于居住生活方式耗能巨大，美国成为了世界上能源消耗最严重的国家。但从紧凑型发展的角度看，橡树园作为研究案例之一，也许与欧洲或亚洲的案例有更多类似的地方，因为很多欧洲和亚洲的郊区对公共交通和当地服务设施都有良好的可达性。

表1归纳了不同研究案例的基本特征。

研究范围与初步结果

第1部分: 自含能量

建筑的自含能量是指建筑在制造与施工阶段所消耗的能量，它包括了建筑材料 (例如外围护结构、地板、玻璃窗、屋顶、配件、器具等) 的生产制作过程所消耗的所有能量。自含能量又可以分成两部分: 初始自含能量 (建筑在初始的施工阶段所消耗的能量) 和循环自含能量 (材料的更换和在其寿命周期内维护所消耗的能量) 。

此项研究分别已对高层建筑与低层建筑所消耗的自含能量做了广泛的文献研究。此前的研究从全生命周期 (LCA) 的角度对低层建筑所消耗的自含能量做了大量案例分析。不同研究人员通过对真实案例和电脑建模的研究，计算出的自含能量值却差别很大，这是由于研究范畴、研究方法和案例本身的不同 (例如，不同建筑的结构和外墙材料是不同的) 造成的。但是所有这些研究都证明了自含能量通常只占住宅生命周期 (50年) 所耗能量的很少一部分，约为10%-15% (Keoleian, 2001) 。事实上，如果再考虑生活中由于出行产生的耗能，这一比例甚至会更少。基于我们所做的文献研究，低层建筑 (1-2层) 的平均自含能量值为750 MJ/sf^2。

相对于低层建筑，由于高层建筑项目的复杂性和数据收集的局限

	The Legacy at Millennium Park 千禧公园 Legacy	Aqua Tower Aqua大厦	Commonwealth Plaza Commonwealth广场	Oak Park 橡树园
Type类型	Urban High-Rise			Inner Low-Rise Commuter Suburb
Completion Year建成年份	2010	2009	1956	71.9% built before 1950 24.7% built 1950-1999 3.4% built after 2000
Height高度	250 m/ (818 ft)	262 m (859 ft)	77 m (253 ft)	<10 m/33 ft
Number of Floors楼层数量	73	82	27	1-3
Number of Units住户数量	356	747	160 (N)/215 (S)	1 per abode
Structural Material结构材料	Concrete	Concrete	Steel/Concrete	Wood frame/stone/brick
Location地点	**City of Chicago**			**Suburbs**
	Loop		**Lincoln Park**	**Oak Park**
Population (2010) 人口 (2010年)	29,283		94,368	51,878
Density密度	19,000/sq mi (7,200/ km^2)		30,000/sq mi (12,000/ km^2)	11,037.9 / sq mi (4,262/ km^2)
Distance to Chicago Loop 到芝加哥市区的距离	Walkable		4 miles (average)	7-10 miles (average)
Public Transport公共交通	All CTA Lines, All Metra Lines & Multiple Bus Lines		CTA Red, Purple and Brown Lines, Metra UP-N Line & Multiple Bus Lines	Green & Blue CTA lines, Metra UP-West Line & Pace Buses
Vehicles Available 汽车拥有率	68%*		77.8%**	94.3%
Commuting to Work去上班 - Car, truck, or van - Public transportation - Walked or bicycle - Other means or worked at home - Mean travel time (min) 平均耗时	 17.9%* 15.9%* 60.9%* 5.3%* 19.8 minutes*		 41.1%** 40.7%** 9.0%** 9.2%** 30.2 minutes**	 64.1% 22.5% 5.4% 8% 31.7 minutes

Table 1. Basic characteristics across the two different case studies. Source: created by authors. Data Source: CTBUH Skyscrapercity, 2008 Household Survey and U.S. Census Bureau.
表1. 两个不同研究案例的基本特征。来源: 作者自绘。数据来源: CTBUH摩天大楼中心、2008年美国家庭调查和美国人口调查局。

* These are average figures for the 60603 Zip Code area, which is the core area of the Chicago Loop
这些数据是邮编为60603所覆盖区域的平均值，此区域为芝加哥市区的核心范围。
** These are average figures for the 60614 Zip Code area, which covers the majority of the Lincoln Park neighborhood.
这些数据是邮编为60614所覆盖区域的平均值，此区域覆盖了林肯公园的大部分领域。

is the high quantities of structure and materials required to support, clad and service them, coupled with energy intensive construction at height (Oldfield, 2012). Based on the literature review conducted, the average value of embodied energy of high-rise buildings (15 stories or higher) is 1171 MJ/sf². This early study indicates that a high-rise building requires more embodied energy than a low-rise building per unit of floor area, due to the growing quantities of load bearing materials (concrete or steel) as the building total height increases under increased gravity, wind and seismic loads, the additional performance requirements of the façade under additional environmental loading at height, and the need for increased common MEP services and elevator provision.

However, given that there are more residents per unit floor area accommodated in high-rise dwellings than low-rise dwellings, high-rise buildings could actually consume less embodied energy per person (Norman, et al. and Perkins, et al.). It is expected that the research project will investigate the embodied energy of low rise and high-rise dwellings in more detail in order to report back comprehensively on this.

Field 2: Operating Energy

The operating energy of a building is an ongoing and recurrent expenditure of energy that is consumed to satisfy the demand for heating, cooling, ventilation, lighting, equipment, appliances etc. Building operation alone is responsible for 41.7% of all energy consumed in the United States, and moreover, the U.S. uses 74.9% of its electricity just to operate buildings.[5] Thus it is very important for society to have a better understanding of operating energy consumption in both high-rise and low-rise buildings, especially on a unit and person basis.

Few studies have conducted a comprehensive investigation of the actual operating energy for tall buildings. According to the U.S. Department of Energy (DOE)'s Prototype Building Models,[6] a typical 10-floor high-rise apartment in Chicago[7] consumes 63.3 MJ/sf² for annual operating usage, and a typical single-family house in Peoria, IL[8] consumes 52.9 MJ/sf². However, the results of these simplified digital models need to be verified and adjusted via a full-scale investigation of actual case studies. This research project will track the actual operating energy usage including electric, gas and water of each residential unit across both high-rise and low-rise scenarios via examining the actual utility bills supplied by residents over a 12-month period. It will also take into account, in the high-rise case studies, the actual energy required of the common areas and facilities (lobby, corridors, elevators, centralized MEP plant services, etc.). All the actual energy data will be monitored over a 12-month period.

Field 3: Mobility & Transport Movements

Typically, it is believed that people living in the suburbs drive more than people living in an urban center. The Illinois Department of Transportation (IDOT) shows that the average household in the Chicago downtown drove 6,949 miles in 2007, while the average household in Oak Park drove 13,412 miles. In additional to assessing vehicle miles traveled (VMT) for automobiles, it is critical to investigate people's travel behavior via public transit. According to the Share of Total Mileage of Travel by Mode by Residents of each Zone in the 2008 Household Survey,[9] the total mileage traveled per person by other public transportation modes can be calculated shown as Table 2. Due to the limited open data about travel behavior via public travel modes at the city-scale, these statistics assume that the share of total mileage of travel by different modes in the downtown area is the same as the Central Chicago zone, and Oak Park is the same as West Cook zone.

性，很少有发表过的研究对其自含能量进行过计算。高层建筑受到批评的原因之一是其支撑体系、维护体系和服务体系所需的大量结构与材料耗材，以及高度所带来的施工中的高能耗 (Oldfield, 2012) 。基于基于我们所做的文献研究，高层建筑 (15层以上) 的平均自含能量值为1171 MJ/sf²。这些以前所做的研究表明，高层建筑比低层建筑在单位居住面积需要更多的自含能量，这主要是由于高度增加，建筑所受的重力荷载、风荷载和抗震荷载都相应地增大，这就需要使用更多的承重材料 (混凝土和钢铁) ; 同时，高度增加所带来额外的环境荷载需要高性能的建筑外墙，也带来对建筑设备服务要求的提高和电梯数量的增加。

然而，考虑到高层建筑比低层建筑在单位居住面积有更多的人居住，因此高层建筑自含能量的人均消耗可能实际上反而更低 (Norman, etc. and Perkins) 。研究计划对低层与高层住宅的自含能量进行更详细的研究与计算，从而对这一课题做出更全面的分析。

第2部分: 运行能量

建筑的运行能量是建筑满足采暖、制冷、通风、照明、设备、家电等要求所持续、循环消耗的能量。在美国，建筑本身的运行占总能源消耗的41.7%; 同时，美国产生电能的74.9%用于建筑的运行[5]。这说明对高层与低层建筑运行能量有更深刻的研究是非常重要的，特别是在单位面积和人均使用的层面。

目前，很少人对高层建筑实际运行能量进行过全面的研究。根据美国能源部 (DOE) 所创建的标准建筑模型[6]，一座位于芝加哥的典型的10层高层公寓住宅[7]每年的运行能耗为63.3 MJ/sf²，而位于伊利诺伊州皮奥瑞亚市的一座典型的独栋住宅[8]每年的运行能耗为52.9 MJ/sf²。然而，这些简单化的电脑模型所模拟的能耗结果需要通过对真实案例全面研究进行验证和优化。本研究课题将通过收

Characteristics/Study Areas 特征/研究区域	Chicago Loop 芝加哥市区	Oak Park 橡树园
Household Size住户人数	1.8	2.4
Vehicle Number per Household 每户所有的车辆数目	0.67	1.61
Annual VMT (Automobile) per Household 每户每年使用小汽车的VMT值	6,949 miles	13,412 miles
Annual VMT (Automobile) per Person 每人每年使用小汽车的VMT值	3,860.6 miles	5588.3 miles
Annual VMT (Public Transit) per Person 每户每年使用公共交通的VMT值		
CTA/Pace/School Bus公交汽车	760.6 miles	262.7 miles
CTA Train地铁	552.1 miles	424.7 miles
Metra火车	139 miles	357.7 miles

Table 2. Average residential mileage traveled by all the transportation modes in Chicago Loop and Oak Park . Source: created by authors. Data Source: 2008 Household Survey and U.S. Census Bureau.
表2. 芝加哥市区与橡树园居民通过各种交通方式出行的平均行驶里程。来源: 作者整理。数据来源: 2008年美国家庭调查和美国人口调查局。

5: Source: Architecture 2030. Data Source: U.S. Energy Information Administration (2012).
5: 资料来源: 建筑2030. 数据来源: 美国能源信息署 (2012) 。

6:The prototype building models were developed by Pacific Northwest National Laboratory in support of the U.S. Department of Energy's (DOE's) Building Energy Codes Program.
6: 标准建筑模型是在美国能源部 (DOE) 的建筑节能规范项目资助下，由西北太平洋国家实验室开发。

7: The model was created based on ANSI/ASHRAE/IES Standard 90.1. There is no Chicago-based model, so we chose the one in Peoria, IL, which is the closest location to Chicago in this series of energy simulating models.
7: 此模型是基于ANSI/ASHRAE/IES Standard 90.1最新的标准创建。由于没有模型是位于芝加哥的，所以我们选择了伊利诺伊州皮奥瑞亚市，这一地点是在所有这一系列的能耗模拟模型中离芝加哥最近的。

8: The model with gas furnace heating system and unheated basement, which is the most common type of a single-family house in the Midwestern region of US, was created based on 2012 International Energy Conservation Code (IECC).
8: 此模型 (使用煤气加热炉制暖但制暖范围不包括地下室，这在美国中西部地区是最常见的独栋住宅类型) 是基于2012国际节能规范 (IECC) 创建。

9: The Chicago Regional Household Travel Inventory (CRHTI) did a comprehensive study of the demographic and travel behavior characteristics of residents in the greater Chicago area.
9: 芝加哥地区居民出行统计署 (CRHTI) 对大芝加哥地区居民开展了一项关于人口和交通行为特征的综合研究。

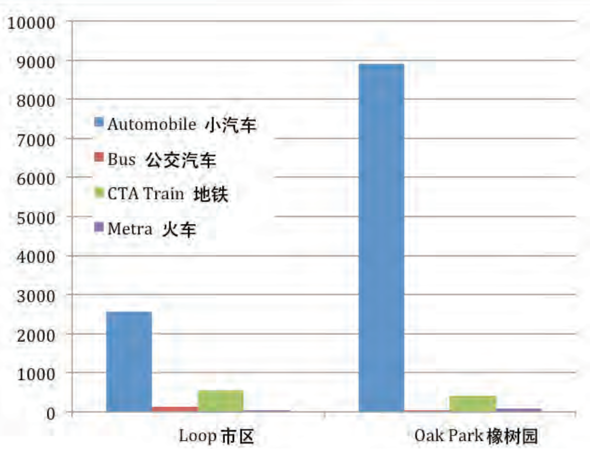

Figure 4. Embodied energy (MJ) of transport infrastructure shared per person via four transportation modes based on the residents' travel behaviors in the Chicago Loop and Oak Park. Source: created by authors.
图4. 芝加哥市区与Oak Park不同出行方式所带来的每人消耗交通基础设施的自含能量 (单位MJ) 。来源: 作者自绘。

To further investigate the mobility & transport movements across both urban patterns, the research questionnaires completed by each household will track occupant's transport movements during a typical period of time, then be extrapolated for a longer period. Data to be recorded includes: travel distance, journey frequency, mode of travel (including walking, bicycling, automobile, bus, CTA train, Metra train, etc.), travel time, etc. In addition, car ownership and the implications of types of cars will be investigated.

Field 4: Infrastructure
Urban infrastructure includes networks of roads, transportation, water, sewage, communications, power supply, etc. – all the elements that are required to support inhabitation. This phase of the research will assess the life-cycle energy (embodied and operating energy) of the infrastructure in both the urban and suburban setting, and assess the relative share of infrastructure energy cost per unit in both the high-rise and low-rise scenarios. This is perhaps the most tricky part of the research project to assess, and allocate across households accurately. Thus a large number of assumptions will have to be made, but it is important to factor in share of infrastructure at some level.

Specifically in transportation systems, recent studies have developed a comprehensive environmental LCA energy and greenhouse gas emissions for automobiles, buses, trains, and airplanes in the US, including vehicles, infrastructure, fuel production and supply chains (Chester 2008, Chester and Horvath 2009). The components inventoried in vehicles include manufacturing, operation, maintenance, replacement and insurance, and the components inventoried in infrastructure include construction, operation, maintenance, parking, insurance, etc. Based on the methodological framework and database of the transportation LCA database (tLCAdb)[10], as well as the data summarized in Table 2, the initial research in this phase conducts a LCA of the residential mobility associated with residents' travel behaviors in two urban scenarios in Chicago. Specifically, the components inventoried in the embodied energy of transport infrastructure include the construction and maintenance of roadway, station, railway track, station parking, etc. The research shows the embodied energy of infrastructure shared per person via automobile is far more than all public transportation modes in the Chicago Loop and Oak Park (see Figure 4). This seems to confirm the benefits of transit-oriented development (TOD), and also demonstrates that reducing automobile usage and new roadway construction is a key point in lowering the embodied energy of infrastructure.

集居民的12个月的水电气账单，分别对高层与低层住宅每个住户的实际运行能耗 (包括电、天然气和水) 进行追踪记录。其中在高层建筑的案例研究中，还将考量其公共区域和公共设施 (大厅、走廊、电梯、设备服务区等) 所消耗的实际能量。所有的实际能耗数据都将以12个月为周期进行调研。

第3部分: 交通与出行
一般来说，我们认为居住在郊区会比居住在城市中心区需要更多的驾驶里程。伊利诺伊交通部 (IDOT) 的研究显示，2007年居住在芝加哥市区的家庭平均驾驶里程为6,949英里，而居住在橡树园的家庭平均驾驶里程为13,412。除了统计小汽车的行驶里程 (VMT) ，对人使用公共交通的行为分析也是非常重要的。根据2008年美国家庭调查[9]中对居民使用不同交通方式所消耗行驶里程的比例分配统计，计算出人均使用公共交通出行方式所消耗行驶里程 (见图表2) 。由于在城市尺度下公共交通出行相关公开数据的局限性，这些通过不同交通方式所消耗行驶里程的比例分配的统计数据是假定芝加哥市区与芝加哥中心区是相同的，而橡树园与Cook西区是相同的。

此项研究通过让居民完成调查问卷来记录他们在一段典型周期中的所有交通出行，进而推断至更长的时间，来进一步研究两个不同城市形态下人们出行的交通与出行。获取的数据包括: 行驶距离、行程频率、交通方式 (包含步行、自行车、小汽车、公交汽车、CTA地铁、Metra火车等) 、出行时间等。另外，研究还将调查所拥有车辆的信息以及车辆不同类型所带来的影响。

第4部分: 基础设施
城市基础设施包含了道路、交通、供水、排水、通讯、供电等各种网络，所有这些要素支撑着整个居住生活。这一部分将研究城市与郊区不同基础设施的全生命周期能耗 (包括自含能耗和运营能耗) ，并得出高层住宅与低层住宅中每户所消耗的基础设施能耗 (按相对比例计算) 。以所有住户为样本进行准确地评估和使用份额分析也许是此项研究中最困难的部分。因此，研究不得不做出大量假设，但在一定程度上定量基础设施的使用份额是非常重要的。

特别是在交通体系中，最近的研究已经开发出一套对美国的小汽车、公共汽车、火车和飞机 (包括车辆、基础设施、燃料生产和供应链) 的全生命周期耗能与温室气体排放的全面评估 (Chester 2008, Chester and Horvath 2009) 。其中，车辆的研究包括了制造、使用、维修、更换、保险等方面，而基础设施则包含了施工、运营、维护、停车、保险等方面。基于交通体系全生命周期数据库 (tLCAdb) [10]开发的研究方法架构和数据，以及图表2中列出的数据，这一部分的初始研究结合芝加哥这两种不同的城市模式下不同的居民出行方式，对其交通出行做了全生命周期评估。其中，交通基础设施的自含能耗计算考虑了道路、车站、铁轨、车站停车场等方面的施工和维护。研究结果显示，无论是在芝加哥市区还是Oak Park，每个人通过小汽车出行所消耗基础设施的自含能量远大于通过使用其它所有的公共交通方式 (见图4) 。这似乎证实了公交导向发展 (TOD) 的所带来的益处，也说明减少小汽车的使用和新的道路系统的建设是降低基础设施自含能量的关键点。

第5部分: 生活质量
生活质量在此项研究中被定义为"个人对生活的整体满意程度"(Foo, 2000)，并通过通过调查问卷中的客观性指标与主观性指标被量化 (见图5) 。客观性指标包括个人、家庭和土地使用的特征，主观性指标则包括了生活满意程度的具体方面。其中，对土地使用特征和生活满意度的调查会具体到以下四个方面的: 交通、可达性 (通向各种资源、设施和机会) 、社会交往和安全性。

10: The transportation LCA database (tLCAdb) is a repository of greenhouse gas environmental results from research developed by Dr. Mikhail Chester, Dr. Arpad Horvath, and colleagues.
10: 交通体系全生命周期数据库 (tLCAdb) 是由Mikhail Chester博士、Arpad Horvath博士及其他同事一起开发的分析温室气体环境影响的评价体系。

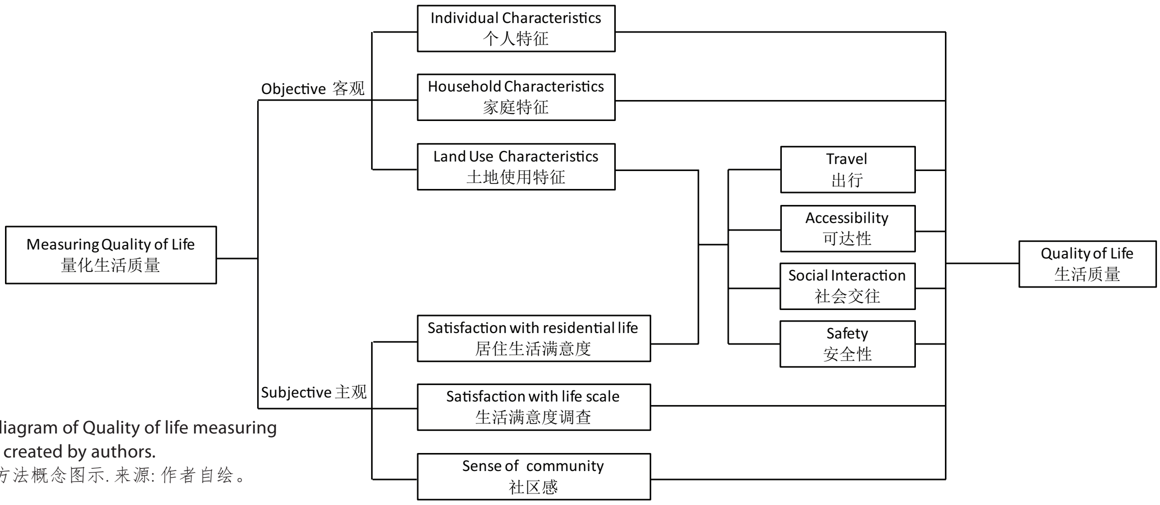

Figure 5. Conceptual diagram of Quality of life measuring methodology. Source: created by authors.
图5. 生活质量的量化方法概念图示. 来源: 作者自绘。

Field 5: Quality of Life

In this study the Quality of life (QoL) is defined as "individual overall satisfaction with life" (Foo, 2000), and will be measured using both objective and subjective indicators via the questionnaires (see Figure 5). The objective indicators include individual, household, and land use characteristics, and the subject indicator is the specific aspect of satisfaction with life. Specifically, the investigation for both land use characteristics and satisfaction with life will be scaled down to the following four categories: travel; accessibility to resources; facilities and opportunities; social interaction; and safety. In addition, the research will integrate the Satisfaction of the Life Scale[11] and the Sense of Community[12] into the subjective measures in order to find more associations between different factors within QoL.

Toward the Conclusion of the Research

The expected findings are not intended to give a simple answer concerning which urban living scenario is more sustainable. Instead, the findings are expected to give us a better understanding of what factors really do contribute to "sustainability" in an urban/suburban context, not only including such quantifiable factors as energy/carbon expenditure, but also including less-quantifiable aspects of "sustainability", such as Quality of life. The remaining parts of the research are expected to be completed within the next year, and the final output is expected to be released in early 2016. The final report will be published by CTBUH within its Technical Guide series.

此外，此项研究还将"生活满意度调查"[11]与"社区感"[12]作为主观性指标，来寻找生活质量中各种不同指标之间的关联度。

研究结果展望

此项研究预期的调查结果并非是要对"哪一种城市居住模式是更可持续的"这一问题给出一个简单的回答，而是希望为了让我们更好地理解在城市/郊区不同的环境下，真正与"可持续发展"相关联的影响因素。这些影响因素不仅仅包括那些可以量化的方面 (例如能耗和碳排放)，也包括了"可持续发展"中难以量化的方面 (例如生活质量)。此项研究的剩余部分预计在明年完成，最终的报告也将预计在2016年初出版。最终的研究报告将会作为《CTBUH技术指南》系列出版物由CTBUH出版发行。

11: Satisfaction of the Life Scale is a short 5-item instrument designed to measure global cognitive judgments of satisfaction with one's life. The scale usually requires only about one minute of a respondent's time.
11: "生活满意度调查"由5个简单的问题组成，用于量化一个人对生活满意度的认知与判断。此项调查通常需要参与者在一分钟之内完成。
Source (来源): Diener, E., Emmons, R. A., Larsen, R. J., & Griffin, S. (1985). The Satisfaction with Life Scale. Journal of Personality Assessment, 49, 71-75.

12: McMillan & Chavis's (1986) theory (and instrument) is the most broadly validated and widely utilized in this area in the psychological literature. McMillan & Chavis (1986) define Sense of Community as "a feeling that members have of belonging, a feeling that members matter to one another and to the group, and a shared faith that members' needs will be met through their commitment to be together."
12: McMillan & Chavis's (1986)的这一理论 (和阐释) 在心理学文献中的此领域是最被广泛验证和使用的。McMillan & Chavis's (1986)定义"社区感"为"社区成员的归属感、一位成员对另一位成员和一个群组产生影响的感受，或者是成员对其彼此的需求有共同的认识"。

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- Aqua at Lakeshore East Condominium
- Commonwealth Plaza Condominium
- SCB Architecture
- Studio Gang Architects
- Walsh Construction

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