The Form of Clean Energy Neighborhoods

How It Is Guided and How It Could Be

By

Jue Wang

Master of Engineering in Urban Planning and Design, Tsinghua University
Tsinghua University (2008)
Bachelor of Architecture,
Tsinghua University (2005)

Submitted to the Department of Urban Studies and Planning
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MASSACHUSETTS INSTITUTE OF TECHNOLOGY

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Author ____________________
Department of Urban Studies and Planning
Aug 6th, 2010

Certified by ____________________
Professor Dennis Frenchman
Department of Urban Studies and Planning
Thesis Supervisor

Accepted by ____________________
Professor Joseph Ferreira
Chair, MCP Committee
Department of Urban Studies and Planning

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Abstract

The subject of "clean energy city" has attained increased attention in recent year. However, almost all studies to date about "clean energy" are either at the building scale or the regional scale and little touches the real estate development scale, or in other words the neighborhood scale. The research project "Making the 'Clean Energy City' in China" – funded by Energy Foundation, China – is the first attempt to dress the relationship between neighborhood form and energy consumption. As part of the research, my thesis proposes the framework to address the energy-form relationship in in-home operational energy use, to be further developed in the future stages of the research project.

The thesis poses two questions, how does neighborhood form affect in-home operational energy consumption and how do we guide designers and developers on the design of neighborhood form in order to reduce in-home operational energy consumption? The thesis approaches these questions through a review of existing energy-related simulation tools including building energy analysis tools, microclimate analysis tools and tools that address energy concerns at the neighborhood scale. The thesis proposes to use a simulation approach based on prototypes and their variations at the cluster scale – a form descriptive system developed by the research project – as the direction to establish this form-energy relationship as well as to convey this relationship to designers graphically. Finally as a demo, the thesis examines the relationship between operational energy use and neighborhood form under Prototype "Small Perimeter Block" with DeST, a building simulation tool that can also be applied to a cluster of buildings.

Thesis Supervisor:
Dennis Frenchman, Professor of Urban Design and Planning
Thesis Reader:
Chris Zegras, Assistant Professor of Transportation and Urban Planning

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Chapter I
Introduction

1.1 The Research Background

In 2009, the Energy Foundation, China granted MIT the funding for a two-year research project "Making the 'Clean Energy City' in China[1]" to (1) understand how urban form, especially at the neighborhood scale, influences the carbon performance of the city, and (2) provide a practical tool assisting designers and developers to pursue low carbon development projects.

I worked on this research project during its first year as a member of the MIT team. The MIT research team is led by Prof. Dennis Frenchman and Prof. Chris Zegras, members including Jan Wampler, Yang Jiang, Daniel Daou Ornelas, Nah-Yoon Shin, Ira Winder, Aspasia Xypolia, Heshuang Zeng, Yun Zhan, and Jiyang Zhang.

The research resulted in two major products[2] that will directly relate to this thesis, the pattern book and the Energy Pro Forma ©, all in their pilot versions. The pattern book provides a full list of prototypes from best practices of clean energy developments worldwide, as a replacement to existing real estate pattern books that were developed with little energy consideration. The energy pro forma is a

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[1] Dennis Frenchman, Christopher Zegras (Principal Investigators). *Making the 'Clean Energy City' in China (draft)*. (Cambridge: Massachusetts Institute of Technology with Tsinghua University, June, 2010). Research sponsored by the Energy Foundation, China. Research team included: Dennis Frenchman, Chris Zegras, Jan Wampler, Yang Jiang, Daniel Daou Ornelas, Nah-Yoon Shin, Jue Wang, Ira Winder, Aspasia Xypolia, Heshuang Zeng, Yun Zhan, and Jiyang Zhang. Partner institutions of this research are Tsinghua University, Shandong University, Beijing Normal University, and the Lawrence Berkeley National Laboratory.

[2] Other products of the research project include but not limited to:

- A comprehensive study of current practice of clean energy neighborhoods, which resulted in the preliminary pattern book to be developed further
- A study of the relationship between neighborhood form and energy consumption based on data collection from nine neighborhoods representing four key prototypes of neighborhood form. The data collection was carried out by Shandong University, Beijing Normal University (GIS), and Tsinghua University.

design tool based on empirical data from neighborhoods selected in Jinan, China, aiming to establish a quantitative relationship between a neighborhood's carbon performance and its form. The pro forma is composed of three modules: embodied energy use, operational energy use, and transportation energy use[3]. The goal of the pro forma is to estimate *"net present energy value"*, similar to a financial pro forma in real estate development, as feedback to designers and developers during the preliminary design process. Building on this product of the research, my thesis will explore further the relationship between urban form and in-home operational energy use.[4] Chapter II will return to the research project as the context of my thesis.

1.2 The Research Questions

As an extension of the research project tackling the relationship between neighborhood form and operational energy consumption, this thesis poses two questions. Firstly, how does neighborhood form affect in-home operational energy consumption? Does the concern of operational energy efficiency at the neighborhood scale differ from that at the building scale? Is the former (neighborhood) the aggregation of the latter (buildings), or have they fundamental differences besides size?

Secondly, how do we guide designers and developers on the design of neighborhood form in order to reduce in-home operational energy consumption? In other words, what tools are needed to make informed decisions about form for

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[3] The research project's definition for these three types of energy uses are:
"Transport – is energy consumed during travel. Automobile use is the major factor in transport energy use."
"Embodied energy – is embedded in the materials construction and eventual demolition of buildings, infrastructure, and landscape that make up a neighborhood."
"Operational energy use – refers to energy consumed both by households in their apartment for heating, cooling and appliance (in-home) and outside the individual units in buildings and neighborhood common area, which would include elevators and site lighting for example."

[4] Here I only tackle how to save energy through reduction of in-house operational energy use, the issue of energy efficiency. This is slightly different from "clean energy" or "low-carbon" - the goal of the research project, as the latter two can be achieved through renewable energy production and the project itself can still be energy intensive, while "energy efficiency" focuses on how to save energy regardless of the source of the energy itself.

reduced operational energy consumption, in the context of the broader energy pro forma?

This thesis approaches these questions through a review of existing energy-related simulation tools. It proposes to uses a simulation approach based on prototypical clusters[6], which shows the direction to establish this form-energy relationship as well as to convey this relationship to designers graphically. The thesis therefore aims to replace the placeholders in the pilot version of the energy pro-forma with real proposals that strengthens the pro-forma's weak points regarding in-home operational energy use.

1.3 The Thesis Structure

This thesis is divided into three parts in search for the answer to these two questions – whether and how form matters in in-home operational energy use and how to therefore guide designers. The first part, Chapter II, discusses the research project, points out its limitations in predicting in-house operational energy consumption, and finally proposes a simulation approach to address the form-energy relationship that will go hand-in-hand with the social/economic-energy relationship established in the energy pro forma. In general, Part I sets up the context of the whole thesis.

The second part reviews existing simulation tools, discusses their pros and cons, and explores how they can be employed to address the in-home operational form-energy relationship. This part is divided into three chapters in review of three types of simulation tools – building energy analysis tools, microclimate analysis tools and tools that address energy concerns at the neighborhood scale. A summary of the previous three chapters proposes the framework for a tool that can address the form-energy relationship in predicting in-house operational energy consumption, in particular, heating and cooling energy use, a tool that uses existing simulation programs based on prototypes/prototypical clusters developed by the research.

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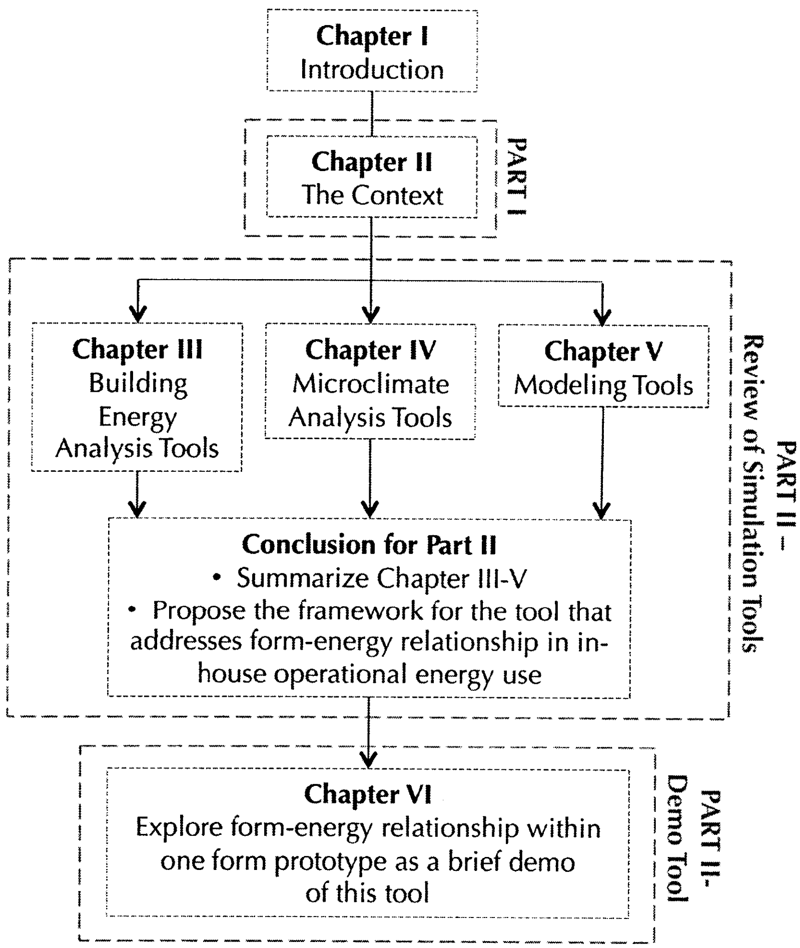
[6] The concept of "cluster" and "prototypes" is developed by the "Making the 'Clean Energy City' in China" research project. Their definitions will be further discussed in Chapter II, and this thesis will use the prototypes at the cluster scale developed by the research team to explore the form-energy relationship.

Finally, the last part, Chapter VII, is a demonstration of a simplified version of such a tool. It uses an existing building-scale simulation tool, DeST, to examine the relationship between operational energy consumption and neighborhood form, taking as an example one of the prototypes developed by the research project.

Figure 1-1: Thesis Structure



PART I – The Context

Chapter II
Energy Pro-Forma, Pattern Book and Else

The subject of "clean energy city" has attained increased attention in recent year. However, almost all studies to date about "clean energy" are either at the building scale or the regional scale and little touches the real estate development scale, or in other words the neighborhood scale. However, the research team of "Making the 'Clean Energy City' in China" suspects that neighborhood forms have inherent characteristics in their design that either directly influence the energy performance of the neighborhood, or influence the patterns of human activity that affect actual energy consumption. This form-energy relationship therefore became the focus of the research project – "Making the 'Clean Energy City' in China". Given that China is urbanizing rapidly and thousands of neighborhoods will be built for hundreds of millions of people over the next 25 years, new developments with energy efficient neighborhood forms will result in huge amounts of saving in energy use.

2.1 Context I – The Energy Pro-Forma

2.1.1 What is the Energy Pro-Forma?

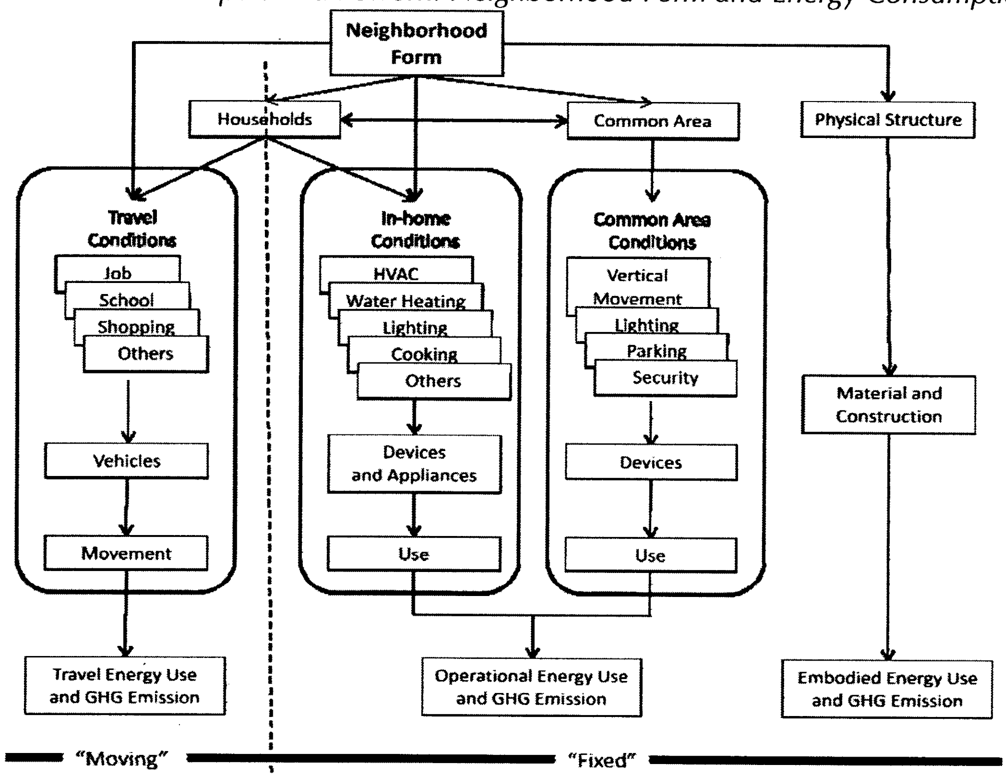
The pro-forma is a tool that aims to inform designers and developers in making decision about how to maximally save energy incorporating all trade-offs within the framework of their design and get moment-to-moment feedback from concept to final product. The goal is not to provide an exact energy reading, but rather a relative direction. The research project describes the energy pro-forma as:

"a decision support tool that ..... enables users (e.g. urban designers, developers, and policy makers) to explore and compare energy performance across existing or proposed development projects and patterns. Formatted as a spreadsheet, it helps users to estimate and forecast the potential energy consumption and CO2

emissions of urban development plans that have different project forms and physical typologies.

It contains three sub modules: 1) embodied energy use, 2) operational energy use, and 3) transportation energy use. Users can explore how much is the total energy consumption and GHG emission of each neighborhood, or cluster, they chose to analyze, as well as the share of different sources of energy consumption. A fourth component of the Energy Pro-forma, renewable energy production within a neighborhood will be added in future versions of the tool.[1]*"*

Figure 2-1: The Conceptual Framework: Neighborhood Form and Energy Consumption[2]



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[1] Dennis Frenchman, Christopher Zegras (Principal Investigators). *Making the 'Clean Energy City' in China (draft).* (Cambridge: Massachusetts Institute of Technology with Tsinghua University, June, 2010). Research sponsored by the Energy Foundation, China. p.142

[2] Dennis Frenchman, Christopher Zegras (Principal Investigators). *Making the 'Clean Energy City' in China (draft).* (Cambridge: Massachusetts Institute of Technology with Tsinghua University, June, 2010). Research sponsored by the Energy Foundation, p.98

Figure 2-1 illustrates the framework of this tool (the current stage) regarding the relationship between neighborhood form and energy consumption. The three modules of the tool are relatively independent, each giving a number for energy use and GHG emission and then combined together into the energy profile of the neighborhood.

Figure 2-2 is a snapshot of its input and output sheet for household transportation and in-home operational energy use. The coefficients in the spreadsheet/tool for background calculation come from analysis based on data collection[3] of 2400 households in nine neighborhoods from Jinan, China. Multiple regression analyses are conducted to establish the relationship between neighborhood form and energy consumption in these two areas. Non-form factors are included as control variables such as household income, appliance ownership, individual attitudes, demographic information, etc. The advantage of using regression on empirical data lies in its non-deterministic approach, as transportation and in-home operational energy consumption are very much dependent on the behavior of individuals and households, and therefore cannot be simply derived from the attributes of the neighborhood. For common area operational energy use and embodied energy use, two elements less influenced by occupants' behavior, coefficients come from literature review and the energy consumption of each household is estimated linearly and deterministically based on the physical attributes of the neighborhood.

[3] The information gathered from the data collection includes household weekly travel activities, in-home energy expenses (gas, electricity, heating bills, etc.), fuel choices, vehicle and appliance ownership, individual attitudes, income, and other socio-demographic factors. The data collection was conducted by Shandong University, Beijing Normal University (GIS) and Tsinghua University

Figure 2-2: Example of the Input Sheet and Output Sheet of the Energy Pro Forma[4]

INPUT

NEIGHBORHOOD FORM CHARACTERISTICS

LAND USE AND LOCATIONAL CHARACTERISTICS

These variables are used in the calculation of travel behaviors and related impacts on energy consumption.
The calculation can be provided in "Intermediate Calculation" section.

			Units	Sector		
	Neighborhood (cluster) size	0.20	Sq. km	E, O, T	*Total gross area of the neighbourhood/community/development*	
	Distance to Central Business District	10.00	km	T	*Distance from approximate centre of development to centre of nearest downtown*	
	Brt Corridor	1	if yes	T		
	Building coverage	0.28	%	O, T		
	Average Home construction area	120	Sq. m	O, E		
	Road construction area	12895.96	Sq. m	E		88371.899
	Road density	644.798	m2/sq.km	O, T		*8.83719*
	Land use mix	0.25		T		
	Building function mix	0.0774		T		
	Green space coverage	0.24		O, T		
2nd	Parking (# of parking lots/100 HHs)	57	#	T		
1st	Surface parking space	7236	Sq. m (1 parking lot=10sq.m)			
1st	Undergroundparking space	0	Sq. m	O_common area		
	Community facility space	10000		*O_common area*		

CLUSTER DESIGN CHARACTERISTICS

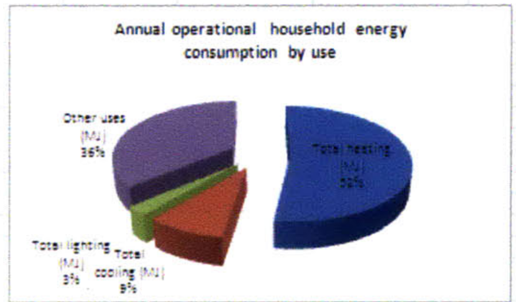
	Total # of households	**1280**		E, O, T
	Population Density	**43.27**	(# of 1000ppl/sq km)	T
	Total # of buildings	**28**		E
	F.A.R.	**2.12**		T
	Average buidling heights	**7.47730443**	Avg. # of floors	E, T
Heights				
	Percentage in super-high rise (19+)	50%	%	O_common area
	Percentage in high-rise(13-18)	30%	%	O_common area
	Percentage in mid-rise (4-12)	20%	%	O_common area
	Percentage in low-rise (1-3)	0%	%	O_common area
	Low rise (1-5)			E
	Mid-rise (6-10)			E
	High-rise (10-15)			E
	Building parameter		m	E
	Floor area	**896**	Sq. m	E
	Residential buidling with street-level shops	**0**		T

[4] Dennis Frenchman, Christopher Zegras (Principal Investigators). *Making the 'Clean Energy City' in China (draft)*. (Cambridge: Massachusetts Institute of Technology with Tsinghua University, June, 2010). Research sponsored by the Energy Foundation, p.98

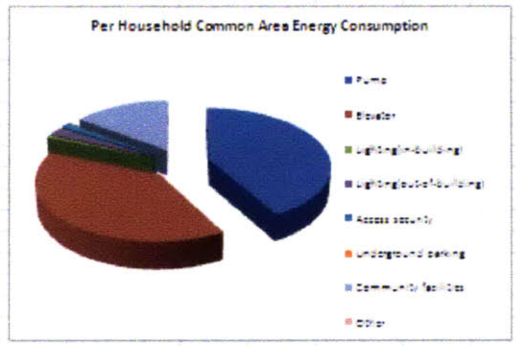
OUTPUT

OPERATIONAL ENERGY

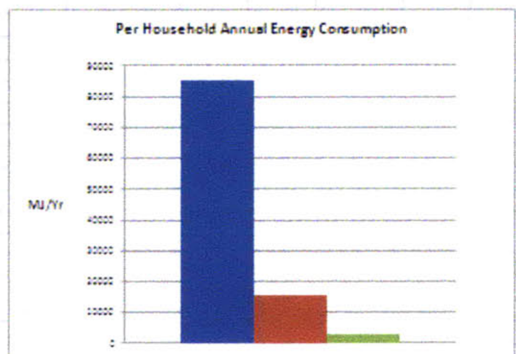
Output: Adjusted per Household Energy Consumption	
By Energy Source	
Electricity (MJ)	33214
Gas (MJ)	6552
Centralized heating (MJ)	37205
Sum	76971
By Use	
Total heating (MJ)	40302
Total cooling (MJ)	6792
Total lighting (MJ)	2014
Other uses (MJ)	27863
Sum	76971



Output: per HH Common Area Energy Consumption	
Pump	3568
Elevator	3327
Lighting(in-building)	55
Lighting(out-of-building)	195
Access security	109
Underground parking	0
Community facilities	1246
Other	0
Sum	8500



FINAL OUTPUT	
OPERATIONAL ENERGY USE/ GHG EMISSIONS	
Annual Inhome Energy consumption per I	76971
Annual Common Area energy consumptio	8500
Annual operational energy consumption	85471
Annual CO2 emission per household	7029
TRANSPORTATION ENERGY USE/ GHG EMISSIONS	
Predicted Car Ownership (# cars/ 100 H	52
Predicted Annual Energy (mj)	15632
Predicted Annual CO2 Emission (kg)	909
EMBODIED ENERGY USE/ GHG EMISSIONS	
Annual embodied energy consumption p	2753
Annual CO2 emissions per household (K	3096



The beta version of this tool has been developed and tested by architecture, landscape and urban design students during the 2010 MIT-Tsinghua Beijing Studio, with the site located in Jinan. It proved to be highly valuable in providing feedbacks for designers to make informed decisions during the design process. On the other hand, designers also found it difficult for the tool to account for some specific building and site layout that they designed aiming at reduced in-home operational energy consumption, mainly heating and cooling energy use.

2.1.2 *The Limitations of the Pro Forma in In-Home Operational Energy Use*

The frustration that designers experienced was expected. A close look at the pro forma indicates that parameters regarding the relationship between form at the cluster or neighborhood scale (versus at the building scale) and in-home operational energy use are very limited. Figure 2-3 displays all input regarding "cluster design characteristics", under which "Building Characteristics" and "Building Facility" mainly go toward calculating energy consumed in elevators and local travel behavior ("street level shops"), "Renewable Energy Technology" is irrelevant to in-home energy use, and "Insulation Condition" is building level information. The only parameters relevant to in-home energy use reflecting design characteristics at the cluster/neighborhood scale fall under "Enhancing Solar Energy Gain", "Shading Conditions" and "Wind/Ventilation Condition". Using dummy variables, these parameters are more similar to indexes in a rating system rather than inputs in a pro forma, as they can fully reflect neither quantitative nor qualitative relationships between variables and energy use. Taking "wind buffer" for example, it uses a "yes" or "no" input with "the presence of blocking walls or buildings" as a criteria. However, in practice, the number, size and actual layout of the blockages (with relationship to streets and buildings) matter significantly and all these considerations cannot simply be summarized into a binary question. Similar is the case with "courtyard to create microclimate". How courtyards help adjust microclimate depends on the number of courtyards and their size relative to the heights of surrounding buildings.

In this pilot version of the energy pro-forma, the research team understands that many inputs are listed in the pro-forma only as placeholders until more knowledge upon the energy-form relationship is unveiled and more appropriate inputs replacing current ones. However, on the other hand, data limitations do obstructed the research from addressing the relationship between cluster form and in-home operational energy consumption. These limitations are twofold. Firstly, the current survey failed to relate surveyed households to the actual units where they live. The only location information is the name of the neighborhood. Within the same neighborhood or cluster, actual in-home operational energy use for heating and

Figure 2-3: "Cluster Design Characteristics" Session in the Input Sheet[5]

	CLUSTER DESIGN CHARACTERISTICS				
	Building Characteristics				
1		Average buidling heights	6.35	#	Avg. # of floors
1		Height per floor	3	m	Assume all buildings have equal height per floor
1		Percentage in super-high rise (19+)	10%		
1		Percentage in high-rise(13-18)	5%		
1		Percentage in mid-rise (4-12)	70%		
1		Percentage in low-rise (1-3)	15%		
1		Avg. Building perimeter	300	m	
2		Average Residential floor area	991.42	Sq. m	Total residential floor area/ (average building heights * # of buildings)
1		Average thickness of building envelop	0.3	m	
2		Residential buidling with street-level shops	0.85	The fraction of n	Ground level shops in the residential buildings only; other cases should be classified as business buildings
	Enhancing Solar Energy gains (reduce energy consumption for heating water or living spaces, or providing electricity)				
2		Surface-volume ratio	0.30		Surface of roof is not inlcuded in the calculation (current version)
		The presence of green Roof	1	Yes=1; No=0	Cooling mpact
		The fraction of green roof	1	Large =3; Medium=2; Small=1	Green roof area/building construcion areas (all building types) Index=3, if the fraction is >= 0.7; Index=2, if 0.3 ≤ the fraction < 0.7; Index=1, if 0 ≤ the fraction <0.3
1		The fraction of wall surface facing south (southern exposure wall ratio)	0.4		
1		Window-to-wall ratio	0.3		
	Shading conditions	The index of shading conditions	3	High=3; Medium=2; Low=1	Index=3 if 4 < (shading-1)+(shading-2)+(shading-3)+(shading-4) ≤ 6 Index=2 if 2 < (shading-1)+(shading-2)+(shading-3)+(shading-4)≤ 4 Index=1 if 1 ≤ (shading-1)+(shading-2)+(shading-3)+(shading-4)<2
1	**Shading -1**	The presence of courtyard	1	Y=1; N=0	Cooling impact: This would impact ventilation and shading conditions; the temperature chan
1	**Shading -2**	Use of shading devices or overhangs	1	Y=1; N=0	Reduce energy consumption for cooling
1	**Shading -3**	Mutual building shading	2	High=3; Medium=2 Low=1	High=70% or higher of building construction areas are shaded; Medium=30%-70% of building construction areas are shaded; Low= 0-30% of building construction areas are shaded
1	**Shading-4**	The presence of trees around buildings	1	Y=1; N=0	Reduces temperature by approx. 1°C of surrounding environment
	Wind/Ventilation Condition				
	Ventilation condition	The collective index of ventilation condition	2	High=3; Medium=2; Low=1	Index=3 if 4 < (ventilation-1)+(ventilation-2)+(ventilation-3)+(ventilation-4) ≤ 6 Index=2 if 2 < (ventilation-1)+(ventilation-2)+(ventilation-3)+(ventilation-4) ≤ 4 Index=1 if 0 ≤ (ventilation-1)+(ventilation-2)+(ventilation-3)+(ventilation-4) <2
1	**Ventilation-1**	Wind buffer	0	Y=1; N=0	The presence of blocking walls or buildings
1	**Ventilation -2**	Courtyard to create microclimate	1	Y=1; N=0	Reduces temperature by approx. 4°C lower than surrounding environment
1	**Ventilation -3**	Wind channel	0	Y=1; N=0	
1	**entilation -4**	Water area within clusters	2	High=3; Medium=2 Low=1; No water=0	Includes small ponds, pools, water fountain and any kinds of water area. This overlaps with w area listed in the land use characteristics. Index=3, if water area is 10%-30% of the size of cluster. Index=2; if water area is 5%-10% of the size of cluster. Index 1; if water area is larger than 0 but lower than 5%.
	Renewable Energy Techno	Collective index of renewable energy use	1	High=3; Medium=2; Low=1; No renew. Tech =0	Index=3 if (renewable-1)+(renewable-2)+(renewable-3)=3 Index=2 if (renewable-1)+(renewable-2)+(renewable-3)=2 Index=1 if (renewable-1)+(renewable-2)+(renewable-3)=1 Index=0, if no renewable technology is used.
1		Photovoltaic (PV) systems (Solar Electric system)	0	Yes=1; No=0	Use of renewable energy in electricity and pumping
1		Geothermal heat use for heating	1	Yes=1; No=0	Use of renewable energy mainly in electricity and heating
1		Wind turbines usage	0	Yes=1; No=0	
	Insulation condition	A collective index of insulation condition	3	Bad=1 Normal=2 Good=3	
		The use of trombe wall	1	Yes=1; No=0	
		The presence of elevator	1	Yes=1; No=0	
	Building facility	Elevator intensity	2	Low=1 Normal=2 High=3	How frequent people are using the elevator. If you do not know, assume that it is normal.

[5] Excerpted from the spreadsheet of the "Energy Pro Forma", as part of the research project *Making the 'Clean Energy City in China'*, Sponsored by Energy Foundation China, Massachusetts Institute of Technology, Tsinghua University, June 2010

cooling could vary significantly unit by unit (both as a result of location-specific microclimate conditions and human behavior). When running regression to establish the relationship between cluster form and in-home energy use, this location information should be used as a control variable to eliminate variations in energy use due to the units' different locations within the neighborhood. Without control for location factors, the research project concluded that *"beyond the indirect impact on AC ownership (and subsequent effects on electricity use), neighborhood typology exerts no direct effect on residential energy use, after controlling for other factors*[6]*, "* which I think deserves further deliberation. During the second year of the project, this limitation might be addressed, as another round of surveys will be conducted with added information including unit location.

However, an additional data limitation might not be easily resolved even with a second round of surveys as it lies in the way heating bills are calculated in most Chinese cities. (According to the research report, centralized heating constitutes up to 40% of total in-home operational energy use.) Traditionally for centralized heating, units cannot adjust the temperature of the room and the heating bill corresponds directly to the size of the unit in the form of a lump sum payment for the whole winter regardless whether the unit is under-heated or over-heated. For recent development projects, this situation has been very much improved, with temperature adjustable heating becoming more prevalent. However, for the nine neighborhoods surveyed, six of them are old neighborhoods and whether the three new developments calculate heating bill by demand is unknown. Therefore, the heating bills reported by households neither reveal the heating needs of the building (determined by building's thermal performance) nor that of the occupants (varying by the individual's behavior and preference). This situation means that when running regression on heating bills provided by households, unit area was the most significant influence and other factors irrelevant. This is probably another reason why residential energy use seems to be unaffected by neighborhood

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[6] Dennis Frenchman, Christopher Zegras (Principal Investigators). *Making the 'Clean Energy City' in China (draft)*. (Cambridge: Massachusetts Institute of Technology with Tsinghua University, June, 2010). Research sponsored by the Energy Foundation, p.112

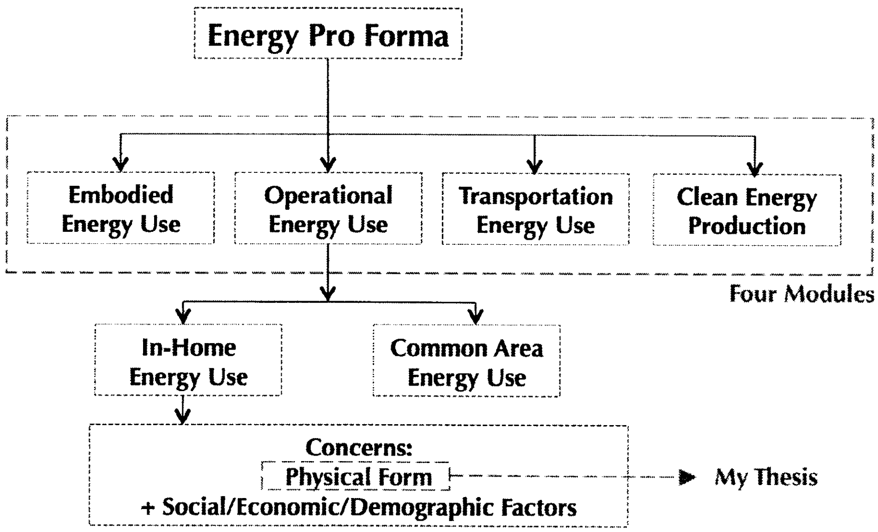
typology under the current research. This limitation might be hard to address unless the second round of surveys is solely based on new development projects with temperature adjustable heating and the data reflect real needs for energy.

2.1.3 A Simulation Approach to Address the Limitations

The inability of the pro forma to account for the form-energy relationship in in-home operational energy use is hard to resolve for the current stage of the research project. However, for designers, this relationship is principally important, as the physical form of the neighborhood is what designers work with to create a neighborhood with better energy performance. It is important to note here that neighborhoods with better energy performance do not necessarily lead to a reduction in realized energy consumption, as other factors such as human behavior and socio-demographic factors might also contribute, sometimes in a more significant way. However, designers can exert control over the physical form of the neighborhood unlike other factors involving human behavioral and socio-demographic factors, therefore feedback on this form-energy relationship is indispensable in the energy pro forma from a designer's perspective.

Since the form-energy relationship in in-home operational energy use – especially regarding heating and cooling – is difficult to establish through regression on empirical data, other alternatives await exploration. ***I propose using a more deterministic approach – simulation tools based on physics principles – to address this limitation of the energy pro forma. This form-energy relationship can be eventually combined with the behavior/socio-demographic-energy relationship to predict in-home operational energy consumption as a module of the pro forma.*** This thesis evaluates to what extent existing simulation programs serve the purpose of the energy pro forma and outlines a framework for more effectively informing designers of the project's energy consequences during the preliminary design process.

Figure 2-4: Relationship between the Thesis and the Energy Pro Forma

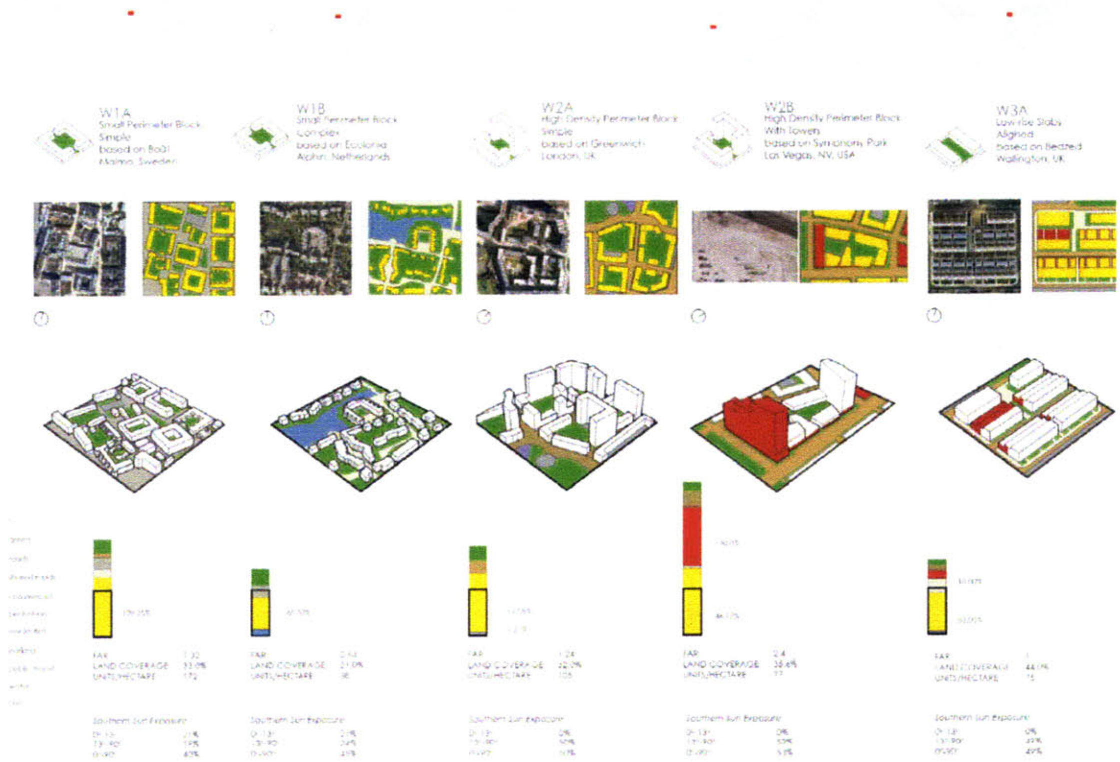


2.2 Context II – Cluster and Prototypes

Another important product of the research project is the "Pattern Book" based on the analysis of international best practices of clean energy neighborhoods. The pattern book is developed recognizing the fact that there exists no ideal approach towards clean energy neighborhoods, which in reality take various forms. However, repetitive patterns across these numerous forms were found and these patterns are summarized into six prototypes and fifteen sub-prototypes (see Figure 2-5), which are abstracted and distilled into this pattern book. The definition of these prototypes is attached in Appendix A for reference.

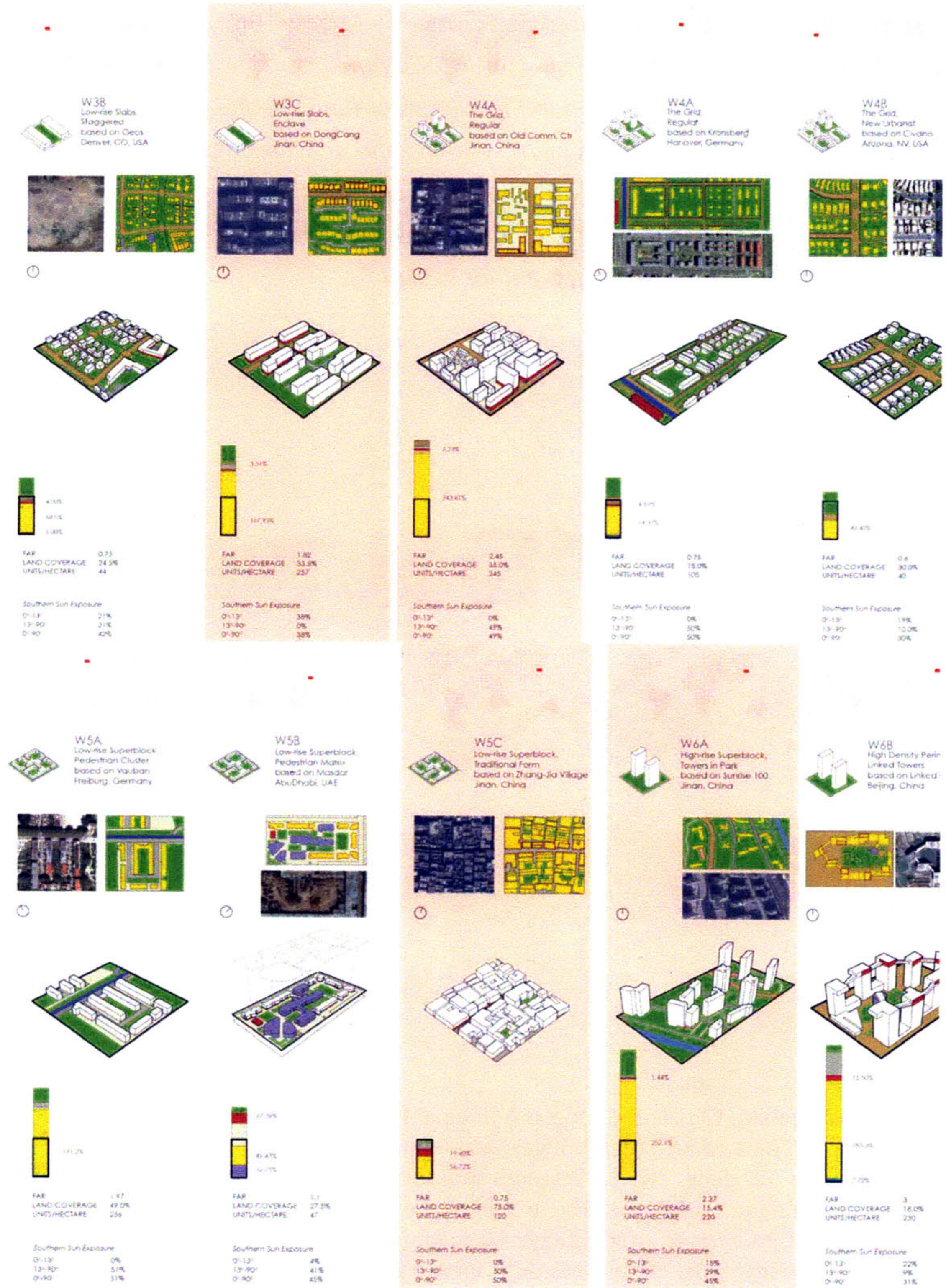
One key word in the pattern book is "cluster" – a basic unit to describe forms. According to the research project, cluster is defined as *"the basic unit of form-energy systems. Clusters are intended to capture a fundamental set of relationships between buildings, spaces, movement systems, and activities that underlie patterns of energy use in the urban environment (of course, they have profound social implications for the people living within them, as well). Ideally, clusters can be used as a unit of analysis and a starting point for design.*[8]"

Figure 2-5: The Prototypes and Pattern Book[9]



[8] Dennis Frenchman, Christopher Zegras (Principal Investigators). *Making the 'Clean Energy City' in China (draft)*. (Cambridge: Massachusetts Institute of Technology with Tsinghua University, June, 2010). Research sponsored by the Energy Foundation, p.135

[9] Dennis Frenchman, Christopher Zegras (Principal Investigators). *Making the 'Clean Energy City' in China (draft)*. (Cambridge: Massachusetts Institute of Technology with Tsinghua University, June, 2010). Research sponsored by the Energy Foundation, p.137-139


W3B
Low-rise Slabs, Staggered
based on Geos
Denver, CO, USA
FAR 0.75
LAND COVERAGE 24.5%
UNITS/HECTARE 44
Southern Sun Exposure
0°-13° 21%
13°-90° 21%
0°-90° 42%
W3C
Low-rise Slabs, Enclave
based on DongCang
Jinan, China
FAR 1.82
LAND COVERAGE 33.3%
UNITS/HECTARE 257
Southern Sun Exposure
0°-13° 38%
13°-90° 0%
0°-90° 38%
W4A
The Grid, Regular
based on Old Comm. Ctr
Jinan, China
FAR 2.45
LAND COVERAGE 35.0%
UNITS/HECTARE 345
Southern Sun Exposure
0°-13° 0%
13°-90° 49%
0°-90° 49%
W4A
The Grid, Regular
based on Kronsberg
Hanover, Germany
FAR 0.75
LAND COVERAGE 18.0%
UNITS/HECTARE 105
Southern Sun Exposure
0°-13° 0%
13°-90° 50%
0°-90° 50%
W4B
The Grid, New Urbanist
based on Civano
Arizona, NV, USA
FAR 0.6
LAND COVERAGE 30.0%
UNITS/HECTARE 40
Southern Sun Exposure
0°-13° 19%
13°-90° 10.0%
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
AbuDhabi, 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° 29%
0°-90° 45%
W6B
High Density Peri
Linked Towers
based on Linked
Beijing, China
FAR 3
LAND COVERAGE 18.0%
UNITS/HECTARE 230
Southern Sun Exposure
0°-13° 22%
13°-90° 9%
0°-90° 31%

This pattern book aims to display in the abstract a full range of form approaches towards clean energy neighborhoods in their basic unit - prototypes at the cluster scale. Meanwhile, these prototypes are also to be measured by the energy pro-forma to test their usability, as these prototypes came from projects with actual energy data. ***In addition to their function as guidance for designers and a test for the energy pro-forma, prototypes can also assume an integral part of the energy pro-forma by simplifying predictions of in-home operational energy consumption.*** The use of prototypes provides instant feedback and elegantly portrays a direct, graphical relationship between form and energy consumption. This recommendation comes from my review of existing modeling tools relevant to neighborhood energy consumption. How prototypes should be employed to complement simulation tools will be further discussed throughout my thesis.

2.3 Context III – Rating Systems and Clean Energy Projects

In addition to the energy pro-forma and the pattern book, the research project also reviewed rating systems on projects at the neighborhood scale and model clean energy development projects. These reviews not only provided the context of the research project, but, more importantly, evaluated existing sources of information where designers seek guidance. In the case of rating systems, they may also exert tangible influence on the project, in addition to guidance, by offering certification that might enhance the marketability or even financing of certain projects.

The review found existing sources of information not very much helpful in guiding designers towards a clean energy neighborhood. For rating systems, *"none of them is primarily targeted at clean energy, nor are they fully conscious of the energy consequences of their criteria*[10]*; Standards often include criteria expressed in abstract principles that do not involve measurement or do not have a clear benchmark to evaluate against; Standards often include criteria that do not provide*

[10] There often exists the disconnect between criteria and their implication on energy performance of the project. In other words, although fulfilling certain criteria seems to result in reduced energy consumption as indicated in the criteria, no quantitative relationship with energy use is actual mentioned throughout these rating systems under evaluation.

design guidance. Therefore, designers aiming at high ratings can only use those criteria for score-checking purposes after completion of the design rather than guidance during the decision-making process; Design instructions are based on individual criteria, ignorant of overarching strategies that coordinate the relationships/tradeoffs between criteria. In other words, people either use the rating systems to rate the final product as a whole or rate against individual criteria, and they might overlook the fact that earning credits in one area might result in a loss (or increase) of credits in another; No feedback system assists designers to modify their design according to the standards on the neighborhood level.[11]"

Another source of information, cases of existing clean energy development projects demonstrate the numerous forms that a clean energy neighborhood might take and provide detailed information on the design of individual projects. These completed projects also provide the possibility to evaluate energy-saving design strategies against realized energy performance. However, as realized energy performance is usually given as a raw total, it is impossible to discern to what extent each variable of the design contributed to energy savings. Finally, the diversity of completed projects, which together contain thousands of different forms, is not easily distilled into guidance for designers making preliminary decisions about future projects.

Our review of what is missing from existing sources of information underscored some basic principles for what designers need during decision-making for clean energy developments. Designers need guidance presented in an organized and understandable way. By organized I mean categorized rather than raw information; by understandable I mean guidance that is precise rather than abstract, and information that carries the relationship between methods and results. Meanwhile, a designer also needs overarching guidance as well as strategies covering discrete concerns of clean energy neighborhoods, and this overarching guidance might be further enhanced by certain feedback systems such as the energy pro-forma under

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[11] Dennis Frenchman, Christopher Zegras (Principal Investigators). *Making the 'Clean Energy City' in China (draft)*. (Cambridge: Massachusetts Institute of Technology with Tsinghua University, June, 2010). Research sponsored by the Energy Foundation, p.33-34

study of the research project. These principles inform my proposed framework to address the form-energy relationship in in-home operational energy use. I refer back to the studies on rating systems and cases of clean energy projects throughout the thesis, especially in my evaluations of simulation tools.

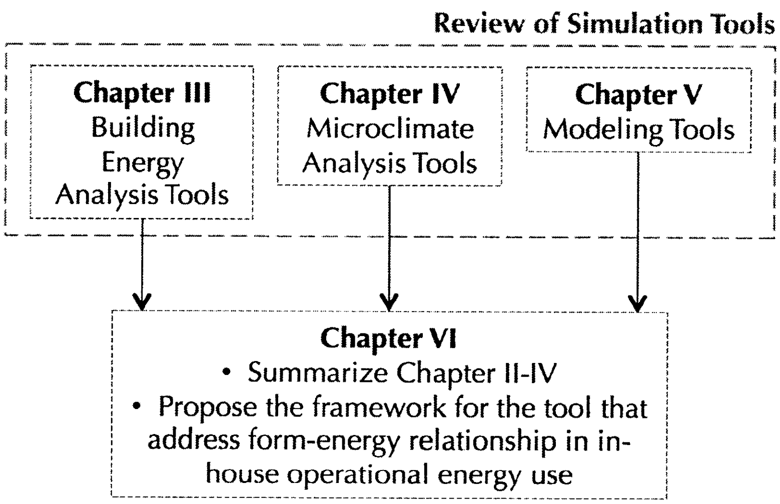
PART II – Modeling Tools

In search for simulation tools appropriate for constructing the module in the energy pro-forma that accounts for the relationship between neighborhood form and in-home operational energy use, I review existing simulation tools, discuss their pros and cons, and explore how they can be employed to address this form-energy relationship.

In my review of these tools, I am especially interested to know how they might facilitate decision-making at the very early stage of a project when decisions about site layout, massing and uses are made. These are the major elements that define a neighborhood's form and might impact energy performance of the project without going into building details such as fenestration, HVAC system, materials' thermal attributes, etc. As simulation tools directly or indirectly predict energy performance of a building or a whole project, my review considers to what extent these tools translate preliminary site design into the project's projected energy use and the elements (at the neighborhood scale) regarded by these simulation tools as the most influential on a project's energy consumption.

Although the thesis is energy-focused with a perspective at the neighborhood scale, the simulation tools under discussion will be divided into three categories, building energy performance analysis tools; microclimate analysis tools, and finally tools that address the issue of neighborhood form and energy consumption. This is because (1) many energy-related simulation tools are developed to predict the energy consumption of individual buildings and only very few are targeted towards neighborhoods; (2) many building energy performance analysis tools might also be applied to a whole neighborhood; (3) microclimate analysis tools, though they do not usually provide a concrete number for the neighborhood's/building's energy consumption as a simulation result, identify the influence that building clusters have on their immediate environment, which will in turn affect the heating and cooling load of the buildings themselves; (4) tools trying to address the issue of neighborhood form and energy consumption are often based on the combination of the previous two types of tools, trying to establish conversation in-between.

Part II will be divided into three chapters. The first part gives an overview of energy performance analysis tools mainly at the building scale, including their attributes and limitations; the second part briefly introduces microclimate analysis tools and discusses their relevance to our studies; the third part is focused on the limited attempts to predict building energy consumption within its context or predict neighborhood energy consumption with regard to urban form, with one of the approaches being to bridge the previous two types of tools together. The world of simulation tools is highly complicated. Giving a comprehensive overview within the confines of this thesis is difficult hard if not impossible. As most simulation tools are licensed and require a fair amount of effort to learn, my analysis is mostly based on a review of the literature instead of first-hand experience with the tools.



Chapter III
Building Energy Performance Analysis Tools

3.1 The Function of Simulation Tools

Simulation tools used by architects and planners are mainly building-scale tools that predict the energy consumption of specific design proposals. In their 2005 report, Hand et al compared the features and capabilities of the 20 most commonly used building energy simulation programs[1]. Their report provides me with a roadmap out of hundreds of similar tools developed over the past 50 years.

The major function of building energy analysis tools is to predict space load, both for heating and cooling, based on weather information, building construction and building operation details, such as envelope material, HVAC system, occupant number, etc. From space load, the actual energy consumption can therefore be predicted. By providing the data of projected yearly energy consumption, these tools enable users to receive instant feedback on the energy consumption of their design. One limitation discussed in the chapter of rating systems, the inability to deal with trade-offs between different energy concerns is therefore also addressed in these simulation tools. Although the designers might not fully understand exactly which element of the design contributes to the increase of solar gain in winter (saving energy) and at the same time decreases shading in summer (consuming energy), they can make decisions based on the final yearly energy consumption which already reflects these trade-offs. Some programs can further calculate cost based on the information above so that by using one program, the designer can interactively see how the energy consumption and the financial budget are impacted by the change of the design.

In addition to these basic functions, some programs have other extensive analysis functions dealing with separate aspects that are related to a project's energy

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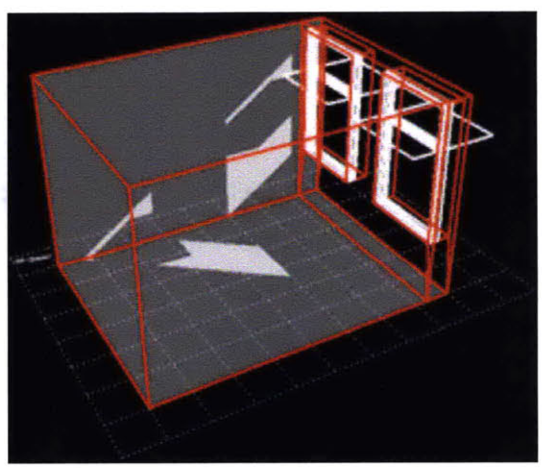
[1] Crawley, Drury B., Jon W. Hand, Michaël Kummert, and Brent T. Griffith. "**Contrasting the capabilities of building energy performance simulation programs." *Building and Environment* 43, no. 4 (April 2008): 661-673.

consumption, these aspects may include lighting, heating, cooling, radiance and shadow, natural ventilation, photovoltaic, etc. For example, Bsim is a package of tools including SimLight (daylight), XSun (direct sunlight and shadow), SimPV (photovoltaic power), NatVent (natural ventilation). Some of these functions are merely used to simulate indoor environment, while others apply to both indoors and outdoors. For example, ECOTECT's solar tool can calculate and visualize solar radiation on building surfaces throughout the year at a neighborhood scale as well as simulate sun penetration into individual rooms to help with shading design. Another example is XSun in Bsim, which can analyze shadows from neighboring buildings as well as indoor solar environment. XSun's ability to account for neighboring buildings seems to be highly relevant to the thesis, however, I failed to obtain a copy of the software and therefore cannot offer an evaluation. The capability of these additional functions indicate that building energy simulation tools can be used beyond the building scale; however, the product might not be necessarily presented as an absolute number of energy consumption, and some conversion of the raw data into energy-related indicators might be required.

Figure 3-1: ECOTECT Solar Tool for Site Analysis and Internal Sun Penetration

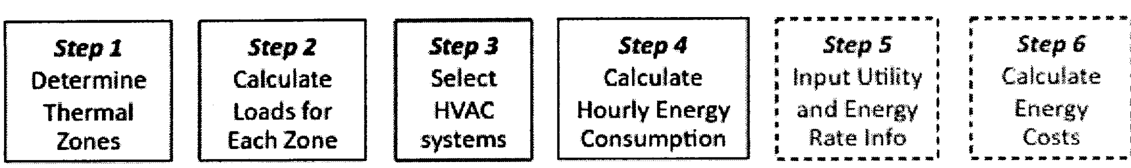


Simulation result by Duoduo Zhai, Tsinghua Univ. ECOTECT Tutorials

3.2 How Simulation Tools Works and the Interface

The core of most simulation tools is space load prediction. According to Crawley et al, "*Space Load Prediction computes hourly space loads given weather data and building construction and operation details, using a radiant, convective and conductive heat balance for all surfaces and a heat balance of the room air.*[2]" When space load is predicted, the actual energy needed can be calculated given the detailed information of the HVAC system. The complete process is shown in Figure 3-2. Most programs only have steps 1-4 to calculate energy consumption, while others also include steps 5-6 that calculate the cost. Only step 1 to step 2 require information regarding form. The whole process is a mechanical approach based solely on physics principles, which might be extremely complicated and time consuming to predict. Many of the tools conduct hourly-based simulations, and to test a proposal's yearly energy consumption might easily take hours or even days depending on how detailed and complicated the calculation is. Instant feedback is not really "instant". In addition, designers at the preliminary site design period might not even be able to provide detailed information regarding building construction and operation details, ruling out many of the more advanced tools. Within the tools Crawley et al reviewed, ECOTECT is recommended as more flexible and suitable for early-stage designs.

Figure 3-2: Flowchart of Simulation Process[3]



[2] Crawley, Drury B., Jon W. Hand, Michaël Kummert, and Brent T. Griffith. "Contrasting the capabilities of building energy performance simulation programs." *Building and Environment* 43, no. 4 (April 2008): 661-673.

[3] Richard Paradis, Energy Analysis Tools, National Institute of Building Sciences, Retrieved July 3rd 2010 from: http://www.wbdg.org/resources/energyanalysis.php#desc

Different tools often cross-reference each other. The core of EnergyPlus is BLAST and DOE-2; ECOTECT uses EnergyPlus and radiance; DOE-2 calculates at the background for eQUEST; etc. This phenomenon implies there are limited mechanisms behind various tools and most tools do not reinvent the wheel but instead build on or combine existing tools to address issues that weren't addressed before. As partial purpose of the thesis, to provide quick-to-use tools for designers at the very preliminary stage of neighborhood design, a similar approach might be adopted, even though it might help solve only a small portion of the overall objective.

The inputs and outputs of different tools vary greatly, however they fall into two broad types: data input-output and 3D model input-output. Widely used tools such as EnergyPlus, DOE-2, etc. only accept data input in the form of an ASCII text file and are therefore less user-friendly. Designers at the early-stage of a project might find it burdensome doing all the calculation for the input data each time they explore various alternatives. In addition to extra work, incorrect data inputs might easily lead to erroneous outcomes that are hard to identify, misleading the designer. To address this problem, various subsidiary tools and interfaces are created to facilitate the user creating input files for the simulation tool. Taking EnergyPlus as an example, dozens of subsidiary tools exist, among which 17 are listed and recommended on EnergyPlus' official website. Besides specifically designed interfaces, the interconnection between different simulation tools also simplifies input for text-only software. For example, ECOTECT, a user-friendly simulation tool where designers can build 3D models directly in the software, exports files that work in EnergyPlus and Radiance.

3.3 The Factors That Influence Simulated Energy Consumption

To discover the factors regarded as influential by simulation tools, I selected EnergyPlus, which uses text inputs, because for programs with visualized interface, users do not really know how the program translates 3D models into parameters, as this is also a process done in the background. I used EnergyPlus Example File Generator, a web-based interface that generates an EnergyPlus input file from building information that the user fills in on the website[4]. A scan through the inputs tells me that required form-related information is limited only to the building type, orientation, the number of building stories, the geometric parameters of the plan, and fenestration, information related only to the individual building under study. From EnergyPlus Example File Generator, it seems that EnergyPlus regards each building under study a freestanding individual uninfluenced by its surrounding environment and only information regarding the building itself affects the projected energy consumption. However, further study into the literaure tells me that EnergyPlus does account for the surrounding environment through calculating the shading effect both from neighboring buildings and trees[5]. Similar are many other building simulation tools such as BLAST, DeST, etc.

Shading is important both for the accuracy of simulation results and as a bridge linking building energy performance with the neighborhood form. Shading from neighboring buildings and trees might block solar gain in winter or help create shading in summer. Although in some cases, the increased heating load in winter and decreased cooling load in summer might counteract each other; in most cases, the two numbers do not match depending on the combined effect of building layout and local weather information. Meanwhile, as the shading effect is determined by the relationship between building-building and building-site, it necessitates consideration beyond individual buildings when talking about building energy consumption.

In addition to shading effect from neighboring structures and plants on individual buildings, DeST, software developed by Tsinghua University in China can calculate the total energy consumption of a group of buildings accounting for the inter-shading effect among these buildings. The capacity of DeST to simulate a cluster of

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[4] This generator might require only simplified information, based on which the program automatically generates a full input file for EnergyPlus. However, a scan through the required information can generally give an idea of the key elements regarded by EnergyPlus as influential to building energy consumption. Source: U.S. Department of Energy, Energy Plus Example File Generator, http://apps1.eere.energy.gov/buildings/energyplus/cfm/inputs/index.cfm

[5] Henninger , Robert H., and Michael J. Witte, "EnergyPlus Testing with IEA BESTEST Multi-Zone Non-Airflow In-Depth Diagnostic Cases MZ320 – MZ360," U.S. Department of Energy, April 2010

buildings makes it a viable tool to explore the relationship between different building layouts and their total energy consumption. However, similar to other building level simulation tools, DeST requires fair amount of detailed building information such as floor plans and materials to conduct simulations. For designers at the preliminary planning stage working with the geometry and layout of buildings and the site design, providing such details is unrealistic and involves unnecessary extra data that slows down the simulation.

Even for simulation tools that keep in mind the interrelationship between buildings and site, one key issue is often neglected by building-level simulation tools that hinder the accuracy of simulation results: site-specific weather information. The weather information from nearby weather stations[6] is not the same as the actual weather conditions of the site. Weather information is crucial for building energy analysis programs, but most programs use the city's average temperature information and regional dominant wind direction and speed of the season as weather data inputs. A 2002 article by Li et al demonstrated an increase of 20% to 50% in cooling load when using CTTC simulated outdoor temperature as compared to the scenario using temperature from nearby weather stations[7]. In addition to the heat island effect caused by a combination of building layout, heat emission from buildings' HVAC system, etc., a potential discrepancy between information acquired from a weather station and the actual onsite weather conditions also involves the change of wind speed and direction, two elements that

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[6] This is the ideal situation that yearly weather information comes from the nearest weather station. However, in many cases, the weather data file for a certain simulation tools is limited and sometimes only data at the city level is available as is the case for EnergyPlus. Detailed data for certain parts of the city requires additional efforts to collect and regenerated in the right format.
[7] The indoor temperature is set up at 27°C, assuming full ventilation every 2 hours. The article simulated the cooling and heating load of three rooms in the same building under two outdoor temperature scenarios, the temperature from a nearby weather station and the temperature simulated based on the modified CTTC model. The result showed that the difference in cooling load under two scenarios differs according to various time of the day and generally range from 20% to 50%, increasing to 70% at night. The simulated temperature is generally higher than the temperature provided by the weather station by 4°C. The heating load, assuming 18°C indoor temperature, doesn't vary much under two scenarios. Source: Li, Xianting, Li, Ying, and Chen, Jiujiu, "Effect of Urbanization on Cooling Load of Residential Buildings." *Heating, Ventilation and Air Conditioning*, 2002 32(2)

determine the effectiveness of natural ventilation and influence the heat island effect. How the building-building and building-site relationship affect urban heat island and subsequently the energy consumption of the buildings themselves will be further discussed in the section on microclimate simulation tools.

Another limitation of most building energy simulation programs is also worth noting. As these tools often adopt a mechanical approach, the prediction is based on physics principals regardless of the actual occupants. However, research has demonstrated the strong influence of occupants' behavior on energy consumption. An early paper by Seligman et al[8] showed that " *variation in energy consumption was found to be as great as two to one*" among units *"identical in floor plan, position in the interior of a townhouse row, builder, construction materials, and climate"; and "the energy consumption of the house with the new residents cannot be predicted from the energy consumption of the same house with the previous residents"*. A recent paper by the same authors further showed that *"immediate feedback to homeowners concerning their daily rate of electricity usage would reduce electricity consumption"*[9]. Neglect of behavioral issues shadows the accuracy of predictions by simulation tools, and the incorporation of behavioral factors into future tools is critical in providing meaningful feedbacks for designers.

3.4 Summary of Building Simulation Tools

The approach facilitated by building simulation tools is different from rating systems and best practices. These tools do not tell architects and planners what to do instead, they predict the energy consumption of proposed designs, from which planners and architects can make adjustments until a satisfactory energy profile is reached. The scale of building simulation tools varies from one individual building to a cluster of buildings.

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[8] Seligman, Clive, John M. Darley, and Lawrence J. Becker. "Behavioral approaches to residential energy conservation." *Energy and Buildings* 1, no. 3 (April 1978): 325-337.

[9] Seligman, Clive, and John M. Darley. "Feedback as a means of decreasing residential energy consumption." *Journal of Applied Psychology* 62, no. 4 (August 1976): 363-368.

Building simulation tools have three major **advantages** in informing designers as compared to rating systems and model projects, the provision of feedback on specific designs, the consideration of complicated trade-offs, and the applicability to different climate conditions.

Feedback on specific designs –Building energy simulation tools provide feedback on energy consumption on specific physical design. This function fulfills the limitations of rating systems and model projects in informing designers, as the latter two fail to establish the linkage between form and actual energy consumption, preventing designers from estimating the energy consumption of their own designs.

Consideration of complicated tradeoffs – Rating systems often neglect or treat separately trade-offs between different design elements such as solar gain in winter versus shading in summer, orientation for solar gain versus orientation for better ventilation, etc. Best practices demonstrate the importance of these tradeoffs, however they fail to quantify the energy consequences of different measurements to address these tradeoffs. Building simulation tools take into concern these tradeoffs when predicting the energy profile of a design, and designers can make informed decisions based on predicted energy profiles.

Universal applicability – The reliance of building analysis tools on physics principles enables them to apply to projects across locations, as long as local weather information is available as an input of the simulation.

On the other hand, building simulation tools also have **limitations** that hinder their accuracy and ability during the preliminary design stage. The foremost limitation is **a poor understanding of the built form's impact on microenvironment**. The weather information from nearby weather stations used by simulation tools as weather data input might differ significantly from the site-specific weather information modified by the interplay between buildings and the site, causing inaccuracy in the simulation result, as discussed above and in the following section. A second limitation is the **disregard of occupants' behavior**. In addition, building simulation tools usually require **too many details of the individual building** and are therefore less efficient to use during the preliminary design process. Finally, simulation programs only provide ex post evaluations but **no design guidance** for planners and architects from the outset.

A review of building simulation tools also provides several insights. As some tools such as DeST can also simulate the energy consumption of clusters of buildings, it is possible to explore the interrelationship between building energy consumption and the neighborhood form with existing tools in a simplified manner focusing on layout and massing rather than the details of individual buildings (plan, material and HVAC system, etc.). In addition, as many simulation tools are based on the combination of different core programs, other tools or approaches might supplement the limitations of building energy simulation tools in guiding preliminary site design.

Chapter IV
Microclimate Simulation Tools

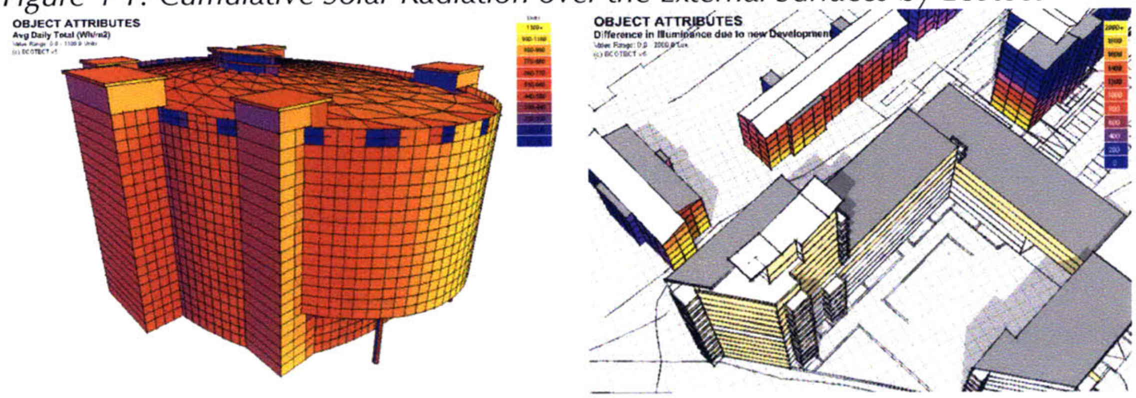
As mentioned in the previous chapter, building energy analysis tools fail to take into account the surrounding environment. This chapter briefly examines outdoor environment simulation tools to see how these issues are addressed from three aspects: shading / solar radiation from neighboring buildings, airflow/wind regarding air pressure, direction and speed, and temperature / heat island effect. These three aspects are chosen because (1) they are proven to have influence on building energy performance and (2) they are greatly affected by the layout of buildings, streets and trees, or in short the neighborhood form. When the scale expands from buildings to the neighborhood, the fundamental concerns in terms of operational energy consumption lie in solar and wind and how they interact with the built form.

4.1 Shading, Solar Radiation and Microclimate

Increased solar radiation can help decrease heating load in winter and, on the other hand, might increase cooling load in summer if not properly shaded. Solar gain of a freestanding building is quite different from one closely surrounded by other buildings and trees. In addition to an individual building's solar gain, the ground and building surface's receiving and reflection of radiation also plays an important role in the urban heat island effect. Increased shading, either on neighboring buildings or the ground, proves to help mitigate this effect.

Many building energy analysis tools include modules dealing with solar radiation such as Ecotect, Bsim, DeST, etc. Ecotect, for example, can simulate and visualize total solar radiation on ground and building surfaces over any period. These analyses give us qualitative as well as quantitative information on irradiation that buildings receive. However, this information is not interpreted into energy data and the tradeoffs between summer and winter are hardly reflected.

Figure 4-1: Cumulative Solar Radiation over the External Surfaces by Ecotect[1]



One tool that goes beyond calculating accumulated solar gain is City-Sim's "evolutionary optimization algorithms[2]", a solver that finds the scenario under which the building surfaces receive the maximal irradiation. Experimental applications of the solver were discussed in Kampf and Robinson's 2010 paper. One of the applications was a cluster of 25 cubic buildings, and the objective was to maximize total solar radiation on all surfaces of those buildings by optimizing building heights. The only variable was the height of each building ranging from 0-124 floors, resulting in 25 parameters and 124^{25} possible combinations. A series of 124^{25} simulations pinpointed the optimal combination as shown in Figure 4-2. A second experiment also used cubic buildings but this time maximized solar radiation by optimizing the position of each building and kept the building height identical. Two variables were used to describe the location of each building, and the optimal locations are shown below.

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[1] Marsh, Andrew, "ECOTECT and EnergyPlus," *Building Energy Simulation User News*, Vol 24, No.6, November/December 2003

[2] Kämpf, Jérôme Henri, and Darren Robinson. "Optimisation of building form for solar energy utilisation using constrained evolutionary algorithms." *Energy and Buildings* 42, no. 6 (June 2010): 807-814.

Figure 4-2: Maximizing Solar Radiation by Optimizing Building Height[3]

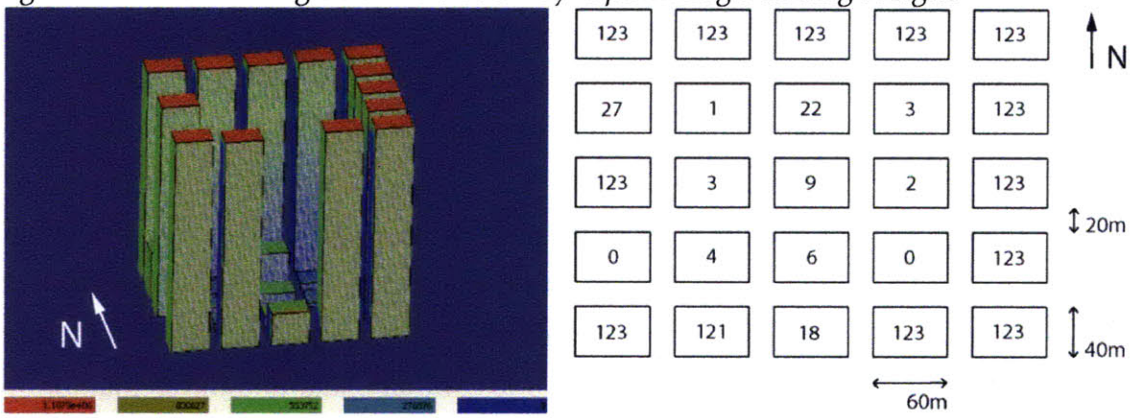
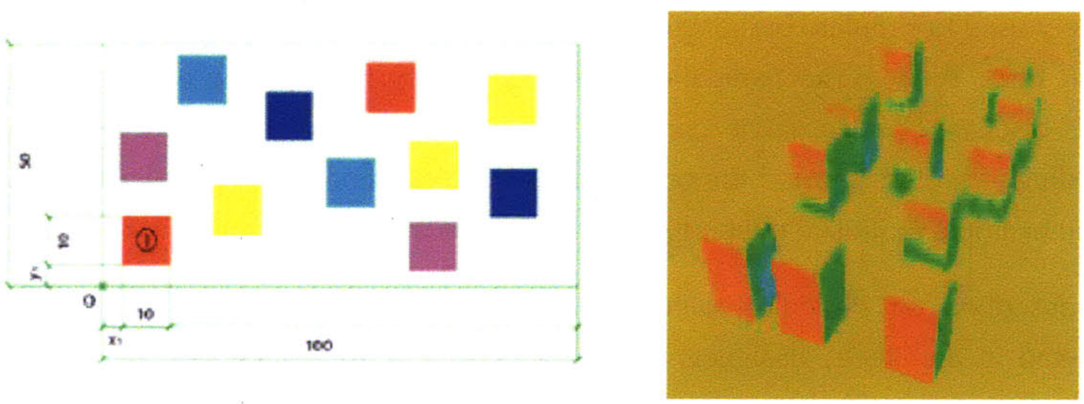


Figure 4-3: Maximizing Solar Radiation by Optimizing Building Location[4]



These experiments demonstrate the possibility for simulation tools to generate designs in addition to passive evaluation of completed ones. How geometric information is interpreted into parameters in a simplified way also provides insight into how variations within prototypes might be described (as discussed in the next section on neighborhood level simulation tools).

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[3] Pheonics Case Study – Flow Around Buildings, Music House Site, by CHAM Limited, Retrieved on 2nd July, 2010 from: http://www.cham.co.uk/casestudies/FlowAroundBuildings_2.pdf
[4] Robinson, Darren, Christophe Giller, Frédéric Haldi, Fei He, Jérôme Kämpf, André Kostro, and Adil Rasheed, "Urban Level Performance Prediciton: City-Sim", Presentation Slides

4.2 Wind, Airflow and Microclimate

The shape and orientation of the building will change wind speed and wind-flow patterns, and in return, the wind pressure determines the rate of heat transfer on the building surface[5]. In building energy analysis tools, the input of wind information usually uses that of the dominant wind of the season. However, the actual wind pattern surrounding a building is different after passing through various buildings before reaching the targeted building. As a consequence, careful combinations of buildings and streets are used as strategies to improve microclimate in various ways: to reduce wind speed in the case of Bo01, to facilitate natural ventilation in the case of Masdar, and to achieve both in places with cold winter and hot summer.

Computational Fluid Dynamics (CFD) is a major tool to simulate fluid flows and is widely used to simulate building outdoor and indoor airflow/heat flow as well as in other fields such as mechanical engineering. Among the building energy analysis tools discussed above, some contain CFD modules to project airflow within the building as well as around the building. Here I pick Phoenics, a popular CFD tool as an example to illustrate their functions and relevance to the study.

As described on Phoenics' official website, FLAIR, a subset tool of Phoenics targeted at architects, designers and engineers who are concerned for the built environment, *"enables the user to visualize, evaluate and refine air-flow patterns on a micro- as well as a macro-scale"*, and *"predicts velocities, pressures, temperatures and smoke concentrations everywhere in the domain being simulated[6]"*. The simulated result could be visualized onto the 3D model of the project, both revealing the impact of wind on the buildings as well as on the open space at different height as shown on the figures below. Similar to shading/solar radiation tools, these visualizations give us qualitative as well as quantitative perception of the wind environment surrounding the buildings, however, no guidance is

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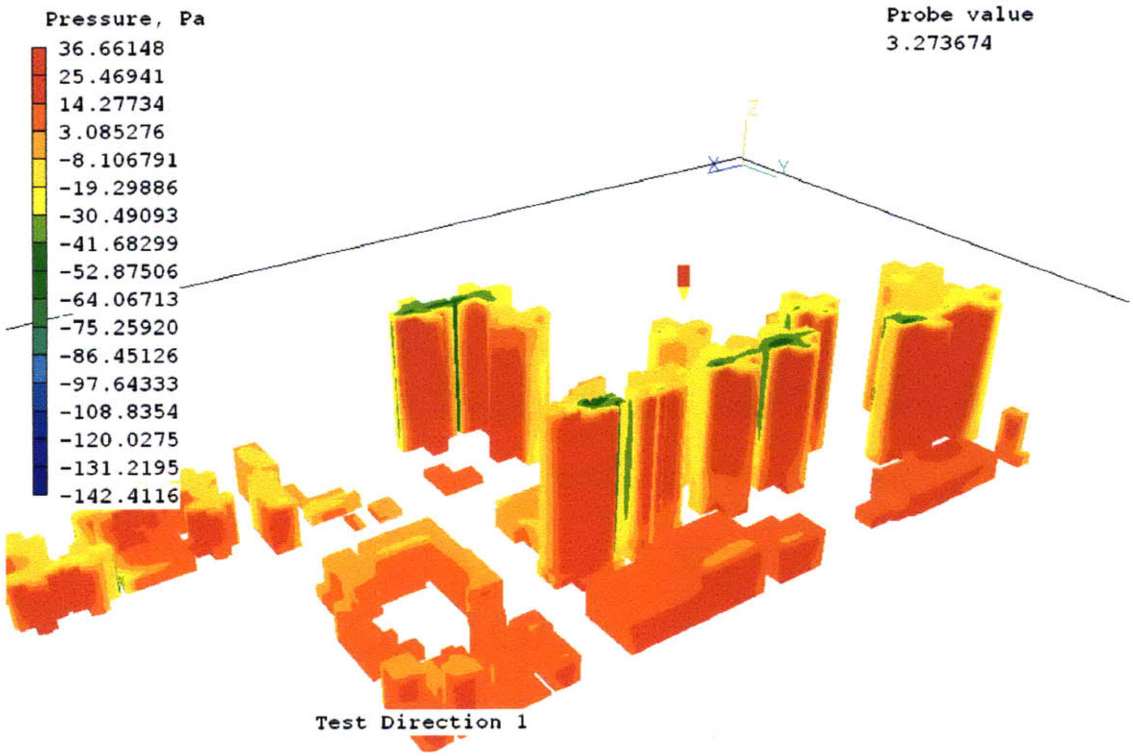
[5] Arens, Edward A., and Philip B. Williams. "The effect of wind on energy consumption in buildings." *Energy and Buildings* 1, no. 1 (May 1977): 77-84.

[6] Pheonics/Flair Product Description, by CHAM Limited, Retrieved on 2nd July, 2010 from http://www.cham.co.uk/casestudies/hvacapps.php

provided in terms of how to translate this information into energy data. What does a wind pressure of 36Pa imply versus that of 14Pa? Does a higher wind pressure imply better ventilation? If so, what is the magnitude of the potential energy saving as a consequence of better ventilation?

Figure 4-4: Wind Pressure on Buildings, Simulated by FLAIR, Phoenics[7]



[7] Pheonics Case Study – Flow Around Buildings, Music House Site, by CHAM Limited, Retrieved on 2nd July, 2010 from: http://www.cham.co.uk/casestudies/FlowAroundBuildings_2.pdf

Figure 4-5: Wind Speed on Buildings, Simulated by FLAIR, Phoenics[8]

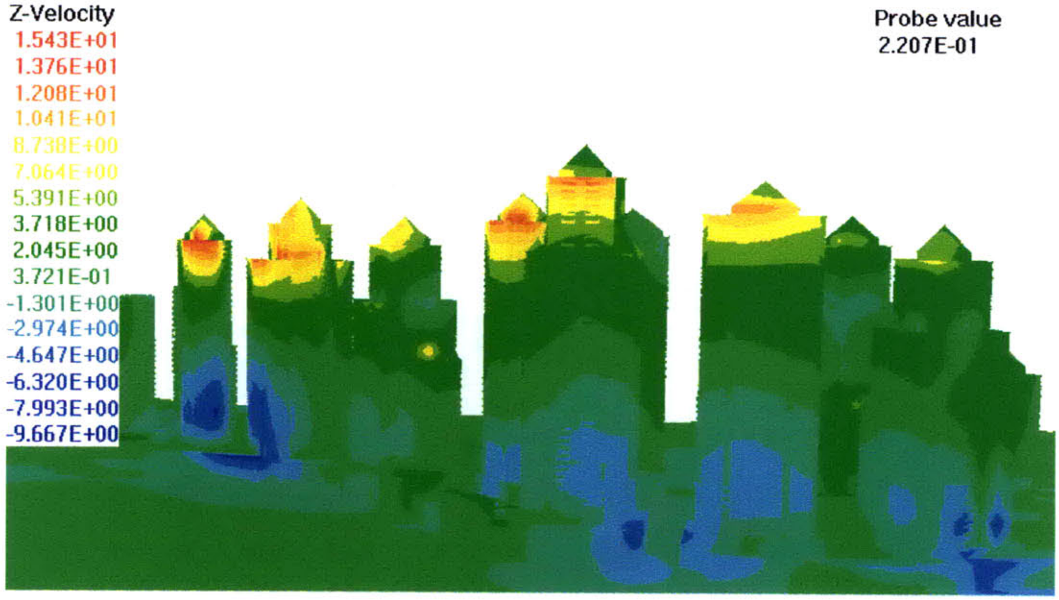


Figure 4-6: Wind Speed at 20 Meters above Ground, by FLAIR, Phoenics[9]

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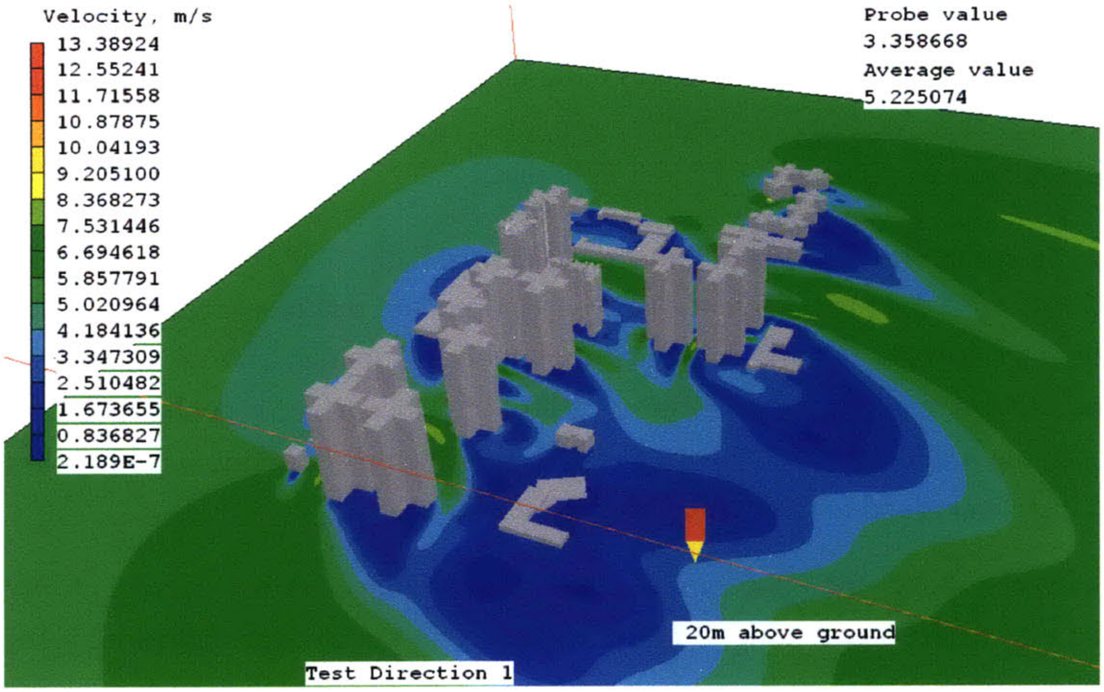
[8] Pheonics Case Study – Flow Around Buildings, Jubeirah Beach Complex,by CHAM Limited, Retrieved on 2nd July, 2010 from://www.cham.co.uk/casestudies/FlowAroundBuildings.pdf
[9] Pheonics Case Study – Flow Around Buildings, Music House Site, by CHAM Limited, Retrieved on 2nd July, 2010 from: http://www.cham.co.uk/casestudies/FlowAroundBuildings_2.pdf



In addition to 3D visualization of temperature, velocity and pressure, FLAIR also claims in its online description to serve as *"a guide to HVAC settings that will provide a comfortable environment"* and *"help designers reduce the capital cost of HVAC systems by avoiding over sizing"*. It seems FLAIR can calculate the heating and cooling load of a building and therefore directly or indirectly predict energy consumption. However, no information is given regarding whether and how it connects indoor airflow information with the outdoor wind environment. It does not seem that the predicted building energy consumption has taken into account the variation of the outdoor situation, and is most likely using weather information from the nearest weather station as the simulation context.

In addition to the two limitations discussed above – the inability to interpret the outdoor wind environment into energy data and the disconnect between indoor and outdoor information, another limitation of FLAIR as well as other CFD simulation software is their daunting complexity in calculation. A snapshot simulation of the outdoor wind environment might easily take hours or even days to conduct, depending on the complexity of the surrounding buildings. The time-consuming nature of the software prevents it from acting as an exploratory tool to inform designers during the decision-making process. Finding ways to utilize the simulation tool during research, explore the relationship between simulated results and parameters defining the built form, and represent this relationship in a simplified way will be explored later in this thesis.

4.3 Temperature/Heat Island Effect and Microclimate

As discussed above, the difference between indoor and outdoor temperature plays a dominant role in building energy consumption in summer, and the urban heat island effect might contribute to a 20%-50% increase in cooling load [10]. Measurement data from Santamouris et al further identified a doubling of cooling load with heat island intensity exceeding 10 °C[11].

On the other hand, the built form is a key factor influencing the intensity of heat island effect. Stone and Rodgers found in 2001 that radiant heat emission, a key factor contributing to the form of heat island effect, is correlated to density and *"lower density patterns of residential development contribute more radiant heat energy to surface heat island formation than higher density development patterns"*[12]. Bourbia and Boucheriba further proved that *"the geometry of streets defined by height/width ratio, sky view factor (SVF) and the orientation… directly influences the absorption and emission of incoming solar and outgoing long wave radiation which has a significant impact on the temperature variations within the street as well as the surrounding environment.*[13]*"* Similar is the effect of other urban open spaces.

In addition to three-dimensional building forms, open space design regarding trees, pavement, etc. also significantly influence the outdoor temperature. The ability of

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[10] Li, Xianting, Li, Ying, and Chen, Jiujiu, "Effect of Urbanization on Cooling Load of Residential Buildings." Heating, *Ventilation and Air Conditioning*, 2002 32(2)

[11] Santamouris M, Papanikolaou N, Livada I, Koronakis I, Georgakis C, Argiriou A, Assimakopolus DN. On the impact of urban climate on the energy consumption of building. Solar Energy 2001; 70(3):201–16.

[12] Stone, Brian, and Michael O. Rodgers. "Urban Form and Thermal Efficiency: How the Design of Cities Influences the Urban Heat Island Effect." *Journal of the American Planning Association* 67, no. 2 (2001): 186.

[13] Bourbia, F., and F. Boucheriba. "Impact of street design on urban microclimate for semi arid climate (Constantine)." *Renewable Energy* 35, no. 2 (February 2010): 343-347.

material to absorb and reflect solar radiation determines the surface temperature of the ground, and increasing a material's albedo has been proven to be one of the most effective approaches to mitigate urban heat island effect[14]. Research on advanced materials has shown a surface temperature difference ranging from 2°C - 10°C using the same material only with different colors[15]. The material of surrounding buildings serves a similar role as ground paving. In addition, trees and plants also significantly reduce air temperature through shading and evapotranspiration. *"Shaded surfaces, for example, may be 11°C –25°C cooler than the peak temperatures of unshaded materials. Evapotranspiration, alone or in combination with shading, can help reduce peak summer temperatures by 1°C – 5°C."*[16]

Generally speaking, outdoor temperature/heat island effect is closely related to solar radiation, wind, and their interaction with the built environment. Solar radiation is positively correlated to heat island effect, while the increase of wind speed mitigates heat island intensity[17].

There are various programs that can simulate urban heat island effect at various scales. Although none of them dominates the field, simulation tools at the micro-scale is most relevant to my study. The mechanisms of these simulation tools are highly complicated and deserve a more extensive explanation than this thesis can provide. According to Mirzaei and Haghighat[18] who summarized various

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[14] Mirzaei, Parham A., and Fariborz Haghighat. "Approaches to study Urban Heat Island - Abilities and limitations." *Building and Environment* 45, no. 10 (October 2010): 2192-2201.
[15] Santamouris, M., "Heat Island Mitigation Using Advanced Materials, " Group Building Environment Studies, Univ. Athens, internal material
[16] "Heat Island Effect", U.S. Environmental Protection Agency, retrieved on July 14, 2010 from http://www.epa.gov/hiri/mitigation/trees.htm. Original source: kbari, H., D. Kurn, et al. 1997. Peak power and cooling energy savings of shade trees. Energy and Buildings 25:139–148; and Huang, J., H. Akbari, and H. Taha. 1990. The Wind-Shielding and Shading Effects of Trees on Residential Heating and Cooling Requirements. ASHRAE Winter Meeting, American Society of Heating, Refrigerating and Air-Conditioning Engineers. Atlanta, Georgia.
[17] Arnfield AJ., "Review Two Decades of Urban Climate Research: A Review of Turbulence, Exchanges of Energy and Water, and The Urban Heat Island, *International Journal of Climatology* 2003;23:1e26.
[18] Mirzaei, Parham A., and Fariborz Haghighat. "Approaches to study Urban Heat Island - Abilities and limitations." *Building and Environment* 45, no. 10 (October 2010): 2192-2201.

approaches to study urban heat island effect, UCM (urban canopy model based on energy balance equation), and CFD (computational fluid dynamics model) are two major approaches with numerous simulation tools under each. In addition, CTTC (cluster thermal time constant model) and its various modifications are relatively simple approaches to predict canopy layer temperature[19]. Whatever approach, solar radiation, the thermal attributes of materials, both for pavement and building elevation, wind and building layout are all factors to be considered in heat island simulations. As simulations trace solar radiation and its reflection among various surfaces, and the heat storage and transfer during this process, these simulations are even more time-consuming than wind simulation tools discussed above. A snapshot simulation predicting air temperature requires at least several days to conduct.

4.4 Summary of Microclimate Simulation Tools

A review of outdoor environment simulation tools from three aspects: shading/solar radiation, airflow/wind, and temperature/heat island effect further demonstrates the close relationship between buildings' energy consumption and neighborhood form. This relationship is embodied in the critical influence of building layout and site design on the buildings' immediate microclimate, which in turn determines the buildings' energy consumption. Therefore, the microenvironment defined by airflow conditions, air temperature and the extent of radiation/shading is the key linkage between building energy consumption and neighborhood form. Discussion of building energy consumption without taking into concern the microclimate is therefore incomplete.

In terms of the simulation tools themselves, none of them are currently connected to the building's energy performance in addition to descriptive analysis of the elements - solar, wind, and temperature - under study. Nor is sufficient information provided that links these descriptive data with their potential energy implications even in a very preliminary manner. Another limitation of these tools in informing

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[19] Shashua-Bar, Limor, Hanna Swaid, and Milo E. Hoffman. "On the correct specification of the analytical CTTC model for predicting the urban canopy layer temperature." *Energy and Buildings* 36, no. 9 (September 2004): 975-978.

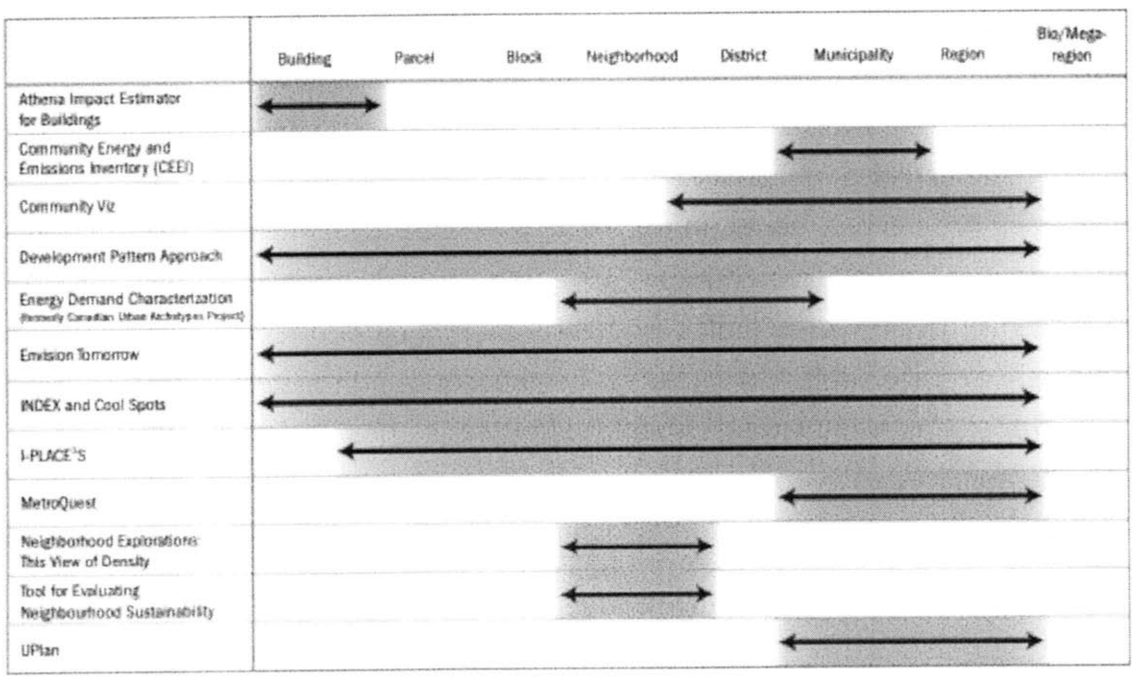
designers is the extent of their complexity. It takes hours or even days to simulate individual elements, and a synthesis of all elements, if there exists such an approach, would involve daunting calculations requiring superior computer performance and a huge amount of time. A means of establishing the relationship between design parameters and the microenvironment in a simplified manner based on these simulation tools, and further linking the microenvironment to building energy performance, would be of great value to designers in the preliminary site design stage.

Chapter V
Energy Simulation Tools at the Neighborhood Scale

5.1 The Common Approaches

Various neighborhood-wide or citywide simulation tools try to establish the relationship between the built form and energy consumption. A report by Lincoln Institute of Land Policy summarizes existing tools to assess GHG (greenhouse gas) emissions with scales ranging from the building level to the regional level.

Figure 5-1: Scales of Existing Tools to Assess Greenhouse Emissions[1]



A scan through these tools indicates that (1) most tools are pretty comprehensive covering energy consumption/greenhouse gas emission from transportation, building operational and life cycle energy consumption; (2) many of these tools focus on the relationship between land use, road system design and transportation

[1] Condon, Patrick M., Duncan Cavens, and Nicole Miller. "Urban Planning Tools for Climate Change Mitigation." Policy Focus Report. Lincoln Institute of Land Policy, 8, 2009. P.14

energy consumption; (3) for those tools covering building operational energy consumption, the total consumption of a neighborhood or district is calculated based on the aggregation of a prototypical building's energy consumption as represented by "Envision Tomorrow". Discussion will follow regarding the third point. That said, understanding of the built form's impact on energy consumption is focused either at the macro level (land use and street layout) or the micro level (buildings) while the intermediate scale, neighborhood form, and the relationship between building-building and building-site are ignored.

Figure 5-2 represents the approaches that aggregatea prototypical building's energy consumption to calculate the energy consumption of the entire neighborhood or district. This bottom-up approach classifies residential buildings into different categories according to their characteristics and energy performance, then simulates the energy consumption of each building type and finally sums up the total consumption at a city or district level[2]. Similar approaches are summarized in the 2009 paper of Swan et al. These approaches attribute energy consumption only to the characteristics of individual buildings and disregard the influence of their neighbors, or in other words, the layout of a cluster of buildings. This influence, however, was verified in a 2009 paper[3], in which the heating and cooling loads of a wooden structure were simulated against different outdoor conditions defined by building coverage, adjacent building height, surrounding trees, etc. The result showed meaningful differences under various scenarios, indicating the influence from the immediate environment on operational energy consumption.

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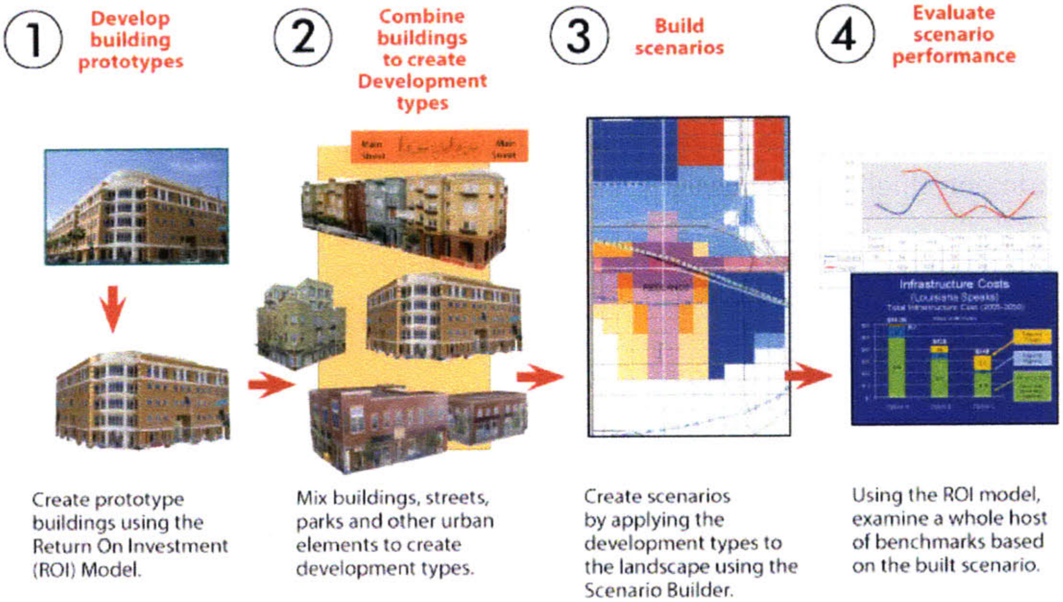
[2] Swan, Lukas G., and V. Ismet Ugursal. "Modeling of end-use energy consumption in the residential sector: A review of modeling techniques." *Renewable and Sustainable Energy Reviews* 13, no. 8 (October 2009): 1819-1835.
Shimoda, Yoshiyuki, Takahiro Asahi, Ayako Taniguchi, and Minoru Mizuno. "Evaluation of city-scale impact of residential energy conservation measures using the detailed end-use simulation model." *Energy* 32, no. 9 (September 2007): 1617-1633.
[3] He, Jiang, Akira Hoyano, and Takashi Asawa. "A numerical simulation tool for predicting the impact of outdoor thermal environment on building energy performance." *Applied Energy* 86, no. 9 (September 2009): 1596-1605.

Figure 5-2: Approaches That Calculate Neighborhood/District Energy Consumption based on the Aggregation of Individual Building Prototypes[4]



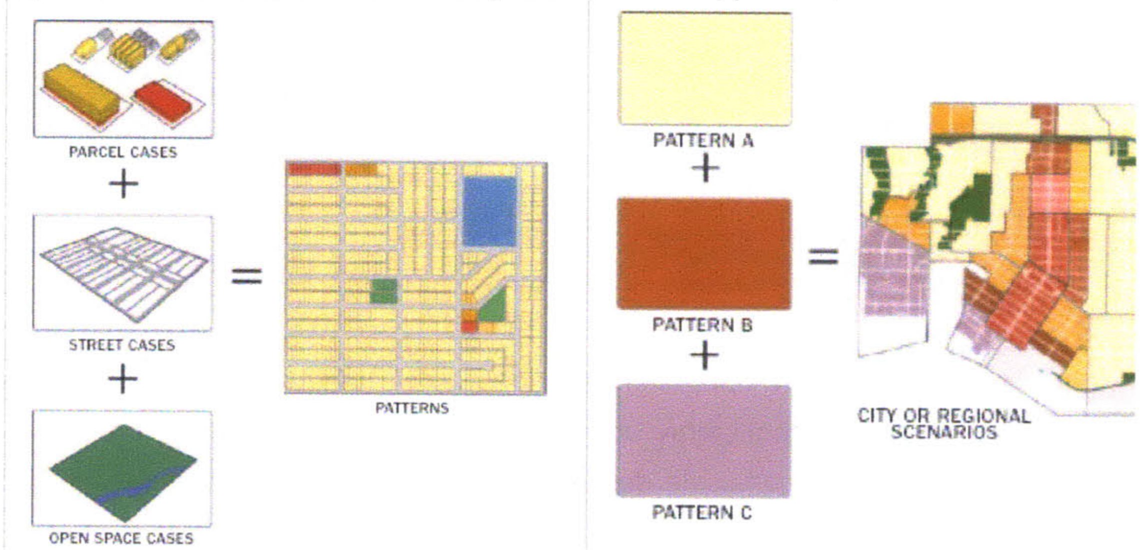
Despite the limitations, the approach described above might shed some light on how to make simulation tools more accessible to designers. The use of prototypes and the aggregation of small-scale design elements simplifies and accelerates the simulation process, as an individual building's energy consumption is pre-simulated. If the scale of individual buildings can be expanded into clusters of buildings that take into account the relationship between buildings and the site, the aggregation of prototypical clusters instead of prototypical buildings might serve to predict neighborhood energy consumption for decision makers during the preliminary design stage in a quick way. Flexibility might be enhanced if certain variation in parameters such as density, orientation etc. can also be integrated.

The use of prototypes proves to be a common approach and is repeatedly employed in other tools. One of these tools, Development Pattern Approach, attempts the use of prototypes at a larger scale. Each "Pattern" integrates concerns of parcel layout, street types and open space. In addition, *"each of these examples contains visual and quantitative information, including three-dimensional digital*

[4] Condon, Patrick M., Duncan Cavens, and Nicole Miller. "Urban Planning Tools for Climate Change Mitigation." Policy Focus Report. Lincoln Institute of Land Policy, 8, 2009. P.32

models, site plans, and data on floor-area ratios, uses, parcel coverage and the number of residential units.[5]" Despite the attempt to classify prototypes on a cluster scale, the tool fails to predict total energy consumption beyond the aggregation of individual buildings as the simulation is based on individual building's energy profile classified into single-family detached houses, duplexes, row houses, low-rise apartments, high-rise apartments, etc.

Figure 5-3: Patterns in DPA (Development Pattern Approach)[6]



5.2 Approaches That Go Beyond – Taking Shading into Concern

There are also efforts to simulate energy consumption at the neighborhood level that go beyond the simple aggregation of individual buildings. These attempts fall into two broad categories. The first category is essentially an upgraded version of building-based simulation tools. However, it tries to take into account the interface between individual buildings, mainly the shading effect among clusters of buildings. The second category is far more complicated, addressing the inter-relationship between buildings and their surrounding built environment. In other

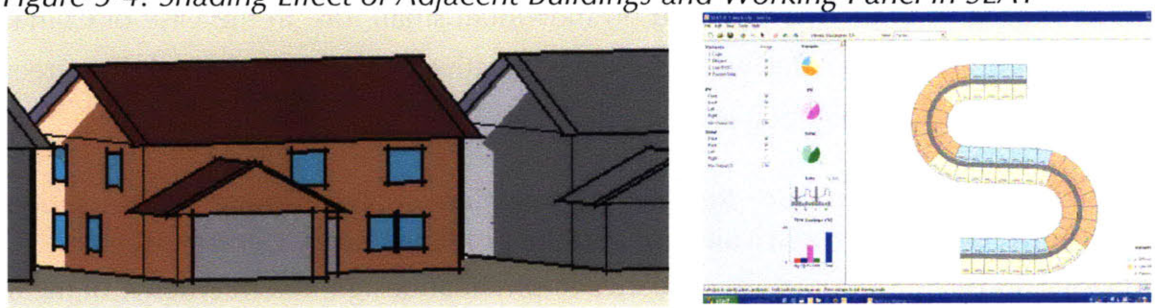
[5] Condon, Patrick M., Duncan Cavens, and Nicole Miller. "Urban Planning Tools for Climate Change Mitigation." Policy Focus Report. Lincoln Institute of Land Policy, 8, 2009. P.38

[6] Condon, Patrick M., Duncan Cavens, and Nicole Miller. "Urban Planning Tools for Climate Change Mitigation." Policy Focus Report. Lincoln Institute of Land Policy, 8, 2009. P.37

words, they are usually combined tools trying to establish conversation between a building energy simulation tool and a microclimate simulation tool.

One preliminary attempt of the first category is the Subdivision Energy Analysis Tool (SEAT) developed by National Renewable Energy Laboratory, a national laboratory of the U.S. Department of Energy. The researchers aimed to connect energy consumption with street layout, a factor that determines neighborhood form to some extent, as they believe *"housing orientations are largely determined by street layout"* and *"housing orientation affects energy consumption for heating and cooling"* as well as energy production[7].

Figure 5-4: Shading Effect of Adjacent Buildings and Working Panel in SEAT[34]



The program uses predesigned house plans simulated through traditional building energy simulation tools. It provides several (five, for example) housing types with variation of energy strategies (four, for example) for each type, which generates 20 combinations/sub-housing-types. Each sub-type is then run through a building energy simulation program, in this case BEopt, to predict energy consumption in different orientation scenarios. When a street curve is drawn which determines the orientation of lots and buildings, and the designer specifies the percentage of certain building types, the program can thereafter predict the energy consumption of the entire neighborhood. The result is detailed into information such as heating consumption, cooling consumption, PV roof assignment, etc.

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[7] Christensen, C., and S. Horowitz. "Orienting the Neighborhood: A Subdivision Energy Analysis Tool; Preprint." Conference Paper, to be presented at the 2008 ACEEE Summer Study on Energy Efficiency in Buildings. National Renewable Energy Laboratory, 2008.

The first version of SEAT is in essence still an aggregation of the energy consumption of individual buildings. The developer claims to incorporate the issue of shading, both from neighboring buildings and from trees, into later versions. This approach will fulfill the program's mission as a neighborhood-scale simulation tool and it would be interesting to know how the shading issue is actually addressed. Another merit of this tool is its simplified calculation. As it tries to address the issue of neighborhood form in terms of street layout, building level information is pre-simulated according to prototypes, an approach that significantly accelerates simulation speed.

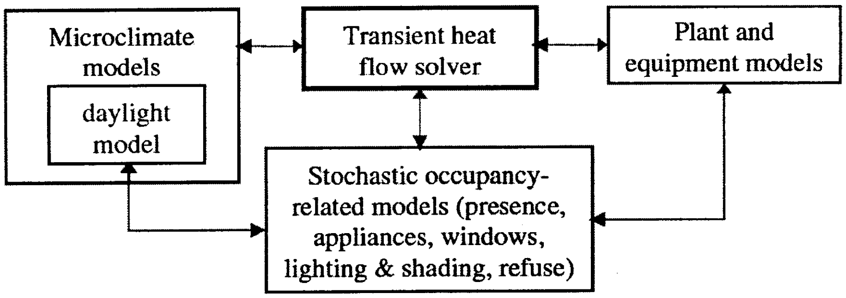
Another issue that jeopardizes the tool's applicability to our research is its primary focus on single-family houses based on individual small lots. In the case of China, as we have larger blocks with buildings relatively less constrained by street orientation, this tool might be less useful.

5.3 Approaches That Go Beyond Aggregation – Establishing Conversation between the Microenvironment and the Building Energy Consumption

Attempts to establish conversation between physical design, the microenvironment and building energy consumption are far more complicated, and SUNtool (Sustainability of Urban Neighborhoods) is one of them, although not fully developed yet. SUNtool is targeted at scales ranging from a cluster of several buildings to the whole city. Compared to building level energy simulation tools, it adds the microclimate models to simulate immediate climate information surrounding buildings as the input for the transient heat flow solver, the module calculating heating/cooling load, as well as a stochastic occupancy module to account for factors related to occupants' behavior. Figure 5-5 illustrates the conceptual process flow of the SUNtool software.

Figure 5-5: The Conceptual Design of SUNtool software[8]

[8] Robinson, D., N. Campbell, W. Gaiser, K. Kabel, A. Le-Mouel, N. Morel, J. Page, S. Stankovic, and A. Stone. "SUNtool - A new modelling paradigm for simulating and optimising urban sustainability." *Solar Energy* 81, no. 9 (September 2007): 1196-1211.



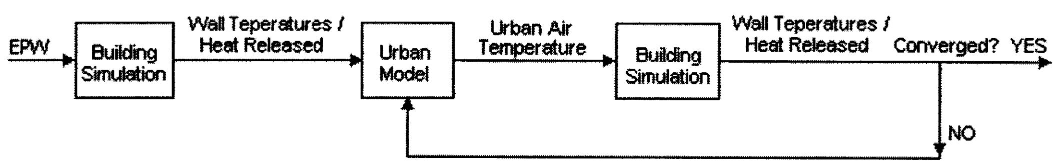
The two primary aims in microclimate models are to (1) trace radiation *"for prediction of radiation exchange at building envelops"* and (2) *"account for the temperature difference between rural weather stations where the climate data is measured and the local urban context.*[9]*"* However, due to the high complexity of thermal microclimate models, they were not included in SUNtool until its successor – City-Sim – was developed. City-Sim adopts the basic structure of SUNtool with a coupled meso/microclimate model to simulate microclimate surrounding the buildings for more accurate input of weather data. However, as City-Sim has not yet been released, and all information about it comes from journal articles, I am not sure whether it is fully developed or these functions are yet to be materialized, nor do I know the complexity of operating this program and whether it serves to inform designers at the preliminary design stage.

A less ambitious attempt comes from MIT's Building Technology Group. In their 2009 paper, Unzeta et al introduced a program that couples a building simulation model with an urban canopy model to provide site-specific weather information. The abstract clearly explains the purpose of this program: *"Building simulation programs predict the thermal performance of buildings under certain weather conditions. Weather information is usually taken from an available weather data file obtained from the closest meteorological station. However, the differences between the local urban climate and the conditions at the closest meteorological station can lead to inaccurate building simulation results. This paper presents an Urban*

[9] Robinson, D., N. Campbell, W. Gaiser, K. Kabel, A. Le-Mouel, N. Morel, J. Page, S. Stankovic, and A. Stone. "SUNtool - A new modelling paradigm for simulating and optimising urban sustainability." *Solar Energy* 81, no. 9 (September 2007): 1196-1211.

Weather Generator (UWG) that couples a building simulation program (EnergyPlus) with a physically based urban canopy model. The UWG scheme modifies weather data files in order to provide site-specific weather information applicable to building simulations.[10]" The mechanism of the program is illustrated in Figure 5-6; the building energy simulation tool calculates heating emission from buildings' HVAC system and the wall temperature based on outdoor temperature from nearby weather station, which are thereafter used as inputs for the urban model, the urban model then calculates its outdoor temperature based on the temperature information from the first step, the wind information from nearby weather stations, and the boundary information defining the outdoor space under study (usually the length, the height and the width of the urban canyon). A balance is reached after several rounds of calculation when the wall temperature simulated by the building model equals the air temperature simulated by the urban model.

Figure 5-6: The Coupling Process of UWG



This approach enables UWG to reach a relatively accurate site-specific outdoor temperature that takes into account the form of the open space (urban canyon) and the impact of building HVAC system's heat release on the site's heat island effect. However, as a preliminary attempt, currently this tool only deals with a simplified geometric definition of the outdoor space, and complicated spaces interpreted as the combination of several canyons are yet untested and might require a significant amount of time to conduct the simulation.

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[10] Unzeta, Bruno Bueno, Leslie K. Norford, Rex Britter, "An Urban Weather Generator Coupling Building Simulations with a Physically Based Urban Model," Building Technology Program, Massachusetts Institute of Technology, presented at *The seventh International Conference on Urban Climate*, 29 June - 3 July 2009

5.4 Summary of Simulation Tools at the Neighborhood Scale

Various neighborhood level simulation tools exist covering issues ranging from transportation, lifecycle, and operational energy consumption. Some of them even take into account behavior of the occupants. Tools dealing with operational energy consumption usually aggregate the energy profile of individual buildings into a neighborhood or city scale regardless of the urban form's impact on building energy consumption.

This chapter discusses approaches that go beyond simple aggregation of individual buildings. These approaches either try to account for irradiation's impact on building energy consumption, embodied in the inter-shading effect within buildings; or use a more sophisticated approach that establishes the relationship between a building simulation tool and a microclimate simulation tool in order to create site-specific weather information for more accurate energy profile. Both approaches acknowledge the importance of the interplay among buildings and the open space in-between. Some of them, like the UWG, go further, taking into account the building energy consumption's impact on the microclimate and as a consequence, back onto the building energy consumption again. However, due to the complexity of these tools, a mature tool that can help designers for decision-making is not available yet.

In addition to the ability to account for building-building and building-site relationships, the tools' applicability to medium-higher density development is also critical to the study of this thesis. Some tools such as SEAL are targeted solely towards single-family dwellings. Although they might also account for neighborhood form information, these tools are not very useful in the urban context.

The use of prototypes and the aggregation of small-scale buildings clusters into a large area might be a viable means to provide simulation tools with simplified calculations. The energy profile of individual prototypes can be pre-simulated with variations in parameters such as cluster density, orientation, distance between buildings, etc. to provide more flexibility. These methodologies will be further discussed in the following chapters.

Summary of Part II

Part II reviews three types of analysis tools related to energy performance: building energy consumption analysis tools, microclimate analysis tools and tools at the neighborhood scale that bridge the previous two kinds of tools.

Neighborhood form impacts energy consumption of buildings in two primary ways: one of them is the inter-shading effect among buildings that determines the direct solar gain of individual buildings. Irradiation impacts both heating load in winter and cooling load in summer. The other is the outdoor temperature or in other words the heat island effect influenced by the interplay among building layout, wind direction and pressure, and the surface material. The variation of outdoor temperature significantly impacts energy consumed in cooling. Finally, if natural ventilation is considered, wind direction and pressure/speed is another factor that links neighborhood form with building energy consumption. The layout of building groups can be engineered to change the speed and direction of wind for optimal ventilation. In addition to building energy consumption, these factors also impact the quality of outdoor environment, enhance or jeopardize the livability of the neighborhood, and as a result, might increase or decrease energy consumption beyond operational building energy consumption.

However, there is currently no fully developed tool that takes into account this interrelationship in a way that facilitates decision-making during the preliminary design stage. Building energy simulation tools at most account for the inter-shading effect; microclimate simulation tools fail to translate the status of outdoor environment into energy data; experimental tools at the neighborhood scale provide insight into possible ways to link the building energy consumption with its surrounding conditions, but are too complicated and not yet mature for practical use.

An ideal tool that predicts in-home operational energy consumption and facilitates designer at the preliminary site plan stage might come from a combination of a building simulation tool and a microclimate simulation tool. However, in light of the complicated and time-consuming nature of energy simulations, certain means of simplification are necessary. ***One approach is the use of prototypes*** inspired by the review of neighborhood scale tools. The energy profile of each prototype and variations within the same prototype can be pre-simulated, providing designers with a full range of options to mix and match. The total energy consumption might be predicted by the accumulation of energy profiles of clusters (whether of the same prototype or cross prototypes). This approach might simplify the prediction of energy consumption for designers who want immediate feedback. As the research project has already developed the pattern book on the fifteen prototypes as guidance to designers, it can be further explored and utilized in the development of the in-home operational-energy-consumption module of the energy pro-forma.

PART III – Demo Tool

Chapter VI

Explore the Energy-Form Relationship in in-home Operational Energy Consumption

This chapter is a preliminary attempt to explore the relationship between neighborhood form and in-home operational energy consumption, which might eventually inform a tool belonging to the overall energy pro-forma as one module or part of the module on neighborhoods' in-home operational energy consumption.

As proposed in Part II, this tool should predict the operational energy consumption of clusters[1] based on prototypes and their variations (the function of a modeling tool) as well as provide the design guidance through these prototypes (the function of a pattern book). Therefore designers are able to make decisions about the whole neighborhood by mixing and matching clusters and meanwhile receiving feedback on the projects' in-home operational energy profile. This chapter summarizes preliminary research into the energy-form relationship to construct such a module on in-home operational energy use. The research itself is also based on prototypes.

6.1 The Goal and Methodology

Ideally, the prediction function of the fully developed module will enable designers to assess the operational energy use of their own cluster design when information regarding the cluster prototype and variables defining the variation of the designer's cluster (as compared to the prototype) are provided. These variables may include but are not limited to more index-like variables such as density, FAR, etc, and more descriptive ones such as the orientation of individual buildings, the distance between buildings, the height of individual buildings, etc. A less desirable option would be to simply provide a chart listing limited number of variations within

[1] The definition of clusters and their relationship to "prototypes" come directly from the research project "Making the Clean Energy City in China", and details will be further discussed later in this chapter.

prototypes and their energy use, to which designers can compare their design and roughly know the energy use of their own design.

To construct such a tool, researchers should establish the quantitative relationship between a cluster's operational energy consumption and these variables defining its form. One approach to explore this relationship within prototypes might be using existing simulation tools (or a combination of several tools to account for as many factors as needed), run a series of simulations on variations within one prototype, and finally establish a quantitative relationship based on the simulation results.

Theoretically, if such a simulation tool exists that accounts for building-building/building-site relationship (maybe a fully developed version of CitySim) and researchers can use it to explore the form-energy relationship, designers would be able to use this tool to directly predict the energy consumption of building groups of any form (regardless of prototype). However as discussed previously, because these simulation tools are exceptionally time-consuming and detail-oriented targeted primarily at research, they turn out to be less helpful for designers in need of feedbacks for preliminary site design. The idea of prototypes is therefore introduced to simplify processing when used as a tool to provide feedback with all the daunting simulations are run by researchers beforehand, meanwhile filtering the influence of building details.

The purpose of this chapter is not to create a complicated simulation tool similar to CitySim that bridges buildings to the microclimate. Instead, its contribution lies in explaining how prototypes can be utilized for a tool that predicts neighborhood energy consumption in a simplified way and how designers can better understand the cluster form using prototypes and their variations.

6.2 Exploration with The Simulation Tool - DeST

Ideally, the simulation tool used for this exploration should account for the building-building and building-site relationship as concluded at the end of Part II, a combination of a building simulation tool and a microclimate simulation tool. However, due to the fact as reviewed in Chapter V that such a tool does not exist yet even in its clumsy form, I use DeST as an alternative for the time being. DeST is a building energy simulation program developed by Tsinghua University, Beijing, China. It has the following major characteristics:

Scale – DeST can be used for a cluster of buildings as well as individual buildings.

Wind – the software regarded natural ventilation as an important factor in determining building energy consumption, and therefore the influence of wind will be incorporated into the simulation result.

Sun – the software takes into concern the effect of shading, both self-shading and shading from surrounding structures.

Scale – the software can simulate energy consumption of a cluster of buildings, and meanwhile briefly taking into concern the building cluster's effect on wind.

Weather information – The weather information used by DeST is based on 50 years' of weather data from 149 weather stations in China, including solar radiation, temperature, humidity, and wind speed/direction. For convenience and in accordance with the research project, I chose Jinan as the context of my exploration.

DeST is fairly comprehensive in meeting the needs of this exploration except for the fact that it does not fully account for building's impact on the immediate outdoor temperature nor does it incorporate behavioral concerns. As this chapter aims to establish a demo tool under the framework proposed in Part II – an energy prediction tool using prototypes – rather than provide a final product, the actual simulation program used in exploring this form-energy relationship can always be replaced by more advanced ones in the future, and the relationship between form and energy updated throughout time for improved accuracy.

6.3 Exploration within the Prototype - Small Perimeter Block

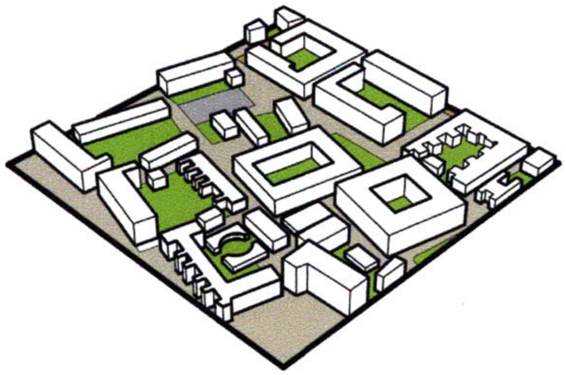
Prototypes used by this chapter are drawn directly from the product of the research project "Making the Clean Energy City in China". Six prototypes with fifteen sub-prototypes were identified in the research project (see Appendix A), and I picked "small perimeter block - simple" to begin with.

I simplified the prototype in the *Pattern Book* based on the project Bo01 into the base case, making it easier for variables to describe the physical characteristics of the prototype and the variation within it. The base case is a square perimeter block with each edge measuring 40 meters long, 11 meters in depth, five stories high, an average dimension of a block in Bo01. The distance between blocks are 10 meters for the base case, and all blocks have two edges parallel to geographical east-west (facing south).

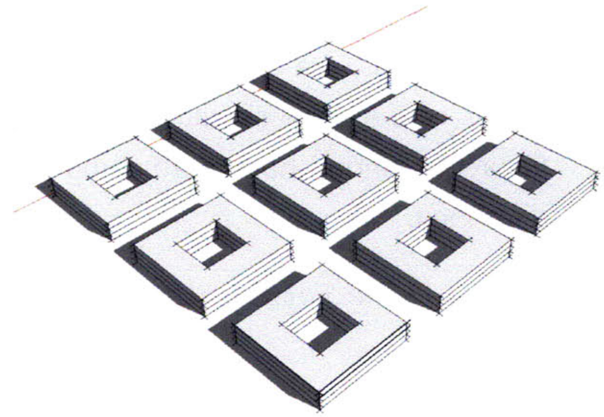
In order to eliminate the impact of buildings' attributes on their energy use (mainly material, fenestration, mechanical system, etc.), I tried to use "identical" buildings in all simulations. As the height and size of the buildings might change (within the same prototype) and even the geometry of the buildings (across prototypes), "identical" is relative and only in terms of the same plan, the same material, the same proportion of windows to walls, the same floor height, etc. I assume therefore, all variation in energy consumption per square meter result from the variation in form at the cluster level rather than the characteristics of individual buildings. However, there might be one limitation of this approach. Although the variation of energy consumption within the same prototype can be accounted for by the cluster form when using the same configuration of individual buildings, the change of building configuration might also influence this form-energy relationship. For example, a cluster composed of buildings with thick walls and few windows might be less sensitive to the surrounding environment than that made of curtain walls, or sensitive in a different way. To mitigate this potential limitation, I used the most common material for residential construction in China – reinforced concrete structure and brick walls – to make sense within the context.

Due to time limitations, this thesis will only test limited variable changes, including orientation, height, and distance between blocks (street width) to see quantitatively to what extent simulated energy use changes with the change of these variables. Future tests hope to add other variables that can describe uneven variations within the cluster, such as a cluster composed of perimeter blocks of different size and orientation, or even different degrees of enclosure to approximate the situation in real life.

Figure 6-1: The Prototype Used in the Simulation



Prototype based on Bo01 by the Research.



Prototype used as base case in the simulation

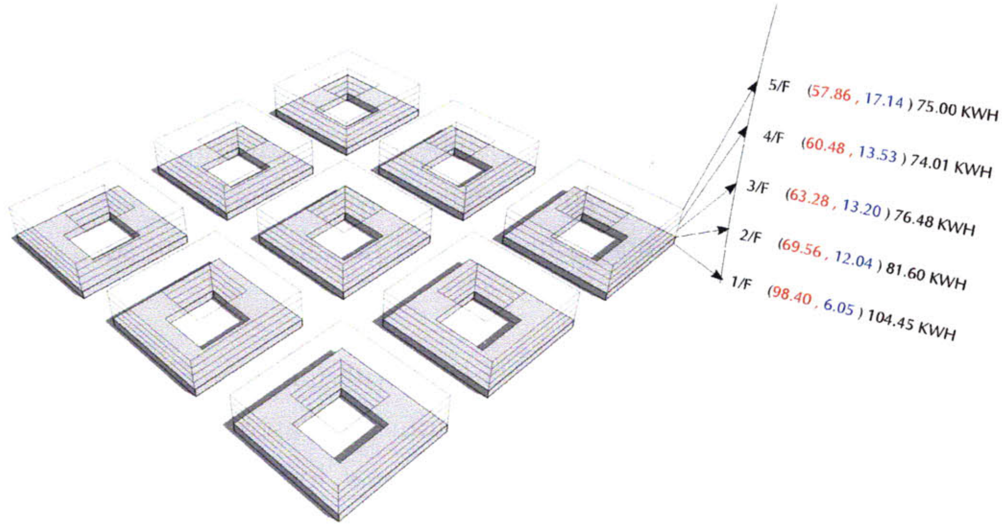
6.4 The Result

A total of 20 simulations are run and the results, including clusters' heating and cooling loads, are listed in Chart 6-1. Figures 6-2 to 6-4 graphically illustrate the results of the three simulations, the variation in height, distance and orientation. Figure 6-5 shows how more complicated variations within the prototype might be described.

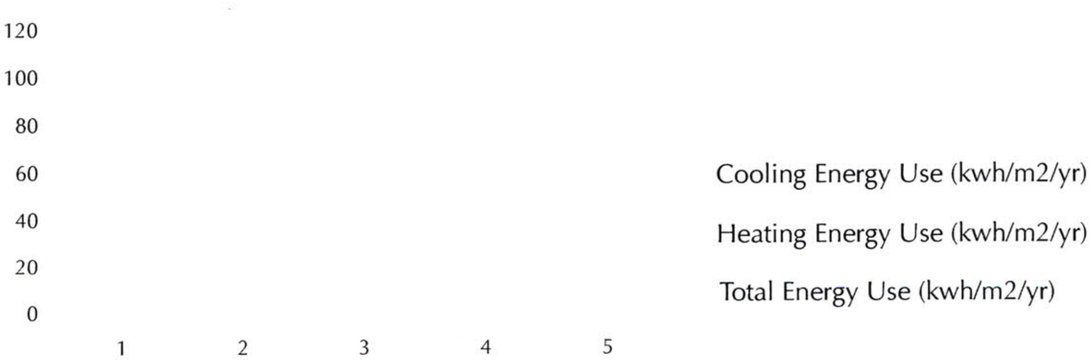
Chart 6-1: The Simulation Results

Name	Floor	Cluster Orientation	Distance	Thickness	Dimension	Heating Load	Cooling Load	Total	Orientation (DeST)
9-50m-1F	1	0	10	11	40*40	98.4	6.05	104.45	270
9-50m-2F	2	0	10	11	40*40	69.56	12.04	81.6	270
9-50m-3F	3	0	10	11	40*40	63.28	13.2	76.48	270
9-50m-4F	4	0	10	11	40*40	60.48	13.53	74.01	270
9-50m-5F	5	0	10	11	40*40	57.86	17.14	75	270
9-60m-1F	1	0	10	11	40*40	90.81	6.93	97.74	270
9-60m-2F	2	0	10	11	40*40	68.29	12.35	80.64	270
9-60m-3F	3	0	10	11	40*40	60.35	13.55	73.9	270
9-60m-4F	4	0	10	11	40*40	53.95	14.14	68.09	270
9-60m-5F	5	0	10	11	40*40	56.32	14.58	70.9	270
9-45m-5F	5	0	5	11	40*40	57.43	12.71	70.14	270
				11					
9-50m-5F-255	5	15	10	11	40*40	58	18.41	76.41	255
9-50m-5F-270	5	0	10	11	40*40	57.86	17.14	75	270
9-50m-5F-275	5	-5	10	11	40*40	57.84	18.17	76.01	275
9-50m-5F-280	5	-10	10	11	40*40	57.9	18.3	76.2	280
9-50m-5F-285	5	-15	10	11	40*40	57.94	18.54	76.48	285
9-50m-5F-300	5	-30	10	11	40*40	58.3	19.27	77.57	300
9-50m-5F-315	5	-45	10	11	40*40	58.47	19.59	78.06	315

*Figure 6-2: Yearly Energy Consumption with Variation in Height**



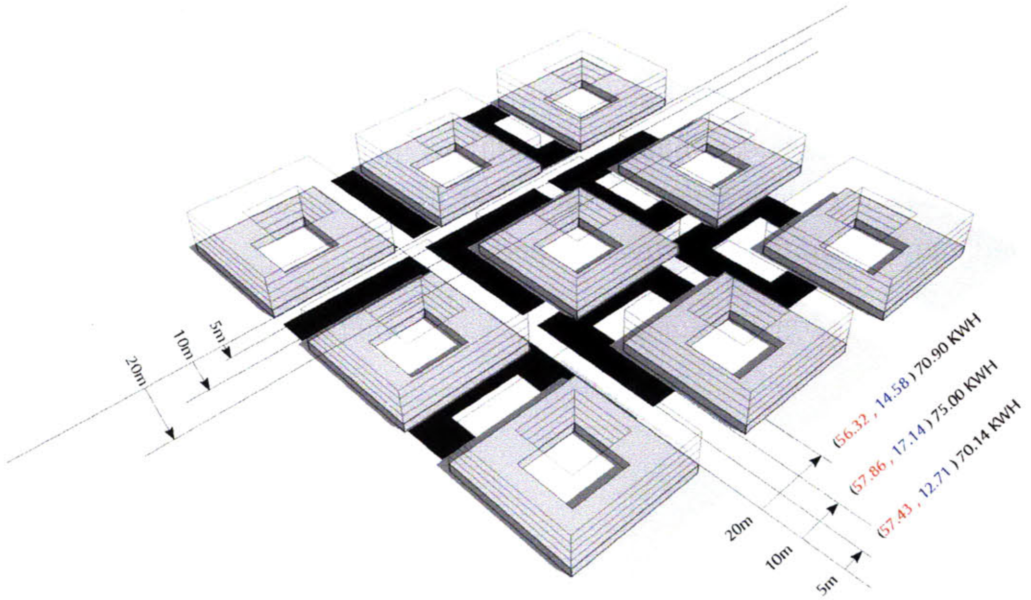
- All buildings are 40m*40m with a depth of 11m, the distance between buildings are 10m, the height of the building varies from one floor to five floors with each floor 2.8 meters.
- "(57.86, 17.14) 75.00 KWH" means "(Heating Energy Use, Cooling Energy Use) Total Energy Use". All units are in KW•H/M^2, accumulated yearly



As can be seen in Figure 6-2, when all else remains the same and the building height changes, both yearly total heating and cooling energy use changes. With the increase of stories, per square meter energy used for cooling increases gradually, while that for heating decreases much faster. The optimal height for heating appears to be four floors and then it increases with the increase of stories beyond four, however, at a much flatter rate. As heating consumes much more energy than cooling, it dominates the trend of yearly total energy use (cooling and heating only) and for the prototype "small perimeter block", floor stories seems to be the optimal height. However, there might also be possibilities that with the change of other parameters, such as the distance between buildings, the size of the building itself, etc. this trend might change as well; or when the building height goes beyond a certain threshold, new trends might emerge. However, the parameters of the small perimeter block, the limitations in its size and height, eliminate such possibilities within this prototype.

The reason why heating energy use decreases with the increase in building height from one floor to five floors might result from decreased surface-volume ratio, a factor commonly known to affect building's heat loss. The sharp ratio is much higher at lower floors (in particular, when the building height changes from one floor to two floors) than higher ones, corresponding to the decrease in surface-volume ratio when adding each additional floor. However, when the building reaches a certain height, additional floors no longer exert as much influence on surface-volume ratio as is the case when building heights are relatively low. Meanwhile, the inter-shading effect might emerge when the building reaches a certain height and the subsequent decrease in solar radiation gain counteracts with or even exceeds the decrease in heat loss (from the decrease in surface-volume ratio), the total heating energy use thereafter increases with the increase of building height, resulting in four floors as the height for minimal heating energy use. In terms of cooling energy use, lower density layout might facilitate natural ventilation and meanwhile increase surface-volume ratio for better heat emission from the building. This might be the reason why the energy use for cooling increases with the increase of building height.

Figure 6-3: Yearly Energy Consumption with Variation in Distance *



- All buildings are 40m*40m with a depth of 11m, the height of the building are five floors with each floor 2.8m, and the distance between buildings varies from 5m to 20m.
- "(57.86, 17.14) 75.00 KWH" means "(Heating Energy Use, Cooling Energy Use) Total Energy Use". All units are in KW•H/M^2, accumulated yearly

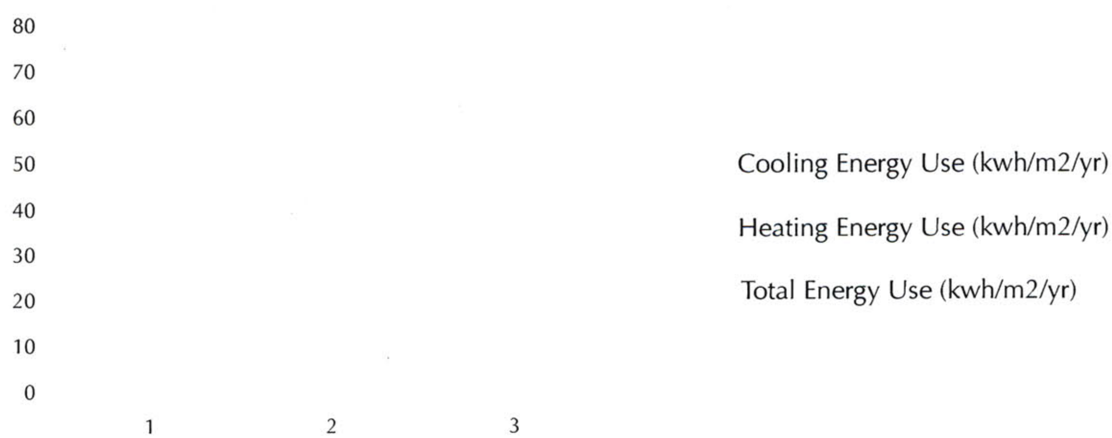
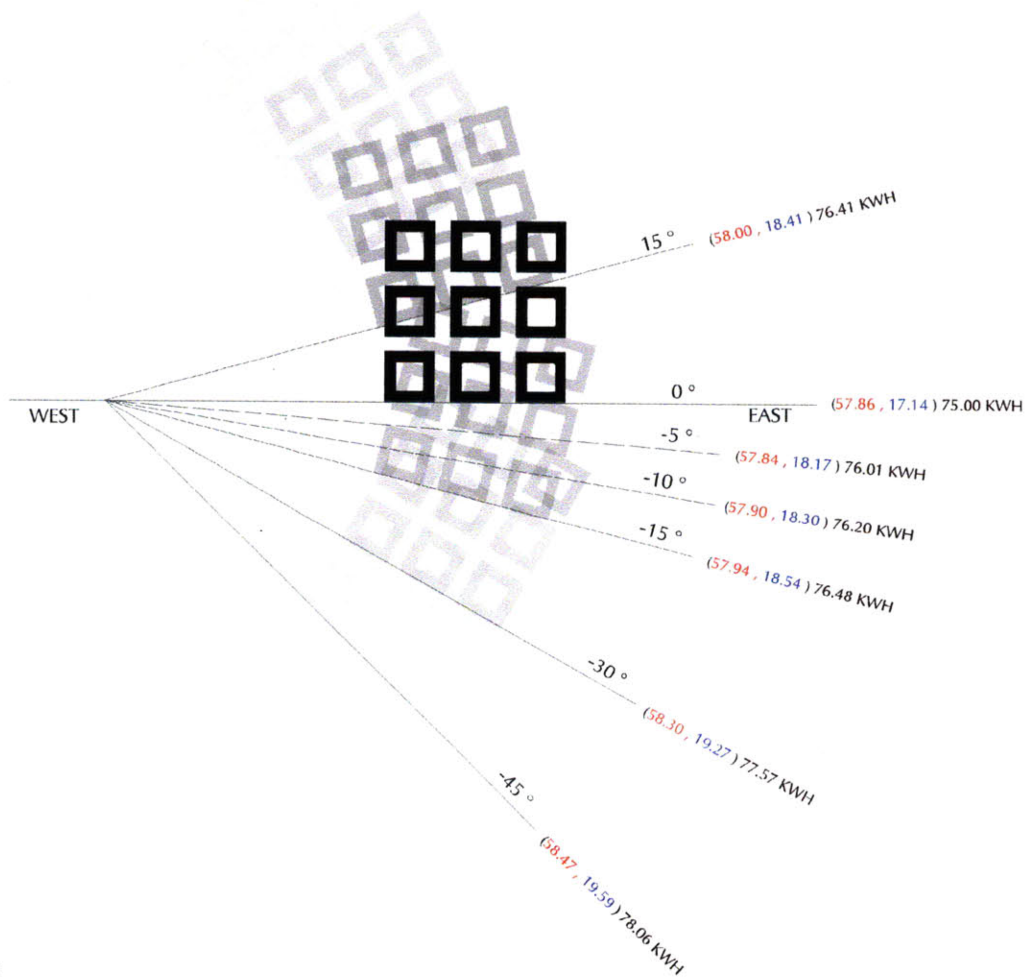
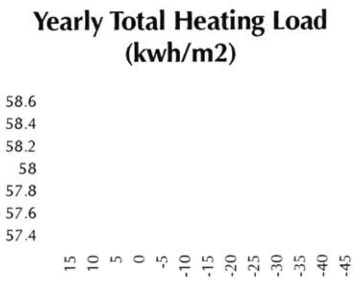


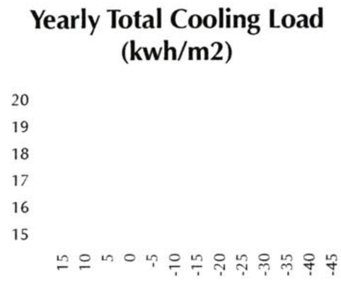
Figure 6-3 demonstrates the change in energy use with the change in the distance between buildings. It seems that with the increase of distance between buildings, total cooling energy use increases and then decreases again while heating energy use remain steady. This might result from the fact that cooling energy use is more sensitive to the surrounding microclimate than heating. The trend in cooling needs might be accounted for by the fact that when the two buildings are close to each other (5m), shading might help decrease cooling needs; with the increase in distance between buildings, less shading from neighboring buildings requires more cooling needs; meanwhile, ventilation conditions might improve with the increase of distance which counteracts with the effect from decreased shading, therefore resulting in an upward then downward trend.

*Figure 6-4: Yearly Energy Consumption with Variation in Cluster Orientation**



- All buildings are 40m*40m with a depth of 11m, the height of the building are five floors with each floor 2.8m, the distance between buildings are 10m.
- "(57.86, 17.14) 75.00 KWH" means "(Heating Energy Use, Cooling Energy Use) Total Energy Use". All units are in KW•H/M^2, accumulated yearly





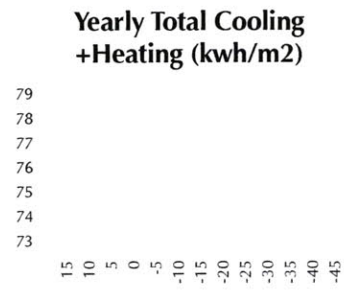


Figure 6-4 demonstrates that southern orientation proves to be the most energy efficient for both cooling and heating within the prototype "small perimeter block". Energy use for heating changes steadily with the change of orientation (of the whole cluster). Cooling seems more sensitive to change of orientation within 5°, and the trend flattens beyond that point. However, generally speaking, compared to the change of building height and distance in-between, orientation variation has a much smaller influence on total energy consumption regarding heating and cooling. A total difference of around 3kwh/m^2 was detected when the whole cluster is rotated 90°. The reason why cooling is sensitive to direction within smaller angles away from southern orientation might be related to the dominant wind direction in summer. Heating energy is saved when the cluster is oriented south and receives the maximal solar radiation[2].

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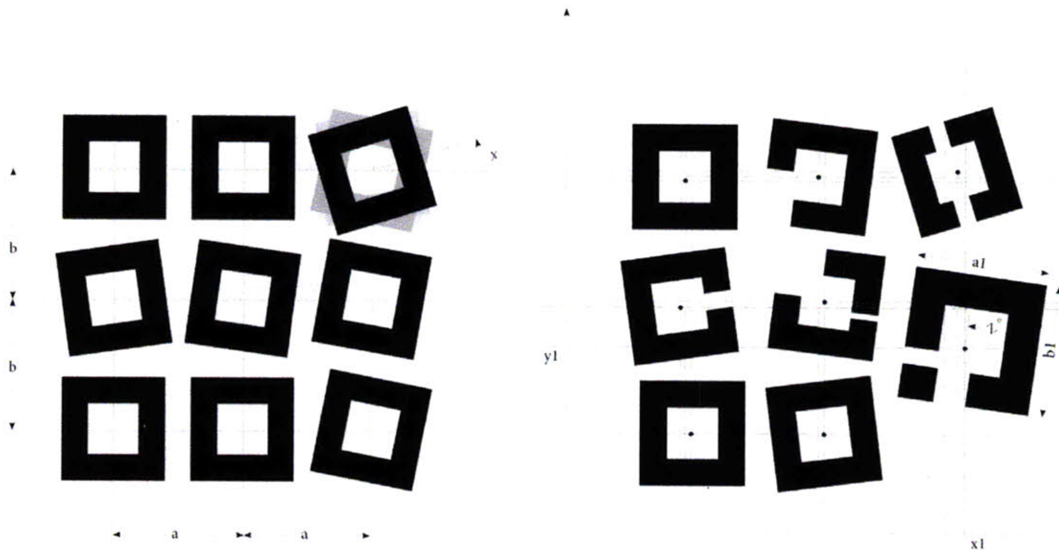
[2] To receive maximal solar radiation is different from maximal solar exposure, the accumulated time that certain parts of the building can receive direct sunlight. The amount of solar radiation is also related to the intensity of sunlight in addition to exposure time. The intensity of sunlight peaks during midday.

Figure 6-5: Other Types of Form Variation within the Prototype



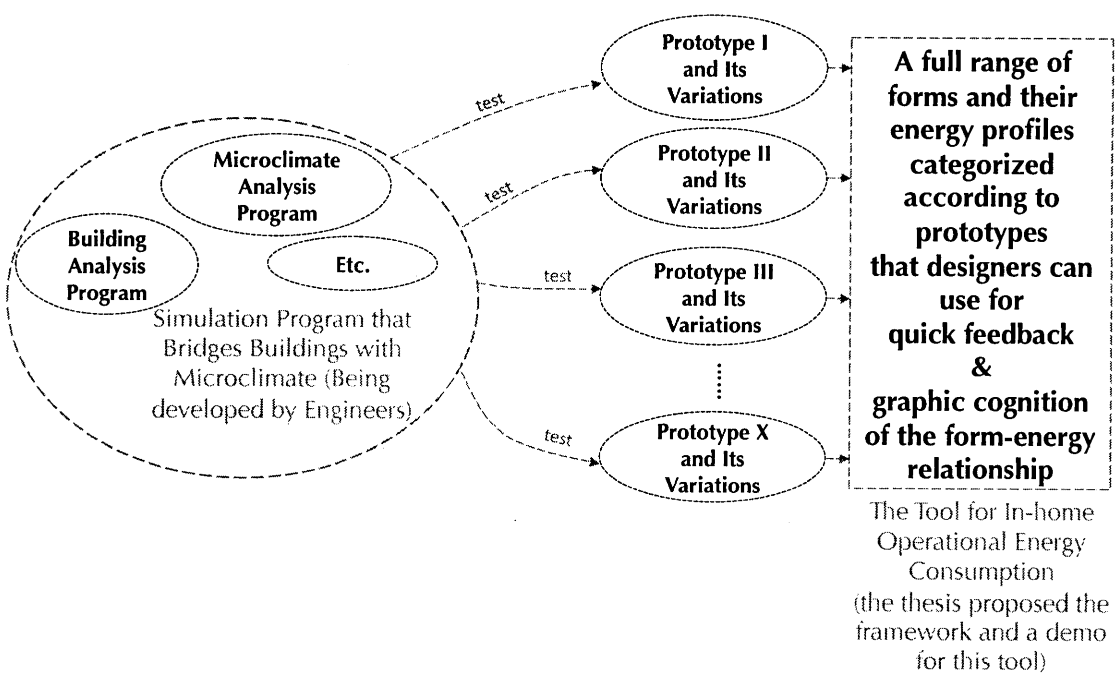
Conclusions and Next Steps

The three groups of simulations demonstrate a tangible relationship between cluster form and their operational energy consumption in terms of heating and cooling. The relationship between variables and the energy needed for cooling and heating is non-linear and sometimes the form needed for minimal heating conflicts with that for minimal cooling. This indicates that a linear approach based on regression might not work in estimating cluster energy use, and this form-energy relationship might only be established within the context of certain form patterns. Or in other words, the form-energy relationship cannot be simplified into the relationship between energy and abstract parameters describing form such as density, coverage, building height, etc, but rather the form itself.

Figure 6-6 illustrates the overall framework and purpose of a tool (for in-home operational energy use only) based on simulation programs and prototypes. As I mentioned before, the contribution of the thesis is not to develop a simulation program that meets the criteria I argue for in Part II, rather it proposes a tool based on prototypes utilizing existing simulation programs (or future simulation programs that better meets the criteria I advance) during the research stage – when the form-energy relationship is examined. This tool (based on prototypes) will therefore provide a full range of forms and their energy profiles under each prototype, which, compared to a simulation tool, greatly speeds up feedback and allows for graphic cognition of the form-energy relationship. This thesis replaces the placeholders of the pilot version of the research project's energy pro-forma with a more developed framework for the operational energy consumption module.

More tests with smaller intervals of variation are needed to confirm the trends discovered in this thesis. In addition, more complicated variations should also be tested, as real world designs usually take less uniform and more complicated forms. Tests against different prototypes can be gradually added to fulfill this in-home-operational-energy-use module in the energy pro-forma. With the development of more advanced simulation tools from engineers, the actual data can be updated from time to time for improved accuracy. Last but not least, how this module based on a deterministic physics approach can integrate the findings from the research project regarding behavioral, socio-economic and demographic influence on operational energy use is critical for it to align with the broader energy pro-forma.

Figure 6-6: Summary of the Tool for In-Home Operational Energy Use



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Appendix A – Prototypes

Excerpted directly from

Dennis Frenchman, Christopher Zegras (Principal Investigators). *Making the 'Clean Energy City' in China (draft)*. (Cambridge: Massachusetts Institute of Technology with Tsinghua University, June, 2010). Research sponsored by the Energy Foundation, China. p.36-142

From the study of 25 examples of best practice, we recognized several repetitive formal patterns across the projects, which allowed them to be grouped into prototypical approaches. The prototypes represent very basic ideas about urban form including relationships among buildings, sites, routes of access, and the surrounding city. They capture the essence not only of physical form, but also activities and patterns of behavior engendered by the form, and finally, strategies for saving and producing energy. In all, six prototypes with several variations on each were identified.

Projects that were most representative of each prototype were selected for analysis in greater detail to provide a foundation for the pattern book to be developed later in the research. Collectively these projects stand out for their comprehensive energy goals and/or performance, although the degree of documentation varies (an issue we will discuss later). They also represent a range of scales and types of development; the aim was to highlight projects that were relatively successful within their prototype category. Finally, the projects stand out as examples of livable, high quality design.

The livability aspect was based on the success of the development in attracting residents and providing a good place to live – facilitating 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 not be acceptable to the public, 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, we regard successful design strategies as those that not only address energy concerns, but also enhance project livability.

The prototypes, variations on each, and key representative projects are presented in Tables 3.X and 3.Y and summarized below:

1. Small perimeter block – A number of the projects consist of small scale connected buildings of 3-4 stories arranged around a central shared space, a quadrangle. The quadrangle allows sun to penetrate to all units, retains heat in the winter, and can mitigate the effects of wind in cold climates. It also allows for individual front doors on the perimeter and semiprivate space inside, a highly livable arrangement. Such schemes can accommodate great diversity within their simple morphology.

a. **Simple** – forms group together many single quadrangles within a largely pedestrian environment, such as at Bo01, Malmo Sweden;
b. **Complex** – forms are characterized by a series of interlocking enclosed and semi-enclosed spaces all oriented to the sun and connected by small access roads, as seen in Ecolonia in the Netherlands.

2. High density perimeter blocks – These projects have many of the advantages of their smaller cousins but they are larger in scale and density. Typical projects may include 8-10 story or even taller buildings grouped around the edges of an urban scale block 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 be developed for a variety of uses.

a. **Simple** – forms are low- to mid-rise and repeat variations on the basic block structure, such as Millenium Village in Greenwich, UK, where taller buildings are located to the north to allow sun penetration and to deflect wind off the Thames.
b. **With towers** – include high-rise buildings among perimeter structures. At Symphony Park, Las Vegas, 30 story buildings are located to shade streets and courtyards.

3. Low-rise slabs – 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. Spaces between buildings are used for auto access and parking alternating with "backyard" common space for the residents. These forms are typical in many clean energy projects because they are cheap to build and when aligned east-west, can maximize solar gain.

a. **Aligned** – forms follow a rigorous east-west arrangement with no variation for local conditions or community space, as found at the iconic clean energy project of Bedzed outside London.
b. **Staggered** – a variation where the linear structures are staggered and arranged to create more livable community and semi-private spaces. Geos in Denver, Colorado arranges linear buildings to make space for greenways and geothermal wells.

A-1 PROTOTYPICAL FORMS OF ENERGY EFFICIENT NEIGHBORHOODS

	Prototypes and variations	Representative project	Location
1.	SMALL PERIMETER BLOCK		
	A. Simple	Bo01	Malmo, Sweden
	B. Complex	Ecolonia	Alphin, Netherlands
2.	HIGH DENSITY PERIMETER BLOCK		
	A. Simple	Greenwich	London, UK
	B. With towers	Symphony Park	Las Vegas, NV, USA
3.	LOW-RISE SLABS		
	A. Aligned	BedZed	Wallington, UK
	B. Staggered	Geos	Denver, CO, USA
4.	GRID		

4. Grid – These forms represent a return to the traditional 19th century urban pattern of rectilinear public streets and private blocks. A wide variety of low and higher density housing types may be built within the blocks, with shops and services along principal routes of movement, all unified by the system of streets. This allows for high accessibility and walkability within a mixed use, livable environment.

a. Regular – forms are strictly rectilinear, such as Kronsberg in Hanover, Germany, where density increases toward the main street, which contains a tram line, shops and services.
b. New Urbanist – projects use more organic grids with mid-block alleys and small lots to encourage high-density and walking. More popular in the US, Civano is a good example, where the grid focuses on a town center with shops and services.

5. **Low-rise superblocks** – This pattern of development is in many ways the opposite of the grid. Superblocks encompass large, sometimes gated areas with no public streets. They are largely accessed by pedestrian movement or alternative forms of transportation. Freed from the car, more of the surface environment is turned over for social, family and community use and buildings may be more densely arrayed with a finer grain of mixed uses.

a. Pedestrian clusters – group buildings in various ways around pedestrian movement systems. Vauban in Freiberg, Germany clusters units in different ways, an environment where private cars are largely forbidden, people move by tram or foot power, and shops and services are closely integrated.
b. Pedestrian matrix – represents a return to preindustrial urban forms which were tightly integrated and where public pedestrian spaces were interwoven with the buildings. Masdar, Abu Dhabi, will have no cars. Tightly spaced buildings will shield pedestrians from the sun, while wind towers provide natural ventilation.

6. **High-rise superblocks –** It is significant that none of the clean energy projects we surveyed included the traditional "tower in the park" modernist urban form. Such forms are typically single use, highly oriented to the car, dependent on elevators, and not very energy efficient. Nevertheless, we did find examples of innovative tower forms that were striving also to be pedestrian oriented, mixed use, low energy environments.

a. Linked towers – connect high-rise structures at an upper level to create an interior public realm with shops and services, potentially reducing elevator traffic. This emerging form is best illustrated by Linked Hybrid in Beijing, which is also heated and cooled by geothermal energy.

A-2. Prototypes and International Cases

Making the Clean Energy City in China / MIT-Tsinghua University / China Energy Foundation

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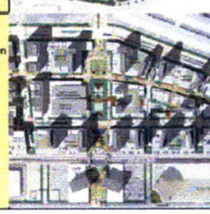
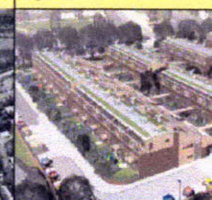
PROTOTYPES AND INTERNATIONAL CASES OF ENERGY EFFICIENT NEIGHBORHOODS

Prototype	Project/context	Form character	Size/dens./program	Transport	Plan	Image	Energy Strategy	Energy Performance
W1 Small Perimeter Block 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.	•25 ha site •10,000 residents planned (6000 today), •20,000 workers and students; •80 companies, •Malmo University.	•Limited parking of .7 cars per household. •Reliance on bus stops within 300 meters of any flat, 7 min.intervals. •Extensive bicycle use.			•105kWh/m^2/year for res. units goal •100% locally renewal renewable energy sources. •Heat storage in underground aquifer. •Central wind power plan. •Biogas from waste. •PV + solar collec.	•120-150 kWh/m2/yr for residential units achieved. (did not achieve target) •Shortage of parking.
W1 Small Perimeter Block B. Complex	**Ecolonia, Alphin, Netherlands** Reclaimed poulder 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.	• 280 housing units	• Center with shops 10 minute walk. • Extensive bicycle paths. • Low speed roads. • No marked parking spaces.			•85kWh/m2/year energy consump. for res. units goal. •Solar orientation; passive sun spaces to south. • Solar thermal HW and PV on 80% homes.	•40% decrease in gas consumption from average unit. •10% decrease in electricity consumption. •25% reduction in household energy use overall (did not meet target)
W2 High Density Perimeter Block A. Simple	**Greenwich Millenium 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.	• 30 ha site • 97 du/ha • 1157 dwelling units • 4,500 m2 retail + cinema, hotel • primary school • central park	• Car parking restricted and sited away from individual properties. • Excellent bus service to new North Greenwich tube station. • Network of walking and bikeways.			•80% reduction in primary energy goal. • 50% reduction in embodied energy goal. • High residential density. •Natural day lighting and passive solar gain. • Home office to reduce work trips CDH.	•67% decease in primary energy consumption from average. •25% decrease in embodied energy. •BREEAM Excellent rating.
W2 High Density Perimeter Block B. With Towers	**Symphony Park, Las Vegas, Nevada USA** Downtown brownfield site, a former railroad 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.	• 24.4 ha site • 3094 housing units • 1000 hotel rooms • Performing arts center • Ruvo Center for Brain Health	• Compact, walkable district • Easy access to BRT on Grand Central Avenue			• Walkable streets formed by perimeter shops. • Well connected with rest of downtown. • LEED buildings. • Tower placement to provide shade. • Parking structures with energy efficient roofs reduce heat island and cooling loads.	•33% fewer car trips than conventional suburban project in city. • Electric and gas energy savings each year enough to power 2100 standard homes.

Prototype	Project/context	Form character	Size/dens./program	Transport	Plan	Image	Energy Strategy	Energy Performance
W3 Low Rise Slabs **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.	• 1.6 ha site • 82 dwelling units • 50 du/ha • Life-work office space incorporated • Convenience shops	• Car sharing with electric vehicles (charged with PV). • 5 min walk to transit stop at Hackbridge Village. • Shared pedestrian/vehicular site roads.			• E-w orientation with south glass; work spaces/retail on north. • Roof forms for sun exposure+updraft. • Wind cowls for natural ventilation. • Roof gardens for insulation. • PV's charge cars. • CDH plant fired by local wood chips.	• 48 kWh/m2/yr heat + hot water. • 34.4kWh/m2/yr electricity. • 88% less energy on heating than average. • 57% less energy on hot water. • 25% less electricity. • 65% less car mileage on fossil fuel than average.
W3 Low Rise Slabs **B. Staggered**	**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.	• 10 ha • 282 dwelling units • 9 du/ha • 1,200 sm neighbor-hood services • local shopping • 3.5 ha park	• Reduced parking in central garages near "main street". • Pedestrian environment with limited car access. • Arveda-Denver Fast Tracks transit within walking distance.			• Buildings orient e-w for sun exposure. • PV on roofs. • Geothermal loops beneath "green fingers." • Careful placement of deciduous trees for shade in summer and sun in winter. • Live-work homes. • Social program to "Be the Resource"	• 0 net fossil fuel energy use. • All heat and power is produced on-site by geothermal and PV systems. • LEED Silver Certification.
W4 Grid **A. Regular**	**Kronsberg, Hanover, Germany** Model low energy development on the urban edge. Borders countryside at t 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.	• 1200 ha • 3000 dwelling units; 3000 more planned. • 15,000 residents. • Library, Sr. citizen center, three kindergartens, primary school • Nearby commercial and industrial areas: 2750 office jobs across street.	• Tram line extended to edge of development with 3 stops in Kronsberg (550 m max. walk to station). • Parking .8 cars/unit; 1/3 underground, rest in small clusters. • Extensive foot and bike paths.			• 56kWh/m2/yr heating goal. • 35kWh/m2/yr elec. goal. • PV district with thermal storage tanks to provide 40% of heating. • Electricity from two MV turbines in countryside. • 36 passive solar dwellings.	• 56kWh/m2/yr heating (42% reduction). • 50kWh/m2/yr elec. (goal not met). • 45% less CO2 emissions than conv.: (from PV, solar district heating, wind power, passive houses). • 15-20kWh/m2/yr heating with passive solar houses.
W4 Grid **B. New Urbanist**	**Civano, Tuscon, Arizona USA** Located in suburban Tuscon of 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 Polyzioides.	• 328 ha • 200 dwelling units completed; 5000 people at build out. • Industry, office, retail cultural activities clustered in village center.	• Compact plan encourages walking; shops, services and jobs planned within walking distance. • Walking and bike paths. • No public transportation.			• 50% reduction from Tucson model energy code. (= 58kWh/m2 less). • PV electric energy • Solar hot water heating. • High efficiency heat pumps, insulation, windows.	• 64.5kWh/m2/yr heating and cooling (44% less than av.). • 131kWh/m2 total energy use (33% less than city average; goal met).
W5 Low-rise Superblock **A. Pedestrian Clusters**	**Vauban, Freiburg, Germany** 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)	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.	• 15.2 ha site • 5000 residents • 600 jobs • Primary school, kindergartens, markets, shopping center, businesses within walking distance.	• Tram and bus service down main spine of site. • No cars allowed on private property. • No car access to central area except for pick-up and delivery; • Fee paid parking on periphery near tram. • Car sharing.			• 65kWh/m2/yr heating energy goal. • CHP fired by wood chips. • PV electricity. • Solar collectors for hot water. • 150 "passive houses." • Reduced car travel. • Social participation in energy planning and savings.	• 65kWh/m2/yr average energy use (goal achieved). • 15kWh/m2/yr energy use for "passive houses". • 60% CO2 savings through heat supply. • 40% households do not own a car.
W5 Low-rise Superblock **B. Pedestrian Matrix**	**Masdar, Abu Dhabi, UAE** 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.	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.	• 600 ha (6 km2) • 40,000 residents (planned) • 135/ha • 40,000 jobs in 1500 businesses (planned) • Integrated residential, offices, shopping, services, institutions. • Masdar Institute of Science + Technology.	• Automated PRT on lower level, connecting all parts of city; 85 stations. • No cars on living surface of city. • High capacity overhead train connects to airport and Abu Dhabi. • Ubiquitous pedestrian/bicycle network.			• 30kWh per person/ day energy budget to reduce demand. • Reduce heat gain by maximizing shade and reflecting sun. • Wind towers for natural ventilation. • PV on all roofs. • Concen. solar power. • Geothermal wells for energy storage.	• 0 net fossil fuel energy use (100% renewable sources: 26% solar power; 52% PV, 14% thermal tube; 7% waste to energy). • 70% reduction in energy usage below average in Abu Dhabi. • Exceeds LEED Platinum standards.
W6 High-rise Superblock **A. Linked towers**	**Linked Hybrid, Beijing, China** Located in central Beijing, the project in intended to provide an alternative form for efficient high rise communities by interconnecting the towers with fine grained mixed use.	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.	• 6.18 ha • 750 dwelling units • 2500 residents. • Hotel, schools, conference facilities, offices, restaurants, health, shops and services: a town within the city. • Public park and recreation at ground level.	• Within walking distance to public transit. • Below grade parking. • Reduce need for commuting by providing live-work within the complex.			• Linked buildings reduce need for vertical transport/ elevator use (47% of high rise energy). • 600 geothermal wells, circulate water 61-70 degrees F, reducing heat and ac needs. • Green roofs and thermal mass retain heat.	• Geothermal and linked configuration dramatically reduce energy demands for heat, ac, and elevators. • LEED Gold certification.

Dennis Frenchman, Heshuang Zeng, Jue Wang / MIT