A Study of Shanghai Residential Morphology and Microclimate at a Neighborhood Scale based on Energy Consumption

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ABSTRACT
This study is to assess the impact of residential morphology and microclimate on energy consumption at the neighborhood scale (200m×150m) in Shanghai. At the 200m×150m scale, based on Shanghai's common residential forms, five real residential districts are selected as research object, including garden houses, 6-storey flats, 14-storey flats, 28-storey flats and lane houses. The effect of residential morphology (e.g. building distance, density) and microclimatic (e.g. wind speed, temperature) on building energy consumption is quantitatively assessed using a whole-building energy simulation program, EnergyPlus. In sum, the data and analysis of the comparison among the energy consumption of five distinct districts is usable for the optimal design of residential district in energy supply. Furthermore, a case study is conducted to analyze the effects of different morphology index on the energy balance of 14-storey residential districts in the same Floor-area Ratio (FAR).

KEYWORDS
Morphology, microclimate, residence, energy consumption, simulation

INTRODUCTION
Urbanization in the recent years has significantly increased the necessity for the city to further develop itself to accommodate the incoming inhabitants, in which ameliorate the urban microclimate. Urban morphology is the foundation of the whole city, which can affect the different levels of energy consumption. In some cities, per capita energy consumption has grown at approximately the same rate as their spatial growth (Baynes and Bai, 2009) rate. Linking urban energy consumption to urban form, density and morphology provides an opportunity to tackle the impact of each morphology index changes.

This research primarily analyzes existing literature and qualitative research in China. Researchers recognize that spatial structure can impact the low carbon city development has been recognized by academic circles which analysis framework and ideas have involved regardless of the empirical studies. However, if lacking empirical research support, it is impossible to analyze different urban spatial structures of the

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As can be seen from the chart, flats are expected to account for the largest proportion, followed by garden house and listed residence respectively. Thus, five real residential districts are selected as research object, including garden houses, 6-storey flats, 14-storey flats, 28-storey flats and lane houses.

METHODOLOGY

Simulation Methodology

District construction load and energy prediction play a key role in the process of regional energy planning, which are also the important methods for estimation and analysis of regional carbon emissions and heat island effect. Regional construction load and energy consumption prediction require a forecasting model of energy consumption. There are two kinds of basic methods: top-down and bottom-up. Top-down approach is to estimate the overall energy consumption of buildings first, then estimate the downscaling of time and space; While the bottom-up approach which is utilized in this study is the opposite. In other words, calculating the energy consumption of a single building takes priority over that of the regional scale. Bottom-up approach is divided into three types: physical models, statistical model and hybrid model.

Procedure

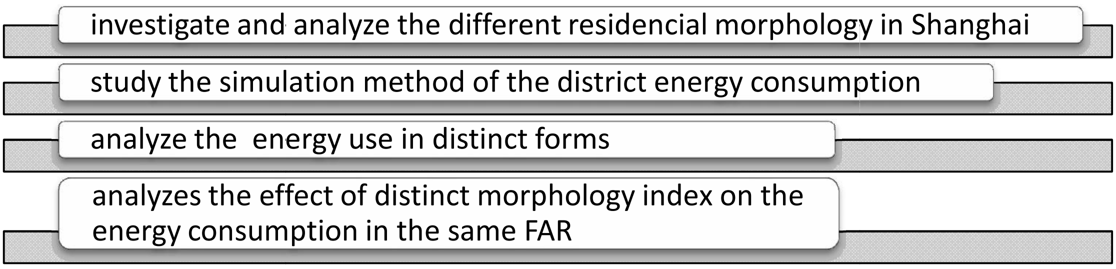


Figure 2. *the procedure of the study*

There are three main steps in the study (Figure 2). In the first place, due to the selection of the typical form types, the residential morphologies are investigated attentively in Shanghai. Then do the analysis in terms of the simulated result.

Simulation tools

EnergyPlus 8.1 is utilized in this work. EnergyPlus, developed by U.S. Department of Energy, has been widely applied in building energy simulation field. EnergyPlus models heating, cooling, lighting, ventilation, other energy flows, and water use. EnergyPlus includes many innovative simulation capabilities: time-steps less than an hour, modular systems and plant integrated with heat balance-based zone simulation, multizone air flow, thermal comfort, water use, natural ventilation, and photovoltaic systems.

Case study

We conduct two case studies to demonstrate the effect of the residential morphology. The first scenario displays the energy consumption of distinct residential region morphology in Shanghai at the neighborhood scale (200m×150m).

The other is the analysis of the effects of different morphology index on the energy consumption of 14-storey residential districts in the same FAR.

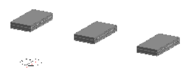
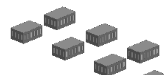
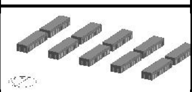
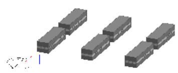
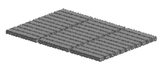
THE ANALYSIS OF ENERGY CONSUMPTION OF FIVE DISTRICT RESIDENTIAL TYPES

The research of the morphology of the residential district is based on the typical real district in Shanghai, including garden houses, 6-storey flats, 14-storey flats, 28-storey flats and lane houses.

Building Information

The schedule is taken from the prototypical model of Shanghai. And the prototypical model contains kitchen，toilet，living room，staircase，balcony，bedroom and study room. The schedule of this study is weighted average based on the area with all kinds of scenarios.

Table 1. *Settings of EnergyPlus simulations*

		morphology	Total building area(㎡)	Floor area ratio (FAR)	Planning area(㎡)	Floor space(㎡)	Quantity
2-storey garden houses			13260	0.44	30000	2210	3
6-storey flats			33078	1.10	30000	5513	10
14-storey flats			62832	2.09	30000	4488	6
28-storey flats			171360	5.71	30000	6120	6
Lane houses			96948.3	3.23	30000	19389.66	33

Day lighting and natural ventilation

This study considers the daylighting that the reference point of daylighting control set at the center of each building at 500lx.Namely if the illuminance of the reference point is more than 500lx, the daylighting will be accepted.

Natural ventilation is also taken into account. Specifically, according to the standard, January 1st to February 18th and June 15th to August 31th are the air conditioning period, so that the natural ventilation is enable to be used in the rest of years. And during the air conditioning period, if outdoor temperature is less than 28 degree centigrade and the wind speed is less than 3m/s, the natural ventilation will be operated. The outdoor temperature and wind speed is from the hourly TMY data of typical meteorological year.

Result

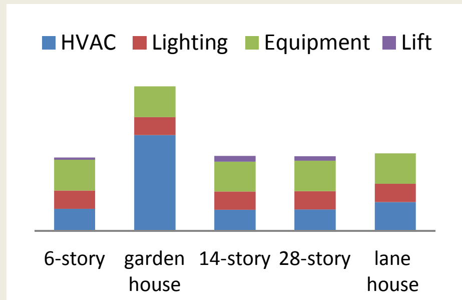
As can be seen from the chart, garden house costs the most total energy consumption than other districts, followed by lane houses and 14-storey buildings. However, 14-storey buildings, 28- storey buildings and 6-storey buildings share the similar figure. The daylight saving of garden house ranks first as well as the natural ventilation. Garden house consumes the most HVAC consumptions. Lane house is in the second place.

Table 2. *Output of the energy consumption*

	Initial energy consumption(KWh/m2)	Day lighting saving(KWh/m2)	Natural ventilation saving (KWh/m2)	Total energy consumption(KWh/m2)
6-storey	20.61	-0.14	-1.49	18.98
garden house	53.77	-10.5	-4.79	38.48
14-storey	21.35	-0.52	-0.86	19.97
28-storey	21.02	-0.19	-0.92	19.91
lane house	22.19	-0.19	-1.30	20.70

Table 3. *Output of the energy consumption*

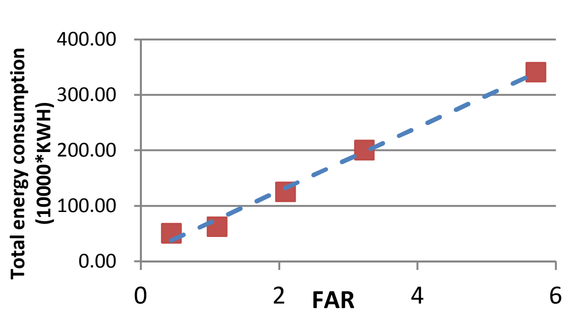
	HVAC	Lighting	Equipment	Lift
6-storey	5.88	4.91	8.19	0.57
garden house	25.50	4.76	8.22	0.00
14-storey	5.70	4.83	7.92	1.51
28-storey	5.75	4.90	8.04	1.22
lane house	7.72	4.84	8.14	0.00



Below is the section about the results for total energy consumption against floor-area ratio (FAR). In general, it can be concluded that there exists a strong positive correlation between the two, so that we can easily speculate the total energy consumption by the specific FAR.

Table 4. *Relationship between FAR and total energy consumption*

	FAR	Total energy consumption (10000*KWH)
Garden house	0.44	51.02
6-storey	1.1	62.78
14-storey	2.09	125.48
28-storey	5.71	341.18
Lane house	3.23	200.68



THE EFFECTS OF DIFFERENT MORPHOLOGY INDEX ON THE ENERGY CONSUMPTION OF 14-STOREY FLAT RESIDENTIAL DISTRICTS IN THE SAME FAR

This section analyses the relationship between the headline results for heat-energy demand, calculated by the modeling exercise, and four spatial characteristics – building distance, building height, orientation and building density - that describes the different samples of urban morphology. The object of the case is based on the 14-storey flats which can be seen above. The FAR of the model is 2, that planning area is 200m×150m and total building area is 60000m^2.

Building distance

The building distance of baseline is 50m. While the distance is changed to 10m, 20m,30m,40m,60m respectively so as to compare the energy consumption. The result is below.

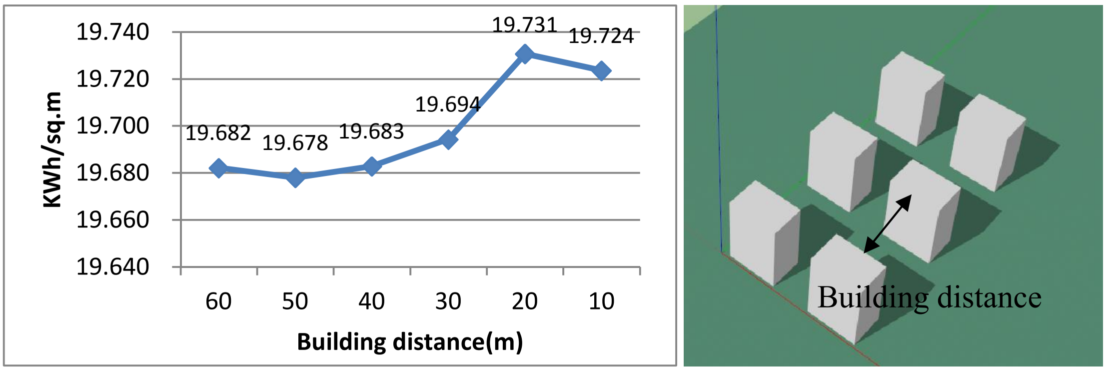


Figure 3. *The building distance and energy consumption*

As can be seen from the chart, different building distance consumes different energy. The energy consumption increases by the decrease of the building distance. Additionally, the energy consumption appears to be almost the same numerical value.

Building Height

This section displays the results for energy demand against building height. The buildings are divided into four different height scenarios to simulate below.

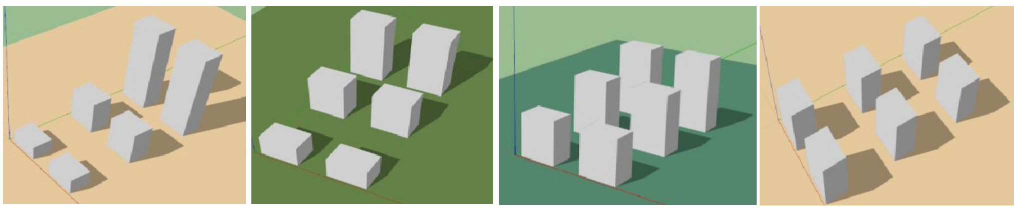
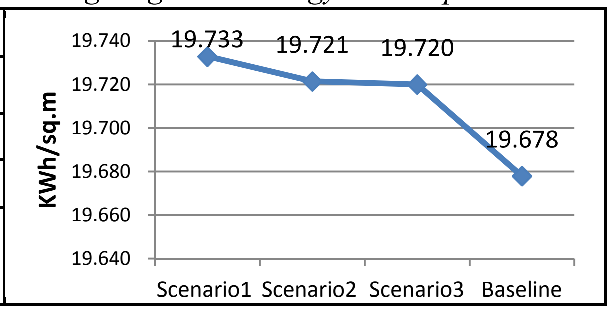


Figure 4. *Scenarios of building height (from left to right is scenario1,scenario2,scenario3 and baseline)*

Table 5. *Relationship between building height and energy consumption*

	Front row	Middle row	Third row
Scenario1	6-storey	14-storey	22-storey
Scenario2	10-storey	14-storey	18-storey
Scenario3	12-storey	14-storey	16-storey
Baseline	14-storey	14-storey	14-storey



There is a slightly negative correlation between built height and energy demand. There seems to be no significant difference in the energy demands of buildings between scenario2 and scenario3– all average around 19.72 kWh per square meter. However, as can be seen from the graph, the smaller the difference in height, the less energy consumption.

Orientation

The orientation of the baseline is south. The figure below shows how the building north axis can be rotated to correspond with one of the major axes of an actual building. Simulate the energy consumption every 15 degree.

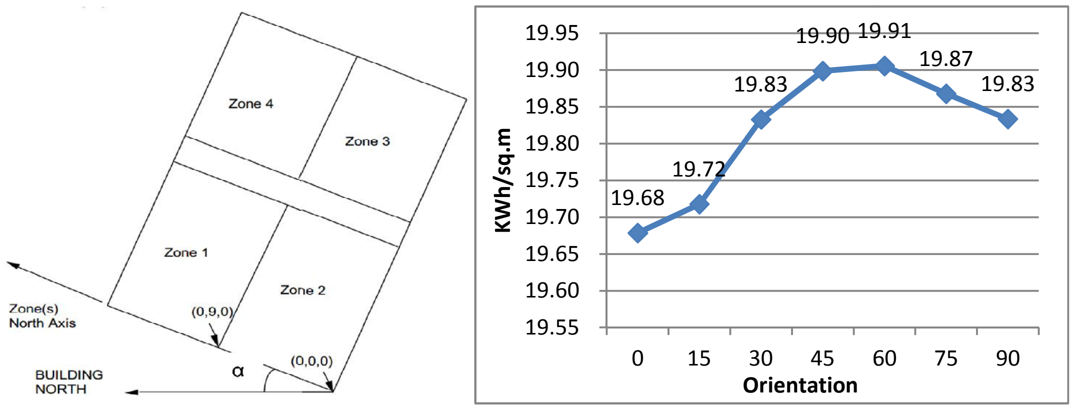


Figure 5. *Orientation and energy consumption*

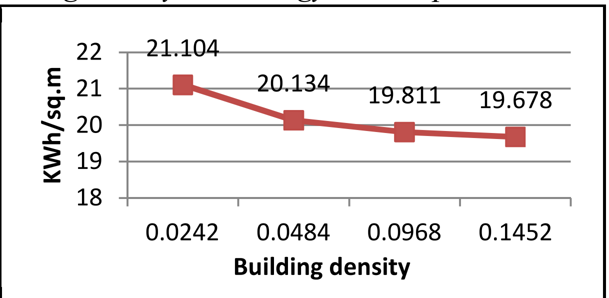
The change of buildings orientation is primarily because of the variation of the acceptance of solar radiation. The graph displays that the minimum energy consumption occurs to the South.

Building density

This section displays the results for energy consumption against building density. Building density means the proportion of the total building bottom space and planning space. Keeping the same total building area and floor space of each building, the buildings are divided into four scenarios to simulate respectively. Baseline is the 14-storey buildings mentioned before.

Table 6. *Relationship between building density and energy consumption*

	Building density	Storey	Quantity
Scenario1	0.0242	84	1
Scenario2	0.0484	42	2
Scenario3	0.0968	21	4
Baseline	0.1452	14	6



Overall, it can be concluded that there exists a strong negative correlation between the two. That is to say, energy consumption per unit area decreases with the increase of density of buildings. According to the data, with the same building area (60000m^2), the energy use can be totally different. Indeed, of all the variables displayed in this chapter, building density shows the strongest correlation with energy demand. Therefore, it is of importance to program an appropriate building density.

CONCLUSION

Five types of residential morphology on energy consumption

The research of the morphology of the residential district is based on the typical real districts in Shanghai, including garden houses, 6-storey flats, 14-storey flats, 28-storey flats and lane houses. Garden houses costs the most total energy consumption than other district, followed by lane houses and 14-storey buildings. However, 14-storey buildings, 28- storey buildings and 6-storey buildings share the similar figure. The daylight saving of garden houses ranks first. The natural ventilation of garden houses as well.

Morphology index of energy consumption

The result is that different building morphologies feature distinctively different energy consumption. Building distance, building height, orientation and building density are found to be good indicators for energy consumption, each correlating well with the energy use. While among the four index,the best performance is building density, followed by the figures of orientation. In addition, building height and building distance seem to have no relationship with energy consumption.

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