Energy and bioclimatic efficiency of urban morphologies: towards a comparative analysis of Asian and European cities

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ABSTRACT

The fundamental energy pattern of a city consists of various buildings and spaces. This urban morphology interacts with buildings, with people behavior and with the local climate. The growth in energy consumption in cities obeys quite simple laws derived from physics and thermodynamics. By using the passive zone concept and a set of indicators, such as density, rugosity, porosity, sinuosity, occlusivity, compacity, contiguity, solar admittance and mineralization, and by using an environmental oriented conceptual model of urban fabric, the paper connects architectonics, urban planning, energy flows, climate, and human patterns of behavior. Comparing different urban morphologies, the paper samples such six cities as Beijing, Shanghai, Paris, London, Toulouse and Berlin and makes comparison and contrast of their development in bioclimatic and energy efficiency.

KEYWORDS: Energy, Urban morphology, Climate, Passive zone

1. INTRODUCTION

As noted by the Intergovernmental Panel on Climate Change [1] ''the balance of evidence, from changes in global mean surface air temperature and from changes in geographical, seasonal and vertical patterns of atmospheric temperature, suggests a discernible human influence on global climate''. Home of interaction between people and buildings, the city is where human civilization changes patterns of living and of energy consumption. Its development challenges the future of our human society. UK data show that the energy requirements for buildings in the domestic and non-domestic sector exceed those for transport and industrial processes (see [2,3]).

Contemporary cities share similar experiences in their growth: they develop with great heterogeneity, dissociating them permanently from the original homogeneous state. What urban reality presents us is concrete appearance. What interest us, nevertheless, are the laws hidden behind.

There is a specificity of the "Asian urban experience" (see [4]). Asian countries share a lot in common (high speed urbanization). Through comparative studies between Asian and European urban morphologies, between Shanghai and Paris, we will better understand this specificity and contribute to develop a specific Asian and Chinese way of sustainable development.

2. MORPHOLOGY STUDY

2.1 Problem considered

The fundamental energy pattern of a city consists of various buildings and spaces defined by those buildings. This urban morphology interacts with people behaviour and with the local climate. The development of cities parallels the growth in energy consumption with quite simple laws derived from physics and thermodynamics.

At the neighbourhood scale, the heterogeneities of structures within the urban canopy (i.e., the layer between the surface and the tops of the buildings) exert a strong influence on the urban boundary layer (UBL) wind and thermodynamic structure and a subsequent effect on the pollutant dispersion and resulting air quality predictions.

2.2 Cases analysed

In order to form a database that can help identify the underlying interaction mechanism between the urban morphology and the energy patterns, a number of cases were constructed by studying the GIS of different cities one square kilometre morphology.

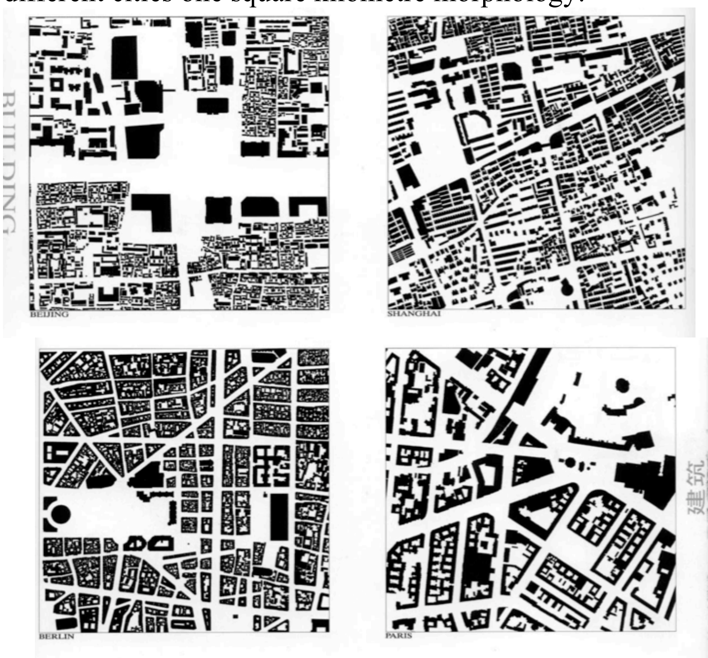

Figure 1. Beijing , Shanghai, Paris , Berlin 1square kilometer urban fabric

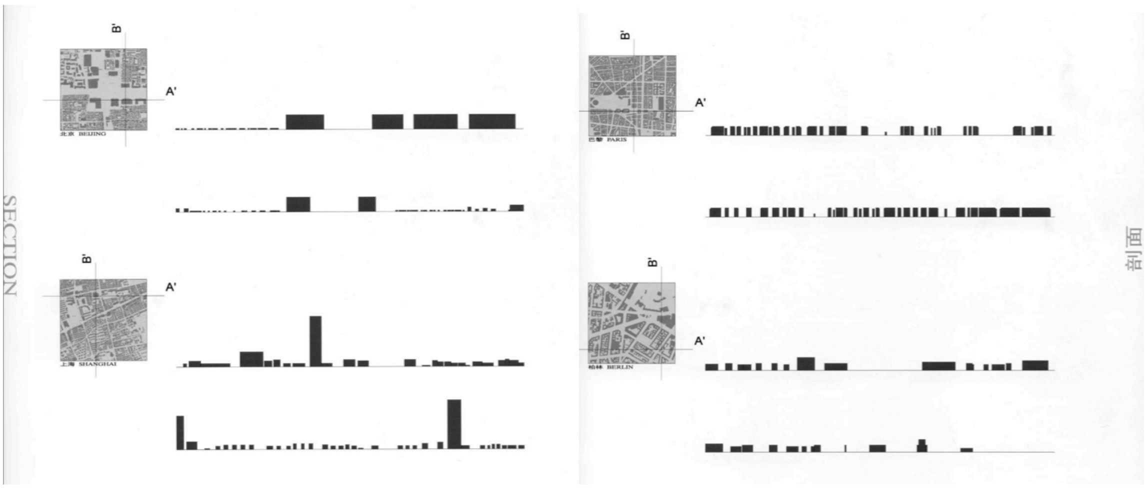

Figure 2. Beijing , Shanghai, Paris , Berlin 1square kilometre urban fabric section analysis

2.3 Methodology

The important variation of the microscopic morphology of cities has direct effects on the disparity of the outdoor climates as well as indoor climates: wide range of dry air temperature, of wind speed, of the heat radiation exchanged with the sky voltage and of the natural lighting. Thus, as it is difficult to describe and simulate the interactions between urban morphology and climate conditions, this paper is proposing a simplified spatial modelling of Shanghai urban morphology complexity resulting in defining a set of environmental indicators.

The DEM (Digital Elevation Model) is a compact way of storing urban 3D information using a 2D matrix of elevation values; each pixel represents building height and can be displayed in shades of grey as a digital image. The analysis of DEMs with image processing techniques has already proven to be an affective way of storing and handling urban 3D information, and being very conducive to a number of urban analyses [6,21–23].

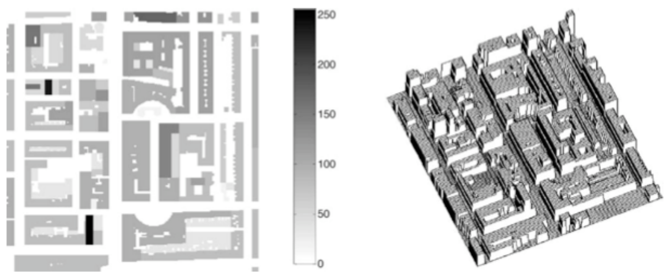

Figure 3. Case study site in central London in the digital elevation model (DEM) format (left) and its axonometric view (right).

Our ongoing project with Tongji University in Shanghai is structured into the following main tasks:

- The proposition of a set of innovative environmental indicators typical of microclimate conditions in urban spaces, through a large bibliographic survey, and experts' analysis,
- The validation of a set of indicators, such as density, roughness, porosity, sinuosity, occlusivity, compacity, contiguity, solar admittance and mineralization, through the environmental survey,
- An implementation of the final set of indicators in a comparative GIS analysis of Shanghai and Paris, using an environmental oriented conceptual model of urban fabric.

2.4 Urban morphology parameters

Computer-based analysis techniques and methodologies will be applied to various datasets, including digitized buildings, land use/land cover, and other essential datasets for the Shanghai and Paris. This effort will use a database of urban morphology parameters:

- Mean and standard deviation of building height
- Mean and standard deviation of vegetation height
- Building height histograms
- Area-weighted mean building height
- Area-weighted mean vegetation height
- Surface area of walls
- Plan area fraction as a function of height above the ground surface
- Frontal area index as a function of height above the ground surface
- Height-to width ratio
- Sky view factor
- Roughness length
- Displacement height
- Surface fraction of vegetation, roads, and rooftops
- Mean orientation of streets

3. ENERGY STUDY

3.1 Problem considered

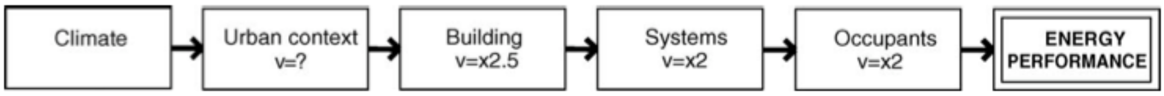

Figure 4. Factors that affect energy consumption in buildings; according to Baker and Steemers [6,2] building design accounts for a 2.5 variation, system design and occupants behaviour for a 2 variation each; the contribution of the urban context is not quantified.

According to Baker and Steemers [2] building design accounts for a 2.5 variation in energy consumption, systems efficiency for a 2 variation and occupant behaviour for a 2 variation. The cumulative effect of these factors can lead to a total variance of 10-fold. In practice, variance in energy consumption of buildings with similar functions can be as high as 20-fold. Is urban geometry the 2 factor missing?

3.2 Modelling the passive zone concept

According to C. Ratti et al. (2005[7]), the surface-to-volume ratio is an interesting descriptor of urban texture. It defines the amount of exposed building envelope per unit volume, and can be used in a number of different applications. Its relevance to the energy consumption of buildings, however, must be considered carefully. Minimizing heat losses during the winter requires minimization of the surface-to-volume ratio; but this implies a reduction of the building envelope exposed to the outside environment, thus reducing the availability of daylight and sunlight and increasing energy consumption for artificial lighting and natural ventilation.

In fact, the main energy distinction to be drawn within buildings is a function of the exposure to the outside environment. This concept is made explicit with the definition of passive and non-passive zones, which quantify the potential of each part of a building to use daylight, sunlight and natural ventilation. By a simple rule of thumb, based on empirical observations, all perimeter parts of buildings lying within 6 m of the facade, or twice the ceiling height, are classified passive, while all the other zones are considered non-passive.

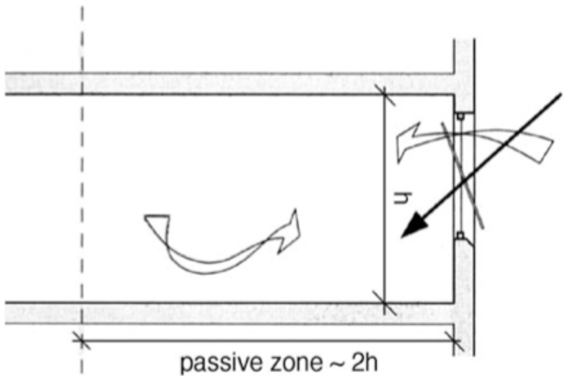

Figure 5. Parts of a building which can be naturally lit and ventilated are called ‘passive zones’. By a simple rule of thumb given by the LT method, they extend approximately for 6 m (or twice the ceiling height) from the facade. Image adapted from Baker and Steemers [2].

According to C. Ratti et al. (2005[7]), the surface-to-volume ratio, while being an interesting morphological parameter, does not describe the total energy consumption in urban areas. A better indicator seems to be the ratio of passive to non-passive zones, although accurate energy consumption values can only be derived from an integrated simulation such as LT (where LT stands for lighting and thermal).The proportion of passive to non-passive areas in buildings provides an estimate of the potential to implement passive and low energy techniques. It should be noted, however, that this is only a potential: the perimeter zones of buildings can still be wastefully air-conditioned or artificially lit. In some cases, passive zones can consume more energy than non-passive zones, especially when excessive glazing ratios and untreated facades make them particularly vulnerable to overheating during the summer and to heat losses during the winter.

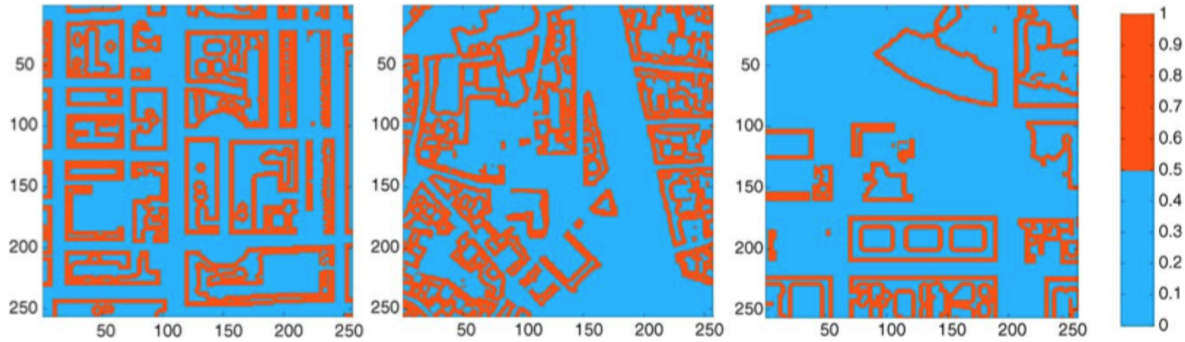

Figure 6. Passive zones (within 6 m from the facade) in London, Toulouse and Berlin, second floor; the image was obtained by thresholding the Euclidian distance transform (from C. Ratti et al. 2005[7]).

	London	Toulouse	Berlin
Total passive volume [%]	*77*	*84*	*61*

Figure 7. Data for London, Toulouse and Berlin(from C. Ratti et al. 2005[7]).

According to C. Ratti et al. (2005[7]) two conflicting exigencies for energy conservation appear: reducing the building envelope, which is beneficial to heat losses, and increasing it, which is favourable to the availability of daylight and natural ventilation. Which of the two phenomena prevails in the global budget of buildings? The above question is not likely to have an absolute answer. At very high latitudes, where solar gains are scarce and temperatures harsh all year long, heat conservation strategies might well be prevalent over the collection of daylight and natural ventilation. In these cases energy efficient buildings should probably minimize the external envelope, while at low latitudes they might try to maximize them. More generally, the relative importance of the two phenomena (losing heat and receiving beneficial gains through the facades) will be climate-dependent and differ between, say, Beijing and Shanghai. For a given climate, it can only be assessed by a comprehensive analysis, which takes into account all the energy processes that happen in buildings.

33. Coupling of the Digital elevation model analysis with the light and thermal simulation tools

The analysis of DEMs (Digital Elevation models) will be used to explore the effects of urban texture on building energy consumption in various areas of Shanghai. DEM is an effective support to derive morphological urban parameters quickly. Some of these will then be passed to a simulation tool (LT), in order to get energy consumption figures. CSTB's LT (where LT stands for lighting and thermal) models are well suited to simulate energy consumption at the urban scale, as they capture the principal energy flows of buildings with reasonable accuracy without necessitating the computational demands of full dynamic simulation. Nevertheless, the LT models requires numerous inputs to perform energy consumption calculations, including building U-values, interior and exterior reflectances, illuminance data, heating efficiency and setpoint, etc.

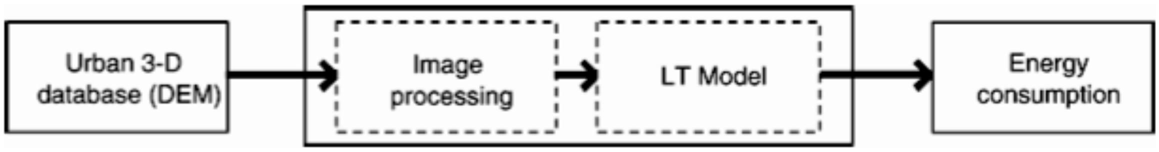

Figure 8. The image processing/LT interface and data exchange (from C. Ratti et al. 2005[7]).

4. CONCLUSIONS

Studying multiple cities at different periods of time, we will make a comprehensive comparison and contrast of city morphology efficiency between regional cultures in the west (Paris, Berlin, London, Toulouse) and in the east (Shanghai and Beijing), between periods of time of the rapid growth (Shanghai and Beijing) and the steady growth (Paris, Berlin, London and Toulouse).

A number of results will emerge on the relationship between Shanghai city texture and energy consumption. The morphology of Shanghai will be characterized and quantified in considerable detail primarily for simulation, and analyses, but this can also be used for improved urban planning, and other urban related activities. A new integrated computational analysis for the prediction, evaluation and optimization of Shanghai morphologies will be developed. This will be applied to several case study sites to develop new knowledge regarding optimal means for urban growth and change, based on a scientifically rigorous interpretation of sustainability.

The proposed approach allows a simplified diagnosis of urban sustainability, useful for comparing the bioclimatic and energy efficiency of different urban morphologies, useful for design and planning, but also monitoring of the long term urban planning. This cross-regional study therefore, is an attempt to explore the general laws that govern energy flows and climate in cities in many distinct ways. It is also an attempt to maintain in this global world the cultural distinctiveness in city evolution and architectural design.

ACKNOWLEDGEMENTS

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