Thermodynamic Prototype Research of Vernacular Architecture Based on Climate Adaption

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Abstract. Climate adaptation represents the thermodynamic state of building systems by feedback of form, material and spatial organization. This article proposes a new method to research the climate adaptability of vernacular architecture. Taking Shentan Village settlement as a case study, we search for the architectural prototype from the perspective of thermodynamics by simulations of LADYBUG+HONEYBEE tools, extract the architectural elements related to the specific climate characteristics, and systematically analyse the internal logic of energy flow in vernacular buildings by energy systems language.

1. Vernacular architecture and thermodynamic prototype

The contemporary evolution of energy and thermodynamics provides a special perspective for architectural autonomy and climate adaptation problem[1]. Kiel Moe put forward the concept of "energy formation" in his book Convergence: an Architectural Agenda for Energy in 2013, and explicated materials, energy systems and amortization as three factors that should be converged through design to maximize the architectural and ecological power of buildings[2]; in 2015 William W. Braham explored the architectural implications of system ecology in Architecture and Systems Ecology, extended the principles of thermodynamics with the resilient self-organization of ecosystems by means of energy systems language; in their book Essays on Thermodynamics, Architecture and Beauty, Inaki Abalos and Renata Sentkiewicz presented the arguments and designs around the new category of "thermodynamic beauty"[3]. For vernacular architecture, due to the relatively primitive local materials and construction technique, buildings must be simple but efficient. By studying the vernacular architecture in different climatic conditions, extracting their form elements and energy flow modes, we can understand the historical experience by people adapting to climate through buildings, that is, thermodynamic prototype.

2. Research method of vernacular settlements from the perspective of thermodynamics: a case study of Shentan Village in Yiwu

Shentan Village in Yiwu is located in Zhejiang Province, China. It belongs to the “hot summer and cold winter” region of Climate Regionalization of Architecture in China, characterized by distinct seasons and heavy rainfall. The local settlement in the village is situated on a slope, consists of typical vernacular dwellings with courtyards in Zhejiang.
2.1. Visualizing Climate Data with Parametric Performance Software

The LADYBUG + HONEYBEE Tools based on Grasshopper have the ability to customize the visualization of simulation results and the target time period to be analyzed. LADYBUG can be used to generate diagrams of temperature, humidity, wind roses, solar radiation, etc., and generate psychrometric chart to show the effectiveness of passive strategies. HONEYBEE can simulate environmental performance such as energy consumption and thermal comfort calculation. By inputting the climate data in EPW file of Shentan village into LADYBUG (Figure 1, Figure 2), the related climate data will be visualized and analyzed.

![Figure 1. Dry Bulb Temperature of Shentan-Hourly (Legend: 0°C-35°C)](image)

![Figure 2. Relative Humidity of Shentan-Hourly (Legend: 20%-90%)](image)

2.2. Analyzing energy demand based on climate characteristics

Through data visualization we can intuitively understand the climate characteristics, whether annual or seasonal, occasional or general. According to the analysis results of L+H tools, the important climatic data of Shentan Village are as follows (Table 1). The table shows that the temperature of Shentan Village varies greatly throughout the year. The annual total precipitation and humidity are high and makes people necessary to pay attention to rain-proof and moisture-proof in structure and material. Radiation resource is rich and should be fully utilized. The most significant problem in energy demand is how to deal with the contradiction between heat insulation in summer and heat preservation in winter.

![Table 1. Major Climate Data of Shentan Village](table)

2.3. Summarizing the energy strategies of vernacular architecture

According to the demand, the energy strategies of vernacular architecture can be analyzed from the following aspects: (1) reasonable location and layout; (2) adapt to the topography and actively utilize existing local construction materials; (3) heating with natural heat source and cooling with natural heat sink by rational organization; (4) programming the functions to achieve energy coordination of various indoor spaces; (5) with certain low-tech ways to create better thermal environment conditions. Based on field research and measurement of Shentan settlement including assessment of indoor physical environment and infrared thermal imaging, the energy strategies of vernacular dwellings to cope with climate were summarized as follows:

- Street space with intensive road network: shading and ventilation;
  The widest main road in Shentan Village is only 4m, and the aspect ratio of street space is more than 2:1. According to the sunlight hour simulation by L+H tools (Figure 3), the sunshine inside Shentan is far less than outside open space due to mutual occlusion. Open spaces such as ponds and squares in village form good conditions for wind pressure ventilation.

- Patio with appropriate scale: lighting, ventilation and drainage;
  Patio is a prominent spatial feature of vernacular architecture in Zhejiang Province, an important way of lighting the interior rooms. Due to the strong solar radiation and the stack-ventilation function,
the size of the patio is relatively narrow. Also there are kennels inside the patio to guide rainwater from indoor to outdoor drainage ditches.

![Figure 3. Sunlight hour analysis of vernacular settlement in Shentan](image1)

![Figure 4. Thermograph of the patio in Feng Xuefeng's former residence](image2)

![Figure 5. Enclosed envelope](image3)

![Figure 6. Comfort zone before and after passive strategy comparison(0~120h)](image4)

![Figure 7. Energy systems language diagram of vernacular dwellings in Shentan Village.](image5)

- Insulated envelope: thermal storage;

Wood and stone are abundant in the middle of Zhejiang Province, and the construction materials of vernacular architecture are basically draw on these local resources. The exterior wall is mainly made
of materials with good thermal stability and inertia, such as brick wall and earth wall, which are adapted to the variable local climate.

- Sloping tiled roof: thermal storage and rain-proof;

  It can be seen that the tiled roof of Feng Xuefeng's former residence has a strong heat storage capacity from thermographs (Figure 4). In winter night, the temperature of the roof surface can be higher than elevation surface by more than 5°C. In addition, the double eaves slope roof guides rainwater to the kennels inside the patio to prevent rain from scouring the wall.

- Corridor space: buffer zone;

  Measurement data shows that the air temperature in the corridor on second floor is always between patio and rooms (Figure 5). The corridor is another buffer zone between indoor and outdoor space, which stabilizes the amplitude of indoor temperature.

- Compact centripetal layout: reducing heat loss;

  Feng Xuefeng's former residence is one of the most representative local dwellings in Shentan Village. It is a quadrangle with rooms arranged compactly around the central square patio. Relative to the exterior enclosed wall, the interior rooms facing the patio have light wooden plank partitions toward the patio. The compact centripetal layout prevents the influence of external environment fluctuation on the internal space.

  Feedback their passive strategies to L+H software for thermal comfort simulation can verify which passive strategies are more effective and become the key link in architectural thermodynamic system. The indoor thermal comfort zone of Shentan vernacular dwellings can be increased from 4.6% to 37.6% (about 3298h) by the strategies above (Figure 6).

3. Architectural thermodynamics prototype method based on climate characteristics

The research of vernacular architecture types from the perspective of thermodynamics involves a comprehensive influence of natural environment factors. It summarizes how the climate strategy is expressed through types in specific sites and how the prototype be reconstructed.

3.1. According to the basic types of energy transfer modes

Energy flow from renewable resources such as wind, sunlight, heat and rainwater always circulates in the open system between buildings and environment, and buildings utilize or block energy flow from the environment through spatial organization, material construction and technical equipment[4]. The energy transfer structure in vernacular architecture can be simplified into three modes: energy capture, energy programming and energy regulation, it is the basis for prototype extraction. The main ways of energy capture mode include radiation, conduction and convection, and the object is the natural energy outside the buildings; energy programming mode means the heat sources and heat sinks in buildings are organized carefully to form a good cooperation based on the energy balance; energy regulation mode is an auxiliary structure to control natural energy or internal heat gain by means of low-tech and low-cost methods[5]. Take vernacular dwellings in Shentan Village for graphical analysis in energy systems language, the energy and material flows in the system will be presented in three scales: space, building and environment (Figure 7).

3.2. According to energy demand types based on climate characteristics

External climate factors related to vernacular architecture include air temperature (T), diurnal temperature difference (D), humidity (H), precipitation (P), wind (W) and solar radiation (R), different elements correspond to different energy requirements: heat storage (+) or heat loss (-) according to (T); need (+) or no need (-) to control indoor temperature fluctuation according to (D); humidify (+) or dry (-) according to (H); storage water (+) or drain off water (-) according to (P); ventilation (+) or windproof (-) according to (W); increase or reduce heat gain according to (R). The factors affecting energy demand also include indoor heat sources (S), whether to increase (+) or decrease (-) heat production, and whether the heat produced needs to be accumulated (+) or dissipated (-). The final results can be presented as a list. Different energy demand types directly lead to the climate strategies of a building, which is reflected in the architectural form.
3.3. According to energy strategy types of different architectural element scales

Energy prototype elements can be divided into five levels: group layout, plane level, vertical level, interface porosity and auxiliary technology. These elements establish an effective link between climate conditions and human comfort. Thermodynamic prototypes of vernacular architecture in different cases can be analyzed in a graphical way in combination with climate characteristics. Table 2 shows the thermodynamic prototype comparison of four cases of vernacular settlement from different climatic zones in China.

| Settlement                  | Climate          | Group layout | Plane level | vertical level | Interface porosity | Auxiliary technology |
|-----------------------------|------------------|--------------|-------------|----------------|--------------------|----------------------|
| Shentan Village, Yiwu, Zhejiang |                  | ![Diagram](image1) | ![Diagram](image2) | ![Diagram](image3) | ![Diagram](image4) | ![Diagram](image5) |
| Hushan Town, Quanzhou, Fujian |                  | ![Diagram](image6) | ![Diagram](image7) | ![Diagram](image8) | ![Diagram](image9) | ![Diagram](image10) |
| Baishe Village, Sanyuan, Shanxi |               | ![Diagram](image11) | ![Diagram](image12) | ![Diagram](image13) | ![Diagram](image14) | ![Diagram](image15) |
| Yaozhan Village, Fushun, Liaoning |             | ![Diagram](image16) | ![Diagram](image17) | ![Diagram](image18) | ![Diagram](image19) | ![Diagram](image20) |

4. Conclusion

To study the process of thermodynamic prototype of vernacular architecture, it is necessary not only to analyze the relationship of energy I/O between environment and buildings, but also to consider the organization of energy flow in building systems[6]. The thermodynamic prototypes can be regarded as a reference to study the logic of architectural spontaneous generation in specific climate, and applied to contemporary architectural design.

5. References

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