Regional Space Strategy and Zero-energy Engineering Strategy: An Analysis of “In-Between Nature” for Solar Decathlon China 2018

WANG Shaosen¹, SHI Feng¹, YAN Shurui¹, and CHEN Hong¹
¹School of Architecture and Civil Engineering, Xiamen University, 182 Daxue Road, Siming District, Xiamen, Fujian, China 361005.

ymcai@xmu.edu.cn; 347605132@qq.com

Abstract. With an analysis of the project “In-Between Nature” for SDC2018 that got 3rd place in the competition, this paper explored a combined approach to achieve zero-energy consumption building: space strategy learning from local architecture prototypes which is mainly passive, and engineering strategy which covers life-cycle of the building. During the competition, statistics such as temperature, humidity, energy produced and consumed are measured, proving that this combined strategy is feasible and the house has achieved the goal of zero-energy in Dezhou during early August, when the temperature and humidity is highest of a year.

1. Project Background
During both urban construction and rural renovation, we must respond to the problem of reserving traditional culture while fulfilling the demand of current living method. Traditional and regional architecture often means old in public opinion, but old doesn’t necessarily mean outdated. On the contrary, it contains experience accumulated by multi-generations that finally combines architectural form, building function, climate characteristics and geographical environment. Nowadays, hi-tech and modernization rather than traditional architecture are many people’s first impression of green building. However, simple and efficient wisdom are embedded in traditional constructions in wide-spreading regions. That’s the reason we use tradition prototypes, local materials and combine traditional wisdom to modern technology to build a zero-energy residence.

Team JIA+, which means Home Plus, consists of faculty and students from Xiamen University, Shandong University and Team Solar Bretagne in France. Taking the opportunity of 2018 Solar Decathlon China, we placed our site in a village inside the city of Xiamen to reflect the building environment and climate features of South Fujian Province. Each team is required to build a 100-200 m² zero-energy consumption residence within 20 days.[1] In order to meet the demands of the competition, we built a 1:1 frame model of surrounding houses in the competition site in Dezhou, illustrating the spatial relationship between old and new. The whole process from design, management to construction was carried out by students under the instruction of the faculty, and was completed in 2.5 years. In the final competition, we achieved the third place with a total score of 915.82.
Figure 1. Current situation of site

Figure 2. Bird’s-eye view

Figure 3. Southeast view

2. Space Strategy: Prototype from Regional Architecture

2.1. Two Spatial Prototypes: DaCuo and Shoujinliao

South Fujian DaCuo, a kind of big shady house widely distributed in this region, has been proved as an effective way of adaptation to the local climate. Overhanging roof shades the porch in front of the house, providing a heat-buffering zone between natural and artificial environment. Rather than stone which is also commonly used in the roof construction in Fujian, the roof of DaCuo is built with wood structure and covered with tiles, both of which are low thermal conductive materials. Sky-windows and building-gaps on the slope roof enhance the chimney effect of the interior space, making full use of natural ventilation.

Shoujinliao, which means Handkerchief House because of its narrow shape, consists of a series of small-scale yards connecting different building blocks. Houses and yards work together as a self-shading system, sheltering each other from the sun. Space is linear distributed to minimize the heat gained by radiation, and a typical 4-meter wide Shoujinliao is usually 20-30 meters in length. It can contain as many as 9 yards and 31 rooms in a single group that are diverse in size and shape. Variation of space dimension also leads to imbalanced air density, which accelerates the interior wind speed to keep the air fresh and cool down the temperature.
2.2. Embracing Traditional Wisdom: Passive Space Strategies

Learning from these two types of traditional architecture, we researched into the relationship between interior space and exterior environment, especially the design of in-between space, and try to adopt climate adaptive strategies of traditional architecture in modern technical design, making full use of passive method to reduce cost of energy.

In the plan, we introduced 3 space to promote the thermal performance. Firstly, a 3-meter-wide porch space to the south of the building is covered with louvers, insulating the rooms from the heat and meanwhile guarantee the natural lighting. Secondly, inside of the new building, a heat-buffering inner-yard, which is narrow and high enough to block its floor-ground from the radiation, is placed along with the porch and adjusts the micro-climate and further advances the ventilation. Nearby rooms open to the small yard, which uses its skylight window to work as a heat buffering space. In the winter, the skylight windows are closed, converting the yard into a greenhouse which warms up surrounding spaces by heat convection. Filler materials in the yard floor helps to accumulate the heat and keep a stable temperature. In the summer, the skylight window is open with louvers blocking the sunlight, assisting the ventilation of neighbouring space with chimney effect. According to previous research on Shoujinliao, in such yards located in South Fujian, the average air temperature near the floor-ground can be 2.1℃ lower than the outdoor space, and temperature range per-day is also reduced from 10.7℃ to 6.2℃. Compared to its modern opponents, average temperature of the bedroom in a typical Shoujinliao is also 1.1℃ lower than that of a concrete-structure house in the same district.\(^{[3]}\)

The overhanging attic increases the aspect ratio of the yard, and further shelters the living-room underneath. Finally, the new building places itself just 6 meters from the old one, leaving a gap space consist of two 1.5-meter corridors adjacent to each house and a 3-meter-wide yard between them, so that the old house and the new can work together as a yard-block self-sheltering system, just like the case in a traditional dwelling. These three spaces all derive from the study of traditional prototypes and form a series of hear-buffering space between indoor and outdoor.

In terms of section, the south and north roofs are separated, leaving space for motor-driven skylight windows facing the north which enhances the natural ventilation by heat and wind pressure and fills the space with gentle lighting. We choose a slope roof based on two factors. Firstly, the site is surrounded by slope-roof South Fujian DaCuo. By creating formal similarity between new and old, the visual consistency was acquired.\(^{[4]}\) Secondly, for a higher generation rate of PV panels, slope roof takes advantage of the angle between solar panels and incident sunlight, achieving high solar energy gathering efficiency. Considering annual incidence angle and height limit, we adopted a 20° slope to balance among various aspects. In addition, the 15cm cavity between PV panels and roof structure allows the wind flow to reduce solar heating of the roof and cools down the panels, improving their electricity generation efficiency.
3. Engineering Strategy: Zero-energy Techniques

The goal of zero-energy consumption is a full-cycle process, from material selection, construction management, daily operation to maintenance. There are 3 technical strategies that we proposed for this project, each focusing on different aspects of the life-cycle of building.

3.1. Prefabrication and Fabrication

An eco-responsible house has to be built quickly with a dry and healthy process. The team works on a modular solution to optimize the assembly time through simple and accessible construction modes. The wet blocks are bundled with integrated networks to prevent plumbing on site. The bearing structure, that is to say, the perimeter walls, the ground floor slab and the roof, have been designed with the same prefabricated method: 2D box including wood frame, insulation and also interior facing. Structural elements are prefabricated, so that only interior decorations need to be made on site. Thus, even untrained students or novices can take over the system and participate in the construction.
Building equipment and pipelines are also highly compacted for the ease of modular construction. The cavity under the north roof works as equipment space for air conditional fans and fresh air ventilator. Air pipes are distributed between decorative boards and kneels. Partition walls of both toilet and kitchen contain water supply and drainage system. Electric wires are also hidden inside wall units. We took full advantage of prefabrication system and integrate structure with equipment.

Figure 12. Prefabrication and assembling

3.2. 90% Eco-materials
In a logic of sobriety, we choose bio-sourced materials, resulting from the biomass, for an architecture respectful of the environment. Four local biomass materials including straw, wood, bamboo and sawdust are the major materials of the building.

We choose straw board insulation because this material is available in large quantities in Shandong, humidity regulator and inexpensive, which is usually burned as agricultural by-product and causes serious air pollution. Wood is mainly used as the structural units, and bamboo as decorations, both natural, recyclable, non-toxic and carbon sink materials. With no chemical treatment in the whole manufacture process, it brings no risk for the health to the builders or the inhabitants.

Figure 13. Straw-wall Configuration

| MATERIAL    | DENSITY (kg/m³) | THERMAL CONDUCTIVITY (W/mK) | HEAT CAPACITY (J/kgK) | GREY ENERGY (kWh/m³) | PHASE SHIFT |
|-------------|-----------------|-------------------------------|-----------------------|-----------------------|-------------|
| Wood Fiber  | 50              | 0.039                         | 2100                  | 60                    | 13          |
| Glass Wool  | 35              | 0.039                         | 1030                  | 470                   | 3           |
| Cork Panel  | 125             | 0.049                         | 1560                  | 450                   | 10          |
| STRAW       | 230             | 0.080                         | 1330                  | 0                     | 16          |

Figure 14. Physical Qualities of Straw
3.3. Combination of passive and active equipment system

The team’s driving line is “the best energy is the one you do not consume”. We prefer the use of the “free” that are the sun, wind and water in a passive design. However, the climate in Dezhou is not always temperate, and when the passive system is not enough to meet the comfort requirements in harsh climatic conditions, the active system can take over the house regulation for some time.

The panels installation on the south roof has been designed to be as efficient as possible. The roof slope (20°) has been set to have the best orientation during summer and produce energy to balance house energy needs. The installation consists of 44 PV panels and one water heating solar panel.

A flexible skin system is used as the envelope of the building. Outer louvers and skylight windows are all electric controlled and adjusted according to the weather for a better micro-climate. Taking the south façade as an example, it is equipped with motor-control aluminium lover and manual-control bamboo lover. The aluminium lover adjust itself automatically to create sunshade, while the bamboo lover is controlled by human to conduct the airflow. Building intelligent control system is introduced to link the building equipment of different brands and different control methods. By integrating and optimizing active and passive methods, environment control measures become more intelligent and energy-saving. The whole design process is optimized by BIM techniques.
4. Testing Data and Conclusion
Climate data during the competition were measured using a meteorological station. Air temperature, humidity and solar radiation during the competition were recorded.

Fig. 20 shows the air temperature and Fig. 21 shows the humidity during the competition indoors and outdoors. The outdoor air temperature often exceeded 40°C at noon and 30°C at night, and the air humidity was also very high. Thus, heat gain had to be reduced and a great deal of heat had to be removed to reach the 22-25°C indoor temperature standard of the competition. The HVAC system was used together with passive strategies, such as creating heat-buffering spaces, using dynamic shading to reduce heat gain from solar radiation and opening the skylight of the atrium for ventilation at night. Meanwhile, the temperature at inner-yard was kept around 30°C without the help from the HVAC system during the test, significantly lower and much more stable than the outdoor temperature, which proves the passive strategies effective.

Solar radiation intensity on the competition site was measured from August 2nd to August 16th. It was sunny and extremely hot, except for a heavy rain on August 14th.

Fig. 22 shows the solar radiation intensity and generation power of PV panels in early August. The peak intensity of solar radiation during those days was approximately 800 W, and the peak power production was approximately 11 kW. Fig. 23 compares the electric power generation and consumption during the period. By the end of the test, there was a total energy surplus of 37.00 kWh, which means that the house can meet the zero-energy building standard, and its energy efficiency strategies are feasible.

For a dwelling building, it’s of vital importance to achieve balance between living comfort and energy efficiency. Passive shading measures shouldn’t obstruct the natural lighting. The simulation of daylighting is made with Ecotect, and we revised the distribution of louvers several times so that the house is correctly lighted except the machine room (housing requires an average of 200 to 400 lux). Thus, during the construction, we guaranteed living quality for resident along with energy performance.
Towards SBE: from Policy to Practice

Figure 24. 3D Daylight Analysis

Figure 25. Daylight Analysis Plan

References
[1] Solar Decathlon China Committee, Solar Decathlon China [EB/OL]. [2018-07-01]. http://www.sdchina.org.cn.
[2] Wang Shaosen. The Perspective of Architecture: An Introduction for the Art of Architecture [M]. Beijing: Science Press, 2000: 88-89.
[3] Chen Xiaoyang, Xuejiawei, Zhen Bin. Field Study on Thermal Environment of Quanzhou Traditional Shoujianliao Residence in Summer [J]. Architectural Journal, 2010(s1).
[4] Wang Shaosen. Study on the Regional Expression of Contemporary Architecture in South Fujian [D]. South China University of Technology, 2010.
[5] Shi Feng, Hu Chi, Zheng Weiwei. An Analysis of Design Strategies of Operable Building Skins with Dynamic Adjustment on Environment Parameters: The Example of the Solar Decathlon [J]. New Architecture, 2017(2).
[6] Biloria N, Sumini V. Performative Building Skin Systems: A Morphogenomic Approach Towards Developing Real-Time Adaptive Building Skin Systems [J]. International Journal of Architectural Computing, 2009, 7(4): 643-675.
[7] Loonen R C G M, Treka M, Cóstola D, et al. Climate Adaptive Building Shells: State-of-the-art and Future Challenges [J]. Renewable & Sustainable Energy Reviews, 2013, 25(5): 483-493.