Available online at www.sciencedirect.com

ScienceDirect

Energy Procedia 57 (2014) 1931 – 1940

Energy Procedia

2013 ISES Solar World Congress

Integration of sustainability in Net-zero House: Experiences in Solar Decathlon China

Hong Zhang[a],Junjie Li[b]*,Lei Dong[c], Huanyu Chen[d]

[a ,b,c,d] *the school of architecture, Tsinghua university, Beijing, 100084China*

Abstract

The integration design between architecture, technology and engineering is an important issue of sustainable building. Facing the problems such as high city density, high performance limitation, construction methods and financial problems, the integration of sustainability issues into a regular residential building is a challenge, especially in China. This article's objective is to set up a framework integrating sustainable strategies to the design and the construction of a net-zero house based on the particular living situation in China. O-house is one of the entries of the solar decathlon competition in 2013, which was designed as a net-zero house for China residential market. By analyzing existing problems and potential opportunities during the market oriented survey, a possible solution by combining an appropriate building mode, solar power technologies and energy saving methods which may suit Chinese residential market is presented in this paper. The case shows specific strategies and steps of integration design, including building composition mode, architecture and material, combination of building and renewable energy technologies, integration of building and its equipment systems and integrated indoor furniture design etc. This experimental design and construction process presents us with a net-zero energy consumption and reasonable construction consumption (e.g. costs, labour, and time). In conclusion, this paper illustrates the scope of usage for integrate sustainable residential building design, and also points out its advantages and limitations that may come out in future.

Keywords: Net-zero energy, Solar house, Design integration

Globally, the development of net-zero houses is gradually becoming the apple of decision makers' and designers' eyes.[1-3] The design of a net-zero solar house is more than a significant aim based on technology innovation, which covers integration and creation of positive/passive eco-design[4], renewable energy technologies, energy system optimization, energy-saving and intellectual household design, building material and building construction methods etc., [5]but also is a creation of design thinking and idea, architecturally and sociologically. Creation established on the requirement of users is the start and foothold of all technological creation. International Solar Decathlon Competition is a forum on which the combination of solar technology and residential house building is presented to social public. [6] Relying on this international competition, a batch of excellent and market potential solar houses have been born, and

* Corresponding author. Tel.: +86-18500234716; fax: +86-010-62785691
E-mail address: qiqiyu_ljj@qq.com.

doi:10.1016/j.egypro.2014.10.057

excitingly, some of them were born with regionalism features. [7] They may play significant roles as references on the issue of designing China's adaptive net-zero residential house.

1. Background and Designing Aim

International Solar Decathlon Competition (SD) is a high level international competition that embraces outstanding universities and colleges from the whole world. [6] SD was initiated by United States Department of Energy, and since 2002, SD was successfully held in America and Europe many times. With the cooperation of China's National Energy Administration, China will host SD in 2013 for the first time. Depending on the technique and creativity of participant teams, that are characterized by excellent research & development ability and designing ability, the competition combines solar energy, energy-saving and architecture design as a whole, promoting each team to design and construct a solar residential house that is featured by function perfection, living comfort and eco sustainability.[8] This competition requires each team (university/college) design and construct independent living house within 2 years, whose area ranges from 60 m^2 to 100 m^2, and whose energy supply totally comes from solar energy. In this way, it aims to demonstrate that a residential house that is completely depending on solar energy could satisfy high level living quality. SD is aimed at promoting the combination and communication between production industry and study & research areas within international solar fields, and boosting the innovation, development and commercialization of relative technologies. [6,8]

2. Integrated designing frame of Net-zero House

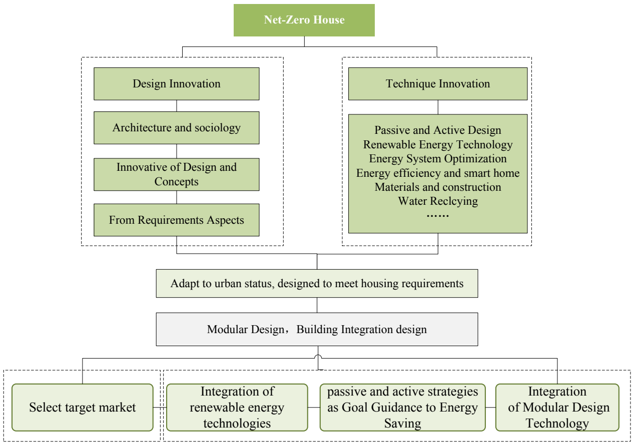


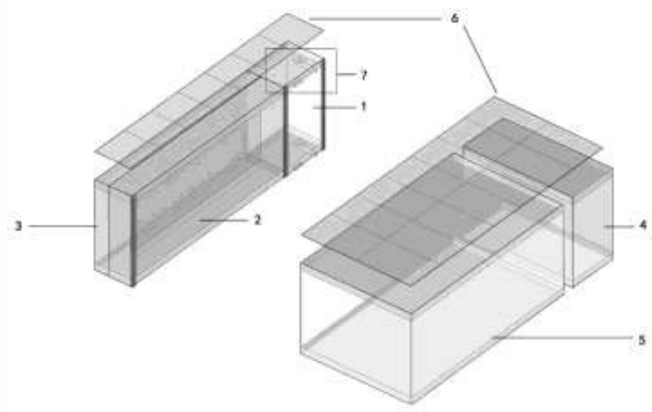
Fig. 1 Design Framework of Net-Zero House

In order to make progress in the field of net-zero housing, it is necessary to discover problems that exist in urban living environment. It is efficient to enhance net-zero houses' value to be popularized only if the research and development start from people's requirement towards living environment, or they would become relic as experimental projects or building models. Facing the problems such as high city density, high performance limitation, construction methods and financial problems, the integration of sustainability issues on a regular residential building is a challenge, especially in China. A framework integrating sustainable strategies to design and construct a net-zero house, based on particular living situations in China, is shown as Figure 1.

3. Modular Design Meets China's Residential Market

3.1. Solution to the issue of urban aging

With the progress of non-stop urban construction, many buildings in urban environment, especially residential houses or apartments[9], are facing the severe issue about its fast aging and urgently needed updating. [10]This issue has two facades. The first is: since the protection and updating of old-city area is insufficient, old, or say "traditional", houses need to be renewed urgently, in the meantime, in order to improve living quality, residents in old cities build some illegal attachment to their old houses, who influence the style and feature of old cities badly. The second is: through decades of fast and massive construction of residential houses in urban areas, the quality and technology level of the houses are improving day by day, many dwelling houses are urgently facing renewing problems such as anti-seismic strengthening, energy-saving transforming, device updating etc., far before the end of their deigning ages. Problems and opportunities are born as twins, updating in the same pace as construction, using reasonable urban renewal mode, combining with sustainable tech methods, are ways to solve the issue of urban aging. (Fig.2)



1. A module; 2. B module; 3. C module; 4. D module; 5. E module;

6. Solar photo-electricity and photo-thermal system; 7. Fast-fix system

Fig. 2 Components of Standardized modules

Inserting standardized building modules is one way to solve the problem of updating urban built environment. Replying to city development problems, we could renew urban areas in this way step by step. Specific method of transforming is according to specific requirement, by inserting standardized building modules, we integrate the former mess which contains many assisting functions. The device systems of these modules make use of renewable energy, realizing the sustainable development of city. Modules and components are prefabricated in factories, could be built up in little time, have a good adaptability. In addition, aiming to the soon-coming problems about mid and high-rising residential buildings' aging, we renew the building structure by technology on the one hand, and on the other hand, we realize the renew of system by device modules, and make use of roof of the building to extend living quality.

3.2. Leveled Modular Solving Method

The design of modules has four levels, they are household product, component modules, prototype of basic building modules and house system respectively. They explore and extend to the market on each of their level. The prototype of basic building modules includes two kinds of product, which are Equipment Basic Module and Space Expansion Module. The size of both of them conform to China's high-way transportation requirement. A, B, C, the three component module compose the Equipment Basic Module, the functions of them include solar thermal system , solar PV system, control system of the electric and water system of the house, and integrated indoor furniture, etc. D, E, the two component modules compose the Space Expansion Module. The indoor function space could be custom made for the requirement of the users. Possible living spaces are listed: the bedroom and lavatory module, dining room and kitchen module, living room and storage module etc. Extend the living space by the composition of these two kinds of modules, goods for the aiming market which are independent dwelling house, renew project of mid and high-rise dwelling houses and solar dwelling community are formed. Modules could be assembled freely and quickly, running independently by solar energy system. Modules could be jointed quickly and easily, adaptive to wide range of custom-made for different kinds of marketing requirement.

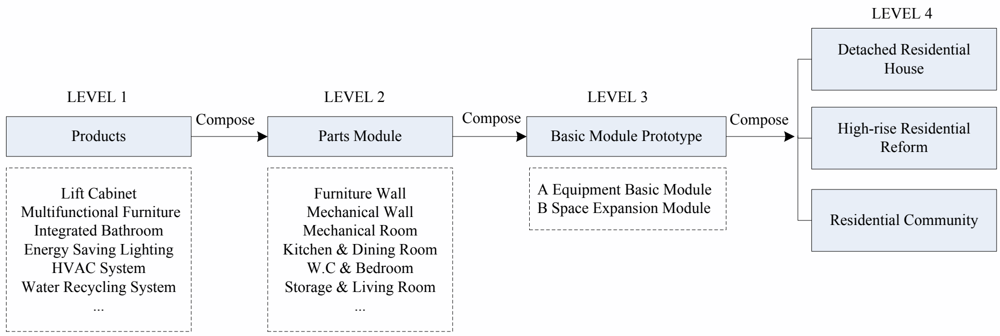


Fig. 3 Level of Standard Module

4. Integrated Design of Solar System and Architecture

Positive use of solar energy includes solar thermal system and solar PV system. [11]The modular strategy requires that the size of these two kinds of device system fits well with the size of the two kinds of prototype of basic building modules. More than emphasizing the use ratio and conversion ratio of the solar system which includes PV panels, Solar thermal panels, controllers and circuits etc., [12]the design focus more on how to level up the solar system's use ratio of architecture space, i.e. producing maximized energy and realizing high-efficient energy conversion in limited roof and elevation areas.

4.1. Solar PV and Solar Thermal System

The basic size of PV panel module is 1650mm (length) * 991mm (width) (prefabricated size in factory). The planning size of the two prototypes of basic building modules are: A, 1100mm in width and 7200mm in length; B, 3300mm in width and 7200mm in length. Thus the area of each module is multiple to the area of PV panels (exclude the area of parapet wall). The fitness of the two sets of sizes not only reduces the cost to pay for custom-made PV panels, but also maximizes the usable area of the roof, thus improving the use ratio of roof area. In order to enhance the conversion ratio of PV panels, the design of their bearings concerns about the ventilation under the panels and distant remote to control their angles to the sun, which means we could change the angle between panels and the sun to get sustainable energy as much as possible according to the changing solar altitude on different seasons, months, days in a year. The basic size of solar thermal panels is 850mm * 1000mm, hence 7 of them could be installed on the roof of Equipment Basic Module (1100mm (width) * 7200mm (length)). They provide heat for radiant floor in winter, and work as water heaters in the whole year. (Fig.4)

Fig. 4 Integration of Solar PV Panel and Solar thermal system components and building

4.2. Energy Balance

A standard house is built by two equipment basic modules and three space expansion modules. The building area is 87 m^2. The area of PV panels on the roof is 69.3 m^2 and the area of photo-thermal panels is 11.9 m^2. The mass .consumption of electricity on all domestic appliances and lighting is estimated in the Table1and 2.

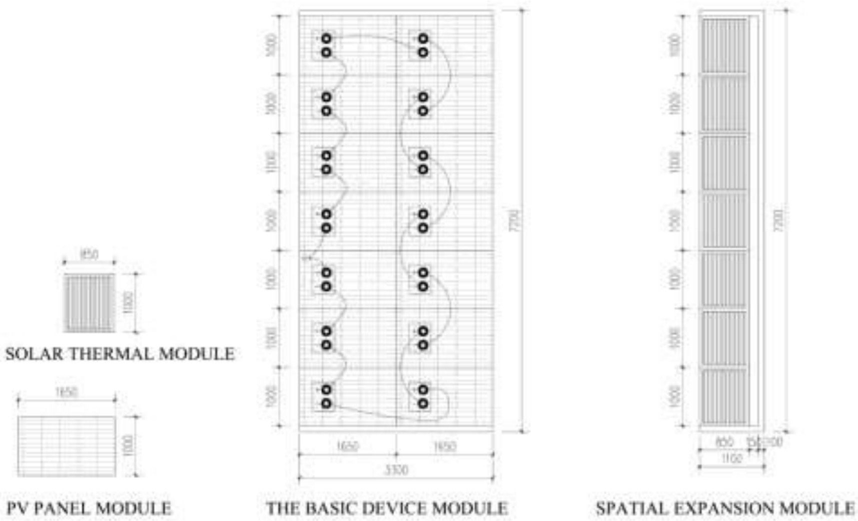


Table 1 Electricity Consumption in a Standard House

Service Feeder Calcs				
General Lighting	efficiency	capacity factor	unit	
General Lighting	1000va At 70%		700	Va
Subtotal			700	Va
Kitchen				
Electric Cooktop	6800va At 50%		3400	Va
Microwave Oven	1000va At 100%		1000	Va
Dishwasher (Nec 220.53)	1650va At 75%		1238	Va
Refrigerator (Nec 220.52)	150va At 50%		75	Va
Rice Cooker	1250va At 100%		1250	Va

Range Hood (Nec 220.53)	200 Va At 75%	150	Va
Subtotal		7113	Va
Living Room And Bathroom			
Television	80va At 100%	80	Va
Washing Machine (Nec220.53)	1100va At 75%	825	Va
Dryer (Nec 220.54)	4000va At 100%	4000	Va
Vacuum Cleaner	400va At 100%	400	Va
Fan	100va At 100%	100	Va
Computer	2*180va At 100%	360	Va
Projector	500va At 100%	500	Va
Sound	250va At 100%	250	Va
Subtotal		6515	Va
Hvac Compressor And Units	2500va At 100%	2500	Va
Water Tank Pump (Nec 430.24)	1000va At 100%	1000	Va
Sum of Loads		17828	Va

Table 2 Electricity Production in a Standard House

PV System Specification	
Total surface area of the array（biggest）	1.65m*0.991m*42=68.68 ㎡
Module Efficiency	16.21%
Electric power capacity	42*0.265kw=11.13kw
Array Tilt	1.15°
Array type	Fixed tilt
DC to AC derate factor	0.675

According to the station identification and PV system specification, we can calculate the output of PV panels during the competition (on August 1st):

Electric power capacity × Sunlight Time × DC to AC derate factor

=11.13×5.126×0.675=38.52kwh.

5. Positive and Passive Strategies Aimed at Energy-saving

5.1. Passive Design Strategy on Floor Planning

To achieve the target of net-zero energy consumption, works on inflow and outflow of energy are both necessary. A sound floor plan could play an important role on the reduction of building's energy dissipation. Functioning as a house, spaces that are the most used and most user-related should be optimized the physical comfort level as much as possible. O-House ensconces the most cardinal and comfort demanding space at its very center, three layers of spaces encircle the core space from inside to outside. The micro environment transits layer by layer, hence the indoor comfort level upgrades when energy consumption is lowered by the passive design strategy at the meantime.

The implemented passive strategy on floor plan is shown in Figure 5.

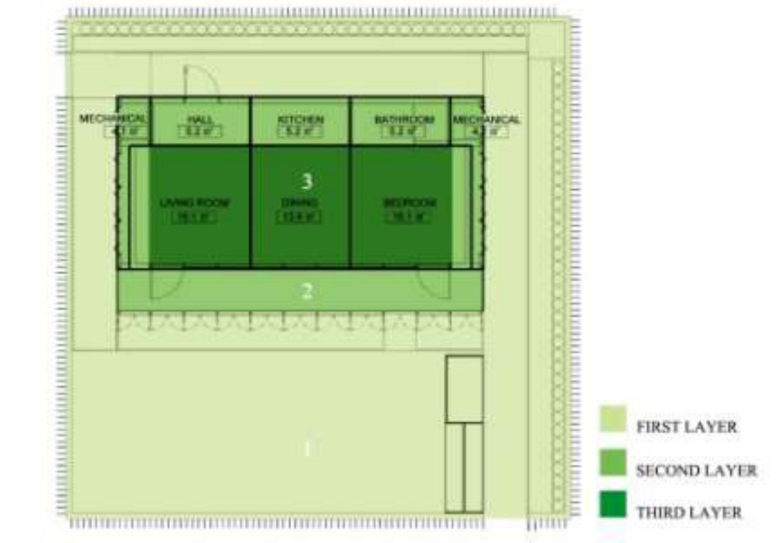


Fig. 5 Passive Design Strategy of Three Layered Spaces

5.2. The Solar House at the South

Shading is another important way to reduce cooling loads and heating loads. This section finds the load difference on O-House between with shading and without shading.

The CHT of glazing material is 0.48 W/ (m^2·K), and SHGC is 0.443. Cooling and heating loads of O-House with and without shading can be calculated by simulation, and the results are shown in Table3.

Table 3 Energy consumption simulation results in Datong (kW.h/day)

		Heating (kW.h/day)	Cooling (kW.h/day)	Total (kW.h/day)
Annual	With shading	2.34	5.84	8.18
	Without shading	1.76	7.42	9.18

Test week	With shading	0.00	9.57	9.57
	Without shading	0.00	10.70	10.70

5.3. Building Materials and Building Construction Methods

With the help of simulation, the energy-efficient O-House has been designed. Key factors that will influence cooling and heating load notably have been established according to simulation results.

Some main conclusions are as follows:

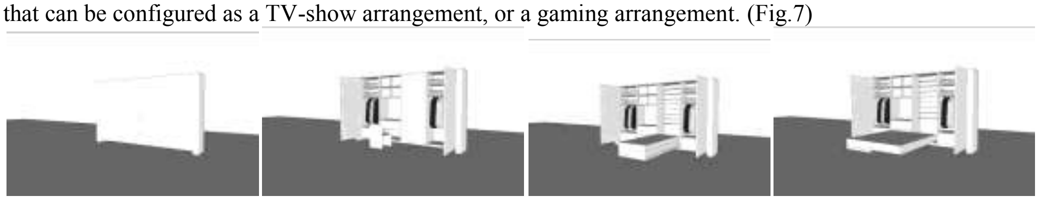
- "Quadrupl LoEClr 5mm/42mm Air" glass is chosen for glazing of O-House, whose CHT reaches 0.48 W/ (m^2·K), and SHGC reaches 0.443.
- The thermal insulation of walls should ensure the CHT of walls reaches 0.2 W/ (m^2·K).
- The thermal insulation of roof should ensure the CHT of the roof reaches 0.1 W/ (m^2·K).
- Removable shading is adopted in O-House, which can be installed in summer and removed in winter.

6. The Integration of Technology on Modular Design

6.1. Integrated Indoor Furniture Design

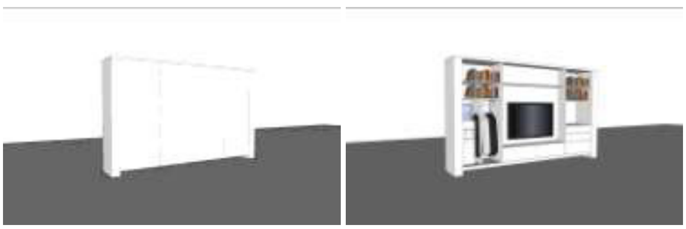
Following the modular market strategy, the household furniture also employs the pre-fabricated modular system. Integrated furniture is inserted to the Equipment Basic Module (1100mm(width) * 7200mm (length)). The principle in furniture design is to satisfy the greatest number of living functions in a minimum amount of space. At present, there are two kinds of furniture modules working for bedroom and living room respectively.

The bedroom module is a combination of a bed, which can be either single or double, a wardrobe, a dressing desk, a bookshelf, which can be configured as a bedroom arrangement at nighttime or a dressing room at daytime. (Fig.6)The living room module is a combination of television settings and their locker, CD shelves and shelves for gaming equipment that can be configured as a TV-show arrangement, or a gaming arrangement. (Fig.7)



a: Non-use status b: Shifting status c: Bedroom status d: Double Bedroom status

Fig. 6 Bedroom Features



a: Non-use status b: Living room status

Fig. 7 Living Room Features

6.2. Jointing Techniques of Modules

Seeing from the structure aspect, the C-shape columns "plug" into each other between modules. In this way, indoor space is saved, the clumsiness of twin-columns is avoided, and the strength of the entire structure is guaranteed. Columns between modules are connected by bolts, making the procedure of installing and uninstalling easier, and both of the procedures are reversible. In order to realize the fast-fix between modules, connections of electricity circuits and water system between modules make use of the plugging method. Pipelines of wire are pre-installed above the ceiling. Every line in one module converges at a terminal. The connection part of the system resembles USB harbor on PC. Users only need to plug and connect the terminal, and the connection of the system is soon accomplished.

Fig. 8 Modular design of O-House

a structure: C column b Electric: terminal plug c：Water system: Pipeline plug

Fig. 9 Jointing Techniques of Modules

7. Future and Vista

This experimental design and construction process present us with net-zero energy consumption and reasonable construction consumption. The following list is the four advantages of our O-House.

1) Self-sufficient by solar energy, net-zero energy consumption

By using positive and passive sustainable strategies and renewable energy, the inflow and outflow of energy are well controlled. Total energy of the house comes from conversion of solar energy. It is a real net-zero house.

2) Modular house design in reply to China's future dwelling market

For the modular concept, this work could be used on the organic urban renewing projects, and also on commercial and tourist estate development projects of which the site is lack of infrastructure support. The modular concept could help to compress the working period under two weeks. In the meantime, the precision of construction is increased to the millimeter grade—one grade higher than normal construction's precision (centimeter).

3) Integrated design of architecture and sustainable technology

The design of the building is more than the deliberation of architectural space or the form of the building. It also involves reconfigurable furniture, reconfigurability of space and marketability. Moreover, in other spaces of the house, solar energy system, intellect controlling system, grey-water and rain water recycling system and atomizing cooling system etc. are integrated. Through an overall consideration of architecture and technology, the integration of architecture and technology is realized.

4) Cost Control

Net-zero houses could be accepted by the market more successfully when the consumption is well controlled. O-House breaks the concept of house up, from the whole into parts. The traditional concept of "building a house" is broken through. The flexible modular design strategy makes the mass production in factory come true. By pre-fabricating modules in factories and jointing them onsite, the cost of production and labor is greatly lowered.

Dwelling and energy-saving are severe issues on the development of cities. We tried to integrate architectural design and technology. We believe our works are meaningful explorations of the development of net-zero houses in China, and are also practical innovations that could open a window of an increasingly vast market.

Acknowledgements

O-House is a multi-party cooperation that including Tsinghua University, many sponsors, government, teachers and students, thanks to all people and organization who make efforts during the whole process.

References

[1] Song Yehao, Lin Borong, Jiang Yong. Green versus Architecture. Time + architecture; 2008/02, p.6-11

[2] Deb K, Srinivasan A. Innovization: innovating design principles through optimization. Seattle, Washington, USA: ACM; 2006. pp. 1629e1636.

[3] Zhang N, Lior N, Jin H. The energy situation and its sustainable development strategy in China. Energy 2011;36:3639e49.

[4] Passive House Institute, www.passiv.de.

[5] Ma L, Liu P, Fu F, Li Z, Ni W. Integrated energy strategy for the sustainable development of China. Energy 2011;36:1143e54.

[6] Solar decathlon official webside. http://www.solardecathlon.gov/

[7] Solar decathlon Europe 2012 official webside. http://www.sdeurope.org/

[8] Solar decathlon China 2013 official webside. http://www.sdchina.org/

[9] Fong KF, Lee CK. Towards net zero energy design for low-rise residential buildings in subtropical Hong Kong. Appl Energy 2012;93: 686e94.

[10] Bojic M, Yik F, Wan K, Burnett J. Influence of envelope and partition characteristics on the space cooling of high-rise residential buildings in Hong Kong. Build Environ 2002;37:347e55.

[11] Strzalka A, Alam N, Duminil E, Coors V, Eicker U. Large scale integration of photovoltaics in cities. Appl Energy 2012;93:413e21.

[12] Shum KL, Watanabe C. An innovation management approach for renewable energy deploymentdthe case of solar photovoltaic (PV) technology. Energy Policy 2009;37:3535e44.