

Zero Energy Houses for China:

Prefabricated Sustainable Housing for Disaster Relief in Sichuan Province

Edgar Stach, Barbara Klinkhammer, Chen Li

University of Tennessee, Knoxville

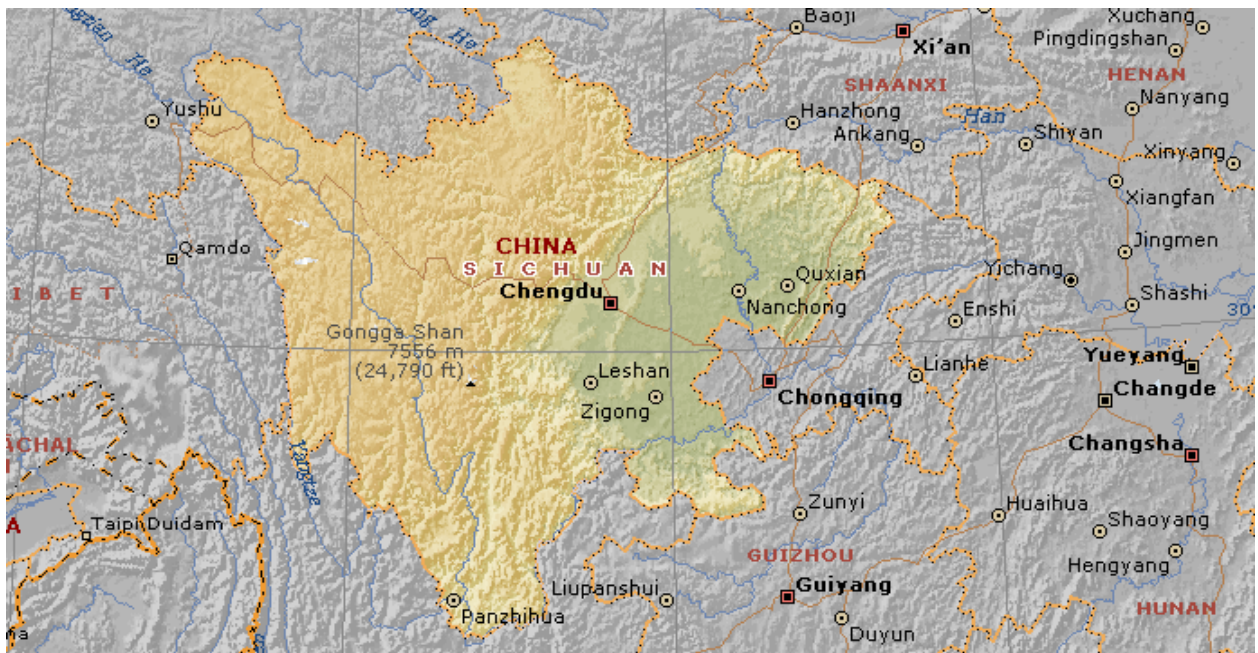


Fig. 1 Map of Sichuan Province, China ([www. msnencarta.com](http://www.msnencarta.com))

1. Abstract

The team proposes to develop a prototype for a sustainable prefabricated Zero Energy House for the Sichuan Province in China.

Sichuan Province in China was recently struck by a major earthquake which left millions of people homeless. In the next six months, the Chinese housing market will provide one million housing units to the affected region as a disaster relief reconstruction effort, and a large

percentage of these units will be completely or partly prefabricated. Sustainability in terms of alternative energy strategies and use of sustainable materials is largely not addressed in standardized prefabricated dwellings. Current strategies for disaster relief shelter commonly involve tents and plastic membranes because they are economical, easily transported, and flexible enough to accommodate various situations. While they are appropriate and convenient for immediate response, they do not provide adequate protection from extreme

conditions or offer long-term solutions for housing. Combining sustainable practices with well-planned design addressing production and transportation costs, shipping and production times, assembly, ability to cool in hot climates, and inclusion of cultural and social norms, sustainable prefabricated housing offers better solutions for long-term transitional or replacement housing.

2. Introduction to Sichuan

Sichuan Province is located in southwest China, with Chengdu as its capital city. The province has a high degree of geographical diversity: plateaus, mountains, ravines, basins, hills, plains, rivers, lakes, hot springs, waterfalls and limestone caves. Most of the rivers in Sichuan belong to the Yangtze River system.

1. Economy

Sichuan has historically known as the "Province of Abundance". Its agricultural output is greater than that of any other province in China¹; its grain yield in 2000 was 35.69 million tons. Also in 2000, its provincial GDP was 401.03 billion yuan and the gross output value of industry and agriculture reached 563.759 billion yuan. However, because of Sichuan's large population, the per capita GDP was only 4,805 yuan. The total volume of imports and exports was US \$2.55 billion, with a total revenue of 23.386 billion yuan.²

2. Government

Like all other governing institutions in mainland China, Sichuan's government has a dual structure, sharing power between the Governor of Sichuan and the Communist Party of Sichuan.³ Sichuan Province has 21 cities, including Chengdu.

3. Demographics

With a population of 87,730,000 as of the end of 2006, Sichuan Province is the third most populous province in China. 34.3% of the people live in cities⁴, giving Sichuan's eastern plains

their higher population density compared to the western hilly areas. Two counties within the province, Wenchuan and Beichuan, were razed to the ground by the earthquake.

3. Geography

Sichuan is situated at 26'03"-34'20" degrees north and 97'22"-110'10" degrees east with an area of 567,000 square kilometers, accounting for 5.1% of China's total area. Sichuan is higher in altitude in the west and lower in the east. Generally speaking, the western part is made up of plateaus and mountainous regions some 4,000 meters above sea level, while the eastern part features basins and hilly land with an elevation between 1,000 and 3,000 meters.⁵ Plate tectonics formed the Longmeng Shan fault, which lies under the north-easterly mountain location of the 2008 earthquake.⁶



Fig 2. A school in Wenchuan after earthquake (www.news.sohu.com)

5. Epicenter: May 12, 2008, 2:45PM, 60Sec.

The epicenter of the recent earthquake was in Wenchuan County, 80 km northwest of the provincial capital of Chengdu, a city of 105,436 people and 4083 square km in area. Wenchuan is a small county with several ethnic minority groups. Surrounded by 3000-meter mountains to the west and north, 48% of Wenchuan is covered by forest. The Min River flows from the north of Wenchuan to the southeast, and all of the county's most economically productive areas are along this river. Because of the county's specific topography, only one national highway connected Wenchuan with other cities, and this highway was destroyed by the earthquake.

Beichuan County, 160 km from Chengdu, was also seriously affected by the earthquake. Beichuan is located on a steep slope, with its northwestern side 460 meters higher than its southeastern side, and is crossed by numerous rivers.



Fig 3. Houses in Wenchuan after earthquake (www.news.sohu.com)

Wenchuan and Beichuan were similarly developed counties before the earthquake. Both had 14-15 middle schools, 170- 200 elementary schools, 50-60 kindergartens, 40 health institutes and one library. There are hundreds of towns and villages affected in lesser measure by the earthquake than Wenchuan and



Fig 4. A residential community of prefabricated houses (photo: Xinhua)

Beichuan, though the big cities in Sichuan were not severely affected.⁷

6. After the earthquake

80% of the buildings in the old town and 60% in the new town of Beichuan collapsed in the

earthquake. The province-wide death toll was nearly 70,000, and the number of people listed as missing and injured reached 17,939 and 374,640 respectively.⁸ The mountain landslide at Beichuan after the earthquake also caused extensive damage. Besides buildings, a great deal of important infrastructure such as transportation, electricity, communication, water supply systems stopped working.

Ten million quake survivors had to move into makeshift houses by August 6th, 2008. About two thirds of the households chose to build their temporary homes by themselves, subsidized with 2,000 yuan (US \$300) by the government, while the remaining third moved into houses built by construction workers from other provinces and municipalities.⁹ The government-built prefabs were relatively concentrated, with public bathrooms, clinics, laundries and supermarkets in close proximity.

7. Current situation

Soon after the earthquake, tent villages were set up in Wenchuan. Each tent village has a water intake site for people to retrieve water, though regular electricity has not been restored and diesel generators are being utilized to provide energy.¹⁰

The Urban Planning Department of the Ministry of Housing and Urban-Rural Development has made the decision to rebuild Wenchuan at a different location within Wenchuan's administrative region. The roundtable discussion and reconstruction effort led by CPN¹¹ emphasizes the long term nature of the rebuilding and restoration after the disaster, focuses on the role of planning, and asks how the academic community can contribute to the rebuilding of the destroyed towns and villages and the restoration of normal life activities. The agenda for the roundtable discussion included the rebuilding of houses, public facilities, industries, eco-environment in the quake zone and issues about the reconstruction funds. According to the agenda, the reconstruction work would cover an area of 132,596 square kilometers, which had a total population of more

than 19.8 million at the end of 2007. Restoration and reconstruction would require a total of 1 trillion yuan (US \$145.8 billion) according to previous evaluation.¹²

8. Housing types

Before the earthquake, residents of Wenchuan towns and cities lived in 5- to 6-story apartment buildings, while village residents lived in single family houses which were usually simply made, built by the residents themselves or passed down in families. Apartment buildings in towns are usually designed by local architectural design firms and do not have any elements indicative of local culture or tradition.



Fig 5. Floorplan of a typical apartment in Sichuan (www. blog.163.com)

Single family houses are characterized by their large tile roofs. The highly populated eastern part of Sichuan has a warm climate with hot summers and high precipitation, and this climate is a main factor affecting the layout of houses. House roofs generally extend far out beyond the walls of the house, even touching the roofs of adjacent houses, in order to shelter from the rain. Courtyards are found in the single family houses of Sichuan, though they are usually very narrow due to the combination of a large population and limited land.

The large-scale relocation of residents from the quake zone has not been specifically planned, but still the estimated cost of the reconstruction efforts is about 1 trillion yuan.¹³

9. Climate

Sichuan Province's climate is highly variable. The Sichuan Basin (including Chengdu, the capital) in the eastern half of the province experiences a subtropical monsoon climate with long, humid, warm to hot summers and short, dry, cloudy, cool to cold winters with China's lowest sunshine totals. The western half of Sichuan has a mountainous climate characterized by very cold winters and mild summers, with plentiful sunshine. The earthquake happened between the two areas.



Fig 6. A typical village house in Sichuan (www. blog.163.com)

In winter, Sichuan's climate is dry with little rainfall. Eastern Sichuan gets abundant rainfall from April to October, but in western Sichuan the rainy season is from May to September. Generally the eastern areas receive more rainfall than the western, and the basin areas get more rain than the plateau regions.

In terms of average temperatures, Sichuan's four seasons are quite distinct. In spring, temperatures range from between 10 and 21.9 degrees Centigrade, and above 22 degrees in summer. Autumn temperatures vary between 10 and 21.9 degrees. In winter, the average temperature is below 10 degrees centigrade. The western Sichuan plateau is quite cool and has an average annual temperature of less than 8 degrees centigrade. The average temperature is 5 degrees below zero in January, 5 to 10 degrees in April, 10 to 15 degrees in June and 5 degrees in October. In fact, western Sichuan has almost no summer.

Sichuan's southwestern mountainous regions have average annual temperatures of between 15 and 20 degrees in valley areas, and 5 and 15 degrees in mountain areas. In January, the average temperature is about 5 degrees Centigrade, 10 to 24 degrees in April, 15 to 26 degrees in June and 10 to 20 degrees in October.¹⁴

4. Sustainability Strategies

The goal of the Zero Energy Houses for China/Sichuan is to develop a sustainable materials database as well as passive and active strategies for prefab houses for Sichuan Province. The focus lies on advancing innovative technologies and further lowering costs. Among the goals of energy research are the enhancement of efficiency and production, the increased share of renewable energies in overall energy use and the reduction of greenhouse gas emissions. For the field of energy-optimized building that means measures to reduce the energy demand of houses.

Two categories of strategies are used in zero energy design.

1. Passive systems and strategies

Passive strategies in architectural design take advantage of natural conditions to minimize energy use without the aid of machines or human intervention. Integrating the passive strategies of day lighting, natural ventilation, and solar gain heating into the design process creates interior space with a greater connection to the environment, lowers energy costs, and requires less maintenance while contributing to conservation and improved comfort.

- Day lighting¹⁵

Day lighting is a passive strategy using natural lighting to illuminate interior spaces. The benefits from day lighting range from improved aesthetic qualities, including better color balance and connection to the outdoors, to increased energy efficiency.

- Natural ventilation¹⁶

Natural ventilation is a passive strategy using both wind and temperature differences to cool or ventilate spaces. The benefits from natural ventilation include improved air quality and increased energy efficiency.

- Solar gain heating¹⁷

Solar gain heating is a passive strategy using radiant heat from the sun to warm spaces. The benefits from solar gain heating include increased energy efficiency and the opportunity to offset day and night temperature variations with thermal mass.

2. Active strategies

Even after passive design strategies have minimized the need for mechanical systems, a home typically needs additional energy for heating and cooling, for daily needs such as hot water, and for appliances and lighting. Active strategies use human intervention or technology to provide for these needs and improve the effectiveness of the passive strategies already designed.

- Climate control¹⁸

A heat exchanger is a mechanical ventilation system that exhausts stale building air and imparts the waste heat to an incoming stream of air, also known as an air-to-air heat pump. When heating the space, a refrigerant absorbs exterior heat and warms a liquid medium, and a fan blowing air over the heated liquid warms the interior air; when cooling the space, the refrigerant extracts interior heat, thereby cooling the liquid medium, and the heat is exhausted to the exterior as the fan and coil unit cools the space.

Evaporative cooling within the cooling unit uses a fan blowing outside air over a wet sponge, evaporating the water and cooling the air.

Active solar space uses collectors to absorb heat from the sun directly into water, which is transferred to the storage tank or to the heat exchanger. Here the water can be used to pre-heat hot water, heat air in a fan-forced system, or can be run through the floor for a radiant heating system.

- Solar systems

Automated sun space: when heating the living space, the thermal blanket is lifted to allow direct gain; at night the thermal blanket is pulled down, trapping the heat inside. When direct gain is unwanted, the thermal blanket can act as a barrier. Operable vents in the sun space either prevent or allow convection depending on heating or cooling needs. Thermal mass absorbs heat from direct gain during the day. At night, both radiation and fan forced convection through the heated thermal mass warm the living space. Thermal mass is cooled by drawing in night air. Interior air is recirculated through the mass during the day to cool the living space.

- Components

Components such as phase change materials, evacuated tube technology, thermocouple actuators and mini-split heat pumps use natural forces to their advantage to aid a larger passive or active system without connection to the utility grid.

- Energy harvesting

Energy harvesting systems collect energy from the natural environment to provide electricity. These systems harvest energy either through an electrical process powered by the sun, a kinetic process powered by the wind, or a chemical process powered by biomass.

- Water

Active water strategies help to reduce water and electricity usage. These strategies include harvesting rain for water supply, absorbing heat for the hot water supply, absorbing heat as a thermal mass, and recycling or limiting water usage.

- Lighting

Supplementary technologies increase the efficacy of day lighting strategies by using either artificial lighting or reflected natural light.

- Control systems

Control devices manage active systems by optimizing energy use. These technologies can be as familiar as a thermostat to control heating and cooling, or as advanced as occupancy sensors to limit energy use when a room is unoccupied.

- Appliances

Energy-efficient appliances help reduce energy costs and promote conservation. Minimally, all appliances should meet Energy Star requirements, using the least energy possible without sacrificing performance.

4. Goals and Methods

Sustainable prefabrication allows for the opportunity for both global development and regional production of disaster relief housing. This provides advantages over current solutions: advanced planning incorporating global development allows for quicker, more effective response when disaster strikes; both socially and environmentally sustainable strategies can be integrated into the planning, production, design, and construction of housing; adaptive designs can allow for regional production and quick construction in various areas; disassembled homes can be reused for other relief efforts; and, finally, well-designed houses are more resilient shelters against extreme conditions.

Goals include:

- Research and development of Zero Energy housing strategies for China/Sichuan addressing economic, cultural, social and political factors as well as material issues, enabling the local housing industry to develop and fabricate better houses for the local market.

- Research and development of low cost and low tech technologies for sustainable housing adapted to local conditions (i.e.: PV cells, heat recovery, thermal insulation, solar hot water systems)

The following key issues will be analyzed:

- Production: Regional and central manufacturing centers in China can take advantage of available green power sources as well as off-peak rates. The controlled environment of the manufacturing center allows for precise construction as well as providing access to a stable workforce skilled in the application of the latest building technologies.

- **Transportation:** Central manufacturing facilities reduce the amount of material and worker transportation. Only regional manufacturing centers can reduce the distance traveled by the finished components to the job site. Building components may be shipped disassembled to reduce bulk or CAD files may be sent to local fabricators.
- **Assembly:** On site construction is minimized to limit time and energy expenditure. Building components are designed to be fastened together without the need for power tools.
- **Disassembly:** The design of the housing units would make use of reusable structural and envelope components that could be easily disassembled and reused. Other materials unsuitable for immediate reuse could be coded for recycling.
- **Operation:** Housing should be designed to take advantage of passive strategies such as solar space heating, day lighting and natural ventilation. Active strategies could include photovoltaic, solar hot water heating, high efficiency appliances, and ventilation.

Sustainable materials:

- **Availability:** A regional approach to prefabrication would make use of locally sourced material. This serves the dual purpose of reducing transportation needs and the preservation of regional differences in construction.
- **Efficiency:** Due to the controlled environment of the manufacturing center, computer aided manufacturing may be employed to reduce waste. Any waste streams may be diverted for recycling.

Social and cultural sustainability:

- **Economic:** The global need for standardized housing must be tempered with the local need for jobs. Regional centers could provide stable factory jobs without robbing opportunities from the local work force.
- **Cultural:** Regional focus would allow for fine tuning of prefab structures for cultural norms such as family size, relationship to land, and

building type. Mass customization has the ability to offset the homogenizing tendency of standardized production.

5. Project¹⁹



Fig 7 UT zero energy house floor plan

Why sustainable prefab?

As world demand for housing increases so does the percentage of prefabricated units. Though some manufacturers are beginning to offer more options, the industry standard is inefficient in its use of material and energy. Equally as important as sustaining resource supplies for future generations is the promotion of economic stability and diversity of regional culture. A system that combines the techniques of prefabrication with sustainable principles has the potential to be both efficient and responsive to social issues. Flexible strategies of regional manufacturing and mass customization offer the best alternatives to either current building methods or centralized production of standardized prefab units..²⁰

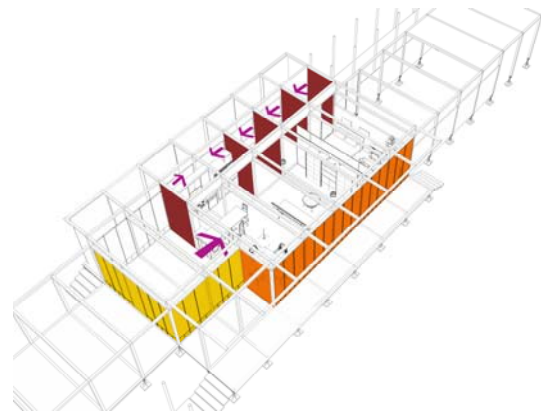


Fig 8 UT zero energy house heating

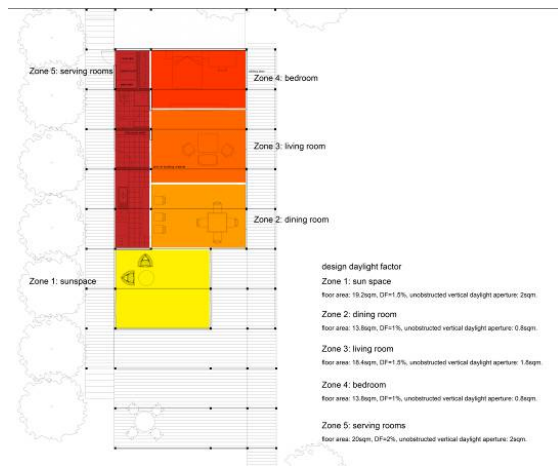


Fig 9 Day lighting zoning

The original configuration of the project derives from two basic units, one of which is a solid box, 1.5 meter x 2 meters x 3.6 meters, working as serving space; the other of which is an open space, 4.8 meters x 2 meters x 2.7 meters, working as served living space. All serving space is organized on one side with served space connected with it, but two served units without serving unit are put in the front. The aim is to keep the served space working as the center of the house with a good view to the outside; to make the serving space the buffer zone protecting the served space from the climate; and to have the front units as a sun space.



Fig 10 Zero energy apartment

The primary structure of the house is the columns and beams which constitute the supporting grids. The secondary structure, which includes the walls, roof, floor and glazing,

works as the thermal envelope. The solar envelope that provides the solar energy is the tertiary structure. The construction sequence of the house is: piers, columns, A beams, B beams, floor, wall panels, glazing panels, shading devices, solar panels. The exterior materials of the house are metal to make sure that the structure is light; while the interior material is wood in order to establish a homelike feeling.

Sliding devices are used to separate the serving space from the served space in the house, which makes the indoor space very flexible. They are also applied at the division of interior and exterior to make the house as open as possible when wanted.



Fig. 11 building performance: summer day - summer night, winter day - winter night

Passive strategies are applied in the design.

First of all, the house has three heating zones. The south-facing winter garden is a sun space, the southeast-facing rooms get direct heat gain, and the northwest-facing serving rooms function as a buffer zone. Second, heat is collected and distributed between the zones. Sun space and glazing areas collect heat, thermal mass on the floor stores it, and the air flow helps distribute it.

Both cross and stack ventilation are created in the house. Openings placed at diagonal in both plan and section make the cross ventilation efficient. Inlet at the lower part of east and outlet at the higher part of west make stack ventilation possible.

The covering of the porches by tinted glass is the main fixed shading device. Operable shading is provided by the sliding panels along both sides of the house and the interior blinds in case that heat is needed in winter.

Outdoor panels on both of the east and the west make the backyard comfortable in summer. The transparent material makes sure the landscape is still viewable.

Active strategies are applied to compensate when passive strategies are not sufficient. A photovoltaic power system generates electricity through the use of PV panels. Apricus water heating tubes that absorb the sun's radiant heat in an insulating layer of air-evacuated glass provide all the hot water for the house, including the water for the radiant floor. The floor is made of a high density wood composite which distributes the heat evenly across the surface. Passive and active strategies work together to make the gained and consumed energy balanced.



Fig 12 Zero energy house

6. Conclusion

By combining sustainable practices with well-planned design, sustainable prefabricated housing can solve previous problems and offer better solutions for long-term transitional or replacement housing. The Zero Energy House for Sichuan Province has the potential to

References

1 www.newsgd.com "Brief Introduction of Sichuan"

2 www.unescape.org/esid/psis/population/database/chinadata/sichuan.htm "Sichuan"

become a future model for sustainable prefabricated family dwellings.

Advanced planning of sustainable prefab housing should occur on a global scale, allowing the collaboration of various countries to develop innovative technologies and adaptive strategies in energy conservation and social sustainability.

Prefabricated housing should be produced regionally to reduce transportation costs, use local materials to incorporate regional differences in construction, and incorporate local customs and norms. Depending on necessity, regional manufacturers have the option to produce kits of building components or service modules containing plumbing and air supply.

Sustainable prefabricated homes aren't appropriate for immediate shelter, but can provide solutions for long-term planning for disaster relief. Because the homes will arrive as kits of building or technology components, the construction will be quicker than on-site construction, and the displaced victims can be involved in the construction of the homes, giving them a sense of self-reliance and ownership.

Low cost housing in the US has to address similar problems to those addressed by housing in developing countries. In both cases, owners face economic pressure due to rising energy costs and poorly designed houses. By addressing energy conscious design strategies, low tech sustainable technologies, and material, social and cultural sustainability, sustainable prefabricated housing can positively impact the well being of the owners, the economy of local businesses and the local and global ecology (depletion of natural resources, global warming etc.).

3 The Governor of Sichuan is the highest ranking official in the people's Government of Sichuan. However, in the province's dual party-governing system, the Governor has less power than the Sichuan Communist Party of China Provincial Committee Secretary; colloquially termed the "Sichuan CPC Party Chief".

4 www.21yb.cn/news/2007/1285.html

5 http://www.chinaculture.org/gb/en_map/2003-09/24/content_21629.htm

6 <http://en.wikipedia.org/wiki/sichuan>

7 www.wendoo.com/group/226/topic9632.html

8 China Daily, 08/12/2008, China solicits advice for post-quake reconstruction

9 China Daily, 08/12/2008, Ten million quake survivors move into prefabs

10 <http://en.epochtimes.com/n2/china/wenchuan-country-quake-reconstruction-1280.html>

11 China Planning Network City Resilience Roundtable (Rebuilding and Restoration after the Sichuan Earthquake) was held in Beijing and Chengdu between July 16th and 18th 2008.

12 China Daily, 08/12/2008, China solicits advice for post-quake reconstruction

13 China Daily, 08/12/2008, Quality key to post-quake rebuilding

14 <http://www.chinatravel.net/Destinations/sichuan.asp>

15 Day lighting diagram (www.arch.utk.edu/Zero_Energy/default.shtml)

16 Natural ventilation diagram (www.arch.utk.edu/Zero_Energy/default.shtml)

17 Solar gain heating diagram (www.arch.utk.edu/Zero_Energy/default.shtml)

18 Active solar system (www.arch.utk.edu/Zero_Energy/default.shtml)

18 Design project, by Chen Li, graduate student of University of Tennessee