# MODERN CLIMATE-RESPONSIVE NATURAL HOUSES IN RURAL CHINA

# EARTH HOUSE DESIGN AND RESEARCH FOR YAITAI A-ONE ECOVILLAGE

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**Abstract:**
*Historically, rural farmer housings in China are mainly built with locally available, cost effective and environmental friendly natural materials. However, those natural houses are now challenged by high cost high-tech modern houses for future rural houses as that are always regarded as rudimentary, less comfortable and energy inefficient. The study explores an innovative way of future rural housing design that can combine the advantages of high-efficiency and comfort from modern houses and low environmental impact from old vernacular natural houses.*
*In this study, an on-going ecovillage project in north China provides a chance to demonstrate an experimental design for small family houses. Rammed earth is used as natural building material. Several climate approaches using passive resources such as sun, wind and ground temperature are defined according to site condition, local climate and client's requirements. Interaction with design team are implemented during the design process. Building performance including daylight, energy consumption and occupants thermal comfort are analysed by advanced simulation tools for improving design concepts and giving design suggestions.*
*The final design achieves 50% less heating energy demanding than local conventional housings and good summer thermal comfort without using active cooling systems. The result indicates natural house with careful climate-responsive design can be an achievable and efficient alternative to government high-tech templates for future rural housings in China.*

## Introduction

Nowadays, the Chinese government is promoting a series of building templates across the whole country to improve and standardized the building quality. However, this policy results in local characteristics and connection of natural environment of rural housings are fading away and the all village in such a large country will basically look the same regardless their distinctive differences in climate and topography.

The study took an on-going eco-village project in north Chin as an exemplary demonstration of a design process of a new form of "modern" natural building to address the inadequacies in conventional construction practices across rural China as an alternative to the government templates. The design house combines the traditional Chinese philosophy of "natural harmony" with modern climate-responsive design and analysis technologies. The target is to design a comfortable and affordable natural house without using expensive high-tech concepts and building systems, in the hope that the demonstration of the design process can be a recall of the connection to natural and inspiration for climate-responsive design for Chinese rural housings.

## Design overview

The project is named "Aone Ecological Farm", locates in the suburban of Yantai city, a port city in north China. The project is developed by "Aone agricultural technology LTD", the design team, "Groundup" founded by Fred Dolmans kindly offered us a chance to implement our ideas. The task is to design some small residential houses on the south facing slopes of the site for long-term or short-term visitors. (see figure 1)

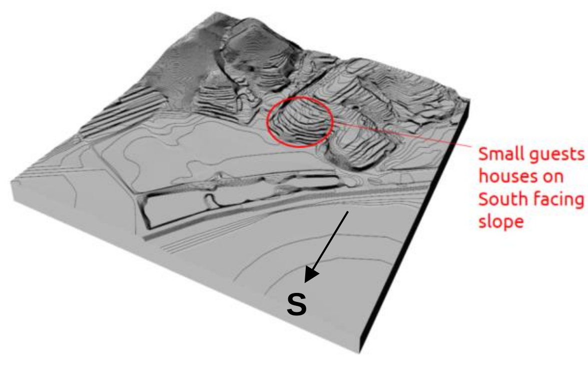


*Figure 1: Site topography and designated building location*

The project was still in master planning stage while the study got involved. The guests' houses need to have one bed room, one bathroom and one multi-function living room with kitchenette to accommodate a small family of

2-4 people. The shape and layout of house are not decided, which leaves a large margin for our design suggestions.

The on-site soil analysis shows there are adequate resources of clay, gravel and sand, indicating a very good potential for rammed earth. Both owner and designer have intention to use rammed earth in the form of compressed stabilized earth blocks (CSEB) as the primary building material. The CSEB has similar thermal properties to building bricks with higher thermal capacity and advantage of better moisture absorption, the cost and embodied CO2 emission is much lower than concretes.

*Table 1: Thermal properties of building materials (EN-ISO 10456:2007)*

| | CSEB | Building bricks | Concrete |
|---|---|---|---|
| Thermal conductivity (W/m.K) | 0.8-1.1 | 0.6-1.0 | 1.65 |
| Specific thermal capacity (kJ/kg.K) | 1.42 | 0.84 | 0.80 |
| Density (kg/m³) | 1540 | 1800 | 1400 |
| Embodied CO2 | low | medium | high |

After the discussion with design team and owner, the design objectives are then defined as follows:

- Rammed earth is the building material, the concept of building design shall accord with this theme.
- Good thermal comfort with reduced energy consumption compared to conventional houses.
- Eliminating the use of active cooling system.
- Good daylighting.
- Reasonable cost and realizable technologies.

**Climate context**

Though the climate in Yantai is categorized into cold climate zone, severe cold days (below -10°C) are very rare and the summer can be as hot as 34°C. The annual average temperature is around 13 ℃. Overall it is heating dominated climate but preventing overheating during hot summer days should also be considered. *(see Figure 2)*

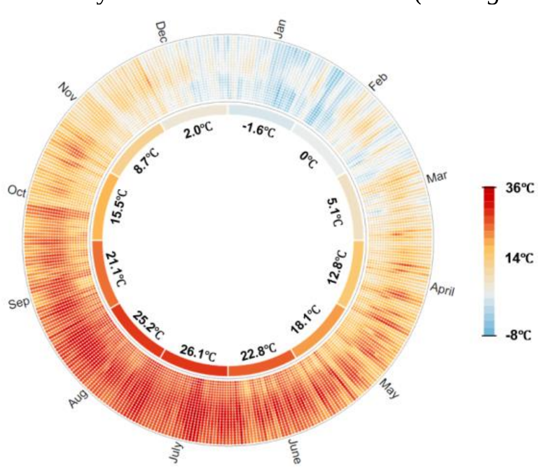


*Figure 2: Site annual hourly temperature*

The climate is humid due to its coastal location. However, rammed earth shows its advantage as building material for its excellent ability of moisture absorption and condensation prevention.

High consistency of prevailing wind direction is revealed from wind analysis, for most time of the year wind comes from the west, indicating a good potential for wind driven ventilation. The solar radiation is also abundant for passive/active solar strategies, annual horizontal insolation is around 1450 kWh/m²a.

The ground temperature swing is significantly reduced below 2m depth and it is almost stabilized at 13°C under 7m (*see Figure 3*). For such hot summer and cold winter climate, it is can be considered to take the advantage of this moderate temperatures to passively heat/cool the building.

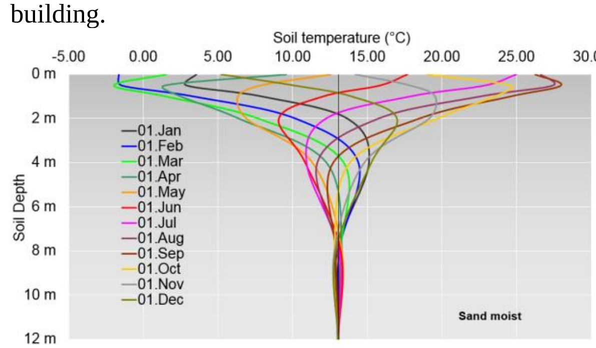


*Figure 3: Site ground temperature*

**Climate design approaches**

Based on the information from the site survey and climate analysis, a discussion is then made with design team to define proper approaches and method to address the design objectives in an effective and responsive way. The initial climate design approaches are listed as follow:

- High insolation in cold climate suggests solar strategies, a south facing sunroom or conservatory with high glazing ratio is considered to maximizing the useful solar gains.
- As the house is sitting on the south facing slope, which provides a chance to the use the slope soil with more stabled temperature as natural thermal buffer and free thermal conditioning resource. Therefore, a topography integration concept is developed by submerging part of building envelope into the slope and ground.
- Proper shading strategy is needed to prevent overheating from exceed solar radiation during summer.
- Use thermal mass from rammed earth to store solar heat during winter and mitigate peak loads during summer.
- Opening on west and east to take prevailing wind from west and boost cross natural ventilation.

**Original design and analysis**

A single zone thermal simulation was firstly performed to evaluate the thermal effect of submerging the house into ground. The result indicates overheating during summer can be significantly mitigated by submerge 50% of the building façade into ground. The room operative temperature can be maintained under 30°C with external shading and sufficient natural ventilation. *(see Figure 4)*

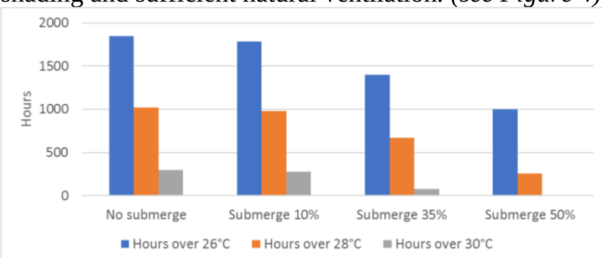


*Figure 4: Effect on overheated hours with submerging rates*

The design team came the first design concept with 50% submerging rate. The building is divided into 3 spaces, a sunroom connecting a bedroom unit and living unit. *(see Figure 5)* CSRE is used for all walls and roof will be insulated by natural insulation materials, climate design approaches described above are also implemented. A validating simulation shows the overheating risks and heating demanding is 15% lower than current common practice. However, the improvements are not as good as expected and there are following problems:

- The sun room it shaded from the east and west, resulting in insufficient solar radiation in the morning and afternoon during winter.
- The sun room is not comfortable most of time, either too cold in winter or overheated in summer.
- In spring, when the air temperature is rising, the rooms are colder as the ground temperature is still low.
- Overheating problems still exist in all rooms despite of using shading and natural ventilation.

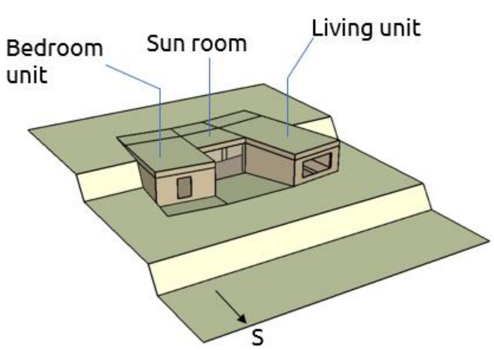


*Figure 5: Original design concept*

**Proposed design and improved design**

To improve the efficiency of sun room, a new layout is proposed. The position of sun room is relocated to the south for better solar exposure, the bed room and living room is assigned to the back and submerged into the slope. *(see Figure 6)*

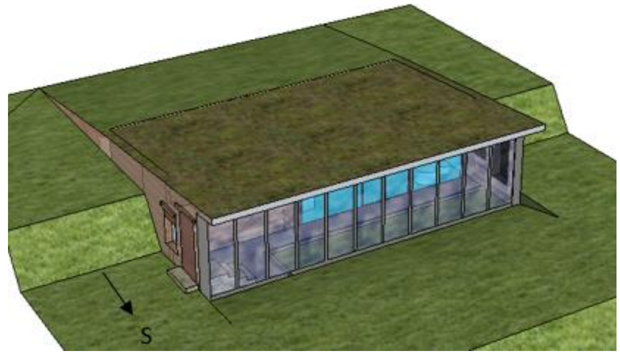


*Figure 6: Proposed design concept*

The passive design elements and climate strategies can be demonstrated on *Figure 7*:

1. During winter when sun elevation is low, solar beams go through south glazing wall and the solar gain is captured to heat up the sun room and pre-heat for other spaces. During summer while sun elevation is high, direct solar beams are blocked by overhang to reduce exceed heat gains. Using the west prevailing wind direction, the sun room is also naturally ventilated by 2 openings on east and west façade.
2. The living room is mainly occupied during daytime. High glazing ratio is used on the partition wall between living room and sun room to allow more solar radiation come into the space and heat up the space quicker.
3. The bedroom, however, is mainly occupied during night, thus the room shall keep more heat from daytime. Thus, the south wall is made with 300mm thick rammed earth for higher thermal capacity, the intention is to absorb and store more heat from solar radiation and warm air in sun room, then release those heat slowly during night and bring up the mean radiant temperature of bedroom.
4. The entire north wall and 70% of east and west wall of living room and bedroom is submerged into the slope to further reduce heating and cooling demanding.

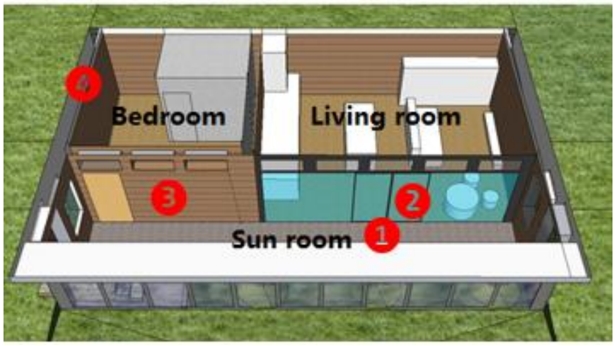


*Figure 7: Climate approaches and elements of proposed design concept*

A validating simulation is then performed, the results show the bedroom operative temperature is always lower than the living room operative temperature during winter, indicating the thermal mass is not working as expected. There are still more than 100 hours when operative temperature of living room and bedroom exceed 30°C, which is not acceptable for thermal comfort.

Therefore, an improved concept is then proposed accordingly to address those problems. As demonstrated on *Figure 8*:

1. The dimension of overhang is recalculated based on simulation results, the length is optimized to allow more solar gains during winter while ensuring sufficient the summer sun protection.
2. The south interior wall of bedroom was shaded by the roof of sun room, causing less solar radiation hit on the thermal mass. Therefore the wall is moved forwards south glazing wall to receive higher solar gains. Furthermore, a trombe wall concept is introduced, by using high solar transmittance and high thermal capacity walls, the air in the wall cavity is heated and circulation with bedroom is formed by buoyancy effect, acting as a natural heater during winter days.
3. The extension of bedroom also allows an additional window opening for bedroom, which benefits the room daylighting and natural ventilation.
4. To address the obstinate overheating problem, an earth duct system is implemented. The air will be pre-cooled by the ground and then supplied into living zones. System sizing and supply air flow rate will be determined by further thermal simulation. The earth duct will also supply pre-heated air at minimum rate for health during winter.
5. The position of bed can be adjusted to either north (close to submerged wall) during summer to take advantage of cooler wall temperature or south (close to warmer tromba wall) during winter to have better local radiant temperature.


*Figure 8: Climate approaches and elements of improved design concept*

**Building performance analysis**

Daylight simulation is firstly performed, the average daylight factor in bedroom, living room and sunroom is 2.1%, 3.0% and 10.4% respectively, indicating good daylighting for all living spaces.

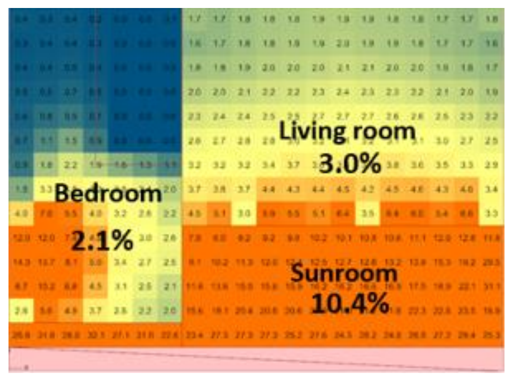


*Figure 9: Daylight factors of proposed design concept*

The effect of trombe wall is simulated with TRNFLOW coupling with multi-zone TRNSYS model. Earth duct is simulated by dividing into 20 thermal air nodes with simplified annual ground temperature profile. The size is finally determined as 20m long and 20cm in radius, buried at 3 m depth to ensure cooling effect during summer.

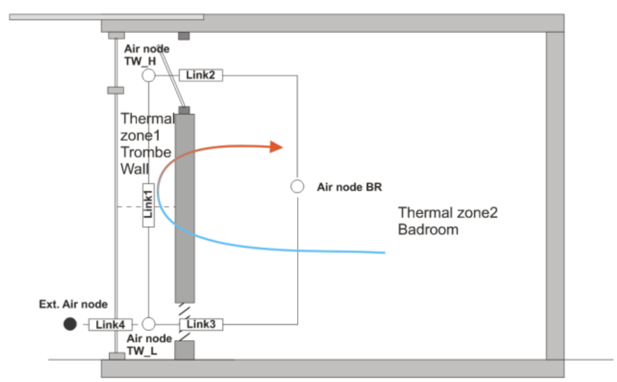


*Figure 10: TRNFlow description of Trombe wall*

The thermal simulation results show operative temperature in both bedroom and living room during summer are controlled in the comfort zone based on the adaptive comfort in naturally ventilated space (EN-15251) (see figure). There are now have basically no hours (0.1% of all occupied hours) outside of comfort range during the occupied hour in summer.

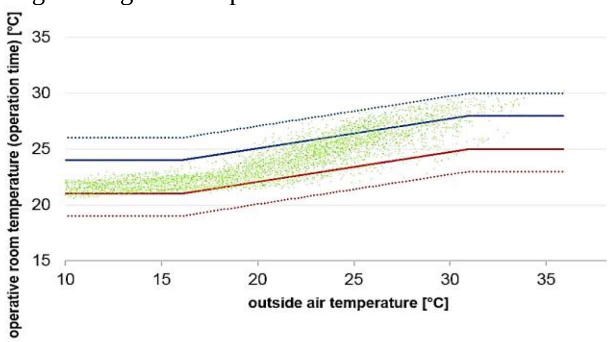


*Figure 11 Perceived room operative temperature over outside temperature during occupied hours. (based on EN15251:2007)*

The energy consumptions on heating has also been largely reduced. Figure 3 compares the heating demanding of three design concepts (original, proposed and improved design) with common practice and lasted energy guidelines. It can be seen heating load is continuously reduce with the design improvement, the final design (improved design) has 30% less heating demanding than original design, which is nearly half of current common practice of conventional rural houses. The should be mentioned the design house only use insulation for the roof to minimize the environmental however heating demanding is close to energy guideline based on new highly insulated government template by using passive solar strategies and topography integration.

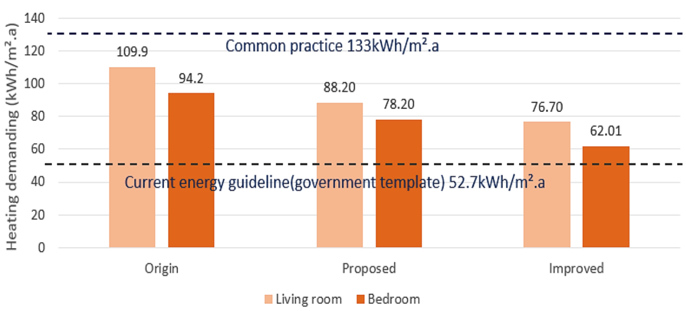


*Figure 12 Comparison of heating demandings*

## Conclusion

The study demonstrates a climate responsive design process of natural rural house and impact making positive impacts in the cooperation with design team as a climate design consultant.

The study implies the "design" is the key to achieve "high comfort, low impact" instead of using high-cost, sophisticated building materials and systems. The demonstration of design process inspires people the design phycology of "building with the nature not against it" and methodology of specified design responding to local climate and topography.

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