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ENVIRONMENTAL ASSESSMENT AND PRESERVATION FOR FUJIAN HAKKA VILLAGES

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Abstract: In 2007 and 2009 research trips were taken mainly in the Fujian province of China to investigate the construction materials and methods, structures and floor plans of Hakka Tulou. Researchers lived in several Tulou to interview residents and experience traditional lifestyle. Typically, Tulou are located at relatively high elevation in regions characterized by hot summers, cold winters and with high incidents of typhoons and earthquakes. The extent of damage and level of preservation was examined given the age of many of these structures, their relatively harsh environment, and changing demographics of the occupants. The majority of occupants are now elderly and they have a traditional and efficient lifestyle utilizing minimum electricity, water and energy. This study will discuss the findings from these two field trips; assess the environmental load and sustainability of Hakka Tulou buildings and the potential to retrofit these complexes to modern living standards while maintaining the traditional building and lifestyle.

Keywords: Rammed earth, earth buildings, thermal environment, sustainable living, energy efficiency, Hakka Tulou, Hakka village

1 INTRODUCTION

This research paper will focus on Cheng Qi Lou, a UNESCO World Heritage Site located in Yongding County of Fujian Province, 150 km from Xiamen at 24^{0} 30’ N, 117^{0} 99’ E with an elevation of 515M. The region is classified as a Hot Summer, Mild Winter Climate (Yoshino Y, 2005a). There are approximately 700 Heating Degree Days (Zhang, 2005). Cheng Qi Lou was selected as a typical example of the Hakka Tulou of this region. It is one of the largest complexes, has a high occupancy with 250 of the 400 rooms being occupied, is 4 storied, and faces south. Its building area is 878.1 m2, diameter is 61m and height is 15.8m. The surrounding area is primarily agricultural, with high tourism levels during the daytime. Some units are available to accommodate tourists overnight. The additional tourist income is important and may, in part, account for the higher occupancy rate of this Tulou.

2 CLIMATE DATA ANALYSIS

To evaluate environmental impact important factors are temperature, moisture and energy utilization. The accurate climate data for this region are not available. Instead the data of nearby city, Xiamen are cited for reference where the temperature range is 10 – 30 degree Celsius and precipitation ranges from 24 - 211 mm, both reaching their maximum in July (Xiamen Climate Guide).

The ASHRE comfortability index temperature range is 20 – 27 degrees, and the moisture range is 0-80% humidity. The Chinese Indoor Environmental Standard has a temperature range of 16 –24 degrees, and a moisture range between 30-60% (Yoshino H, 2005a; 2005b).

In 2009 data loggers were installed at Cheng Qi Lou to measure temperature and moisture. These monitors were installed in five locations. Fig.1 shows the location of each monitor, i.e. 1) Outside abode 1.8m high from ground, under roof exposed; 2) Courtyard 2.5m above ground, under roof exposed; 3) 1st Floor inside dining room 1.5m from ground, mounted on a rammed earth wall; 4) 2nd Floor storage area 1.5m from the floor, placed in the center of the room; and 5) 4th Floor habitable living quarters 2.0m from the floor, on a partition wall. Data for the period of June 28 – July 6 2009 will be used in this study.

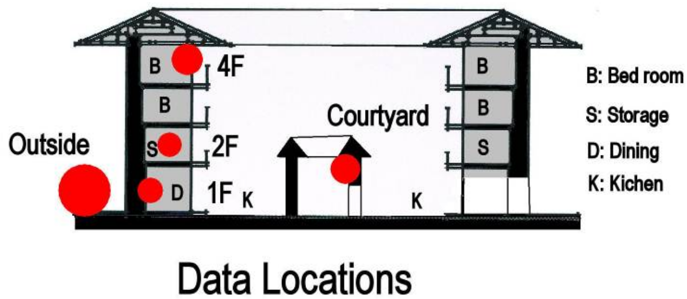
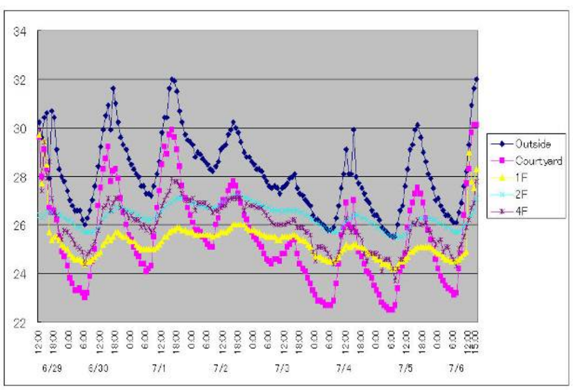


Fig. 1 Data Logger locations at Cheng Qi Lou

2.1 Temperature

The temperature data of Cheng Qi Lou are shown in Fig.2. The greatest impact is seen in the 2nd floor storage area, which exhibits the most constant temperature level with only a 1.7-degree variation in temperature while the external temperature fluctuated 6.5 degrees. The storage area has no windows and the doors are kept shut. On the 1st floor doors are normally left open during the day and closed at night but still the change in temperature at this data logger location is less than 5.5 degree, here the temperature is most constantly cooler. In addition to the doors being open, the doors facing the courtyard are open to the kitchen area where a large amount of water is used so there is a cooling effect on the 1st floor from vaporization. Even the temperature readings at the courtyard data location are 2.2 degree milder than the external temperature. 4th floor habitable rooms have both external windows and doors facing the courtyard. In this area temperatures are more closely correlated to the external temperature and milder by 1 degree.



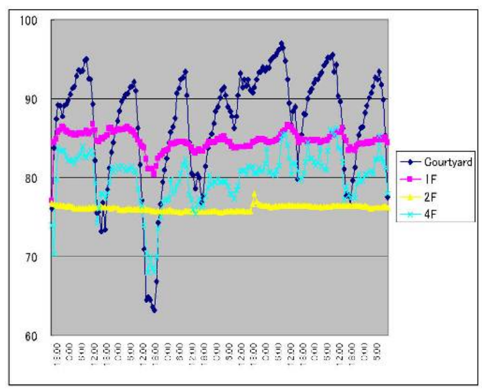


Fig.2 Temperature data for Cheng Qi Lou

Fig.3 Moisture data for Cheng Qi Lou

2.2 Moisture

The relative humidity data of Cheng Qi Lou are shown in Fig.3. The moisture reading in the courtyard was highest each morning at 63 – 97 % relative humidity while the 1st floor remained relatively constant at 85%. As with the temperature reading the 4th floor correlates most closely to the courtyard climate but is 7% milder. Again the greatest impact was seen on the 2nd floor, which remained nearly constant at 76% (± 2%) relative humidity. This also corresponded to the lowest and most constant temperature, as noted above.

From these data we observe that massive rammed earth walls moderate the temperature and moisture levels.

However, only summer period data are presented here. For a total view of sustainability complete seasonal data are required.

3 THERMAL PERFORMANCE

Thermal mass describes how the mass of the structure provides "inertia" against temperature fluctuations. With diurnal (daily) temperature variations the mass absorbs thermal energy during warming periods and emits thermal energy as local temperatures drop. Thermal mass is effective in improving building comfort in regions that experience these types of daily temperature fluctuations -especially during summer. Temperature fluctuates depending on regional topography, such as mountainous areas or vast open plains, as well daily temperature variation increases at higher elevations. The greater the diurnal temperature variation, the greater the potential to improve thermal performance with thermally massive construction.

3.1 Rammed Earth Structures

Rammed earth structures are common among vernacular architecture and are found throughout the world in regions with a wide range of climatic conditions. Along with Cheng Qi Lou other rammed earth construction World Heritage Sites include the Old City of Sana'a in Yemen and the Ksar of Ait Ben Haddou in Morocco. The main functions of these historic structures have been: 1) defence/security; 2) protection from climate; 3) storage/preservation; and 4) necessity to use regional available materials.

The incredible mass of these structures illustrates their function in fortification. More importantly from the view point of sustainable architecture, the principal functions are moderating interior climatic conditions, and the use of local materials. The volume mass of rammed earth structures have high specific heat capacity and high density, thereby moderating the interior climate and improve conditions for preservation and storage. Moreover use of regional materials results in low embodied energy. Rammed earth structures have not been studied comprehensively, however as sustainable architecture understands their importance, the value of the inherent properties of rammed earth structures for sustainable construction methods will be of greater significance.

Cheng Qi Lou is among some of the largest rammed earth structures. It has a mass volume of earth calculated at 3,213 cubic meters, which is 26% of total space. Smaller Tulou structures have similar wall thickness and height, which means the percentage of total mass volume to total space is even greater. These structures provide significant thermal battery potential.

Massive rammed earth structures moderate the interior climate because heat transfer is low, the volumetric heat capacity and thickness prevents thermal energy from reaching the inner surface. As temperatures fall thermal energy is re-radiated, this mass must be sufficient to prevent heat transfer into the interior.

The use of massive rammed earth for sustainable architecture acts as a heat sink and is therefore effective for summer cooling however during winter months these structures have a constant temperature of 5 - 6 degrees, well below today's standards for comfortability. Therefore to improve thermal performance it is recommended to add external insulation to the building envelope and install roof and window insulation. The structure will then be insulated from heat loss during the winter while the summer nighttime heat is released through the canopy and ventilation (Kodama, 2002; 2003a; 2003b; Kodama and Miyaoka, 2005; 2007).

Retrofits can however cause the following problems if not considered within the context of total building performance: 1) Significant heat loss from windows and 2) Design inflexibility due to the installation of external insulation.

3.2 Rammed Earth Structures Retrofit – Perimeter Window Zone

The addition of external insulation or a perimeter building is an effective sustainable solution to improve winter heat retention for rammed earth structures. An envelope/double skin window is one solution. It works as a solar wall by collecting heat (Fig. 4).

Recent rammed earth construction combines vernacular techniques with current concepts for sustainable development. One example of this integration is the perimeter window zone used in the new conference center at the Center for Alternative Technology (CAT) in Wales, UK (Figs 5 and 6).

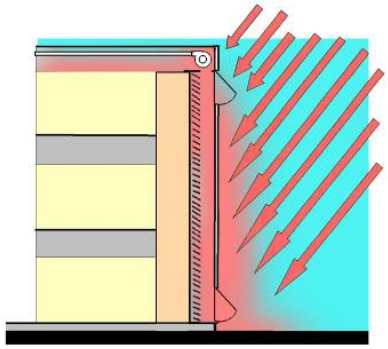


Fig.4 Double skin window

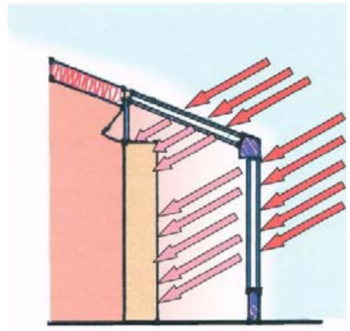


Fig.5 Perimeter window zone

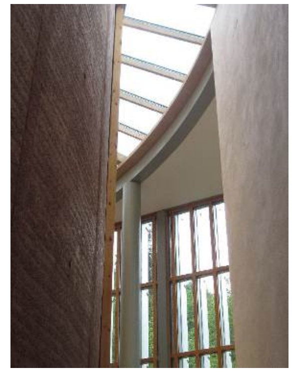


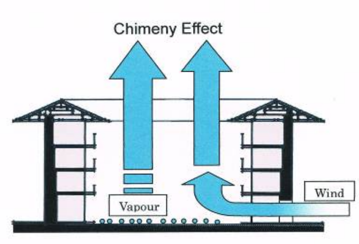
Fig.6 CAT Center

Both of these solutions would be effective to retrofit existing rammed earth Hakka Tulou structures. With a constant winter interior temperature around 5-6 degrees (Kodama, 2002; 2003a) additional heating is required. Historically direct heating was used to heat rammed earth buildings, in many areas this form of heating is still common, but for today's life style space heating will be required for these buildings to meet current standards of comfort.

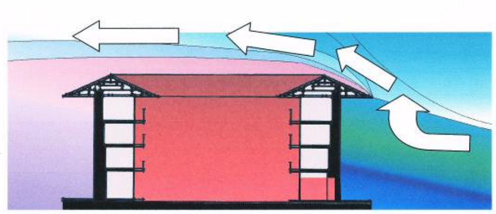
4 NATURAL AIR FLOW

Both thermal mass as discussed above and natural airflow are primary factors in moderating temperature and moisture. Natural airflow is important for energy efficiency and sustainability of buildings. Contemporary sustainable construction is increasingly focused on natural airflow. An early example of this is the Tokyo International Forum (1997), which incorporated an efficient natural ventilation system. Natural airflow is one of the main functions in the design of The Bow, the largest building currently being constructed in Calgary.

Round structures have unique air flow characteristics. Cheng Qi Lou rammed earth building clearly has natural air flow (Yoshino Y, 2005b). Yoshino developed a simulation model and analysis method for round structures. Given the conditions of a round structure with a main gate and building height of 15 meters, his simulation model predicts that when wind passes through the main gate at around velocity of 0.5 m/second, the air passing though the main gate increases in velocity by approximately 0.5 m/second creating a chimney effect. This means that the balance of space proportion is effective for creating the chimney effect.



Summer with gate open



Winter with gate closed

Fig. 7 Evaporation effect at Cheng Qu Lou

In addition to the airflow simulation in the Yoshino model a further consideration in an inhabited building like

Cheng Qi Lou is the evaporation effect from the large volume of water in the kitchen area. Fig 7 illustrates the evaporation effect as natural airflow passes over the 1st floor kitchen area. In summer the main gate is open resulting in both the chimney effect and evaporation effect to moderate temperatures and moisture levels. During the winter period the main gate can be closed to reduce heat loss (Fig.7).

5 ENVIRONMENTAL PERFORMANCE ASSESSMENT

5.1 Environmental Assessment Performance Programs

A number of environmental performance assessment tools have been developed to quantify and evaluate the environmental load/ sustainability of structures. There are three major environmental performance assessment tools:

- Comprehensive Assessment System for Building Environmental Efficiency (CASBEE)
- Leadership in Energy and Environmental Design (LEED)
- Building Research Establishment (BRE) Environmental Assessment Method (BREEAM)

Table 1. Comparison of CASBEE, LEED and BREEAM environment assessment programs

LEED	CASBEE
Sustainable Sites	Q-3 Outdoor Environment on Site LR-3 Off-site Environment
Water Efficiency	
Energy & Atmosphere	LR-1Energy
Materials & Resources	LR-2 Resources & Materials
Indoor Environmental Quality	Q-1 Indoor environment
Innovation & Design	
	Q-2 Quality of Service

	LEED	CASBEE	BREAM
Indoor Air Quality	MAX		
Noise & Acoustics		MAX	MANY
Service Ability	N/A		
Energy	Simulations		Simulations
Rain Recycles		MAX	
Water Wastes		N/A	
Nox, LCCO2	N/A		
Heat Islands Effects			N/A
Flexibility	Exist		

Table 2. Comprehensive Assessment System for Building Environmental Efficiency (CASBEE)

CASBEE-Nce

Q-1 Indoor environment	Noise & Acoustics
	Sound Insulation
	Sound Absorption
	Room Temperature Control
	Humidity Control
	Lighting & Illumination
	Air Quality
	Ventilation
	CO_2 Monitoring
	Control of Smoking
Q-2 Quality of Service	Provision of Space & Storage
	IT Innovation
	Barrier-free Planning
	Perceived Spaciousness & Access to View
	Space for Refreshment
	Décor Planning
	.Durability & Reliability
	Earthquake-resistance
	Seismic Isolation & Vibration Damping Systems
	Interval for Exterior Finishes
	Interval for Main Interior Finishes
	Interval for Plumbing & Wiring Materials
	HVAC System
	Water Supply & Drainage
	Electrical Equipment
	Support Method of Machines & Ducts
	Communications & IT equipment
	Story Height
	Floor Layout
	Floor Load Margin
Q-3 Outdoor Environment on Site	Biotope
	Townscape & Landscape
	Local Characteristics & Outdoor Amenity
	Thermal Environment on Site

LR-1Energy	Building Thermal Load
	Natural Energy Utilization
	Renewable Energy
	Efficiency in Building Service System
	ERR*
	HVAC System
	Ventilation System
	Lighting System
	Hot Water Supply System
	Elevators
	Monitoring
	Operational Management System
LR-2 Resources & Materials	Water Saving
	Rainwater & Gray Water
	Recycled Materials
	Timber from Sustainable Forestry
	Materials with Low Health Risks
	Reuse of Existing Building Skeleton etc.
	CFCs & Halons
LR-3 Off-site Environment	Air Pollution
	Noise, Vibration & Odor
	Wind Damage & Sunlight Obstruction
	Light Pollution
	Heat Island Effect
	Load on Local Infrastructure

$$ERR^{*} = \frac{\text{Total amount of energy saved in the evaluated building}}{\text{Standard primary energy consumption for the evaluated building}}$$

While these programs have similar objectives there are differences in the criteria and assessment methods. Several studies have analyzed and compared these three major programs, including the studies on these various environmental performance assessment tools by Oka (2004; 2005; 2009). A summary of those findings are outlined in the Table 1.

5.2 Comprehensive Assessment System for Building Environmental Efficiency (CASBEE)

CASBEE parameters are summarized in Table 2. A major component of CASBEE is the Building Environment Efficiency (BEE) calculation which includes lifecycle CO2(LCCO2) using the formula below. A BEE rating above 3.0 is rank S; between 1.5-3.0 is ranked A; between 1.0-1.5 is ranked B+; between 0.5-1.0 is ranked B- and 0 – 0.5 is ranked C. A ranking of 1.0 would meet current Japanese Standard Building Codes.

$$\text{Building Environment Efficiency (BEE)} = \frac{\text{Building Environment Quality and Performance (Q)}}{\text{Building Environment Load (L)}}$$

5.3 Results of Preliminary Calculations using CASBEE for Cheng Qi Lou

Although data are not available to provide a comprehensive evaluation it is a valuable exercise to assess Cheng Qi Lou, which was built 300 years ago, from the standpoint of current stringent environmental guidelines. This shows not only the efficacy of vernacular building methods, but also how these important cultural assets can be preserved and brought up to today's environmental and living standards.

Under CASBEE, parameters for New Construction and Existing Buildings are different; both methods were used to capture different aspects of the criteria to evaluate Cheng Qi Lou. The results of the preliminary calculation are as follows.

BEE (New Construction) calculation = 2.9
BEE (Existing Building) calculation = 2.7

These preliminary results equate to CASBEE ranking A for both calculation methods. Following is a more detailed explanation of the results and a discussion of possible solutions to achieve the top environment ranking which will help to evaluate priority areas where retrofit will be most effective.

From the results shown in Fig.8 and Fig. 9 we can then determine the BEE number. The calculation formula is:

$$\text{BEE} = \frac{\text{Q: Building environmental quality and performance}}{\text{L: Building environmental loadings}} = \frac{25 \times (S_Q - 1)}{25 \times (5 - S_{LR})}$$

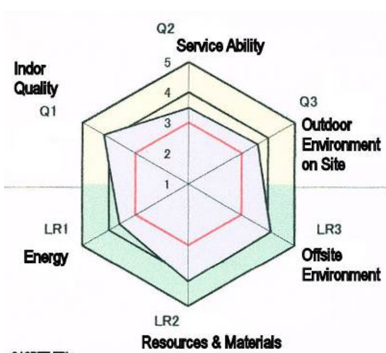


Fig.8 CASBEE existing buildings results

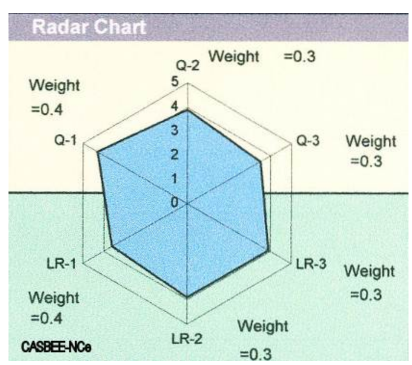


Fig.9 CASBEE new construction results

The CASBEE results in Fig.8 and Fig. 9 show relative weakness in Q3 and LR1, and therefore should be a priority for further examination and evaluation as discussed below.

5.3.1 Quality (Q3) Outdoor Environment on Site

Preserving or creating the biotope site is important to maintain or improve the natural environment surrounding Cheng Qi Lou and other Tulou sites. Many Tulou sites have some aspects of this factor including the selection of naturally sheltered locations and semi-circular ponds as discussed in Katayama's paper (2011). It is important that the function of these natural elements be understood and capitalized on to improve the outdoor environment on site and maintain bio-diversity especially when these sites become more assessable to tourist. For a more comprehensive definition of biotope see Hoshino (year unknown) and Matsuda (2006).

Community design and landscaping is sometimes included as part of the biotope, CASBEE has a separate category. There is also a separate category for improvement of thermal environment on site (changes in microclimate). Considering community design as a whole and increasing the green space around Cheng Qi Lou would improve the overall outdoor environment rating.

Planting large trees especially in the immediate vicinity and installing water permeable materials in parking areas and around tourist facilities should be considered. At least one National park in Canada uses composting toilets this can be an effective solution where water management facilities are limited.

5.3.2 Load (LR1) Energy

The energy section concerns not only the individual components but also emphasizes the overall efficiency of the structure, and its mechanical systems for function, flexibility and ease of maintenance. Both building thermal load and natural energy utilization ranked relatively high. The effectiveness of thermal mass and the existence of natural airflow as discussed earlier have a positive impact on building thermal load and natural energy utilization.

Energy results are most adversely affected by other categories which take into consideration increased utilization of the latest advances in building science, for example HVAC, energy efficient mechanical systems and total water management systems. Another important reason for the weak results in LR1 is the requirement for comprehensive maintenance programs for facilities and mechanical equipment. Building services efficiency and operational management systems are not applicable at this time.

The greatest impact for improving energy efficiency is to use an effective combination of natural energy. Locally manufactured PV panel, LED lighting and solar hot water systems would not only increase energy efficiency, but being sourced locally, also have low embodied energy. A rain water recycling system should be considered within the context of a total water management system. Geothermal may also be considered.

6 CONCLUSION

Ongoing research is required to collect and monitor climate data and use these data and a simulation program to examine existing Tulou within the context of a sustainable energy efficient program. Further study is needed to determine the best solutions for retrofit to increase winter heat retention, taking into consideration sustainability, functionability and design ability. An attractive solution is the perimeter window zone as was used at The Center for Advanced Technology in Wales; a more economical solution is a double skin window.

Given the relatively high preliminary ranking for Cheng Qi Lou there is significant potential for Cheng Qi Lou to obtain the top Environmental Assessment ranking. While the existing site can be ranked as CASBEE A, LEED Gold and BREAM Very Good, to achieve top ranking, improvements would be required on energy source, outdoor environment on site, as well as amenity modernization. Still it is important that retrofits are designed to maximize energy efficiency and environmental sustainability as we become increasingly conscious of environmental impact.

Functionality, maintenance and overall system management must also be considered. In this respect amenity modernization should include: 1) total water management upgrade; 2) small energy efficient heating system; 3) increased use of natural energy sources; and 4) more emphasis on the biotope and improvement in the outdoor environment.

Finally the social environment should be addressed given the decline in habitable populations in this area, primarily with respect to occupancy. How to use and how to maintain these complexes is important. Establishing a monitoring and maintenance program and engaging local inhabitants to undertake these programs will expand knowledge-based opportunities for local residents.

The final stage of this environmental assessment program is to develop a sustainable Hakka Tulou retrofit model program to preserve Hakka Tulou, bring them up to modern living standards while maintaining the traditional building and lifestyle. The study of Cheng Qi Lou illustrates the potential to preserve and maintain the Hakka villages of Fujian province of China.

The Hakka Tulou range in size from 14 -100m in diameter, are normally 4 stories with smaller ones being 3 stories. All have open courtyards with 1-3 entrance gates. From Katayama's work (2011) we can see there are three basic shapes, i.e. round, square and multi-courtyard, but there are many similarities to the Tulou of this region. Observations on thermal performance may relate to all Tulou while airflow data as discussed here would be specific to the circular structures. Most of these regional Tulou are not constrained by the same restriction as world heritage sites like Cheng Qi Lou. As discussed in this paper there are practical and sustainable solution for the preservation and restoration of these sites which would improve the life style of the inhabitants.

REFERENCES

CAT (2011) http://www.cat.org.uk/

Hoshino T (year unknown) Fundamental research in natural management of large biotope aiming for regeneration of nature: Introduction

Katayama, Kazutoshi (2011) Spatial order and typology of Hakka *d*wellings, *Proceedings of International Workshop on Rammed Earth Materials and Sustainable Structures and Hakka Tulou Forum 2011: Structures of Sustainability*, October 28 - 31, 2011, Xiamen University, China

Kodama Y (2002) The Experiment Construction Method of Hanchiku by Self-build and Measurement of Capability, 5608 AIJ 2002

Kodama Y (2003a) The Experiment Construction Method of Hanchiku by Self-build and Measurement of Capability, 5824 AIJ 2003

Kodama Y (2003b) Design Integration of Passive Heating and Cooling Temperate Climate, 41261 AIJ 2003

Kodama Y and Miyaoka F (2005) Passive Cooling Effect of Mass-Ventilation- Influence of Ventilation Mode, 41058 AIJ2005

Kodama Y and Miyaoka F (2007) Difference of Ventilation Mode on Passive Cooling Effect, AIJ 2007

Matsuda M (2006) *What is biotope?* Retrieved December 10, 2006, from Pages of environmental information in Germany

Oka T (2004) Example Results of Assessment for Model Building in Kobe Using CASBEE, BREAM and LEED, 40550 AIJ 2004

Oka T (2005) A Study on the Assessment Results of Various Environmental Performance Assessment Tools, AIJ J. Technol Des. No.21 June 2005

Oka T (2009) A Evaluation on Environmental Performance Assessment Method of Houses, 40503 AIJ 2009

Xiamen Climate Guide, http://www.worldclimateguide.co.uk/climateguides/china/xiamen.php

Yoshino Y (2005a) A Study on Residential Thermal Condition and its Comfortability in Urumqi, 41055 AIJ 2005

Yoshino Y (2005b) A Study on Technical Adaptation Using Wind Simulation in Chinese Traditional Hakka Earth Buildings, 41270 AIJ 2005

Yoshino H (2005a) A Survey on Indoor Thermal Environment of Urban Buildings in China, 41053 AIJ 2005

Yoshino H (2005b) A Survey on Indoor Thermal Environment of Urban Residential Buildings in China, 41054 AIJ2005

Zhang Qingyuan (2005) Regional Characteristics of Heating Degree-Days and Potential of Solar Heating for Residences in China, 41279 AIJ 2005