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Article

A Preliminary Environmental Assessment for the Preservation and Restoration of Fujian Hakka Tulou Complexes

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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, methods, structures and floor plans of Hakka Tulou. Researchers lived in several Tulou, interviewed residents and experienced traditional Hakka lifestyle. Typically, Tulou are located in remote regions at relatively high elevations in climatic conditions characterized by hot summers, cold winters, and with high incidents of typhoons and earthquakes. The extent of damage and level of preservation were examined with respect to the age of many of these structures, the relatively harsh environment, and changing demographics in the region. The majority of occupants are now elderly. They maintain a traditional and efficient lifestyle utilizing minimum electricity, water, and energy. This study discusses the findings from these two field trips and assesses environmental load and sustainability within the context of current environmental standards using the Japanese Comprehensive Assessment System for Building Environmental Efficiency (CASBEE) from data collected at Cheng Qi Lou. The goal was: firstly to undertake a preliminary environmental assessment to determine sustainable elements of Hakka Tulou construction methods; secondly, to identify potential sustainable solutions to preserve existing structure; and finally, to identify appropriate sustainable solutions to repair and retrofit damaged and underutilized structures to modern living standards, while retaining traditional building techniques and lifestyle.

Keywords: rammed earth; earth buildings; thermal environment; sustainable living; energy efficiency; Hakka Tulou; Hakka village

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1. Introduction

There are over 20,000 Tulou in the bordering regions of Fujian, Jiangxi, and Guangdong provinces, with the greatest concentration in Fujian. Buildings normally appear in clusters. The majority of villages are remote, and many of the buildings are poorly maintained or uninhabited. Forty-six Tulou, including Cheng Qi Lou, are inscribed and protected as UNECSO World Heritage Sites.

Tulou range in size from 14–100 m in diameter, are normally four stories, with smaller ones being three stories. All have open courtyards with 1–3 entrance gates. Katayama's research [1] categorizes these structures into three basic shapes, *i.e.*, round, square and, multi-courtyard, and discusses the many similarities of Tulou in the region.

The last Tulou was built over 40 years ago; new buildings in the region are predominantly brick or concrete construction. Therefore, traditional construction methods are beings lost. By recognizing the sustainable features of rammed earth, encouraging vernacular construction methods, and identifying appropriate technology to modernize these structures, many of the Tulou could be preserved and retrofitted. While the UNECSO sites and other historically unique structures should be strictly preserved and restored, others may be candidates for the fusion of traditional and new technology.

A comprehensive approach is required to evaluate the existing structures, select appropriate new technology, and adapt technology to maximize building and community sustainability. Total energy efficiency, water management systems, and regional environmental management should be emphasized. In this respect, recent environmental assessment methods provide a useful tool.

Evaluating Cheng Qi Lou from the perspective of current environmental standards not only provides useful information for the preservation of the heritage sites, but it also helps determine the potential value in restoring or renovating existing structures. It is hoped that demonstrating the inherent sustainability of these structures, and the potential to retrofit existing buildings to current comfort standards, will lead to increased local occupancy and the utilization of more abandoned sites.

This research paper focuses on data collected at Cheng Qi Lou, a UNESCO World Heritage Site located in Yongding County, Fujian Province, 190 km from Xiamen at 24°29'N, 117°00'E at an elevation of 515 m. The region is classified as a hot summer, mild winter climate [2]. There are approximately 700 heating degree days [3].

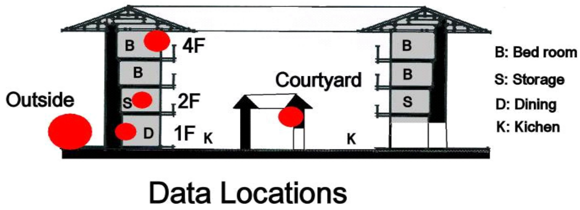
Cheng Qi Lou was selected because it is one of the best examples of a four-storied circular Hakka Tulou structure. It is also one of the largest and best-preserved Tulou in Fujian. The building area is 878.1 m^2; it is 61 m in diameter and 15.8 m high. As with many Tulou, the structure faces South. Cheng Qi Lou has a comparatively high occupancy rate relative to other Tulou in the region, with 250 of the 400 rooms occupied. The surrounding area is predominantly agricultural, with high tourism levels during the daytime. A few units are available to accommodate tourists overnight.

2. Climate Data Analysis

Temperature, moisture and energy utilization are the primary factors for evaluating environmental impact. Accurate climate data for this region are not available. Therefore, data for Xiamen, a nearby city, are cited for reference, where the temperature range is 10–30 °C, and precipitation ranges from 24–211 mm, both reaching their maximum in July [4].

In 2009, data loggers were installed at Cheng Qi Lou to measure temperature and moisture. Monitors were installed in five locations. Figure 1 shows the location of each monitor, *i.e.*, (1) Outside abode, 1.8 m from ground level, under roof, exposed; (2) Courtyard 2.5 m from ground level, under roof, exposed; (3) First floor inside dining room, 1.5 m from ground level, mounted on a rammed earth wall; (4) Second floor storage area, 1.5 m from the floor, placed in the center of the room; and (5) Fourth floor habitable living quarters, 2.0 m from the floor, on a partition wall. Hourly data for the period of 28 June to 6 July 2009 was used in this study. Long term monitoring is continuing and will be reported at a later date.

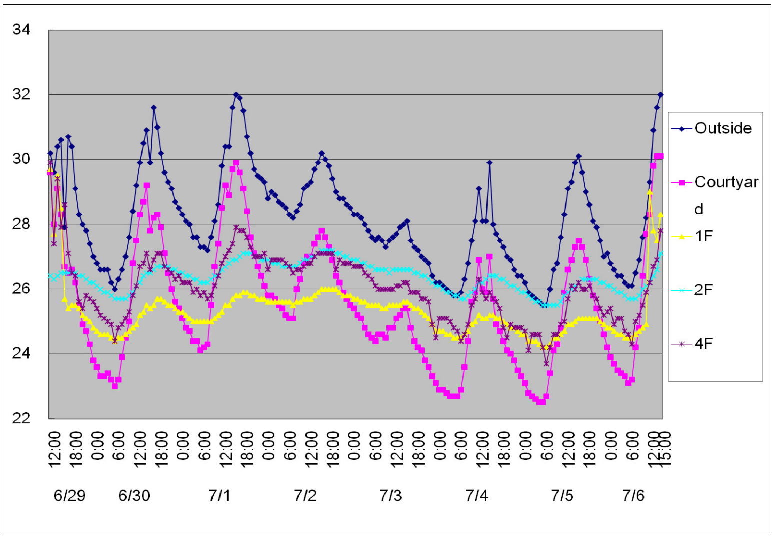
Figure 1. Data logger locations at Cheng Qi Lou.



2.1. Temperature

Temperature data for Cheng Qi Lou are shown in Figure 2. The greatest impact was seen in the 2nd floor storage area, which exhibited 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 doors are kept shut. On the first floor, doors are normally left open during the day and closed at night; the change in temperature at this data logger location was less than 5.5 degrees, and the temperature 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. It is assumed that vaporization had a cooling effect on the first floor. Temperature readings at the courtyard data location were 2.2 degrees milder than the external temperature. Fourth floor habitable rooms have both external windows and doors facing the courtyard. Here, temperatures correlated most closely with the external temperature but were one degree milder.

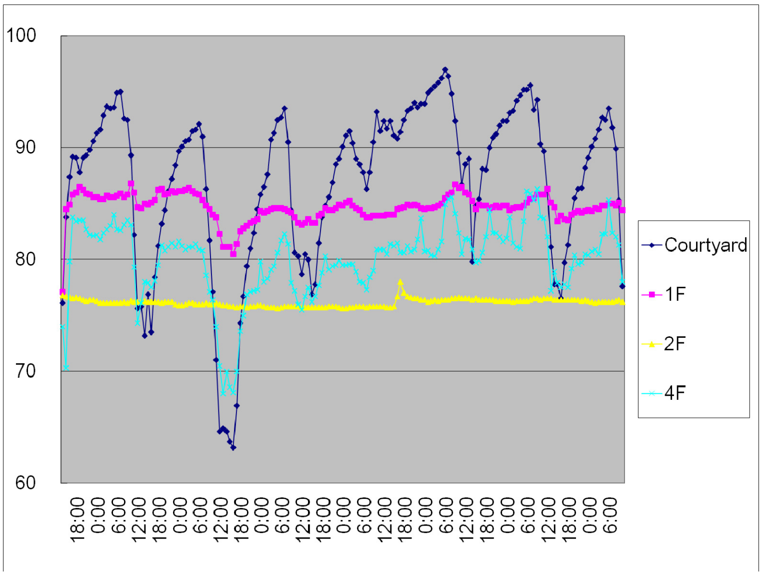
Figure 2. Temperature data for Cheng Qi Lou.



2.2. Moisture

Relative humidity data for Cheng Qi Lou are shown in Figure 3. The moisture reading in the courtyard was highest each morning at 63–97% relative humidity, while the first floor remained relatively constant at 85%. As with the temperature data, the fourth floor data correlated most closely to the courtyard climate, but was 7% milder. Again, the greatest impact was seen on the second floor, were relative humidity remained nearly constant at 76% (±2%), corresponding to the lowest and most constant temperature.

Figure 3. Moisture data for Cheng Qi Lou.



The ASHRE comfort index (Standard 55) 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% [5,6]. Although a moderating effect was seen, most notably in the second floor storage area, the structure would not meet ASHREA or Chinese comfort standards.

The moderating effect observed in the second floor storage area, which is less influenced by other environmental factors, suggests that massive rammed earth walls moderate summer temperature and moisture levels. Similar effects were observed in a study undertaken by Soebarto in Australia [7]. Only summer period data are presented here. Further study is required to establish winter thermal performance in this region. However, it should be noted that research by Soebarto [7] and Kodama [8,9] suggest additional heating would be required in winter. Complete seasonal data will be required to accurately assess Cheng Qi Lou.

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. Temperatures fluctuate more in mountainous regions, and daily temperature variation increases at higher elevations. Thermal mass is effective in improving building comfort in regions that experience these types of daily temperature fluctuations, especially during summer. The greater the diurnal temperature variation, the greater the potential to improve thermal performance with thermally massive construction [7,10].

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 World Heritage Sites, built of rammed earth, 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 were: (1) defense/security; (2) protection from climate; (3) storage/preservation; and (4) necessity to use regionally available materials.

The incredible mass of these structures illustrates their function in fortification. From the viewpoint of sustainable architecture, the principal functions are moderating interior climatic conditions, especially during summer [7], and the use of local materials. The volume mass of rammed earth structures has high specific heat capacity and high density, which moderate the interior climate and improve conditions for preservation and storage. Further research and monitoring of rammed earth structures will help determine the value of rammed earth as a sustainable construction material.

Cheng Qi Lou is among some of the largest rammed earth structures. The mass volume of earth is 3213 m^3, or 26% of total space. Smaller Tulou structures have similar wall thickness and height, and therefore, the percentage total mass volume to total space would be greater.

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, themes must be sufficient to prevent heat transfer into the interior.

Massive rammed earth walls act as a heat sink and are effective for summer cooling. However, research studies lead by Kodama in Japan indicated that rammed earth structures have a constant temperature of 5–6 degrees during winter months, well below today's comfort standards. In order to improve thermal performance, external insulation, roof insulation, and low U-value windows would be required. The structure would then be insulated from heat loss during the winter, while summer nighttime heat is released through the canopy and ventilation [8,9,11–13]. Rammed earth moderates temperature fluctuations retrofits are required to meet current comfort and energy efficiency standards.

Retrofits can 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. Tulou typically have small windows in habitable rooms on the top floor. All Tulou have courtyards which posses a related, but different, challenge. This issue will be addressed in future research. With respect to external insulation upgrades, there are several alternatives.

3.2. Rammed Earth Structure Retrofit—Perimeter Window Zone

The addition of external insulation in 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 and works as a solar wall by collecting heat (Figure 4). Typically, a double skin façade (DSF) consists of two external building skins with a cavity ranging from 20 cm to 2 m wide; the cavity can be vented. Airflow during the day creates a ventilation chimney and also helps prevent moisture buildup. When fully sealed, the interstitial space insulates the building. PV solar-powered, sensor-activated vents optimize performance of a well-sealed air cavity.

Controversy surrounding double skin façades focuses primarily on cost and performance issues related to evaluating new construction projects. A study by the International Energy Agency (IEA) discusses many of these issues [14]. The Intelligent Energy Europe (IEE) Best Façade Project has established best practice guidelines that also address these issues [15]. Performance objectives and costs analysis, especially if they include an environmental audit, depend in part on whether the project is new construction or a retrofit.

The University of Waterloo, Architect Department, has written several reports on the 2001 renovation and environmental upgrade of the 1941 William Farrell Building, now the Telus Corporate Office in Vancouver, Canada [16–18]. The Telus project is applicable here; firstly, because they preserved the historical integrity of the building; and secondly, because the existing concrete structure was retained as a thermal mass inside the cavity to assist in buffering heat transfer. The key "green" features of this double skin retrofit include provision for natural ventilation, control of solar heat gain, provision and protection of shading devices, and a reduction in, and reliance on the size of mechanical systems [17]. This system resulted in 61% less energy consumption than the ASHRAE 90.1 standard [19].

Recent rammed earth construction combines vernacular building techniques with modern sustainable construction practices. One example of this integration is the perimeter window zone used in conjunction with rammed earth for the Wales Institute for Sustainable Education (WISE) at the Center for Alternative Technology (CAT) in Wales (Figures 5 and 6) [20]. This project is particularly interesting, given the similarities in design and materials to those that would be required to retrofit a circular Tulou. Construction on this 7.2 m high circular structure was completed in 2010. Buildings at CAT are monitored. In the future, valuable information may become available on the longer-term performance of this building, which will help in evaluating and designing a Tulou retrofit.

Figure 4. Double skin window.

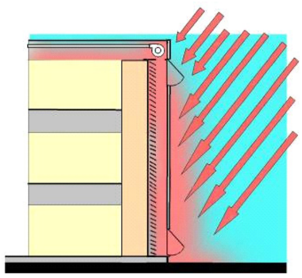


Figure 5. Perimeter window zone.

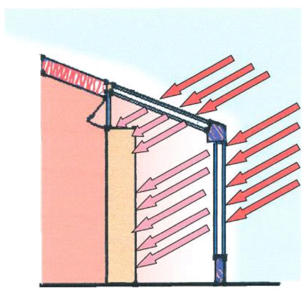


Figure 6. CAT center.

With a constant winter interior temperature around 5–6 degrees [9,10] suggested by Kodama, Hakka Tulou would require additional heating. Historically, direct heating was used to heat rammed earth buildings; this form of heating is still common in Hakka Tulou. Space heating would need to be installed for existing buildings to meet ASHRAE or Chinese comfort standards. Both of these solutions may be effective to retrofit existing rammed earth Hakka Tulou structures.

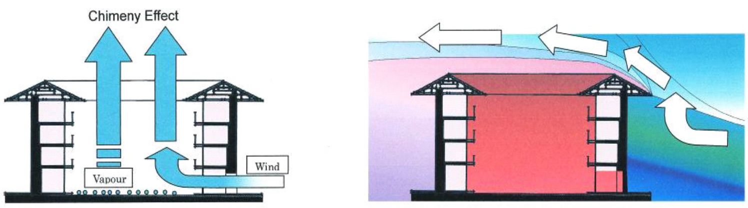
4. Natural Airflow

Both thermal mass and natural airflow are primary factors in moderating temperature and moisture. Natural airflow is important for energy efficiency and sustainability. Contemporary sustainable construction has increasingly focused on natural airflow. An early example 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 many of Lord Norman Foster's projects from his large scale office projects, such as the CommerzBank in Germany and his modularly design school house in Sierra Leone [21,22]. Natural airflow was also a critical design element in the Telus renovation project [17].

Round structures have unique air flow characteristics. According to Yoshino, Cheng Qi Lou clearly has natural air flow [23]. 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 m, his simulation model predicts that when wind passes through the main gate at a 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, suggesting that the balance of space and proportion is effective in creating the chimney effect.

In addition to the airflow simulation shown in the Yoshino model, a further consideration in an inhabited building such as Cheng Qi Lou is the evaporation effect from the large volume of water used in the kitchen area. Figure 7 illustrates the evaporation effect from the first floor kitchen area. In summer, the main gate is open, resulting in a chimney effect and an evaporation effect, moderating temperatures and moisture levels. During the winter, the main gate can be closed to reduce heat loss (Figure 7).

Figure 7. Evaporation effect at Cheng Qi Lou. Summer gate open winter gate closed.



5. Environmental Performance Assessment

5.1. Environmental Performance Assessment 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)

While these environmental assessment programs have similar objectives, the criteria and assessment methods differ. Several studies have analyzed and compared these three major programs, including studies on the various environmental performance assessment tools by Oka [24–26]. A summary of his findings is outlined in the Table 1.

Table 1. Comparison of CASBEE, LEED and BREEAM environment assessment programs. (**a**) LEED & CASBEE Categories, (**b**) Individual Components.

(**a**)

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

(**b**)

	LEED	CASBEE	BREEAM
Indoor Air Quality	Max.	O	O
Noise & Acoustics	O	Max.	Many
Service Ability	N/A	O	O
Energy	Simulations	O	Simulations
Rain Recycling	O	Max.	O
Waste Water	O	N/A	O
Nox, LCCO2	N/A	O	O
Heat Island Effect	O	O	N/A
Flexibility	Exist	O	O

O: Equivalent.

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

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

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, 1.5–3.0 is ranked A, 1.0–1.5 is ranked B+, 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. Detailed information is available on the CASBEE web site [27].

$$\text{Building Environment Efficiency (BEE)} = \frac{\text{Building Environment Quality and Performance (Q)}}{\text{Building Environment Load (L)}} \quad (1)$$

5.3. Results of Preliminary Calculations Using CASBEE for Cheng Qi Lou

First, it should be noted that CASBEE assessment tools are not specifically designed to evaluate historic structures. Second, sufficient data are not available to provide a comprehensive evaluation. Nevertheless, it is a valuable exercise to assess Cheng Qi Lou, built over 300 years ago, using current stringent environmental guidelines. This not only helps illustrate the efficacy of vernacular building methods, but it also indicates the types of upgrades suitable to preserve and/or modernize Hakka Tulou to today's environmental and living standards.

CASBEE includes assessment tools for New Construction and Existing Buildings. Both tools were used in this study to capture different aspects of the criteria to evaluate Cheng Qi Lou. The Existing Building Tool is specification-based and normally used to evaluate technologically and environmentally outdated structures, but it was used here to evaluate durability. The New Construction Tool is performance-based, incorporates the latest environmental technology, and is normally used to increase the overall assessment at the design stage. The New Construction Tool was used here to capture sustainable features such as the use of local materials and the combined use of well water and rainwater, which could not be evaluated with the Existing Building Tool.

Results of the preliminary calculations for both assessment tools are shown in the figures below:

Figure 8. CASBEE existing buildings results.

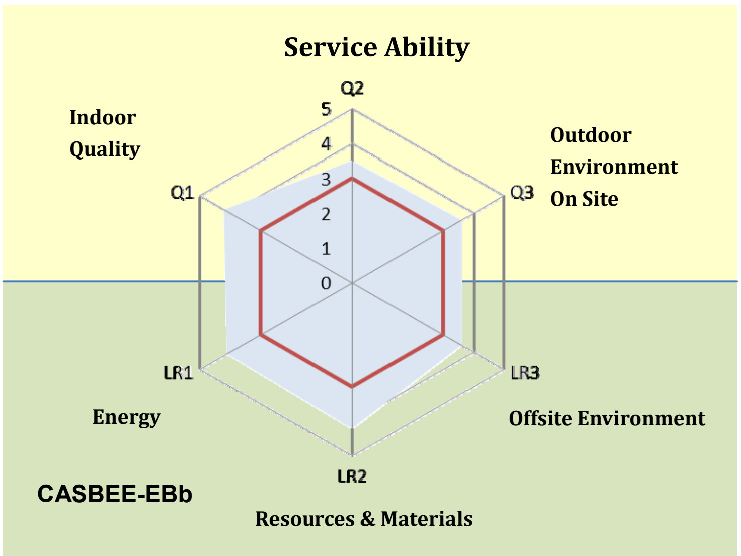
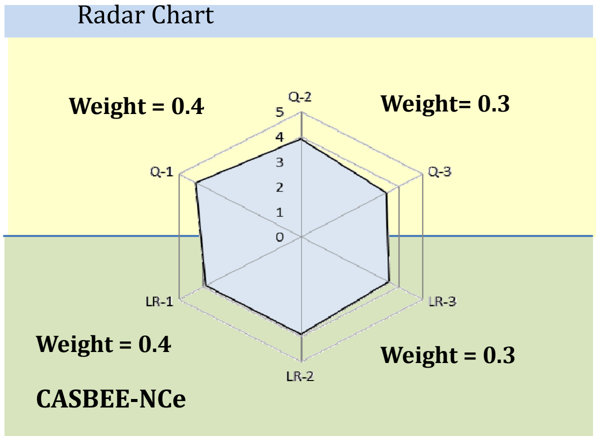


Figure 9. CASBEE New Construction Results.



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

$$\mathrm{BEE} = \frac{\text{Q:Building environmental quality and performance}}{\text{L:Building environmental loadings}} = \frac{25 \times (S_Q - 1)}{25 \times (5 - S_{LR})} \qquad (2)$$

The Building Environment Efficiency rating for each model is:

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

Cheng Qi Lou ranked "A" for both calculation methods. For reference purposes, this would be similar to LEED Gold and BREEAM "Very Good". The assessment also highlights environmental deficiencies.

The CASBEE results in Figures 8 and 9 indicate relative weakness in Q3 Quality of Outdoor Environment on Site and LR1 Energy Load. Individual components for each category are given in Table 2. A discussion of these results follows. Implications for preserving and renovating Hakka Tulou are discussed in the next section.

5.3.1. Quality (Q3) Outdoor Environment on Site

Preserving or creating the biotope site is critical to maintain or improve the natural environment surrounding Cheng Qi Lou and other Tulou sites. Many Tulou sites have some aspects of a biotope, including site selection in a naturally sheltered location and semi-circular ponds, as discussed in Katayama's paper [1]. It is essential that the effects on and balance of these natural elements be understood and capitalized on to improve the outdoor environment on site and to maintain bio-diversity. This is particularly relevant as many of these sites become more assessable to tourists. For a more comprehensive definition of biotope, see Hoshino [28].

Some environmental assessment programs include community design and landscaping 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.

5.3.2. Load (LR1) Energy

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

Energy results were most adversely affected by categories evaluating increased utilization of advanced systems, including HVAC, energy efficient mechanical systems, and total water management systems. LR1 also assesses comprehensive maintenance programs for facilities and mechanical equipment; this was another factor in the weaker results. Finally, building services efficiency and operational management systems are included in this category (while applicable for large commercial buildings, they do not apply here).

6. Implication for the Preservation and Restoration of Hakka Tulou

Cheng Qi Lou and other historically significant structures should be strictly preserved; still the impact from an extraordinary increase in tourism to this site and the other UNECSO sites must be taken into account. Environmental upgrades can protect the biotope and microclimate surrounding these sites. Planting large trees in the immediate vicinity surrounding Cheng Qi Lou would help moderate temperature and facilitate natural airflow throughout the site. Installing water permeable materials in parking areas around tourist facilities should also be considered. Composting toilets are another viable solution. Composting toilets minimize the impact on water management facilities and are particularly appropriate in an agricultural region. Waterless toilets installed in both remote and high traffic areas within the Canadian National Park network have proven an effective component of sustainable water management. A rainwater recycling system should also be developed, within the context of a total water management system.

Reducing energy load could directly impact historical structures; however, developing infrastructure beyond the perimeter of the Heritage Site may be an option. An efficient combination of natural energy sources is the most effective way to improve energy efficiency. Installing locally manufactured PV panels, LED lighting and solar hot water systems would decrease energy load. Renewable energy sources, such as geothermal, may also be considered. Measures such as these can moderate the impact of increased tourism in the region.

As noted earlier, there are over 20,000 Tulou, with the greatest concentration in Fujian province; many of these are poorly maintained or abandoned. The state of repair of many of these Tulou remains an important regional issue. The relatively high preliminary environmental assessment of Cheng Qi Lou, suggests there is significant potential to upgrade Hakka Tulou. From Katayama's research, we see there is a wide variety of Tulou in terms of size, shape, and state of repair [1]. The majority of Tulou are square or multi-courtyard; approximately 20% are circular. Tulou share many similarities, most notably their massive rammed earth structure and open courtyards. Observations on thermal performance relate to all Tulou; natural airflow data, as discussed here, is specific to circular structures. More research is required to evaluate square and multi-courtyard Tulou.

Socio-economic conditions influence to types and extent of environmental retrofits, especially given the decline in Tulou occupancy rates and increased median age of occupants. Amenity modernization and maintenance of Tulou complexes is a serious regional issue. Because of difficult living conditions and lack of basic amenities, local residents are relocating to new concrete and brick buildings. There is also significant tourism development in the region. Assessing and upgrading existing Hakka Tulou to modern living standards could increase Tulou occupancy rates and reduce the demand for new construction. However, retrofits should be designed in ways that incorporate the sustainable features of Hakka Tulou, maximize energy efficiency and environmental sustainability.

Environmental assessment programs can be effective tools in assessing various retrofit alternatives. Environmental Performance Assessment Programs allow a more comprehensive approach addressing: (1) total water management; (2) small energy efficient heating systems; (3) increased use of natural energy sources; and (4) more emphasis on the biotope and improvement in the outdoor environment. Establishing monitoring and maintenance programs is also essential for long term building performance.

The Telus Project and Wise Conference Center are examples of a growing number of projects that have incorporated thermal mass as a building element for sustainable construction, using this as a heat sink to moderate temperature. In this regard, the Telus project is of particularly interest, where the renovation was designed to maximize this potential. In the case of the WISE Conference Center, rammed earth was chosen for its inherent thermal properties. Both projects can also provide valuable information on the feasibility of using a ventilated double skin façade to retrofit Hakka Tulou. The potential to use a ventilated double skin or perimeter window for a rammed earth retrofit should be explored further. An effective solution for increasing thermal comfort during the winter is a critical factor in retrofitting Tulou.

7. Conclusions

Ongoing research is required to collect and monitor climate data and to use this data and a simulation program to further evaluate existing Tulou within the context of sustainable energy efficiency. Further study is needed to determine the best retrofit solutions to maximize winter heat retention, taking into consideration functionality, design flexibility, and sustainability.

There are practical and sustainable solutions for the preservation and restoration of Tulou complexes, both to preserve historic sites and to improve the lifestyle of the inhabitants. The ability to renovate and retrofit these Tulou could increase occupancy rates and preserve a culturally historic lifestyle throughout the region. There is also the potential to convert abandoned Tulou into alternate uses, such as community facilities, schools, and tourist facilities, which, could help mitigate the effects of increased tourism and reduce the demand for new construction in the region.

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