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SUSTAINABLE HOUSING – A CASE STUDY OF HERITAGE BUILDING IN HANGZHOU CHINA

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ABSTRACT

Surrounded by high-rise buildings, some two-storey buildings with black roofs are sited along the Xiaohe (Little River) in the north of Hangzhou, China. The buildings were originally built in the late Qing Dynasty (late 19th century) and restored in 2007 by the Hangzhou municipal government. The architectural materials used in the buildings are mainly concrete for the ground floor and timber to the first floor. Three buildings located at Xiaohe Historical Street were investigated to establish whether traditional buildings performed as well as modern buildings. Hourly temperature and humidity readings from September 2009 to August 2010 were recorded for the selected houses. It was concluded through comparisons that the restored heritage buildings provided similar thermal comfort and conditions to modern buildings.

Keywords: Historic housing protection, building performance, sustainability, thermal comfort, Hangzhoug, China

INTRODUCTION

Historic buildings are important assets for current and future generations. This is because these buildings reflect and record stories of historical evolution, social and economic progress, technological reform and cultural development for the past. Though there are increasing interests and arguments for protecting historic buildings (Lou, 2008; Burby, et al., 2006; Cyrenne, et al., 2006), many historic buildings remain under threat of rebuilding or demolition because limited resources are devoted to their long term protection. The main concerns are that historic buildings are perceived as (a) dated and not sufficiently fashionable to meet the modern living conditions; (b) their poor building performances are detrimental to user comfort; and (c) their spatial layouts are not necessarily the best use of floor space. Other issues include the scarcity of skills and technology for repairing and maintaining these costly historic buildings and thus, protection of these historic buildings face tremendous challenges.

In 2009, the Hangzhou municipal government completed the project of restoring and rebuilding of Xiaohe Historical Street (Little River Street) to restore original functions and characteristics. 285 households lived in the Street originally and a subsequent survey showed that around 60% of these households was willing to return to these newly restored buildings (Baidu, 2008) and that the internal thermal comfort and living conditions was one of their key concerns. This paper addresses the issues of whether historic buildings, especially residential buildings, can be conserved to meet the requirements of current environmental performance. That is; do the newly restored or rebuilt historic buildings perform equally compared to modern high-rise buildings and do they provide the same level of thermal comfort for occupants? The temperature and humidity data of the selected houses from September 2009 to August 2010 were recorded and presented. An introduction to the background of Little River Street is provided. The literature on human comfort is reviewed before the research methodology and methods of collecting data are described, and then followed by a discussion the findings of the test results.

BACKGROUD OF LITTLE RIVER STREET

Little River Street is located in the northern part of Hangzhou, a Chinese city which integrates natural and cultural environments, as well as people who live there with harmony, peace and contentment. The West Lake in Hangzhou is renowned as the "best under heaven", being surrounded by mountains on three sides with its eastern side lying adjacent to Hangzhou city; the natural waters and landscapes make the city a pearl of the Yangtze River Delta Region (Baidu, 2008).

Little River Street is one of the locations for many historic buildings in Hangzhou including remains from the 13th century Southern Song Dynasty. Little River Street adjoins the Beijing-Hangzhou Grand Canal, and the Xiao He and Yuhang Tang River. Thus, Little River Street was an important port with integrated warehouse, transportation, retail and service businesses. The street is around a kilometre in length, with a long history that began as early as the Tang Dynasty (618 – 907) and gradually developed into a community during the late Qing Dynastry (late 19th century). Most of the buildings are two-storeys high with residential accommodation to the first floor and retail businesses accommodated on the ground floor. Figure 1 shows the houses after rehabilitation. The style of the buildings remains as a unique feature of the late Qing dynasty reflecting the living environment of the local surrounding residents. Most of these buildings were low level, high density or two-level independent terraces with mainly timber construction for the first floor and masonry for the ground floor (Figure 1 & 2). These houses featured white washed walls and black tiled roofs with timber-framed windows and doors. These original buildings did not have bathrooms or kitchens, and had low acoustic and heat protection. Between the houses were very narrow spaced alleyways with very little green space.

Figure 1: Houses after rehabilitation

Source: Author's Photo

Figure 2: Timber-framed structure

Source: Author's Photo

Following the restoration of these buildings in 2007 to their original likeness the built environment has been improved. There are total of 120 households and around 450 residents living in the area. 50% of residents are aged over 60 years and 70% are retired (Xiaohe Office, 2009). All the buildings have been modernised by adding bathrooms and kitchens. The newly renovated street now combines residential and retail business, as well as a background for traditional culture activities (Figure 1). At least three benefits of the rehabilitation program can be identified. Firstly, the reuse of housing reduces landfill waste and meets the concept of sustainable development. Secondly, the unique features of historic architecture are maintained and its culture heritage is retained. Thirdly, the local tourism business has improved attracting related business such as restaurants, entertainment venues, transportation providers all of which contribute to the economy of Hangzhou.

LITERATURE REVIEW

Thermal comfort is a measure of building performance. According to Sinopoli (2009), apart from energy efficiency and sustainability, building performance could be also measured by another four aspects which are:

a) Lifecycle costs of a building development from the construction to operation costs and asset value of the building. The lower the costs of development the better the value of the building;

b) Physical protection of its occupants and assets, such as the need to provide doors, lighting, air intake, fire alarm, and video surveillance that protect occupants from crime, terrorism, fire, accidents and environmental elements;

c) Efficient and effective operation and maintenance of a building is critical to its performance; and

d) Productivity and satisfaction of building occupants that includes occupant comfort, physically (thermal comfort, appropriate lighting, etc.) and psychologically (building image, appearance and aesthetics).

Indoor thermal comfort measures satisfaction with the thermal environment in which the body functions and performs well (Frontczak, and Wargocki, 2011) and is measured by indoor temperature, humidity, and air movement. Thermal comfort needs may vary based on climate. For example, according to the occupational health and safety guidelines, the optimum summer temperature range is 21-24^{o}C and winter temperature range 19-22^{o}C (Sydney University, 2011). The optimum air movement is 0.1-0.5 m/s (naturally ventilated), 0.1-0.2 m/s (air-conditioned) and the recommended level of indoor humidity is in the range of 30-60%. In India, 21-23^{o}C for winter and 23-26^{o}C for summer are suggested by the

National Building Code of India (Indraganti and Rao, 2010). In China, around 23-28^{o}C for summer and 18-25^{o}C for winter are recommended as there are hot humid summers and cold winters. When thermally comfortable, people inside a building must feel neither warm nor cool. Discomfort will be experienced when the temperature or humidity is beyond the human comfort level.

There are many studies of indoor thermal comfort. Frontczak and Wargocki (2011) surveyed the different factors influencing human comfort in indoor environments and concluded that thermal comfort is ranked by occupants to be of greater importance compared with visual and acoustic comfort and good air quality. Strategies were suggested to naturally improve comfort in a climate which is hot and humid without air conditioning, such as Malaysia (Zain, et al., 2007). Paul and Taylor (2008) compared occupant comfort and satisfaction between a green building and a conventional building using a questionnaire asking occupants to rate their workplace environment in terms of aesthetics, serenity, lighting, acoustics, ventilation, temperature, humidity and overall satisfaction. They found no evidence that green buildings are more comfortable than a conventional building in Australia. Singh, et al. (2010) studied thermal performance in North-East India by surveying 150 vernacular dwellings and found that the vernacular dwellings perform quite satisfactorily except in the winter months and the occupants feel comfortable in a wider range of temperature. Thermal comfort studies have been applied also to school buildings (Zeiler and Boxem, 2009), office buildings (Hens, 2009) and in air conditioned systems in tropical regions (Sookchaiya, et al., 2010) and the dry-desert climate of Kuwait (Al-Ajmi and Loveday, 2010). Thermal comfort studies of restored historic residential building have not been found indicating a knowledge gap exists.

Field study and survey are methods commonly adopted by many studies on thermal comfort. Indraganti and Rao (2010) received 3962 datasets from survey and measured four environmental variables of thermal comfort between 7am and 11pm three times a day in May, June and July 2008, to study the effect of age, gender, economic group and tenure on thermal comfort in residential buildings in a hot and dry climate with seasonal variations. Guedes, et al. (2009) investigated the thermal comfort criteria and building design in Portugal. Their field work involved monitoring of indoor environment parameters during summer, winter and mid-season, as well as questionnaires of Lisbon office building users and other building types. Similar methods were applied by Wang (2006), who visited 66 residential units in Harbin, China obtaining survey data using an indoor climate analyser to collect the measured parameters of the indoor environment. He found that the neutral operative temperatures for Harbin males and females are 20.9 and 21.9^{o}C respectively and the males are less sensitive to temperature variations than the females. Simulation is an alternative method used for thermal comfort in residential buildings (Peeters, et al., 2009).

RESEARCH METHOD

The purpose of the research is to test whether the restored or rebuilt historic houses performs or provide similar living comforts and conditions as modern housing. In order to answer the question, the features that relate to the indoor environmental quality of a building such as natural lighting, natural ventilation, operable windows, etc. should be examined (Paul and Taylor, 2008). Field study is the method used for the research.

Sample Selection

Six historic dwellings in Little River Street including two types of housing were studied (Figure 3). The first type is two-storey restored housing where the buildings were brought back to the original style and condition using similar materials. The second type is rebuilt two-storey housing where the building is newly built following the same style as original. Bathrooms and kitchens were added into the original structures for people to meet modern living conditions. An apartment in a modern high-rise building in a nearby modern estate was also selected as a control. Figure 3 indicates the locations of the six selected historic houses. Windows of the historic buildings are smaller and some have double glazing which means some parts of the rooms are dark. In comparison, the windows in the modern apartments are bigger with a glass sliding door in the living room leading to a balcony. This allows more daylight into the interior of the apartment during the day. Three dwellings were chosen for discussion, i.e., House A (rebuilt) and House D (restored) are the historic dwellings and House E is the modern apartment. It can be noted from the Figure 3 that House A is close to and fronts the river.

Measurement of Daily Activities

A daily log was created that allows the occupants to record their activities such as when they opened/closed windows and when they turned on/off the air conditionings. The data received from the daily log can be used to investigate how the daily activities affect the energy consumption and thus indoor environmental quality. Each household was given a predesigned Daily log book and they marked the activities performed each day. The collected data were then input to the excel spread sheet for analysis.

Figure 3: Location of the Selected Housing

Source: Authors

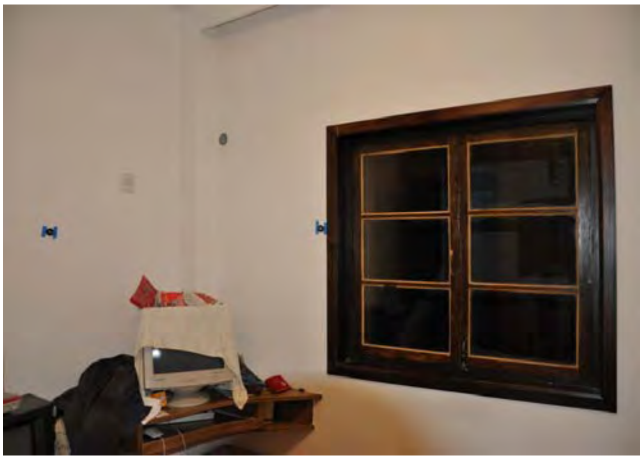
Measurement of Indoor and Outdoor Environmental Data

Indoor Hygrochron iButton (the Monitors) were used to collect data on the indoor environment. The physical data included air temperature and relative humidity. Air velocity and radiant asymmetry were not measured due to budget and time constraints. Seven monitors were installed for each of the selected dwellings. One monitor was installed on an outside wall of the dwellings. The other six monitors were installed on different walls inside the dwelling (internal and external walls), upstairs and downstairs, Figure 4 and 5 are examples of monitors been installed. The purpose was to monitor building performance from all aspects of the dwelling. In contrast to previous studies (Wang, 2006; Indraganti and Rao, 2010; Peeters, et al., 2009), hourly data of temperature and humidity from September 2009 to August 2010 were monitored and collected for analysis. Data from four seasons could be observed and compared.

Figure 4: Monitor Installed Externally

Source: Author's Photo

Figure 5: Monitors Installed Internally



Source: Author's Photo

Data Source and Hypothesises

The daily log was original data collected from each household. The households also provided copies of their water and electricity bills for each month. The indoor environmental variables (temperature and humidity) were downloaded hourly from the installed monitors. The weather data was obtained from the Hangzhou meteorological station. The hypotheses included:

1) The historic dwellings provide similar thermal comfort to the modern apartment, thus there are similar records of temperature and humidity.
2) Since House A is closer to the water, it is expected the temperature of House A is relatively lower and the humidity is relatively higher than Houses D and E;
3) House E is expected to use less hours for lighting since the apartment has a greater number and larger windows, as well as a glazed wall through to the veranda thus using less energy.
4) The indoor environmental quality of all the selected dwellings would be similar to others in Hangzhou city.

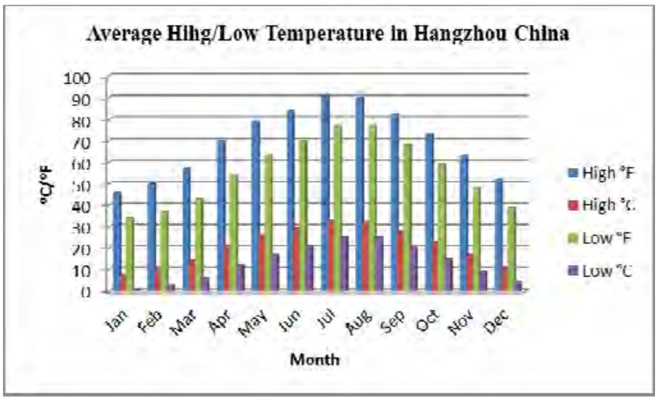
RESULTS AND DISCUSSIONS

The results of each house is discussed individually. For each of the houses, the readings for the ground floor and first floors, internal wall and external walls, internal central and external areas will be compared. Finally, the average indoor environmental performances are used to compare the houses and the Hangzhou weather data and the thermal comfort of the three houses can be concluded.

Hangzhou Weather

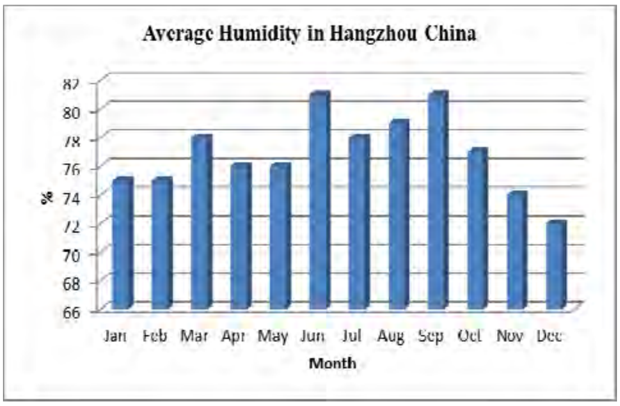
Hangzhou is located at the latitude 30° 15' 19" N (30.2553) and Longitude 120° 10' 8" E (120.1689), and has a subtropical monsoon climate with mild and moist weather (Travel Guide, 2011). Average temperature in summer is 28.6℃ and 3.8℃ in winter. The four seasons are distinct. Spring starts in March, April and May with the average temperature between 9-15℃. Summer begins in June, July, and August with hot and humid. There is a month long rainy season in the end of June to the early part of July. September and October have the best weather with clear skies and average temperature around 22^{o}C. However, the city suffers severe cold weather with around 3-7^{o}C in winter. Figure 6 depicts the average temperature in Hangzhou. Humidity for the city is high all year long around 70-80% (Figure 7). Inhabitants of the city have adapted to and accepted the thermal environment.

Figure 6: Average Temperature in Hangzhou



Source: Hangzhou Weather Bureau

Figure 7: Average Humidity in Hangzhou



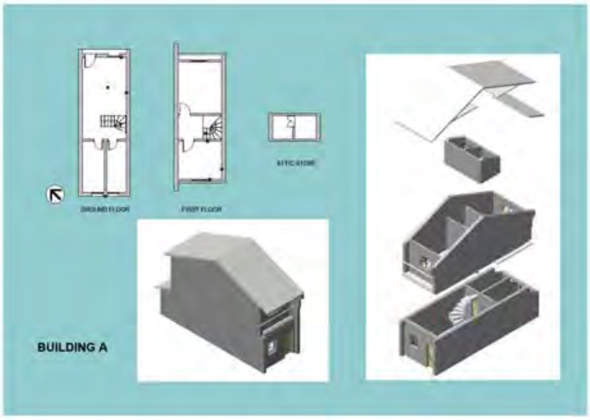
Source: Hangzhou Weather Bureau

House A

House A has been rebuilt with two bedrooms on the first floor and a living room on the ground floor. Three people live in the house with one air conditioner on the ground floor. Three monitors were instaled on the first floor (two external walls and one internal wall). Two monitors were placed at an internal wall and external wall on the ground floor. One moniter were located in the middle of the room and one was placed on the outside of the house. Figure 8 indicates the locations of the monitors. The household regularly turned on lights for one hour from 5-6am and then again at 5pm to around 9pm everyday, for a total of around 5 hours. Windows were opened at 7am and closed around 3-4pm. They used airconditioning often in summer at 10pm to the next morning around 5am from July to September. For the whole of

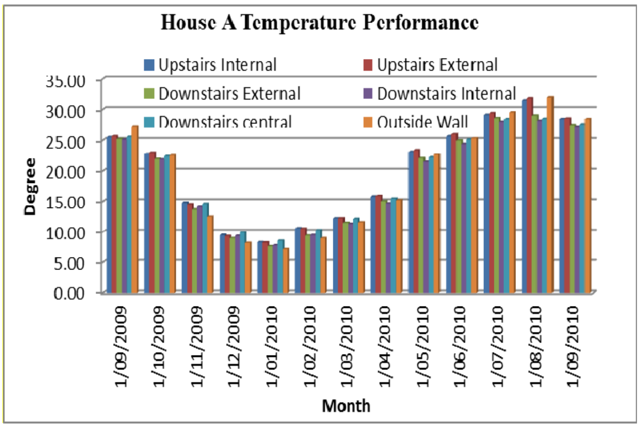
August, they turned on the air conditioning around 10am to 2pm. However, they did not use air-conditioning in winter (only one instance was recorded in February). The occupants stated that they were used to the temperature and do not feel cold at all.

Figure 8: Monitors' Location House A



Source: Author's Drawing

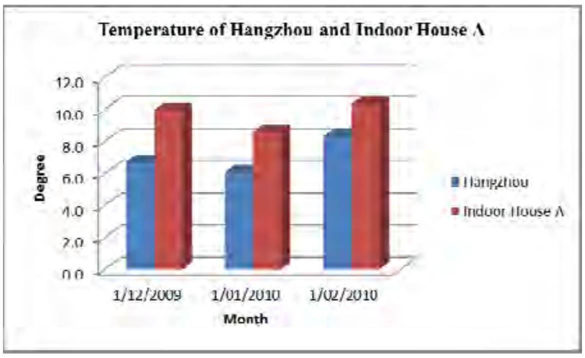
Figure 9: Ground & First Floor Temperature



Source: Author's Statistics

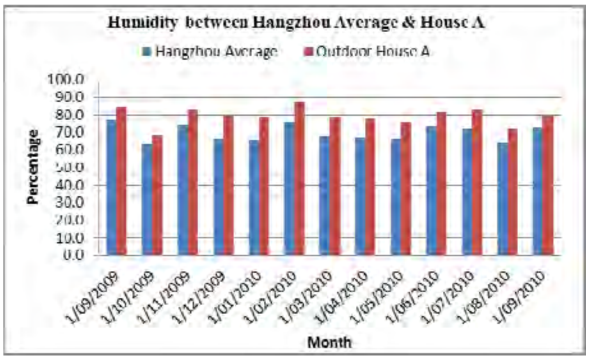
The outside monitor was installed on the wall closest to the water for house A. The records of temperature outside the house were a generally 1.3°C higher than the Hangzhou average temperature. According to Figure 9, July and August were the months with the highest temperature. It can be noted that in August, the average temperature on the ground floor was generally 1-3°C lower than the first floor, since the households had their air-conditioning on the ground floor. In general, the first floor internal wall was 1°C higher than the ground floor and the first floor internally was warmer than outside by 1-2°C in winter (Figure 10) and by similar temperatures in summer. House A's outside temperature is around 1.3°C higher, in particular in the Winter season, some 2-3°C higher than the Hangzhou average. The average temperature of on the street side of the external wall was 0.9°C higher than the temperature on the water side of the external wall; but the avearge ralative humidity was 3.7% higher. The humidity outdoor the house was 5.6-12.9% higher than the Hangzhou average (refer to Figure 11). This is because the house is close to the river. Within the house, the first floor humidity level was lower than the ground floor.

Figure 10: Winter Temperature House A



Source: Author's Statistics

Figure 11: Humidity Hangzhou and House A

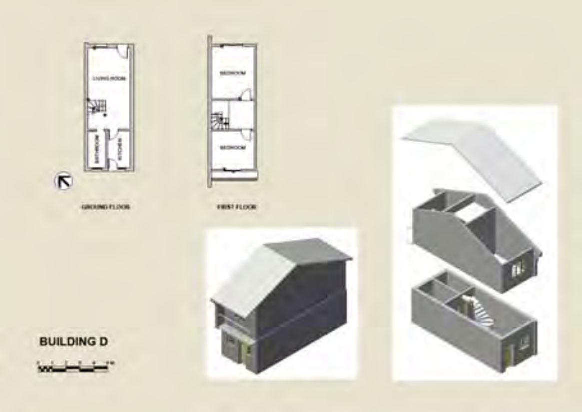


Source: Author's Statistics

House D

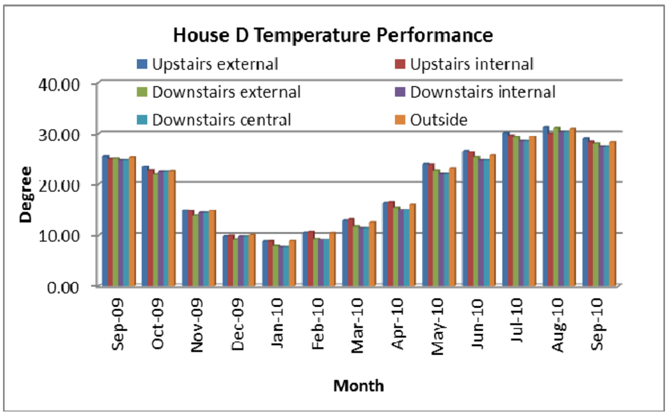
House D is a restored house with two first floor bedrooms and a living room to the ground floor. Four people live in the house and there are two air conditioners. Three monitors were installed on the first floor (two on external walls and one on an internal wall). Two monitors were placed at an internal wall and external wall on the ground floor. One moniter were located in the middle of the room and one was placed on outside wall of the house. Figure 12 shows the location of the monitors. The household turned on and off the lights twice a day, i.e., one hour in the morning from 6-7am and afternoon at 5pm to 11pm, around 7 hours in total daily. The occupants opened the window regularly at 5-6am in the morning and closed them between 8-11pm. They used air conditioning only in the summer for half a month from 3rd July to 15th July and nearly whole month in the August; sometimes twice a day.

Figure 12: Monitors' Locations House D



Source: Author's Drawing

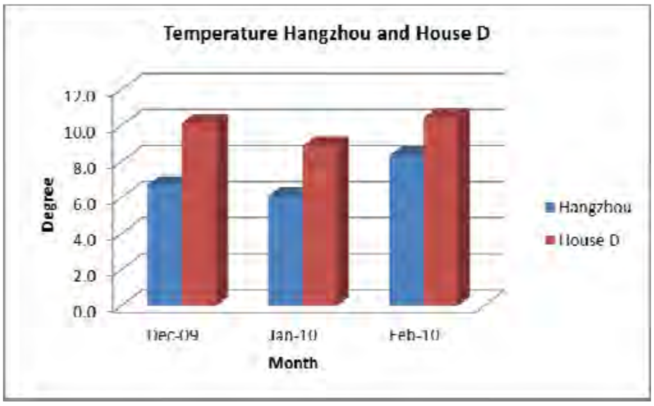
Figure 13: Ground & First Floor Temperature



Source: Author's Statistics

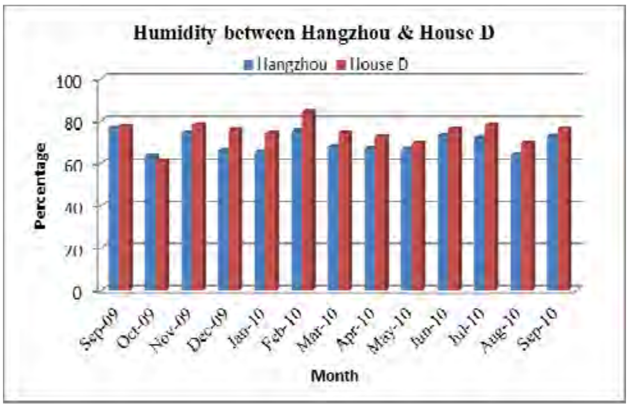
The internal temperatures were around 2^{o}C higher than outside in winter and similar in other seasons (see Figure 13). The first floor temperatures were higher than those recorded to the ground floor. From September to December, the internal wall was warmer than the external wall and then gradually the external walls become warmer than the internal wall both on the first and ground floors. Compared to the Hangzhou average, the temperatures around the house were higher (Figure 14). With the exception of October 2009, humidity around the house D was higher than the Hangzhou average (Figure 15).

Figure 14: Winter Temperature House D



Source: Author's Statistics

Figure 15: Humidity Hangzhou & House D

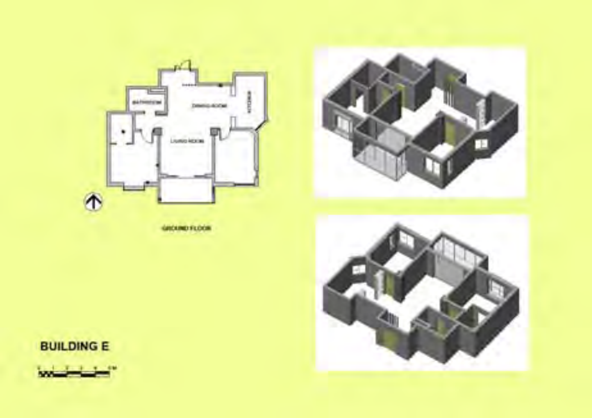


Source: Author's Statistics

House E

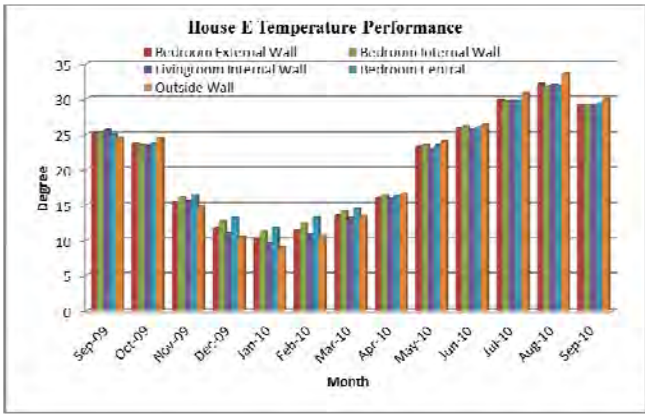
House E is located within a modern high rise building on level 4. Three people live in the apartment which has two bedrooms, two bathrooms and one living room. Three air-conditioners are provided. All rooms (bedrooms and bathroom kitchen) have windows with full glazed doors in the living room opening to the veranda. Five monitors were installed in the apartment as follows; bedroom internal wall, bedroom external wall, bedroom middle, living room internal wall and external wall. From the records of daily log, the family turned on the lights around 5pm everyday and turned them off around midnight, totalling around 7 hours daily. Occupants opened the windows in the morning without a pattern and closed them, also without pattern apart from March when the windows were opened all the time. The occupants often used the air-conditioning from mid December to the mid of February and cooler from mid-June to the early August. Figure 16 shows the locations of the monitors installed in the House E.

Figure 16: Monitor Locations House E



Source: Author's Drawing

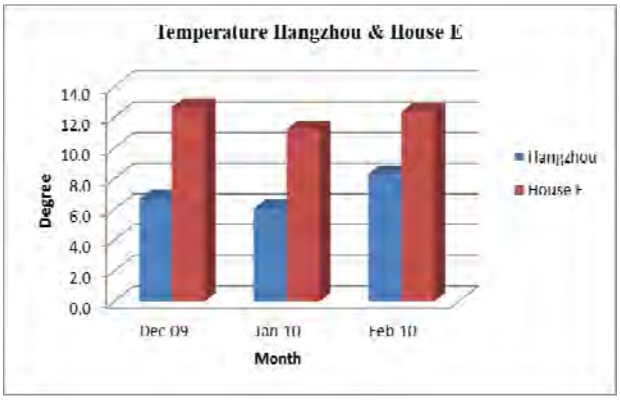
Figure 17: Temperature House E



Source: Author's Statistics

Figure 17 provides a chart comparing temperatures each month over a year period. As with the other two buildings (House A and D), in August the highest temperatures of the year, of over 30°C, were recorded. The temperatures of internal wall in the bedroom and the central of the room were recorded 2-3°C warmer in the winter. The temperatures recorded to the internal and external bedroom walls were the same though out the year except the winter, where about 1°C difference was noted. Comparing to the Hangzhou average, the mean temperature of the house was between 3.5 to 7.5°C higher in the winter (Figure 18) because the air-conditioning was on. The relative humidity of the house internally, represented by the data from internal wall and central, was similar with the average relative humidity of around 70% in Hangzhou generally. Humidity around house E was higher than the Hangzhou average, except during October and November 09. Also the humidity of internal and external walls was different, in particular 6 to 10% differences were recorded in February 2010 when no heater was turned on (Figure 19). This data indicates that the apartment is well insulated.

Figure 18: Winter Temperature House E



Source: Author's Statistics

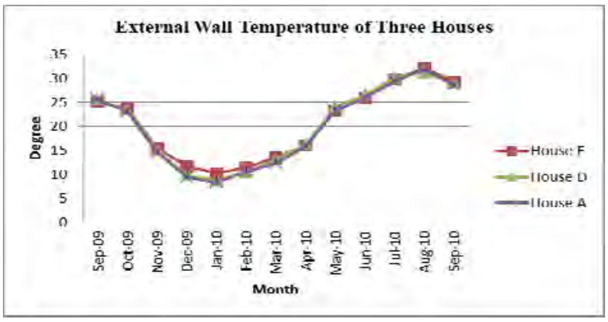
Figure 19: Humidity Performance House E

Source: Author's Statistics

Comparison of Results between Buildings

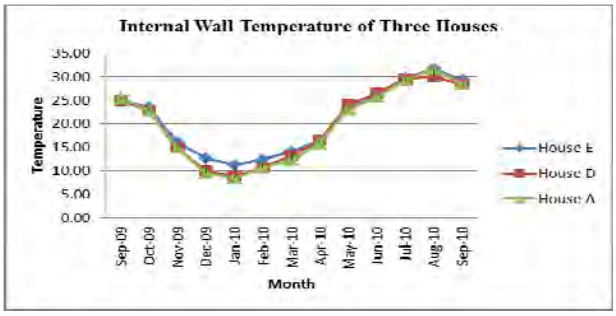
The internal and external wall monthly mean temperatures and relative humidity for the recorded period were compared for the three dwellings. Figure 20 and 21 are charts that illustrate the temperature performance for the three dwellings. House A and House D provided almost identical results. The temperature of House E in the winter was 1-2°C higher than Houses A and D. For the other months, however the temperatures were very similar. The higher temperature of House E could be explained by more frequent use of the air-conditioning from mid-December 2009 to mid-February 2010.

Figure 20: External Wall Temperature



Source: Author's Statistics

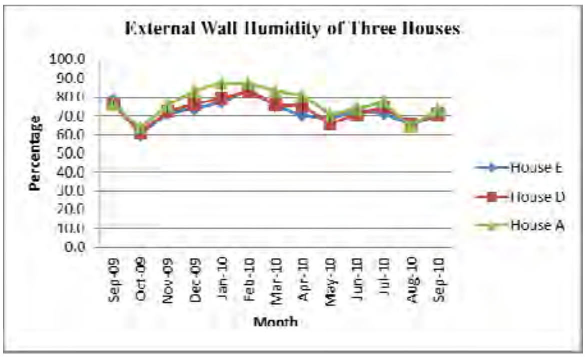
Figure 21: Internal Wall Temperature



Source: Author's Statistics

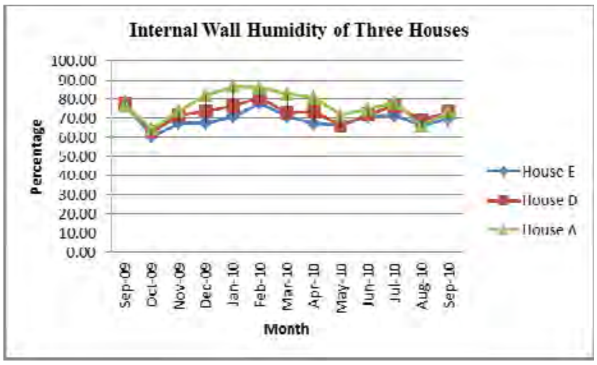
Relative humidity of the three dwellings was compared for both external and internal wall data and it shows that three dwellings provided similar patterns around the year. The relative humidity of House A was higher than both House D and House E according to the external wall data (Figure 22). Inside the dwelling, House A has the highest humidity, followed by House D second and House E (Figure 23). The higher humidity of House A was expected since the house is located near the Little River. House E occupants often used air-conditioning in both winter and the summer; hence its humidity should be lower than other two houses.

Figure 22: External Wall Humidity Houses A, D and E



Source: Author's Statistics

Figure 23: Internal Wall Humidity Houses A, D and E



Source: Author's Statistics

Though the natural day-lighting condition of House E is higher than House A and House D, House E and D used lights 7 hours a day while House A used lighting only 5 hours a day. Overall the electricity and water bills were fairly similar.

CONCLUSION

This paper discusses building performance focused on measuring thermal comfort, in particular temperature and relative humidity for three dwellings: one restored and one rebuilt historic house, and one modern apartment in a high-rise building in Hangzhou China. Hourly readings from September 2009 to July 2010 were collected for the analysis. The conclusions drawn are as follows:

a) Hypothesis (1) is supported. The performance of historic dwellings and conventional buildings are very similar as shown from the performance of temperature and humidity, which indicated that historic buildings should be adapted rather than demolished.

b) Hypothesis (2) is also supported. House A has a relatively higher humidity and lower temperature since it is located near a water front. The result suggests that location of the property and natural environmental elements are important variables for thermal comfort.

c) The performances of historic buildings were consistent throughout the two selected dwelling used for the study for the data collected both inside and outside. In particular, the internal temperatures of the dwellings were 2^oC warmer than the outside in winter and suggested that the buildings were comfortable and also had low energy consumption. In addition, the first floor rooms are warmer than those downstairs.

d) Hypothesis (3) is rejected since electricity and water consumption in House E were similar to the other dwellings. The result show that habits and level of tolerance to thermal comfort are factors contributing to energy consumption. Households in Little River Street have adapted to the thermal environment. On the other hand, economic elements can be a factor since most the occupants of the households in Little River Street were retired or lower income families. Households that can afford to buy a modern apartment usually have higher and more stable sources of income and thus can afford to consume more heating and cooling to improve their living comfort.

e) The data collected from each dwelling was compared with official published data on Hangzhou's thermal Data and the results indicated a consistency in the performance. The historic buildings in Little River were generally 2.5^oC warmer than the Hangzhou average temperature in autumn and winter, and 0.5^oC warmer in spring and summer. These temperature variations represent the microclimate around Little River Street.

f) Historic buildings can remain as original cultural features, provide comfort housing for lower income families and attract business opportunities. This study has demonstrated that the historic buildings are sustainable on social, economic and environmental criteria.

The empirical results from the research imply that historic buildings are sustainable and reducing life cycle costing. Human living comforts were satisfied through updating the historic buildings from disrepair rather than demolishing them and other improvements are made by adding facilities to modernise housing internally. The thermal performance of these historic buildings were also be improved by adding modern insulation materials. Though there is debate on the inefficient use of land since most historic buildings are low-rise and have a lower floor space ratio. The value of historic social influences and cultural heritage these buildings contribute are significant and cannot be necessarily measured in financial terms. The adapted historic buildings could add to a pool of affordable housing because of their lower cost compared to the modern high-rise buildings. The remaining historic buildings help the local government in developing a historic street theme thus attracting tourism into the area and stimulating the local economy and employment for related industries such as transportation, smaller hotels, restaurants, and so on. The long term economic benefits can be foreseen from the multiplier effects around the area. The demand for these modernised historic buildings is likely to increase as more businesses occupy them for commercial purposes and thus adding value to them. In this research, only temperature and humidity have been investigated. Future study can be made to include speed of air-flows and other elements of thermal comfort and building performance.

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