PASSIVE COOLING FOR HOUSES ON WATER IN BRUNEI DARUSSALAM

Search for a New Vernacular

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ABSTRACT*: High humidity levels, which often prevail in hot equatorial countries, leave most passive cooling systems ineffective. Most developing countries do not design buildings for natural cooling, resulting in the extensive use of air-conditioners. The heavy energy-consumption and harmful gases emission of the traditional air conditioning systems contradict the concept of sustainability. Therefore, the optimising alternative means of cooling with very minimal energy become very desirable.*

An extensive study into the technological aspects of vernacular architecture in Brunei Darussalam's Kampong Ayer (Water Village) is presented in this paper. A scientific approach to the passive cooling techniques can improve and sustain its application. Research into this field is recognised as a key effort to achieve the future sustainability in these buildings. Passive cooling technique can achieve its optimum performance and potential benefit with careful and meticulous design. The efficiencies and limitations of the appropriate passive cooling techniques for hot and humid climates are justified and assessed. This study forms the essential starting point towards bridging new sustainable cooling technologies for the buildings on water.

Keywords
Passive Cooling, Thermal Comfort, Sustainability, Vernacular Architecture, Water Village, Hot and Humid Climate

INTRODUCTION

Passive cooling techniques in hot and humid climates are less effective due to the high humidity levels. Many buildings in developing countries are hot and uncomfortable due to the advantages of natural cooling techniques in design not considered, resulting in air-conditioning being used extensively. One way to achieving sustainability is by applying effective passive cooling techniques to buildings. Environmental awareness, depleting fossil fuels and rising energy prices have contributed to research developments in field [1].

Majority of the future's population will consist of low-income earners, mainly in the developing countries of Asia (Fig. 2) [2].

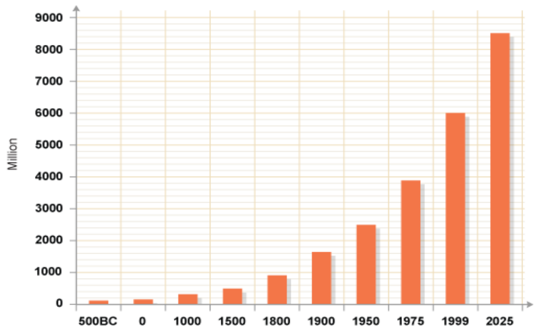


Fig. 1. Global rate of population growth

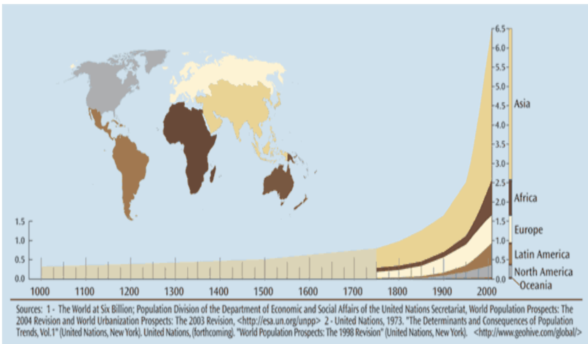


Fig. 2. This graph shows the global population growth distribution.

Most low-cost mass housing is designed with minimal requirements; thermal comfort is often compromised. Asia is the highest consumer of energy for air-conditioning in the world [3]. Depleting oil resource, rising in fuel energy prices may not allow low-income earners to maintain their current standards of living due to increased living cost.

Traditional cooling techniques for hot and humid climates relates closely to passive cooling technology. It requires recognition and validation for its contribution to the technical, environmental, social and economic aspects of low-income community housing [4]. The community's acceptance of the technology applied is important for better understanding sensible application of passive cooling techniques in hot and humid climates.

The architectural features of a traditional Malay house have some passive cooling qualities. Fully ventilated, tall roof space in the centre of the house, entire house is elevated to encourage air circulation (Fig.3). It demonstrated the self-builders' deep understanding for their environment and ability to achieve thermal comfort naturally, without any mechanical aid [5] .

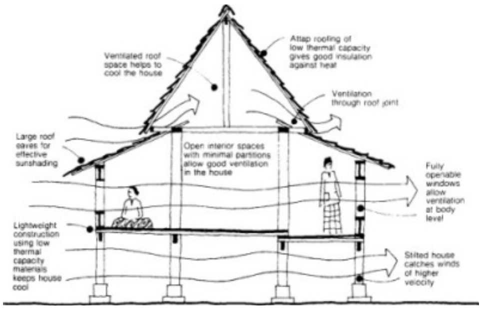


Fig. 3. Climate design of the Malay House.
Source: The Malay House by Lim Jee Yuan

The types of passive cooling currently available are Passive Solar Design, Comfort Ventilation, Nocturnal Ventilative Cooling or night ventilation, Evaporative Cooling – Direct / Indirect, Radiant Cooling (night) and The Earth Soil as Cooling Source [6]. These passive cooling methods have some performance advantages and disadvantages due to the complexity of hot/humid climates. Passive solar prevention and ventilation are considered the most effective for this type of climate. The maximum temperature is not high enough for direct evaporative cooling; the indoor/outdoor temperature difference is small rendering comfort ventilation ineffective without sufficient natural breeze. If applied appropriately, indirect cooling may be effective as it does not involve additional moisture to the air for cooling [7].

This research is in reference to Brunei, located on the northeastern coast of Borneo Island in Southeast Asia, bordered by the Malaysian state of Sarawak. Brunei's landscape is mostly pristine equatorial rainforest jungle drained by small rivers. Brunei has a hot and humid, equatorial climate with high temperatures (24-32^{o}C) and humidity (60-100%).

Weather remains hot throughout the year. The average annual rainfall: 2500mm along the coast, 4000mm inland jungles and hills. Equatorial monsoon winds, blowing from over the sea, influences the climate. Heavy rain falls during the northeast monsoon which is from December to March.

Brunei's Kampong Ayer ("Kampong" meaning village and "Ayer" meaning water) is located in the Brunei Bay, in between the Brunei-Muara and Temburong districts. This unique water village the largest of its kind in the world, situated in the capital itself. There are currently 30,000 inhabitants, 10% of Brunei's population, living on the Brunei River.

Fig. 4. Location of Brunei in South East Asia

Fig. 5. The mouth of Brunei River; Kampong Ayer is located here, across the river from the main capital, Bandar Seri Begawan

Until the early 1900s, the capital of Brunei Darussalam was at Kampong Ayer and it was a hub for governance, business and social life in Brunei at that time (Fig.6). Kampong Ayer is the largest area built on water in the South East Asia. Here, the village's centuries-old web of homes, markets, mosques, schools, medical clinics and police and fire stations were constructed of timber and hovered on stilts over the shallows of Brunei River (Fig. 7).

Fig. 6. Kampong Ayer, 1940's

Fig. 7. Self-build houses2012

PASSIVE COOLING REVIEW

Passive cooling in hot and humid areas is achieved most effectively by wind ventilation and solar protection to cool interior and exterior spaces is the most suitable [8]. Energy-conscious design aims to provide interior thermal comfort by means of minimizing space overheating and maximising airflow. Its efficiency performance are affected by building shape, walls area in relation to orientation, shading devices (thermally optimized to minimize interior overheating), and night-day natural ventilation by thermal forces. Heat flow transmission to the internal living space during daytime may be removed by hybrid cooling systems. The performance of such techniques may only be achieving a fraction of its actual potential and require thorough quantitative investigation, including low-energy consumption techniques. Orientation, climatic characteristics, dimensions, materials and nature of use are all major contributing factors to the performance quality. Some techniques can cross over if the appropriate conditions are simulated or created.

A way to analyse the building energy efficiency and thermal comfort in tropical climates is by using CFD's to determine the optimum level of building energy efficiency; reducing the period of air-conditioning usage, counteracting that with natural ventilation and better bioclimatic design [9]. Models derived from CFD simulation study are developed to estimate the period of the natural ventilation (to reduce the energy consumption due to air-conditioning) and to optimize the surface of openings.

Natural Ventilation. Natural ventilation quality is determined by the opening size, wind direction and speed, temperature and humidity of outdoor air entering indoors. A research in Thailand explored the potential of using natural ventilation as a passive cooling system for new house designs. According to the thermal comfort requirements, local adaptability allows the Thai people to live comfortably, making it possible to use natural ventilation to create a thermally comfortable indoor environment in houses in a Bangkok suburb during 20% of the year. To achieve a comfortable indoor environment, natural ventilation should provide an indoor air velocity of 0.4 m/s. The corresponding total area of the inlet and outlet apertures should be about 40% of the total floor area. If the aperture area were decreased to 25%, the indoor air velocity would be 0.3 m/s. A ceiling fan can be used to increase the air velocity in this case. The prevailing wind direction in the winter in Bangkok is either from the NNE or the SSW. The house can still be oriented facing north-south to avoid excessive solar radiation. It is not necessary to align the house according to the prevailing wind direction. The characteristics of past and present Thai houses are analyzed in terms of climate, culture, and technology [10]. Adaptive thermal comfort is also an important factor.

Night Ventilation. An investigation to find out the effects of different strategies on the indoor thermal environment using a calibrated model of a low cost apartment in hot humid climate of Danang, Vietnam. Very hot summer, during May to September, with daytime temperatures exceed the comfort zone and night time temperatures fall within the comfort zone. Using Brager's comfort model, the study was able to conclude that night ventilation performed better than thermal insulation and high thermal mass. [11].

In another investigation on the effectiveness of night ventilation techniques for residential buildings in Malaysia, full-daytime ventilation is better than night ventilation. Although night ventilation comparatively provided better thermal comfort, but the evaporative heat loss of occupants is less efficient during the daytime due to high humidity conditions .Otherwise, full-day ventilation would be a better option compared with night ventilation [12]

Architectural Design. A solar cooling project for hot and humid climates, involving an experimental solar house built in a Nanning, southern city of China with long, hot and humid summer, monitored for a year. The house was constructed with local building materials where possible, featured with multifunctional solar system and indoor ventilation strategy was proposed. The design included double walls and a triple roof in order to remove heat by ventilation of the building envelope. The external walls were clad with unglazed bricks to allow evaporative cooling. The results showed that the proposed double wall and removing heat from the building's envelope to be most effective in maintaining the diurnal fluctuation of indoor air temperature to within 28^{o}C on a typical mid-summer day [13]. To quantitatively clarify night time natural ventilation is an effective cooling method three passive ventilation strategies were investigated experimentally. Measurements showed that when the windows are closed during the day and opened at night, the rooms can be kept 4^{o}C cooler than if the windows are opened all day. The house has an effect on the humidity of the environment due to use of moisture-absorbing materials in the interior finishing. Coolness stored under the floor creates radiative cooling and achieves a significant comfort improvement for the occupants. However, in extremely hot and humid summers passive cooling techniques alone may not guarantee comfortable conditions and mechanical cooling may still be necessary.

Chimneys and Courtyards. A research study conducted in Thailand, for a year, on the optimum ventilation achievable for solar chimneys, (or roof solar collectors) as natural ventilation for buildings, showed the most effective ventilation achievable was during February-March, compared to June-October. High ambient temperature making the temperature differences of room and solar chimney higher during February – March, provided more ventilation [14]. The use of the solar chimney made a minor difference in the air temperature and the natural ventilation using this device had very little cooling effect. Solar chimneys convert thermal energy to kinetic energy, creating the airflow for ventilation, particularly effective in hot and humid climate. Solar chimney is most effective without the wind effect and can provide 7.5%-15.1% more cooling, but provides insufficient ventilation and requires additional natural ventilation for significance temperature difference. Alternatively spraying water on the metal ceiling and solar chimney, with high ambient air temperatures can reduce the internal room temperature by 2.0-6.2^{o}C, and increase the temperature difference, increasing the rate of airflow from room to solar chimney as well.

A study on ventilated courtyard as a passive cooling strategy in a single storey high mass building in the warm humid tropics, using computer simulation to monitor the airflow. The effect of the courtyard for mass-air heat exchange and thus lowering the daytime indoor air temperatures below the corresponding levels of shade ambient temperature is correlated with the indoor airflow pattern. The relatively better indoor thermal modification is seen when the courtyard acts as an air funnel discharging indoor air into the sky, rather than the courtyard acts as a suction zone inducing air from its sky opening, as suggested by conventional knowledge. Although the airflow rates are proportionate to the opening areas, the levels of indoor thermal modifications are not proportionate to airflow rates [15]. Although the maximum airflow rate does not give the optimum thermal modification, but the potential of courtyards to act as passive cooling in architectural design by means of airflow rates and pattern was shown instead.

Both techniques involved redirecting the hot air from the indoor environment out, without the use of any mechanical assistance.

Vernacular Cooling Techniques. Vernacular is a term that is applied to local building that have evolved over time in one location to suit the local climate, culture and economy [16]. In the southern part of Iran, vernacular cooling technologies have made living thermal comfortably without any mechanical aid [17]. Simple basic rules such as timber framed windows with tainted glazing, lightly rendered walls and roofs, insulation, and building construction using natural material. Architectural features such as louvers, terraces, constructing narrow lanes and shading buildings with adjacent buildings were also then and now. Technical aspects of vernacular architecture, particularly traditional passive cooling techniques, suggest close connections to bioclimatic architectural approaches and principles.

A research on solar passive techniques in the vernacular buildings of coastal regions in Nagapattinam, TamilNadu-India investigate the indoor environmental conditions of a vernacular house [18]. The vernacular houses of Nagapattinam are made up of several passive cooling techniques, maximising ventilation, increase heat resistance, longer heat lag time and intelligent residential planning. With courtyards with wind catchers, thick external walls, verandas, sloped roofs and constructed with materials of heat resistance like mud, mud-brick and appropriate use of materials, spatial organization, construction techniques, utilising the sea breeze and passive design features could achieve the desired comfortable thermal internal environment.

A qualitative analysis was conducted, of the passive environment control system of vernacular residential architecture of Kerala that is known for ages for its use of natural and passive methods for a comfortable indoor environment [19]. The orientation of building internal arrangement of spaces, the presence of internal courtyard, use of locally available materials and special methods of construction, etc. have together created the indoor environment. The use of appropriate materials and adoption of suitable traditional architectural techniques for a sustainable, energy efficient and comfortable human life were the effective methods and techniques adopted in the Kerala vernacular residential architecture, which can be effectively used in the contemporary architecture for warm–humid regions.

Bioclimatic Architecture. The combined approach applying modern technology to enhance traditional cooling systems is the appropriate way to solving thermal comfort issues, thus sustaining passive cooling techniques [20]. Thermal comfort and housing often come under the category of bioclimatic design with vernacular; bioclimatic design addresses the *technical and scientific* aspects and the vernacular part is about *culture, tradition, comfort and aesthetics* [21].

Temperature and humidity are the main factors influencing the application and efficiency of the passive cooling techniques. Therefore, the first part of this research is to understand the relationship of hot and humid climate, like Brunei, as experienced daily. The passive cooling technique explored in this research is natural ventilation by studying orientation and adaptive thermal comfort of the community living in kampong Ayer, Brunei.

PRELIMINARY WORKS AND INITIAL DATA COLLECTION

The house exists as a vessel of ‘cultural phenomenon’ and functions for a ‘complex set of purposes’[22]. Preliminary works in May 2012, began with a photographic study observing internal and external spaces of a typical house in Kampong Ayer. The typical single storey timber house is on stilts, with extended rooms to the rear of the house and an additional outdoor communal space to the front. From a brief architectural critique on the design changes to the houses from 1940’s until now, the effects on thermal comfort were compromised due to reduced roof pitch, lack of insulation, non-local (hygroscopic) materials and layout of house plan.

Further comparisons of the same self-build house with a newly built mass housing scheme also located in Kampong Ayer was considered. A second field study was conducted in November-December 2012, involving 2 houses on water in Kampong Ayer; Self-build (*House*

1) and Mass-housing (*House 4)*. Basic differences to the two houses are:

	House 1	House 2
Occupants	3	11
Age / years	40-60	5-40
No. of bedrooms	3	4
Layout	Single storey	Double
Materials	Timber	Concrete
Construction	Self-build	Mass
Data Loggers	Bed/Dining	Bed/Living

Indoor temperature and relative humidity levels were recorded over a period of 5-10 days continuously. The data loggers are placed in two different locations within each house; bedroom and one other room, preferably the most utilised room during the day (Fig, 8).

1 2 3 4

House 1 – Self-build

1. Side elevation of typical house in Kampong Ayer
2. Dining Area
3. Data logger in Bedroom
4. Data Logger in Dining Area

1 2 *3* *4*

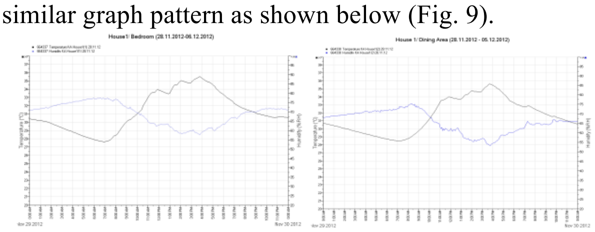
House 4 – Mass housing

1. Mass housing scheme in Kampong Ayer
2. House 2
3. Living Area
4. Data Logger in Living Area

Fig. 8. *Details of House 1 and House 4*

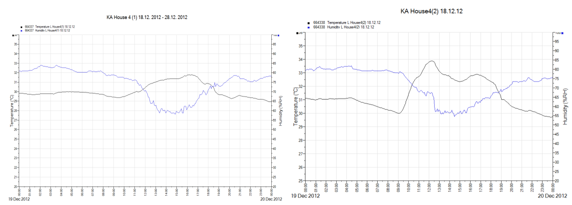
RESULTS AND DISCUSSION

Most of the results from the data loggers show a similar graph pattern as shown below (Fig. 9).



Bedroom Dining Area

House 1 – 29th November 2012



Bedroom Living Area

House 4 – 19th December 2012

Fig. 9. *Results from Data Loggers*

Internal Temp./°C R. Humidity/%RH

	Min	Time	Max	Time	Min	Time	Max	Time
29 Nov 2012	27.7	*6.55*	35.5	*15.45*	57.8	*15.45*	77.4	*6.30*
30 Nov 2012	29.7	*7.10*	36.6	*16.25*	54.9	*12.25*	76.9	*7.25*
01 Dec 2012	29.1	*7.10*	36.8	*15.55*	55.2	*13.55*	76.6	*7.00*
02 Dec 2012	28.8	*7.00*	36.1	*14.00*	58.3	*12.50*	77.1	*7.10*
03 Dec 2012	29.2	*7.05*	35.7	*13.40*	56.2	*14.35*	79.4	*7.20*
04 Dec 2012	27.4	*7.25*	33.1	*16.25*	62.0	*17.15*	84.2	*9.40*

Table 1. Min./Max. Indoor Temperature and Relative Humidity against Time for House 1

From Table 1, the following deductions about House 1 were made. Similar pattern occurs for House 4.

	Min	Max
Temp. range	27.4 – 29.7 °C	33.1 – 36.8 °C
Temp. Average time	7.04 a.m.	15.59p.m.
%RH range	54.9 – 62.0	76.6 – 84.2
%RH Average time	14.21 p.m.	7.38 a.m.

Time: 7.04 a.m. to 15.59 p.m.
Temp. Difference (Min./Max.) is 9.4°C
Approx. average rate of temperature increase is 1.099°C/hour.
Approx. average rate of temperature decrease is 0.608°C/hour.

Time: 7.38 a.m. to 14.21 p.m.
RH% Difference (Min./Max.) is 29.5%
Average rate of RH% decrease is 4.59% /hour.
Average rate of RH% increase is 1.68% /hour.

The rate of temperature rise (daytime) is faster than the rate temperature decreases (night). The rate of Relative Humidity decreasing (daytime) is faster than the rate temperature increasing (night).

The indoor temperature increase and relative humidity decrease between 7.04 a.m. and 15.59 p.m. experiences a shorter period in the day than the indoor temperature decrease and relative humidity increase period between 14.21 p.m. and 7.04 a.m.

CONCLUSION

Considering the indoor and outdoor temperature is similar as recordings for both houses practice natural ventilation, the preliminary data recordings give a clearer understanding of the temperature and relative humidity relationship. This is significant in assigning the appropriate passive cooling techniques. It is expected all techniques will perform differently throughout the day due to the fluctuating temperature and relative humidity. Temperature and relative humidity range, rate of change and time are definitely the determining factors in defining the period of thermal comfort and discomfort. Based on this field study, the approximate duration of most thermal discomfort is identified between 7.38 a.m. to 15.59 p.m. This time of the day is the main focus for the next part of the research. Using computer simulations to predict and achieve a constant thermal comfort during this period can give opportunities to a more efficient selection and use of passive cooling [23]. Natural and night ventilation, and architectural design strategies based on the technological capabilities of the community, such as opening a window, are the main passive cooling strategies concerning this study.

At this stage, although the results of the study show a similar indoor temperature and relative humidity pattern for both houses it is expected to be a significant difference in thermal comfort pattern since both houses differ in many respects. Further to the quantitative study, a thorough survey to find out the users' perception and response to thermal comfort needs to be conducted [24]. A series of interviews based on the findings from the preliminary works will help to form the survey. The results of this survey will be crossed with results from the qualitative study on thermal comfort and passive cooling.

Since most of the research highlighted in the review is in reference to buildings on land, variation to results may occur due to the site in context is on water; contributing to higher humidity, affecting the efficiency of passive cooling techniques.

Vernacular Cooling Techniques were based on availability of materials, local construction knowledge, local understanding of the climate and human sensation. Such local trades are no longer being implemented because of modern materials, air-conditioning and the local knowledge is not being handed down to new generations. Migrating families away from the water village to mass housing developments, mass construction also render such knowledge obsolete. However the basic principles for achieving thermal comfort naturally still apply. Adopting bioclimatic architecture into future designs for housing in Brunei, be it on land or water, a sensible approach which deals with both technical and cultural aspects associated with housing.

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