Manipulation of Thermal Mass with Natural Ventilation; Application for Residential Buildings in Tropics

MALTHI RAJAPAKSHA

Department of Architecture,
Faculty of Built Environment and Spatial Sciences,
General Sir John Kotelawala Defence University,Sri Lanka
malthidzn@gmail.com

Abstract: This paper investigates the integration of thermal mass with natural ventilation for passive climate modification in residential buildings in tropics. Compact house forms found in historic world heritage site, Galle Fort, Sri Lanka is selected as the case study.

In warm humid climates, the ambient daytime dry bulb temperature records around 34 degrees C or higher. This is quite extensive given the daytime humidity around 80 percent and the air velocity up to one meter per second. Since the indoor climate closely follows the outdoor climate, there is a need for lowering the swing of indoor air temperature below the level of ambient.

Bioclimatic buildings (Olgyay, 1963) provide solution to these problems through climate responsive design. This can be effective in skin dependant buildings because of the potential interaction between Climate, Buildings and Occupants, but empirical evidence of the effectiveness of this approach is less visible (Ismail LH, 2006). The paper suggests opportunities for cooling indoors arising from the innovative use of thermal mass effect together with ventilation behavior in climate responsive building forms in warm humid climates. The research useshistoric colonial residential building as a point of departure since these buildings form a model which has been optimized through the experience of time.

The building was tested by a field investigation using on- site thermal monitoring. Further the simulation based methodology is used for data evaluation thus highlighting the efficiency of night ventilation in the critical hot nights by transferring the heat from inside to outside with the air fluid effect of building section and envelope (grab the cool air from lower openings and remove the heated air from the upper openings) in maintaining in-door comfort throughout the day.

The work evidenced supporting the passive influence of building section with night ventilation and manually ormechanically driven hybrid day ventilationwhich can be effective in improving thermal comfort without increasing the electricity demand. The significance of this lies in the need for cutting the energy demand for cooling and to avoid indoor overheating in tropics.

Keywords: Thermal Mass Integration, Natural Ventilation, Tropics

1. Introduction

The increased volumes of carbon dioxide and other greenhouse gases released by the burning of fossil fuels, land clearing, agriculture, and other human activities, are believed to be the primary sources of the global warming that has occurred over the past 50 years. Scientists from the Intergovernmental Panel on Climate, carrying out global warming research have recently predicted that average temperature of the Earth has risen between 0.4 and 0.8 °C over the past 100 years thusaverage global temperatures could increase between 1.4 and 5.8 °C by the year 2100.

Mainly the Warm humid tropical countries are badly affected by the above phenomenon via indoor and outdoor over heating conditions. Fundamental importance in a more energy-efficient architecture and sustainable design, Bioclimatic design elements cannot be considered only in their technical dimensions, as of their nature these systems have profound architectural implications.It requires knowledge of climate, and awareness of the available technologies and materials combined with an understanding of comfort, and how these conditions can be overcome.

Studies on Human thermal comfort in these regions can be conducted either philosophical basis of the climate challenge in this context in the viewpoints of activity patterns and the notion of 'thermal pleasure' or practical techniques which regulates the interaction of the building with its surrounding climate such as enhancing ventilation, shading and greenery etc.

Literature shows that the building form, both plan and sectional and envelope contribute to this interaction. In warm humid tropical climates, environmental loads from outside climate and internal loads due to internal occupancy are two main sources of heat gains in buildings. (Givoni.1969). Buildings designed for passive climate control potential aims at reducing these heat gains through the intervention of building design.

Make use of thermal massfor hot arid climate Buildingsis a tested passive method of decreasing indoor over heating conditions thus increase indoor thermalcomfort.The paper illustrates the opportunities for cooling indoors arising from innovative use of thermal massin warm humid climatesin connection with ventilative cooling whichhas potential in the tropics.

1.1 Passive Cooling in Tropics

Passive cooling approach in a building design focuses on heat gain control and heat dissipation in order to improve the indoor thermal comfort with low or nil energy consumption (Santamouris. M, 1996).

Ventilation can create a heat gain in buildings in warm climates and summer seasons. This results in the interests of controlling overheating and the role of natural ventilation being in conflict. Thus, a reduction of radiant heat in the incoming air is of high priority. Controlling radiant heat at the microclimatic level by good shading can reduce the radiant heat and temperature of incoming air. Under these conditions, ventilation may contribute for space and structural cooling. The efficiency of this technique is limited due to the slight diurnal temperature range in tropical climates but can be enhanced in summers with the large diurnal temperature range characteristics in moderate climates (*Rajapaksha.U, 2003*).

1.2 Thermal Mass and Ventilation

The work of Givoni (*1991:179*) suggests, in the absence of any solar heat or internal heat gain,the indoor air temperature closely follows the outdoor level with daytime ventilation. It also confirms that an air velocity of 1m/s is capable of extending upper limits of acceptable dry bulb temperatures by 3.7 degrees C under warm humid conditions, in a situation, where occupant wear light clothing (less than 0.5clo.) for activity level less than 1 met. The evidence indicates a linear function of the cooling effect by air velocities up to 1m/s but effect is diminishing with elevated velocities after the limit of one meter per second.

Buildings with thermal mass provide "inertia" against temperature fluctuations, i.e. the thermal equilibrium. This is distinct from a material's insulative thermal conductivity, allowing it to be heated or cooled relatively separate from the outside, or even just retain the occupants' thermal energy longer **(**Rajapaksha,I. (2004). "Thermal flywheel effect" (O.H Koenigsberger, Szokolay, S.V, 1973) says when outside temperatures are fluctuating throughout the day; a large thermal mass within the insulated portion of the building form can serve to "flatten out" the daily temperature fluctuations. Thermal mass will absorb thermal energy when the surroundings are higher in temperature than the mass, and give thermal energy back when the surroundings are cooler, without reaching peak values throughout the day by controllingthe building'sdiurnal range.

According to Koenigsberger If the building envelope is a high mass (heavy construction), it absorbs heat and maintain the internal air temperature in a low rate during the ambient peak temperature time. Outdoor Temperature reduction is taking place after the peak time, then the high mass starts to release the absorbed heat to the indoors reaching the indoor maximum temperatures. The time delay between these two maximum temperatures is known as time-lag.

When an insulated high-mass building is ventilated at night its structural mass is cooled by convection from the inside, by-passing the thermal resistance of the envelope. During the daytime, the cooled mass, if of sufficient amount and surface area and adequately insulated from the outdoors, can serve as a **heat sink**. It absorbs radiation and natural convection, the heat penetrating into and generated inside the building, and thus reduces the rate of indoor temperature rise. This is the famous passive cooling system in hot dry climates where the buildings are not ventilated from the outside wind during the daytime. This research intends to investigate the potential of using the above strategy in warm humid tropics as well.

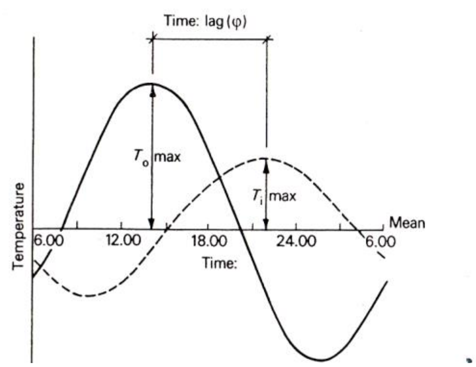

Figure1 : Time-lag and decrement factor
Source-“Manual of Tropical Housing and Building”
O.H Koenigsberger, S.VSzokolay,

Further, high thermal mass is beneficial in warm humid climates in promoting passive cooling in both day and night, subjects to the available ventilation pattern. The integration of thermal mass with a building design becomes significant but depends primarily on the pattern of ventilation during day and night. (Rajapaksha M et al, 2013). Providing daytime ventilation can limit the potential of thermal mass for passive cooling. However, with the presence of diurnal ranges like 6-8 degrees C, cooling effect of thermal mass can be seen very effectively in these compact building forms provided there is night time ventilation (Hyde RA, 2000). The study investigates a pre-modern building, as this is a tested example which can form the basis for establishing climate responsive form and fabric for new modern buildings.

1.3 Research Context

Galle Fort is a World Heritage site, a coastal walled city mainly built during Dutch Period (16th Century), which is located in Southern Province of Sri Lanka. Climate of Galle is found to be warm humid with daily maximum reaching 34-35 degrees C and relative humidity around 70-80 percent (*Met Dept.SL*). This area gets more clear skies and large diurnal ranges around 6-8 degrees C which is quiet unusual which in turn suggest a potential for night cooling with thermal mass. The study has been conducted during northeast monsoon season where dry wind blowing from the Indian terrestrial massing. The cloud cover has been minimal during this period and no rain was recorded. Wind direction during the study period was primarily from south west with a speed around 0.8m/s.

Buildings in Galle Fort are mostly integrated with courtyards and characterized with narrow plan forms, high internal volumes and extensive thermal mass in their envelopes. Anecdotal evidence from the building survey and a pilot investigation held on user response survey of buildings in Galle Fort suggests a diversity of thermal performance behavior with both overheating and cooling conditions. The research investigates both of these indoor overheating and cooling in order to identify problems and opportunities with integration of thermal mass characteristics of particular building design.

2. Methodologyand Experimental Design

The research methodology involved in three main stages. First, Galle Fort was sampled (pilot survey) and out of several historic residences onlyfour residential buildingswhich mostly representing the typical building characteristics were identified and selected for the first thermal investigation.Out of those four, oneresidence was selected for a further investigation(base case)which had extensive thermal performance with thick walls and more openings in the envelope, therefore appears to have the best potential for passive cooling at day and night.

Second, thermal performance of the selectedhouse wasdetail investigated using HOBO data loggers and Wind velocity data using VelociCalc- model TSI 9565. The data was taken for three hour intervals during 24 hours. Latest Ambient climatic data were collected from Meteorological Department of Sri Lanka.

The research hypotheses an agreement for the integration of thermal mass with building sectional characteristics when designed and enhanced with night ventilation. Therefore, thirdlythe base case building was developed as a model using Design-Builder computer based simulation programtaking online climate data and analyzing the outcome of the investigation in to consideration together with established literature**.** Measured indoor, outdoor thermal data of the detail investigation were entered in to the software and validated (Calibrated) the simulation model. Simulation involved interventions introduced to the section of the **base case** building for night time ventilation. Manually operatable long openings were introduced to upper levels and lower levels of walls. Simulation was aimed at exploring these solutions made to the building section to promote stack induced night ventilation, thus passive cooling at night

Figure 2: Calibrated model with integration of openings at the roof level and courtyard levels for nocturnal ventilation by stack effect

A number of assumptions were made, for example, ventilation rates kept as zero, since windows in the building are not opened and approximation to the R value of the materials due to the historic nature of the construction material. The process aimed at identifying the level of passive climate modification and its pattern. The difference of air temperature between ambient and indoor average was taken as the indicator of passive climate modification.

3. Results

Results of the first onsite thermal investigation clearly revealed that the thermal mass of the building envelope contributes to delay heat gain from outside to the building (Results which monitored throughout continuous 48 hours shows a clear time-lag).Passive climate modification is visible during day time and further it shows a strong dependant with the ventilation pattern around and inside the building.

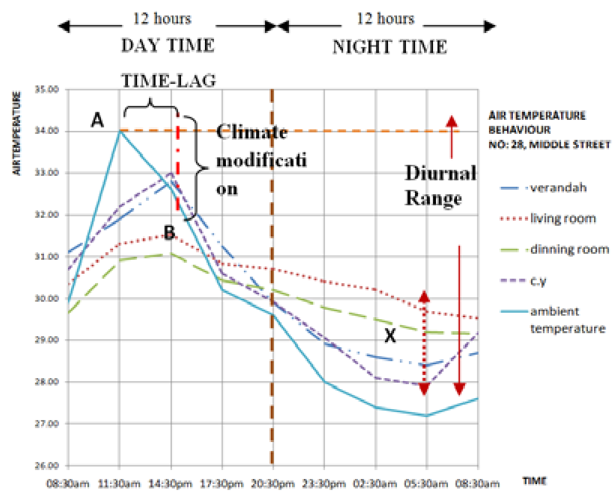

Figure 3: Second investigation results of the best case

Lowering of indoor air temperature by 1-2 Degrees C than ambient was seen during the daytime. However, nights were 3 Degrees C warmer than ambient due to lack of night ventilation potential of building design. Time-lag of reaching indoor peak temperature was clearly found in the day time.

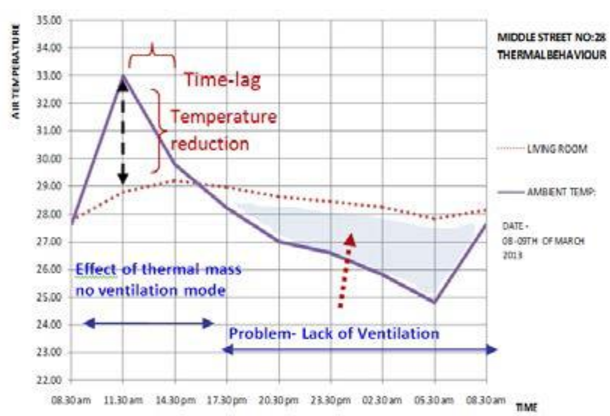

Figure 4: Thermal performance of the base case – potential for night ventilation

Maximum daytime ambient and minimum night air temperature during the investigation was 31 and 25 Degrees C respectively. This shows a diurnal range of 6 degrees C. Findings indicate relatively warm indoor night conditions during investigation which can be a usual behavior as well.

3.1 Thermal mass and night cooling

Indoor air temperature during night moved above the levels of ambient temperature. The advantage of cool night ventilation is not properly integrated with the building design for the reduction of indoor air temperature during night. There are no openings found at the upper level in the building section for the removal of hot air in the night via stack effect.

Therefore long upper openings from the wind shadow and lower level openings at the windward side were introduced in the section of the simulation model for proper night time ventilation. Simulation was aimed at experiment and exploring these solutions made to the building section to promote stack induced night ventilation, thus passive cooling cutting the energy demand at night.

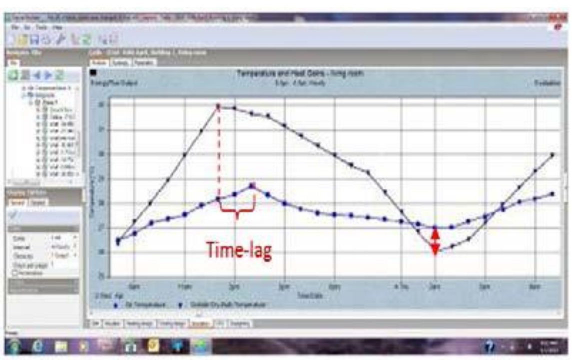

Figure 5: Results of the simulation after providing night ventilation

Calibrated simulation results provide evidence of passive cooling due to night ventilation. The issue of high air temperaturedue to operationalheat during daytime which observed at the first investigation also has been decreased with the introduction of night time ventilation through stack force in the previous night. Indoor air temperature levels were seen moving 2- 3 Degrees C below the ambient levels with the integration of long openings at the upper level in building section. The final results suggest high thermal mass in residential building with an innovative integration of ventilation at Tropics.

4. Conclusion

The integrating night time ventilation with high thermal mass building envelopes is beneficial in warm humid climates in promoting passive cooling in both day and night. This is evident with the filed investigation and simulation results. Further, the concept can be innovatively applied with any complex building forms if plan and sectional from allow it for creating diversified air temperature and air pressure fields within the building's selected volume for night cooling and stack forced ventilation. The work is underway involving a simulation program and more investigations. The objective of selectingresidential built form is to find solutions for the experienced uncomfortablehot nights thus suggesting potential intervention ofbuilding design for night ventilation and passive cooling increasing theenergy efficiency of the building.This may pave way for achieving near zero emission building practices and for adaptive reuse of buildings in the future.

Acknowledgement

Dr.U.Rajapaksha of Department of Architecture, University of Moratuwa, technical staff of University of Moratuwa and the owners of houses in Galle Fort.

References

Capeluto I.G, (2003), Energy performance of the self-shading building envelope, Energy and buildings, Volume 35, 327-336

Coley D and Kershaw T, (2010), Changes in internal temperatures within the built environ-ment as a response to a climate change, Building and Environment, Elsevier Science, Volume 45, pp; 89-93

Flyybierg B, (2006), Five misunderstanding about case study approach, Qualitative Inquiry, 12:219, SAGE, http//www.sagepublications.com, assessed 6 November 2011

Gratia E and De Herde A, (2007), The most efficient position of shading devices in a double-skin facade, Energy and Buildings, Volume 39, pp; 364-373

Howden. SM, and Crimp. S, 2001, Effect of climate and climate change on electricity demand in Australia, In: Ghassemi F, Whetton P, Little R, Littleboy M, editors, Integrating mod-els for natural resources management across discipline, Issue and scales, Canberra, Aus-tralia MSSANZ Inc p 655-660

Hyde R.A, (2000), Climate Responsive Design, Spon, UK

Ismail. L.H and Sibley. M, (2006), Bioclimatic performance of high rise office buildings; a case study in Penang Island, Proceedings of the 23rd Conference on Passive and Low En-ergy architecture, Geneva, Switzerland, September 6-8,

IPCC, 2007, Climate change synthesis report, an assessment of the Intergovernmental Panel on Climate Change (ed. Allali Abdelkader *et al*), Valencia, Spain 12-17 November 2007

Lomas K.J, 2007, Architectural design of an advanced naturally ventilated building form, En-ergy and Buildings, Volume 39, pp; 166 – 181

Olgyay. V, 1963, Design with climate: Bioclimatic approach to architectural regionalism, Princeton University Press

Pfafferott J, Herkel S and WambsganB, 2004, Design, monitoring and evaluation of a low energy office building with passive cooling by night ventilation, Energy and Buildings, Volume 36, pp; 455-465

Rajapaksha I, Nagai H, Okumiya M., (2003). A ventilated courtyard as a passive cooling strategy in the warm humid tropics- Renewable Energy Journal.28, No.11 June 2003, pp. 1755-1778

Santamouris. M, Asimakoupolos. D, (1996), Passive cooling of buildings (1st ed), 35-37, Wil-liam Road, London NW1 3ER UK, James & James (Science Publishers) Ltd

Szokolay, S.V. 1997 *Thermal comfort t*, PLEA notes, Brisbane: The University of Queens-land

Voss. K, Herkel. S, Pfafferott. J, Lohnert. G, Wagner. A, 2007, Energy efficient office build-ings with passive cooling – Results and experiences from a research and demonstration programme, Solar Energy Volume, 81, 424–434

Wagner. A, Kleber. M, Parker. C, 2003, Monitoring Results of a Naturally Ventilated and Passively Cooled Office Building in Frankfurt, Germany, Division of Building Science, University of Karlsruhe