Revealing Skin: Visualization-Informed Facade Design for the Tropics

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TROPICAL LIVING

The relationship between our bodies and the places we make and inhabit has always been a significant consideration for humankind (Heschong, 1979). Through a manipulation of our environment, we create microclimates within which we might comfortably live. Architecture is one device by which we attempt to recreate these favourable microclimates.

Vernacular architectures throughout the world exhibit sophisticated solutions for human thermal adaptation. Tropical vernacular architectures have been developed based on local knowledge, material, lifestyle, culture, and technology. In hot and humid areas, special attention is paid to shade, light density of material, ventilation, and moisture control. In a large percentage of the world, these strategies continue to provide reasonable living accommodations, while depleting only that which is necessary from our natural resources.

P. Ole Fanger identifies five primary factors - humidity, temperature, ventilation, clothing, and mean radiant temperature - which influence human thermal comfort (Mallick, 1996; Nicol, 2004; Ruck, 1989). Humans have invented various methods of thermal adaptation to deal with these thermal comfort issues, including clothing, seasonal migration, and dwelling. We know how to find desirable microclimates through the use of our senses (Heschong, 1979). However, when it comes to the humidity, it is often difficult to deal with exclusive of mechanical means. In the tropics and subtropics, the humidity is often excessively high. People in the tropics learned that by exposing their skins or dressing minimally, moisture is allowed to evaporate with the aid of airflow or ventilation (Feriadi and Wong, 2004; Mallick, 1996; Prianto and Depecker, 2002). These strategies ultimately influenced the way we approached the development of this investigation.

In South Florida, the typical strategy for dealing with these issues today is primarily mechanical. Around the middle of the twentieth century, mechanical devices for thermal comfort became prevalent in the industrialized world. Before then, most houses had no air conditioners. Several cultures and architectural practices began to move away from the time-tested strategies, while architectural design for thermal comfort seems to have become less critical with such technological relief. Designers sometimes employ architecture as a vehicle to investigate irrelevant issues. The designers often articulate architectures as objects instead of necessities or systems for living. This departure from nature results in technology dependent living that consumes a considerable amount of energy.[1] Historically, however, habitation within this context has been dealt with through a number of passive means. The original settlers, for example, established homesteads along a ridge that ran generally in a north-south orientation along the southern Florida peninsula. This location provided for the highest land and the best ventilation, as the ridge guided easterly breezes up to these locations. Houses typically were built in a fashion that increased their thermal comfort conditions. Typical strategies included: raising the house off the ground to allow ventilation below the house, thereby cooling the interior and protecting it from animals and ground moisture; creation of breezeways to increase air circulation within the overall house (Florida cracker or dogtrot house); incorporation of clerestory or high windows in order to create stack ventilation that replace hot air inside the house with colder air from a colder microclimate; design of sleeping porches to maximize comfort during the evenings; design of strategically located porches to shade the surfaces of the house and to cool the air entering the house; the use of indigenous materials for ease of construction/transportation, and that are resistant to local pests.

DESIGN AGENDA

The broad practical design agenda for this paper and project was to study the applicability of various passive building techniques in a typical South Florida suburban house. Specifically, we looked at the development of the skins of the building based on their solar orientation, with a particular focus on the design of the south façade. A particular tropical vernacular architecture called 'dog trot' house in the southern region of the US is a point of departure that inspires a design of a house (Figure 1).

We began first by questioning the relationship of contemporary building practices to the making of space and place. How could we create an architecture that was responsive and responsible to place, not necessarily in terms of style, but relative to its occupation in a specific climate? Suburbia, perhaps the quintessential non-responsive environment, seemed a logical place to address these questions, and the typical developer house program and lot size seemed a logical vehicle for this investigation of ways in which we might build more responsibly and responsively. By building in this particular type of place with this particular program, we hoped to reveal ways in which one could reasonably create an architecture that would satisfy the needs of contemporary American culture, while still being environmentally responsible.[2]

The building is oriented with its longest dimension facing north and south (Figure 2 and 3). Upon entry to the site, one encounters a gravel driveway leading to a carport. The gravel is used as a means to increase the porosity of the site, thus increasing onsite water retention. A reed bed water garden on the north side serves as a water retention pond for roof water runoff. The water overflows down to a series of cascading planting beds that acts as filter for an underground grey water cistern.

Figure 1: Rendered perspective view of a south façade and a pool garden

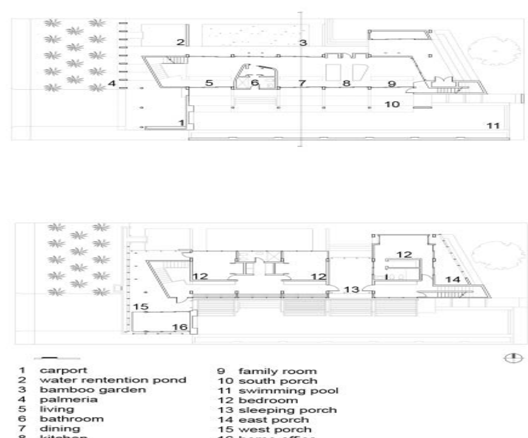

Figure 2: Plans of the house (ground floor above, second floor below)

Continuing into the house, the spatial progression leads to an open plan with a living room, dining room, kitchen, and family room. These programs are anchored at each end by staircases. The north side of the house is articulated with a bamboo grove, which can be harvested to replace various shading and barricading devices on the exterior project, shading slats on the south, railings on the north, and a woven wall made of flattened split bamboo canes. The southern garden consists of a porch bordering a swimming pool, which helps to cool the air before it reaches the house.

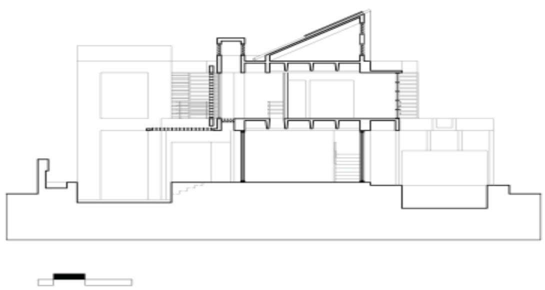

Figure 3: Section of the house looking west (location of cut indicated in ground floor plan)

The second floor consists of three bedrooms and two bathrooms, as well as a laundry, sleeping porch, office and various exterior porches. Louvered openings or dampers are placed in the floors of the upper corridor to allow a vertical movement of hot air to a wind tower or solar chimney located directly above the corridor.

The design can be considered as different strategies that help create favourable microclimates, and promote a healthy environment. The design strategies include:

- Promoting ground plane heat sink
- Promoting outdoor living through an open floor plan, massing strategy that channels and compresses the wind, cross ventilation, shading, visual and spatial connection to gardens, and provision of shaded outdoor spaces
- Minimizing east and west sun exposure: massing orientation
- Creating favourable microclimates by surrounding the house with ground covering and shading plant materials and water
- Creating southern exposure for solar cooling
- Combining buoyancy driven, and wind driven ventilation
- Creating cross ventilation potential through open floor plan and indoor openings
- Removing heat from the wall using vented walls
- Promoting day-lighting
- Insulating roofs
- Collecting rain and grey water
- Employing solar technology (static hybrid solar panel combining solar water heating and power systems)
- Employing mould resistant materials

Although these strategies were applied to various parts of the house, the primary focus of this investigation was on the development and articulation of the southern skin of the building. Detailed discussion about other strategies can be found in a previous paper by this paper's authors (Thitisawat, et al., 2007).

SOUTH WALL MICROCLIMATE

To promote natural ventilation, we take advantage of the significant solar exposure of the south side of the building in order to create buoyancy-induced ventilation. Occupants can adjust shading louver slat angles in order to regulate an amount of solar heat gain. The louver slats also provide impact protection during a hurricane. Hotter air is pushed up and out of the house through a wind tower or solar chimney (Figure 4). Dampers on either side of the top of the wind tower allow the occupants to regulate the airflow regimes, and benefit from wind pressure distribution on the building as well. A previous experiment-based case study shows that a solar chimney can be used to achieve natural ventilation in a building in a tropical region (Khedari, et al., 2000).

When the wind blows through a blunt object, suction or negative pressure occurs on the rear of the object. Knowing the wind direction, the occupants can operate the dampers to allow the hot air to escape to a side of the wind tower with the suction. The occupants must use their senses as biosensors when operating the house. In other words, the house is operated by a bio-actuated control system, a human interaction with the house. By opening north or south airflow dampers while standing in the corridor, they can feel the airflow through their body, and know whether their operation decision works (Figure 4c). In addition, to sense the direction of the wind, they can simply step out to the sleeping porch to feel the breeze, which is in this case a control input of the operation. They can also sense the output or the airflow through openings in the floor on both sides of the corridor.

The floor openings on the north side of the corridor are open to the lower floor, while the ones on the south side are open to the outside. When the occupants leave the house, they can open the dampers on the floor and the wind tower, and let hot air and moisture escape to prevent overheating, and moisture accumulation in the house (Figure 4b). They can operate the dampers in the same fashion in order to allow for night cooling. Figure 4a represents a closed damper scenario that is useful for collecting solar radiation creating a greenhouse effect that heats the house in winter.

Photovoltaic (PV) panels are attached on rafters, which are anchored onto the reinforced concrete structure on their both ends. On the north side, they are anchored with cables. If one of the PV cells in a module of a PV panel is shaded, the module will become inactive to prevent an overheating problem. Therefore, to obtain the most power output out of the PV panels, they are mounted on the roof to minimize or eliminate shadow cast by a neighbouring building on the south. The roof angle is set to the same angle as the optimal angle of the latitude of the site.

The roof angle affects an airflow pattern, thus an airflow performance of the house. Therefore, there may be a conflict between the airflow performance, and power generation performance of the PV panels. This leads to a need for a verification of the south façade and roof designs.

4a **4b** **4c**

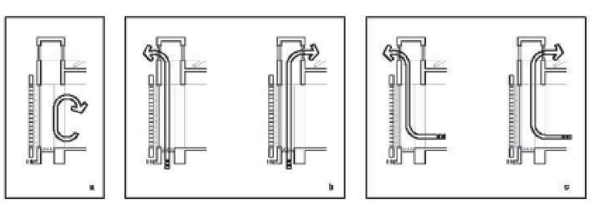

Figure 4: Diagrams of the three primary airflow regimes of the south wall

BACKGROUND ON A VISUALIZATION EXPERIMENT

After development of the design was complete, our assumptions regarding the performance of the south façade were verified using a water table experiment. The roof angle is considered a fixed parameter or constraint since PV panels are expensive, and it is important for the panels to be placed at an optimal angle to achieve the maximum power generation. Moreover, the height of the solar chimney is set at the lowest elevation of the panels to avoid blockage of the solar radiation.

This section presents possible experimental methods and the one that is employed in this study. A flow visualization experiment is conducted using a free surface water table, a timely, cost effective and accurate flow visualization facility. For this investigation, the experiment is intended for verification of the wind tower concept. The water table allows a sheet of water to flow over a flat surface from an upstream tank (settling chamber) to a downstream one (return tank). A pump circulates the water, and replenishes the water in the upstream tank, hence, creating a constant flow (Finger and Amon, 1997; Hughes, 2003; Oms, et al., 1997). A flow rate is controlled by placement of a sluice gate, and a coordinated pump speed. Inside the upstream tank, there is a flow straightener, such as fine wire mesh, and honeycomb structure, or in this case a mesh pad, that minimizes turbulent flow (Oms, et al., 1997; Rani and Wooldridge, 2000). The water table can be used to examine a fluid flow pattern in two-dimensional plane like floor plan or section.

To analyze the flow pattern of natural ventilation, sectional models are used to represent a section of the house. The models are placed on an edge of the table that acts like the ground plane. One can generate a row of hydrogen bubble seeded into the flow by running low voltage electricity through a thin cable submerged under the sheet of water (Hayashibara, et al., 2002; Hayashibara, et al., 2003; Myose, et al., 2006). A chemical can be added to the water in order to encourage more bubble generation. By regulating the electricity in a frequency, one can repeatedly generate rows of bubbles floating in the water at a time interval, literally creating timelines. The rows of bubbles can be seen more clearly in a dark room with a light emitting diode (LED) light submerged under the sheet of water. When the rows of bubbles float pass an object on the water table, some of the bubbles are slower than others due to a difference in pressure distribution around the object or boundary layer. In other words, the timelines reveal flow velocity around the object.

However, in this case, coloured dye, vegetable-based food colouring, is used as a streamline tracer element to visualize the flow pattern (Mueller, 2004). It is not a quantitative method, but is sufficient for validating the wind tower concept. Fluorescent dyes can also be used in combination of a thin but broad sheet of laser light or traversing laser Doppler velocimeter in case of a glass bottom table for illuminating the tracer element in a flow field (Hughes, 2003). Retrievable particulate such as aluminium power, glass balls, Perspex powder, polystyrene beads, and titanium-dioxide-coated mica particles, or darkly coloured threads that act as tufts aligning in a flow direction, can be used as a tracer element as well (Carlson, et al., 1982; Myose, et al., 2006; Oms, et al., 1997).

Digitally, images of the sectional models are captured during the experiment. Subsequently, the colour saturation and contrast of the images are digitally enhanced in order to reveal the flow pattern of the dye. The quantity of dye released in the water should be carefully controlled, as the water is recycled to an upstream tank. We use a dropper with a small tube to release the dye at an investigated area. In the case of hydrogen bubble visualization, one can also employ a video camera with a Charge Coupled Device (CCD) or inexpensive standard video camera to capture bubble profiles representing boundary layer velocity profile for an accurate analysis. The velocity can be determined based on a difference in successive bubble time line positions (Hayashibara, et al., 2002; Hayashibara, et al., 2003; Myose, et al., 2006).

WATER TABLE EXPERIMENT

Different combinations of window operation create different airflow regimes or modes of operation. However, only four sectional models are created from a section of the house to investigate critical design decisions. During the design process the authors are not certain whether an optimal roof pitch for the PV panel will create a positive pressure due to its exposure to the direction of the wind from the south. Figure 5a represents an experiment that verifies that when the wind blows from the south, a negative pressure is created on the north side of the wind tower, and, therefore, pulls the air from the wind tower out.

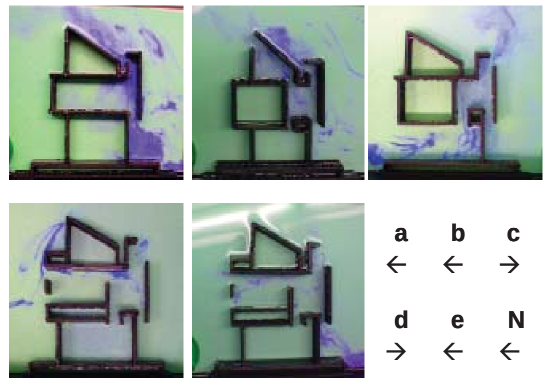

Figure 5: Flow visualization of different airflow regimes

Figure 5b is another variation of the first airflow regime. It is used to investigate whether it is possible to create cross ventilation through the attic. Figure 5c shows another flow regime with the wind blowing from the north. It confirms that the wind tower concept works as expected. Figure 5d shows a cross ventilation flow on the second floor from the north side to the wind tower on the south side. Figure 5e shows the same model with a reverse wind direction. One can see some dye escaping from the top of the wind tower against the wind direction. This regime is interesting, and may need a further investigation with a more elaborate model.

Three main airflow regimes can be developed for strategic operation modes. The first mode is a closed cavity (Figure 4a), which can trap desirable transmitted and absorbed solar heat in winter or at night. The second mode is a vented wind tower with a short cut airflow (Figure 4b), which is created by opening openings on the second level floor to the outside. The shortcut airflow prevents the house from being overheated when the user is not home, or when excessive trapped solar heat needs to be discharged. In addition, this regime also allows for night cooling. The third mode is a vented wind tower with no shortcut flow (Figure 4c). This mode allows the wind tower to pull the air from the lower level up, and draws the air from the outside from open sliding doors on the lower level.

Although the wind assisted airflow through the solar chimney is verified, the amount of airflow corresponding to various wind speed magnitudes is not quantified. Therefore, there is a need for a quantifiable experimental method. Data obtained from such method can be used to create an airflow network model for a coupled simulation combining airflow and thermal domains. The model combines both wind and buoyancy driven flows. In order to develop an airflow model, pressure distribution coefficients at the openings are critical information.

The coupled simulation is required to assess performances of the house. A thermal simulation alone is insufficient to determine a thermal performance of the house (Thitisawat, et al. 2007).

FUTURE STUDY

A quantitative visualization experiment will be explored further to develop an airflow model for the coupled simulation. An image acquisition and analysis software will be employed to acquire motion pictures of the flow. The motion pictures can be used to quantify velocity of airflow around the house. This technique is called particle image velocimetry. The hydrogen bubbles will represent particles in the flow. One can create flow streamlines by tracking individual bubbles.

The flow through wind tower dampers may be assumed as being similar to that of a single story double skin façade. Therefore, an airflow rate can be determined by using a validated airflow model found in a previous study (Park, et al., 2003; Park, et al., 2004; Thitisawat, et al., 2003).

Another study that will be investigated is a comparison between the physical experiments and a Computational Fluid Dynamics (CFD) simulation. Both approaches are more often than not affordable for a School of Architecture.

After a coupled simulation model is developed. It can be used to optimize different components (Prianto and Depecker 2003). Furthermore, it can also be used to examine how the house should be operated.

Ultimately, the authors hope to use the findings from these experiments to refine the design and performance of the building. Precise models could be made through the use of digital fabrication technology in order to quickly test the building's airflow performance. Therefore, the optimization of the roof angle can be performed in a series of water table experiments using digitally fabricated models.

CONCLUSION

The study represents an action research; a research based on a design process. Climate analysis is used to identify design strategies, while previous research informs the design process. Another important process is precedent study of tropical architectures in local or other regions of the world. Designers have to find suitable solutions that can be applied to architectural design of south Florida to suit the modern living.

Modern material and technology, and passive strategies can be employed to achieve a design that is less mechanical equipment dependent. Occupants can be informed, through their senses, about how they should operate the building by manipulating airflow, and shading devices. This increases the awareness of their environment, and restores their intuition. A sensory connection with environment is a significant component for the human actuated system. Additionally, the design demonstrates methods of manipulating heat through the use of the thermal stratification and the wind.

Thermal and airflow performance aspects of the house can be examined through the use of simulation. However, a thermal simulation used to estimate skin loads cannot offer a holistic performance assessment because both thermal and airflow aspects are interrelated and their assessments require coupled simulation. At this point, the visualization experimental method is employed to verify the south façade and roof designs. This project presents a unique challenge that will be explored in the future. The project will continue to explore the quantifiable visualization experimental method that can be used by designers as a simple and affordable method for assessing an airflow performance, and characteristics of airflow patterns around buildings.

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REFERENCES

1. Asfour, O.S. and Gardi, M.B., A Comparison Between CFD and Network Models for Predicting Wind-Driven Ventilation in Buildings, Building and Environment (in press).

2. Bastide, A., Lauret, P., Garde, F. and Boyer, H., Building Energy Efficiency and Thermal Comfort in Tropical Climates Presentation of a Numerical Approach for Predicting the Percentage of Well-ventilated Living Spaces in Buildings Using Natural Ventilation, Energy and Buildings, 38 (2006) 1093.

3. Bretz, S.E., and Akbari, H., Long-term Performance of High-albedo Roof Coatings, Energy and Buildings, 25 (1997) 159.

4. Carlson, D.R., Widnall, S.E. and Peeters, M.F., A Flow-Visualization Study of Transition in Plane Poiseuille Flow, Journal of Fluid Mechanics, 121 (1982) 487.

5. Chandra, S., Moyer, N., Parker, D., Beal, D., Chasar, D., McIlvaine, J. and Martin, E., Alleviating Moisture Problems in Hot, Humid Climate Housing, Position Paper for NSF Housing Research Agenda Workshop, (2004).

6. Emmanuel, R., Thermal Comfort Implications of Urbanization in a Warm-humid City: The Colombo Metropolitan Region (CMR), Sri Lanka, Building and Environment, 40 (2005) 1591.

7. Farhanieh, B. And Sattari, S., Proc. WSEAS/IASME International Conference on Heat and Mass Transfer, Florida - USA (2006) 3.

8. Feriadi, H. and Wong, N.H., Thermal Comfort for Naturally Ventilated Houses in Indonesia, Energy and Buildings, 36 (2004) 614.

9. Finger, S. and Amon, C.H., Design and Prototype of Interactive Fluid Dynamics Exhibits for the Carnegie Science Center: An Undergraduate Team Project Experience, Proc. ASEE/IEEE Frontiers in Education Conference, Pennsylvania - USA (1997).

10. Garde-Bentaleb, F., Miranville, F., Boyer, H. and Depecker, P., Bringing Scientific Knowledge from Research to the Professional Fields: The Case of the Thermal and Airflow Design of Buildings in Tropical Climates, Energy and Buildings, 34 (2002) 511.

11. Hayashibara, S., Myose, R.Y., Heron, I. and Miller, S., Development of a Low Cost Cascade Aerodynamics Test Facility Using a Simple Flow Visualization Velocimetry Technique, Proc. General Aviation and Technology Conference and Exhibition, Wichita, Kansas - USA (2002) 1.

12. Hayashibara, S., Myose, R.Y. and Davies, M.R.D., Development of a Water Table Cascade Aerodynamics Test Facility Using a Simple Flow Visualization and Image Processing Technique, Proc. 33rd AIAA Fluid Dynamics Conference and Exhibit, Florida - USA (2003) 1.

13. Heschong, L., Thermal Delight in Architecture, The MIT Press, Massachusetts (1979).

14. Hughes, S.A., CHL Precision Flow Table: Description and Application (2003).

15. Huang, J., Winkelmann, F., Buhl, F., Pedersen, C., Fisher, D., Liesen, R., Taylor, R., Strand, R., Crawley, D, and Lawrie, L. Linking the COMIS Multi-Zone Airflow Model with the EnergyPlus Building Energy Simulation Program, Proc. IBPSA, Kyoto - Japan (1999).

16. Khedari, J., Boonsri, B. and Hirunlabh, J., Ventilation Impact of a Solar Chimney on Indoor Temperature Fluctuation and Air Change in a School Building, Energy and Buildings, 32 (2000) 89.

17. Luxmoore, D.A., Jayasinghe, M.T.R. and Mahendran, M., Mitigating Temperature Increases in High Lot Density Sub-tropical Residential Developments, Energy and Buildings, 37 (2005) 1212.

18. Mallick, F.H., Thermal Comfort and Building Design in the Tropical Climates, Energy and Buildings, 23 (1996) 161.

19. Mueller, T.J., The 11th International Symposium on Flow Visualization, Proc. the 11th International Symposium on Flow Visualization, Notre Dame, Indiana - USA (2004).

20. Myose, R.Y., Hayashibara, S. and Heron, I., Flow Visualization Study on the Effect of a Gurney Flap in a Low Reynolds Number Compressor Cascade, Proc. 6th AIAA Aviation Technology, Integration and Operations Conference (ATIO), Kansas - USA (2006) 1.

21. Nicol, F., Adaptive Thermal Comfort Standards in the Hot-humid Tropics, Energy and Buildings, 36 (2004) 628.

22. Oms, L.J., Torres, E. and Amon, C., The Water Table: A Fluid Exhibit for the Carnegie Science Center, Proc. ASEE/IEEE Frontiers in Education Conference, Pennsylvania - USA (1997).

23. Park, C.S., Augenbroe, G., Sadegh, N., Thitisawat, M. and Messadi, T. (2003), Occupant Responsive Optimal Control of Smart Façade Systems, Proc. the 8th IBPSA Conference, Eindhoven - Netherlands, (2003) 1009.

24. Park, C.S., Augenbroe, G., Sadegh, N., Thitisawat, M. and Messadi, T., Real-time Optimization of a Double-Skin Façade Based on Lumped Modeling and Occupant Preference, Building and Environment, 39. (2004) 939.

25. Parker, D.S. and Barkaszi, S.F., Roof Solar Reflectance and Cooling Energy Use: Field Research Results from Florida, Energy and Buildings, 25 (1997) 105.

26. Prianto, E. and Depecker, P., Characteristic of Airflow as the Effect of Balcony, Opening Design and Internal Division on Indoor Velocity: A Case Study of Traditional Dwelling in Urban Living Quarter in Tropical Humid Region, Energy and Buildings, 34 (2002) 401.

27. Prianto, E. and Depecker, P., Optimization of Architectural Design Elements in Tropical Humid Region with Thermal Comfort Approach, Energy and Buildings, 35 (2003) 273.

28. Rani, S.L and Wooldridge, M.S., Quantitative Flow Visualization Using the Hydraulic Analogy, Experiments in Fluids, 27 (2000) 165.

29. Ruck, N.C., Building Design and Human Performance, Van Nostrand Reinhold, New York, (1989).

30. Schmidt, F.W., Henderson, R.E. and Wolgemuth, C.H., Introduction to Thermal Sciences: Thermodynamics, Fluid Dynamics, Heat Transfer, 2nd Edition (1993)

31. Stein B., Reynolds, J.S., Grondzik, W.T. and Kwok, A.G., Mechanical and Electrical Equipment for Buildings, John Wiley & Sons, Inc. (2006) 55.

32. Thitisawat, M., Augenbroe, G. and Park, C.S., Model Calibration of a Double-Skin Facade: a Heuristic Approach, *Proc. CISBAT 2003*, Lausanne - Switzerland (2003)

33. Thitisawat, M., Lyn, F. and Moore, S., Making Sense: A Passive Response to Modern Living in South Florida, Proc. PLEA2007, Singapore (2007)

34. Trachtenberg, M. and Hyman, I., Architecture: From Pre-history to Post-Modernism, Prentice Hall Inc., New Jersey, 47 (1986).

35. Wong, N.H., Mahdavi, A., Boonyakiat, J. And Lam, K.P., Detailed Multi-Zone Air Flow Analysis in the Early Building Design Phase, Building and Environment, 38 (2003) 1.

ENDNOTES

1 According to BP Global, there has been an increase in global energy use. In South Florida, buildings represent almost half (47%) of Florida's energy use. Over half (55%) of the building energy use is supplied to residential buildings. More than 90% of the building energy use is from electricity.

2 A design process begins with weather data analyses to confirm our discussion on the tropical living, and architecture, and identify appropriate design strategies. Since comprehensive weather data of Fort Lauderdale is not available, weather data called TMY2 (Typical Meteorological Year) of Miami, Florida is used, and analyzed.. An analysis reveals that for 58% of the time, the temperature is between 24-38 C°, while for 24% the temperature lies between 21 and 24 C°, and for 16% of the time, the temperature is below 21 C°.

The corresponding temperature and relative humidity data are converted into different conditions (i) overheat, (ii) shaded needed, and (iii) cool. The conditions are plotted in another time series plot, a sun chart. Top and bottommost curves of the diagram represent sun angles of a summer solstice, and winter one respectively. This plot can be used to identify times when a shade is needed. This analysis demonstrates that during the summer days the thermal conditions are considered overheating; whereas the shading device can be used to provide a more comfortable condition in the rest of the year when it is needed.

A psychrometric chart is also employed as a tool for analyzing local climatic data and identifying design strategies. The psychrometric chart can be thought of as a contour plot of hygro-thermal properties [i.e., temperature, humidity, water content, and dew point temperature] of air. The following design strategies are identified by the psychrometric analysis:

- Shading: all seasons
- Natural ventilation: all seasons
- High thermal mass: all seasons
- Air conditioning cooling: summer, fall, and spring
- Internal heat gain: winter, spring, and fall
- Passive solar heat gain: every season but summer.

In addition to the use of data analysis, and observation of tropical architecture characteristics for design strategy identification, literature review is another significant approach. By investigating research publications about different projects located in tropical or subtropical climates, the authors and designers apply similar successful strategies in the design.