THE LOGAN HOUSE: MEASURING AIR MOVEMENT

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ABSTRACT

Naturally-ventilated houses in the hot and humid climate of Florida are rapidly disappearing in the wake of air-conditioned developments. As research to find ways to economize on air-conditioning systems and energy use continues, simple strategies to promote natural ventilation are not to be forgotten. Designed to promote passive cooling, the Logan House in Tampa, Florida serves as a model to counter this trend. Images of this house are often used as a teaching vehicle in environmental technology classes because the house demonstrates the principles of cross- and stack-ventilation. However, do we know how this house actually performs? More than 15 years after its construction we found the house still naturally ventilated, but wondered about the ventilation performance. What are the patterns of air movement; the resulting air velocities? Using scale-model test data from a boundary layer wind tunnel at the University of California at Berkeley and field measurements from the Logan House made by students from Florida A&M University we assessed the effectiveness of these methods in characterizing air movement – and tried to understand the performance of the house.

1. INTRODUCTION

The Logan House is located on a federally protected tidal estuary within walking distance of the edge of Hillsborough Bay in Tampa, Florida. Because a large part of the site is flat, sandy, estuary land near the coast, the area is vulnerable to tidal surges. The Logans wanted an energy-efficient, casual house with plenty of daylight and room for entertaining. With these factors in mind, Dwight Holmes of Rowe Holmes Associates proposed a home that expressed the traditional "cracker house" style of Florida. It responded to the climatic conditions and complimented the desires of the clients with deck space, a high, central full-width common space, and was energy efficient through its promotion of natural ventilation.

Fig. 1: The Logan House in Tampa, Florida after construction in 1981. (photo courtesy of the architect)

Completed in 1981, the house features a raised floor and a belvedere set at the peak of a steeply pitched roof that would shed water quickly. Through the stack effect mechanism, rising warm interior air could vent through clerestory windows. In theory, this natural convection current could offer some relief during hot summer months. The house sits on 10" x 10" pressure-treated posts approximately 8 ft. above ground, safely above storm flooding and also allowing air movement below the structure. Palms and live oaks surround the house providing shade and privacy, although reducing the potential for air movement. Decks to the east and west are an integral part of the house, where guests can wander in and out of the house. Bedrooms surround the central living space and were designed using simple awning-type windows with a top hinge, which when open would promote cross-ventilation. In theory, air enters through the lower windows and open sliding doors, rises into the belvedere, and is vented to the outside (see Figure 1 for general arrangement of openings).

Based on information published in various journals, the Logan House is often used as a model of energy efficiency and natural ventilation in environmental technology classes. But, how does the house actually perform? Is the house still naturally ventilated? How accurate are models at predicting patterns of air movement? The objectives of this study were to:

- understand the principles of air movement in and around the building;
- quantitatively test various methods for characterizing airflow;
- qualitatively assess the effectiveness of natural ventilation through patterns of air movement.

2. METHODS

We used a variety of methods to compare design intent with the actual performance in the Logan House -- Figure 2 suggests the design intent for cross-ventilation. These methods included field observations/measurements and wind tunnel studies of airflow performance. The field studies used fairly simple, low-cost instrumentation devices and involved short-term measurements made during a single visit. The wind tunnel studies were made using the University of California at Berkeley Boundary Layer Wind Tunnel and a ¼” scale model.

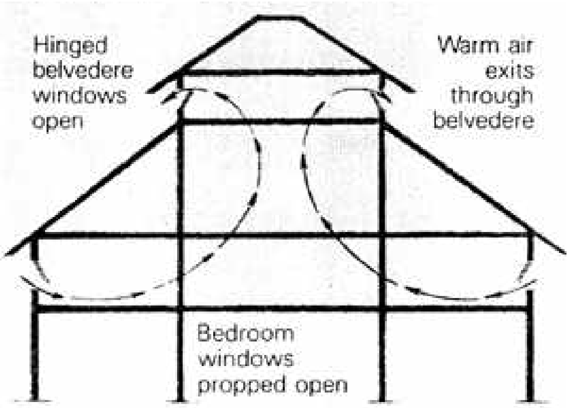

Fig. 2: Patterns of summer airflow. (2)

During a site visit in March 1998, conducted as part of a Vital Signs case study investigation, students from Florida A&M University took field measurements in the Logan House. The usefulness of these measurements was restricted by the limited equipment available to the students and by the excellent weather conditions encountered during the visit.

The wind tunnel investigations were conducted in June 1998. Information from construction drawings provided by the architect was used to build a scale model of the house. The model enabled the visualization of simulated airflow using a white-colored smoke against the black background of the model. The observed airflow patterns in and about the model were used to determine points for hotwire anemometer measurements of interior velocities. Climate data from the online National Climatic Data Center (NCDC) were used to compare model results with anticipated on-site performance.

As neither the field measurements nor the wind tunnel studies provided truly definitive information on the ventilation performance of the Logan House, efforts to identify other analysis techniques were undertaken. One potentially promising technique was computational fluid dynamics (CFD). A request for information on applying such an analysis technique to a residential building, however, led to the conclusion that this would not be a fruitful endeavor. The request, posted to the Society of Building Science Educators (SBSE) listserve, resulted in over 20 responses – the majority of which indicated that CFD analysis would be very time consuming, expensive, and of little benefit in terms of fine-tuning design features of interest (such as window-hinge locations).

Fig. 3: Student investigators arriving at the Logan House.

2.1. Climate Data

Tampa, Florida is located at 27°N latitude along the west central coast of the Florida Peninsula. Very near the Gulf of

Mexico at the upper end of Tampa Bay, land and sea breezes modify the subtropical climate. The climate of this area is characterized by long, warm, and humid summers, with temperatures between 70-90°F; winters are mild, with temperatures between 50-70°F (see Figure 4). Tropical storms and hurricanes are outstanding features of the Tampa climate. Relative humidity is fairly consistent, at around 70% throughout the entire year. Winds of approximately 4 m/s are experienced predominantly from the north, except during the summer months when they come from the west.

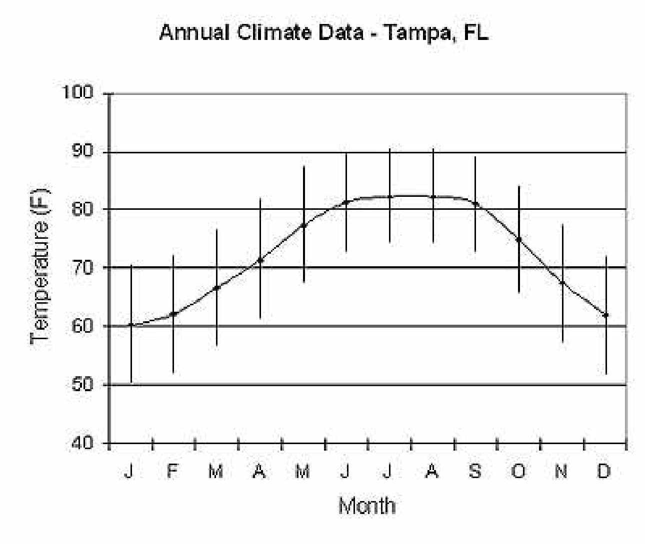

Fig. 4: Annual climate data for Tampa showing minimum, maximum, and average temperatures. (3)

2.2. Model and Flow Visualization

Air flow patterns and spot measurements in the house were determined using a ¼” = 1’-0” scale model (shown in Figure 5). The materials used to construct the model included foam core for the walls and floors, spray painted black; and transparent acrylic roofs and ceilings (drilled with holes for an anemometer probe). This type of construction allowed airflow visualization and velocity measurements to be made with some ease. Wooden blocks placed in the wind tunnel (see Figure 5) are used to simulate the “roughness” of the wind that corresponds to surface winds found in suburban areas.

Using a wand connected to a smoke generator to develop a visible track for air flow, wind flow patterns within and surrounding the house were observed and recorded photographically. For interior velocity measurements using the hotwire anemometer probe, velocities were recorded as a percentage of the undisturbed wind speed in the test area of the wind tunnel (corresponding to a reference height of 10 m). This reference velocity can then be related to the published wind data for Tampa, Florida available from the NCDC.

2.3. Field Measurements

During the spring semester of 1998, under the auspices of a case study grant from the Vital Signs Project (http://www-archfp.ced.berkeley.edu/vitalsigns/index.html), a studio/ technology class at Florida A&M University undertook a case study of the performance of the Logan House. (4) The class formulated a set of questions and hypotheses about air movement and comfort conditions within the house. For example, they believed that the temperature distribution throughout the house would be generally uniform, both horizontally and vertically. To test this hypothesis, students installed a PVC instrumentation pole (with Hobo temperature and humidity dataloggers attached at several heights) in the central belvedere of the Logan House to measure thermal stratification.

To measure air speeds experienced in the house, the students took spot measurements with a handheld Solomat hotwire anemometer and recorded their observations on a floor plan of the house. To observe patterns of air movement, they used a bubble solution and traced the pattern of bubble movements on a sectional drawing of the house (see Figure 7). Although temperature and humidity measurements were recorded over a two-week period using the Hobo dataloggers, it was not possible to obtain long-term air velocity measurements with the equipment available.

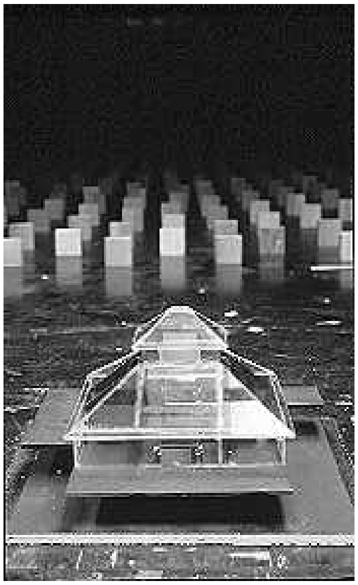

Fig. 5: Model of the Logan House in the Boundary Layer Wind Tunnel at the College of Environmental Design, University of California, Berkeley.

3. RESULTS

From the annual climate data on temperature, relative humidity, and wind speed, a climate analysis shows the potential for natural ventilation in the Tampa area to be excellent. The new owners of the Logan House indicated that temperatures were very cool even during the summer; however, at the time of this study, they had only occupied the house for short time. To our surprise, we learned that the architect specified two air-conditioning units in the original design, which the Logans used intermittently during the summer – "as many Floridians must" (2).

As expected, smoke patterns in the wind tunnel tests (Figure 6) indicated that that the central space seemed to "draw" air effectively through the building when the top windows in the belvedere and the bottom doors adjacent to the deck were open. The smoke visualization test revealed a relatively large portion of the oncoming wind being deflected by the roof, rather than flowing substantially through the lower openings and up through the central belvedere. However, the house did perform well when the high-level openings in the belvedere were open, the lower-level openings were all open, and the wind direction was normal to the patio door openings. In another position, with the top windows closed and the bottom doors open, patterns of airflow were less directional and slightly turbulent.

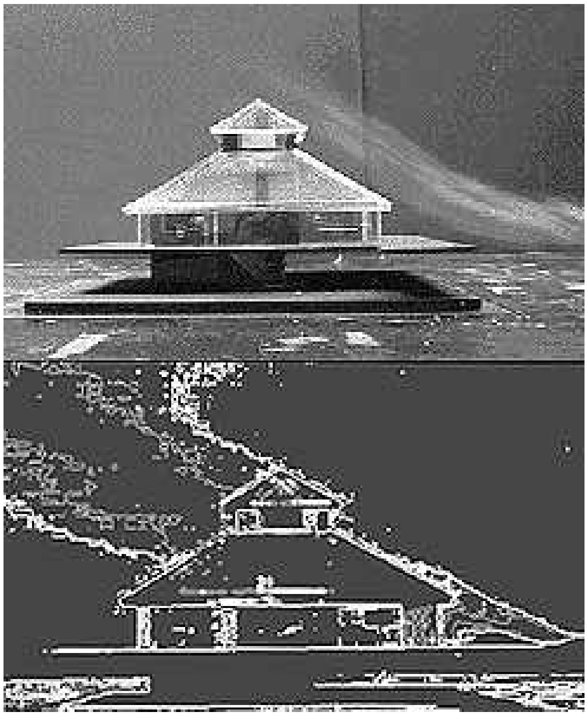

Fig. 6: Airflow pattern around Logan House model; the top is a visual image, the bottom a representation developed from a digital camera image.

To check this observation, an omni-directional anemometer was lowered into the central space of the model. Table 1 shows the resulting readings from the wind tunnel data acquisition system, verifying our observations. Interior air speeds averaged 0.67 m/s with the top windows closed and 0.74 with the top windows open.

An interesting outcome of the wind tunnel studies was the observation of the striking aerodynamics of the bulk form of the Logan House. Airflow around and over the house (at least in the model) was exceptionally smooth, almost as one would expect around a well-designed car, even though the profile of the house is not rounded or continuous (see Figure 6). It is possible that this feature, never likely to be observed in on-site visits or experiences, actually works against cross-ventilation effectiveness by channeling winds over the house instead of through the house.

The "bubble test" conducted during the on-site visit did not clearly validate the stack effect principle (by showing warm air rising). It is possible that the bubble solution was too heavy to demonstrate thermal buoyancy or it was simply too comfortable a day for such an effect to be visible. The students did, however, observe many bubbles travelling across the central living space and falling to the ground floor at the stairway (Figure 7) where there was measurably cooler air. As an aside, the bubble test proved to be a crowd-pleaser.

These qualitative measurements combined with on-site velocity measurements showed the fastest and most turbulent air velocities occurred nearest the open doors. There was virtually no air movement in the central space just below the belvedere (Figure 8).

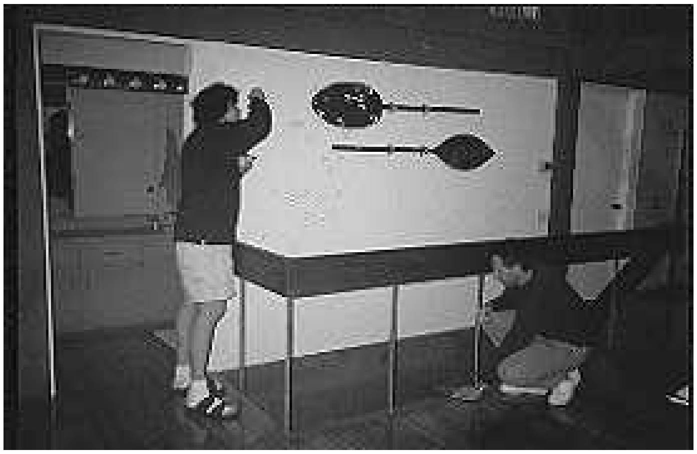

Fig. 7: Students blowing bubbles and measuring air speed with an anemometer.

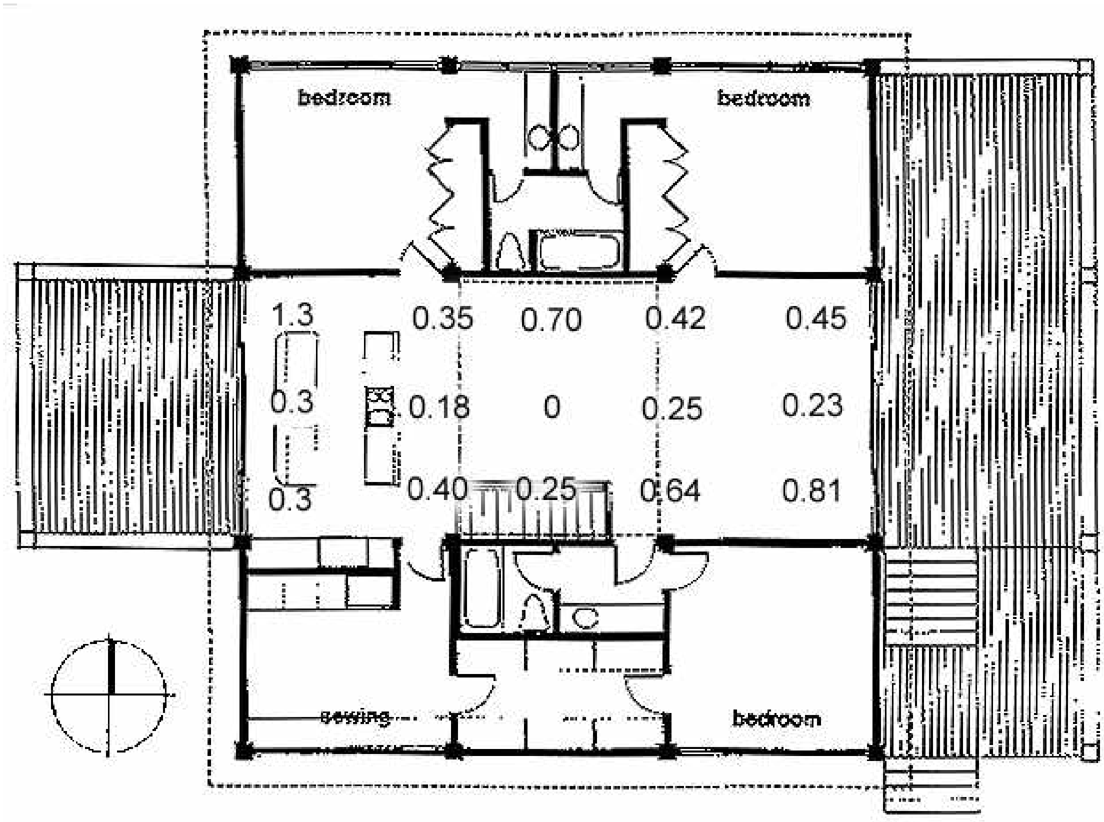

Fig. 8: Plan of the Logan House showing spot velocity measurements taken onsite with a hotwire anemometer in March 1998, with belvedere windows closed and side doors open.

TABLE 1: WIND TUNNEL (SCALE MODEL) VELOCITY TEST RESULTS

Design Condition	Trial	Measured Velocity (m/s)	Velocity Ratio (%) *
Top Closed & Bottom Open	1	0.73	11.54
	2	0.70	11.02
	3	0.57	8.94
	4	0.69	10.87
Top Open & Bottom Open	1	0.70	10.99
	2	0.82	12.95
	3	0.70	11.03
	4	0.79	12.46
	5	0.69	10.84

* *Velocity ratio* = mean interior velocity divided by the mean reference (“ambient”) velocity. The mean reference velocity was approximately 6.3 m/s.

Another interesting outcome of the on-site field measurements is that the students were able to verify the as-built design with the original drawings. We discovered (when building the model) that the original plans showed an additional floor below the belvedere, a feature that would have substantially changed the house’s ability to ventilate through the belvedere clerestories.

4. SUMMARY

One interesting, and un-nerving, outcome of this series of investigations is an increased awareness of the difficulties facing designers of passive systems. Even with tools not normally used during the design process – wind tunnel studies and visits to a completed building – it was exceptionally difficult to get a handle on the performance of this building under design conditions.

Questions directly related to the design features of the building – such as the best type of window to use on the lower floor and whether a top- or a bottom-hinged belvedere window made more sense when designing for natural ventilation – were resistant to analysis through site visits and any reasonably-feasible scale model study. Computational fluid dynamics may fill this analysis void in the future, but the technologies for such analyses are apparently not yet developed to the point where they could be described as user-friendly design tools.

5. ACKNOWLEDGEMENTS

We acknowledge the generosity of the Hepners, new owners of the "Logan House," who shared their house with the Florida A&M students during the case study, allowing poles, dataloggers, and instrumentation to be strewn in various locations for a period of time. Their interest in connecting design intent to performance helps perpetuate traditional designs that shouldn't be forgotten. Support from the Vital Signs Project at the University of California Berkeley made the case study possible. We also are grateful for the use of the Boundary Layer Wind Tunnel at the Center for Environmental Design Research at the University of California, Berkeley and for the assistance in the use of the tunnel provided by Ph.D. candidate, Zhang Hui.

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