THE LOGAN HOUSE: STACK EFFECT EFFECTIVENESS

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ABSTRACT

This is the second of a series of papers addressing the thermal and ventilation performance aspects of the Logan House in Tampa, Florida. The paper focuses on the stack ventilation potential of the house. The likelihood of substantial stack ventilation effect is explored using conventional design analysis calculations and on-site measurements of temperature conditions throughout the house taken during the summer of 1999.

This work is an extension of a Vital Signs case study project undertaken by students at Florida A&M University in 1998. The data reported in this paper were collected by students from Cornell University and the University of Oregon. A previous paper addressed general thermal patterns within the Logan House.

1. BACKGROUND

Designed in part to promote passive cooling, the Logan House in Tampa, Florida literally serves as a textbook model for principles of cross and stack ventilation.(1) Designed by Dwight Holmes, of Rowe Holmes Associates, this house has a raised floor, extensive window and door openings, and a belvedere with operable clerestory windows.

An earlier paper, "The Logan House: Measuring Air Movement," described a study by Florida A&M University students of air movement and comfort conditions within the house.(2) The measurements for that study were carried out during cool weather in March 1998 (to accommodate class scheduling). Patterns of air flow in and about the house were further investigated in the summer of 1998 using a scale model and a wind tunnel.

Fig. 1: The Logan House in Tampa, Florida (view from southeast -- summer 1998).

This second paper dealing with Logan House ventilation focuses on stack ventilation. The paper describes the theoretical potential for stack ventilation and the results of a collaborative effort of students from Cornell University and the University of Oregon who instrumented the Logan House during hot weather (June 1999) to determine thermal patterns throughout the house. The primary question driving this portion of an ongoing study of Logan House performance was: does thermal stratification actually occur and to what extent?

2. BUILDING CONTEXT

The Logan House is located on a tidal estuary within walking distance of Hillsborough Bay in Tampa, Florida. The Logans wanted an energy-efficient, casual house with plenty of daylight and room for entertaining. With these factors in mind, Dwight Holmes designed a home that expressed the traditional "cracker house" style of Florida.(3) The design responded to the climate and site conditions and met the desires of the clients with deck space and a high, central, full-width common space. The design promotes energy efficiency through natural air circulation (both cross and stack ventilation). Figure 1 shows the general character of the Logan House.

Completed in 1981, the house features a raised floor and a belvedere set at the peak of a steeply pitched, water-shedding roof. Operable windows within the belvedere permit rising warm air to be vented out of the house. The house sits approximately 8 feet above ground, allowing free air movement below the structure. Palms and live oaks surround the house providing shade and privacy, but most likely reduce the potential for air movement. Guests can wander in and out of the house through large east-west patio doors. Bedrooms surround the central living space and have large, top-hinged, awning-type windows. In theory, air can

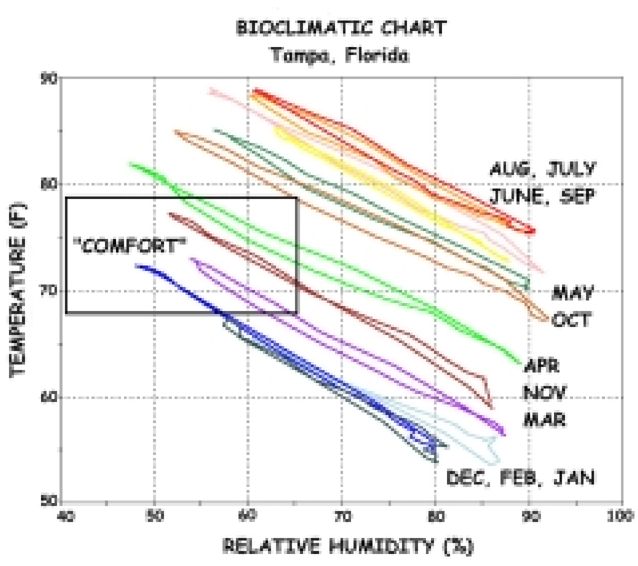

Fig. 2: Bioclimatic representation of Tampa, Florida climate (showing a suggested comfort zone superimposed on typical-day plots of temperature versus humidity for each of the twelve months).

enter the house through the bedroom windows and patio doors, rise through the belvedere as it is heated by building loads, and be vented to the outside.

As suggested by Figure 2, the Tampa climate is a difficult climate for which to design passive cooling systems.(4) A substantial percentage of the ambient conditions throughout the year involves elevated humidity values. Air motion would be a key passive strategy for thermal comfort and removal of internal and envelope heat gains would be a key structural cooling strategy.

3. STACK VENTILATION POTENTIAL

The potential for stack-effect ventilation can be estimated during the design process through use of the following equation.(5)

$$V = 60\ K\ A\ [g\ h\ (Ti - To)/Ti\ ]^{1/2}$$

where --

- V is the estimated air flow rate (cfm);
- K is a factor that accounts for orifice characteristics (assumed = 0.65);
- A is the smallest value of inlet, stack "throat," or outlet areas (sq ft);
- g is the gravitational constant (32.2 ft/sec^2);
- h is the stack height (ft);
- Ti (inside) is the higher of two differential air temperatures (°R);
- To (outside) is the lower of two differential air temperatures (°R).

From a design perspective, there are three variables that will affect the rate of stack-effect ventilation: [1] the area of openings (inlet, outlet, and stack size – with the smallest of these three areas ruling); [2] the difference in elevation (height) between the inlet and the outlet; and [3] the difference in dry-bulb air temperature between the stack inlet and outlet. Of these three variables, the areas and the height are most amenable to architectural decision making. Although temperature difference can be modified through design decisions (location of inlet, solar augmentation, and the like) it is probably a less controllable variable as it fundamentally relies on weather conditions (climate).

As the Logan House has been characterized as a "textbook" example of design for ventilation (both cross and stack), identifying and quantifying these design variables in the actual building should be easy. In fact, things are not quite so simple. The stack ventilation outlets are well defined as the windows located at the top of the belvedere. Determining the effective area of these outlets requires some assumptions. The stack area itself is well defined. The stack ventilation inlets are several: [1] sliding patio doors on the east and west facades; [2] awning-type windows on the north and south facades; or [3] an entry door at the ground level. A reasonable temperature difference between inlet and outlet would be estimated during the design process.

Outlet area: The outlets for Logan House stack ventilation are clearly the operable windows that ring the belvedere on all four sides and are located near the highest point of the house. These windows are well-positioned to serve as outlets and appear to provide ample discharge area. As installed, and likely as a result of several design concerns and compromises, only a portion of the window area is usable as stack outlet. These windows were originally intended to open outward in awning-window fashion – and show as such on most sections of the house. A late design change that removed an upper mezzanine level, however, resulted in these windows being installed as inward-opening, hopper-style windows (primarily to make them operable from the main floor of the house 20+ feet below). A short chain restrains a window when it is unlatched and permits the window to open to an angle of around 20 degrees. As a result the discharge area of each window is substantially less than its view area; and 4 of the total of 12 windows can not be opened, as doing so would interfere with 4 other windows (at the corners). Estimated effective outlet area options are shown in Table 1.

Inlet area: There are three possible inlet "scenarios" for stack ventilation in the Logan House. Use of the entry door at ground level as an inlet would maximize the height of the stack (and perhaps slightly increase temperature differential), but would result in an air flow pattern that did little good other than in the stairwell itself. Except to vent hot air from the top of the belvedere, this is considered an unlikely scenario. Use of the patio doors on the east and west facades as an inlet would maximize air flow through the kitchen and/or living room. Occupants can easily determine the location and velocity of air flow (with velocity highest for the smallest opening area) for comfort. This is a very reasonable scenario. Use of the windows in the private corner rooms as inlets is also reasonable (provided the doors to the rooms are open) and would provide another useful pattern of air flow through the house. These windows are awning-type windows and also open to an angle of around 20 degrees (providing much less opening area than view area). Inlet area options are shown in Table 1.

Stack height: Although seemingly clear from the plans and sections, some assumptions must be made regarding reasonable elevation differences to use to estimate stack-effect air flow. Half-way up the patio doors and 3/4 of the way up the belvedere (outlet) windows seemed reasonable reference points from which to calculate height of stack. The patio door reference closely reflects the bottom of the awning-window inlets. A point mid-way up the ground level entrance door was also selected as a reference point for stack height. These selections are judgement calls, but are expected to be more realistic than use of the full floor-to-ceiling height – which does not correspond at all to opening geometries. These heights are summarized in Table 1.

Temperature difference: During the design phase, an appropriate temperature difference to use for estimating stack ventilation would need to be derived from climate and building load data. Inlet temperature will normally correspond to ambient exterior air dry-bulb temperature. Outlet temperature would correspond to the air temperature near the peak of the belvedere – and would need to be "guesstimated" on the basis of space heat gains and ventilation schedule/operation. A temperature difference of perhaps 5°F might be reasonable for ongoing stack ventilation; higher temperature differentials would be likely if stack effect were used to flush an otherwise sealed (and un-cooled) building.

In practice, the operation options that utilize roughly half of the possible outlet area are those that make the most sense. With any prevailing wind condition other than generally calm, two of the four sets of outlet windows would tend to admit air flow and counteract the available stack effect. Ideally, when there is an ambient wind condition the outlets that are on the leeward side(s) of the belvedere would be opened. Opening those on the windward side would be counterproductive. Even on fairly calm days, it appeared that the owners tended to open only two of the four sets of belvedere windows (on opposing sides).

Opening and closing these windows in their as-installed condition is not at all easy – a long, heavy, telescoping pole (as shown in Figure 3) is used to engage small latches to open and close the windows. This is not a pleasant job and would likely be done as infrequently as possible.

Using half the belvedere windows as outlets, the estimated stack ventilation air flow under a wide range of inlet conditions is consistently around 2,800 cfm. Essentially, inlet variations can be used to localize air flow effects in the living area without changing the overall rate of air flow. Thus, opening half the patio doors can increase air velocity (and occupant comfort) in the vicinity of those doors while not decreasing stack flow rate. A flow rate of 2,800 cfm through half the patio doors would provide an air velocity through the doors of around 62 fpm (0.7 mph), which would be characterized as light air movement (calculated by fpm = cfm / half of inlet area, 2,800 cfm / 45.5 sq ft). Such movement, however, would still be able to extend the limits of comfort by perhaps 2°F.(6)

TABLE 1. ESTIMATED STACK VENTILATION AIR FLOW RATES

Stack Operation Options (for outlets and inlets)	Outlet Area (sq ft)	Inlet Area (sq ft)	Stack Height (ft)	Est Δt (°F)	Air Flow (cfm)
All outlets, all patio doors	**47.2**	91.0	16.5	5	4,065
All outlets, half patio doors	47.2	**45.5**	16.5	5	3,920
All outlets, all windows	**47.2**	60.8	16.5	5	4,065
All outlets, half windows	47.2	**30.4**	16.5	5	2,620
Half outlets, all patio doors	**33.2**	91.0	16.5	5	2,860
Half outlets, half patio doors	**33.2**	45.5	16.5	5	2,860
Half outlets, all windows	**33.2**	60.8	16.5	5	2,860
Half outlets, half windows	33.2	**30.4**	16.5	5	2,620
Half outlets, lower door	33.2	**20.0**	24	6	2,275

Notes: [1] Stack cross-sectional area is constant for all options at 200 sq ft (and is not a constraint).
[2] Values in bold indicate the limiting area for air flow estimates.
[3] Inlet and outlet areas for windows calculated using opening "slot" between edge of open window and frame and some percentage of side (pie-shaped) opening at ends of window sets.
[4] Bathroom windows not included in window inlet calculations.

Even for this simple residence there are a number of modes in which the occupants might "run" the stack ventilation system. It is not clear that the effects of these different modes would be intuitive. A user's manual might not be a bad idea. The outlet window detail also provides an interesting design question. Forgetting rain intrusion effects (assuming this can be controlled by overhangs), would it be better to use an inward-opening awning window to scoop and channel upflowing stack-induced air – or is the current hopper-type hinging a better approach (with outlet area at the highest point, but requiring air flow to change direction to exit). We know of no design tool that can answer this basic and non-trivial question.

4. ON-SITE MEASUREMENTS

During a period of relatively hot weather in June 1999, students from Cornell University and the University of Oregon made observations and short-term measurements of air flow in the Logan House using a hot-wire anemometer. They also installed instrumentation for long-term measurements to determine temperature patterns on a horizontal and a vertical traverse through the house. Hobo XT (temperature) dataloggers were used to conduct these long-term measurements.

To explore thermal stratification within the central area of the house, seven Hobo dataloggers were tied two feet apart along a length of gift-wrapping ribbon (pre-planing for this part of the experiment was lacking), launched to record at 15-minute intervals, and positioned with a telescoping pole in a central location within the belvedere. Figure 3 shows this installation in process. This is the same procedure that must be used (minus helpful students) to open and close the belvedere windows.

Fig. 3: Team of students negotiate a 20-foot pole to attach a ribbon holding 7 Hobo dataloggers.

To explore horizontal temperature patterns, 6 Hobo dataloggers were fastened to "Hobo hangers" (Figure 4) and placed evenly across the living space. Fashioned from a clothes hanger, the "Hobo hangers" were an interesting on-site invention -- the prong at one end conveniently fit between the grooves of the interior wood paneling (Figure 5). Another Hobo datalogger was placed outside of the house in a shaded area to track exterior air temperature.

Figure 6 shows a typical horizontal temperature traverse through the Logan House as recorded mid-afternoon on June 6, 1999. Temperatures are very consistent across this east-west section, varying by only 2°F and with the higher temperatures appearing near the glazed exterior walls. As noted, exterior dry-bulb temperature at the time was 88°F.

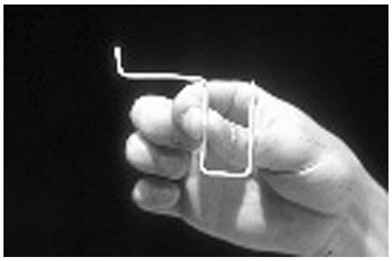

Fig. 4: “Hobo hanger” (previously a clothes hanger) holds a Hobo datalogger and nicely wedges between wood panels.

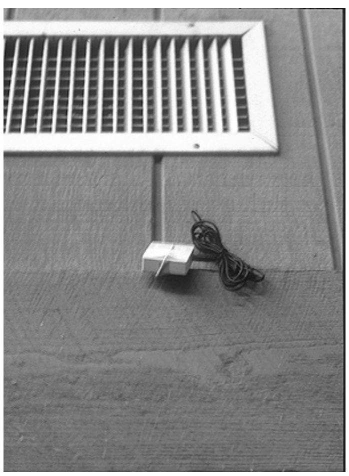

Fig. 5: Hobo XT installed to measure horizontal temperature pattern (the external thermistor is adjacent).

The vertical temperature traverse, on the other hand, shows a 20°F difference between the occupied zone of the central living space and the top of the belvedere. This represents substantial stratification. At this time (under a “button-up” operating mode) the stack-effect temperature difference is 10°F (interior top – exterior temperature). Figure 6 also illustrates the stack heights that were discussed earlier in the paper when estimating stack-effect potential. Note also the swing of the belvedere windows as shown in this section versus the inward-opening hinging actually installed. Figure 7 provides a longer term view of the vertical temperature differentials that occurred during this period of measurement.

5. CONCLUSIONS

Calculations on the Logan House verify the potential for stack-effect ventilation and suggest this to be a valuable element of the design process. Although stack-effect induced air flow would not be of high velocity, it appears to be adequate to temper thermal conditions for occupants by shifting the comfort zone by perhaps 2°F. A stack air flow rate of around 2,800 cfm - which is typical of several of the more likely operating scenarios – would be capable of removing approximately 15,000 Btuh (Btuh = cfm x 1.1 x Δt), equivalent to a cooling capacity of 1.3 tons. All-in-all, stack-effect potential for the Logan House looks very promising. On-site measurements conducted during June 1999 tend to confirm this potential by documenting a substantial thermal stratification in and below the Logan House belvedere. Ideally, this potential for stack-effect air flow would be confirmed by on-site measurements of air velocities during periods of natural convection. The large number of hot-wire anemometers required to make such direct measurements of performance, however, have not been available to the authors.

6. ACKNOWLEDGMENTS

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7. REFERENCES

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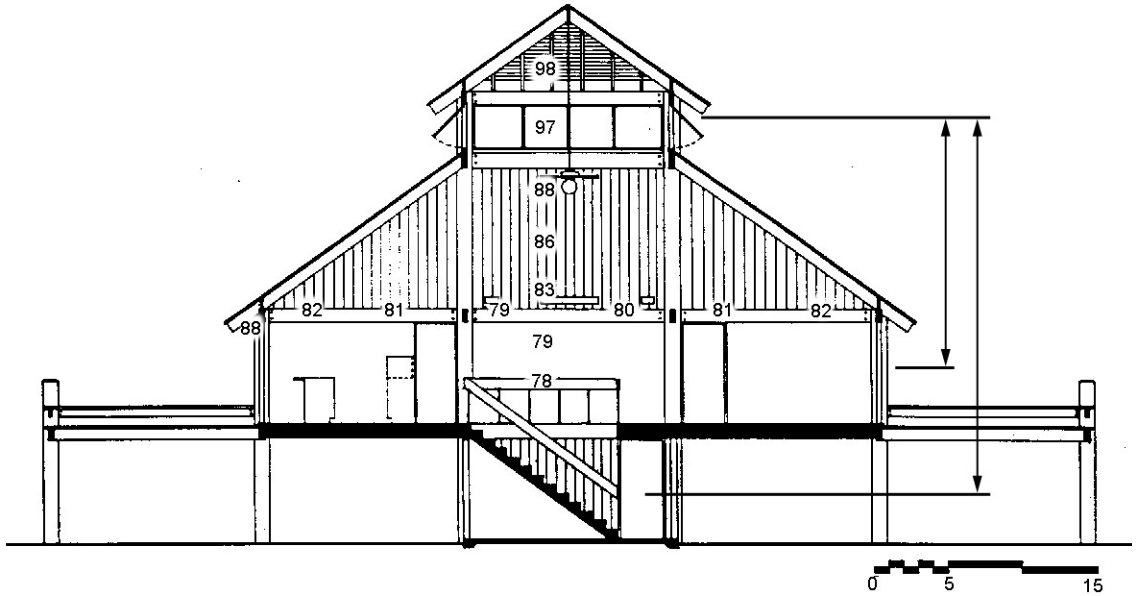

Fig. 6: Horizontal and vertical temperature patterns (°F) for the warmest period of the day on 6 June 1999.

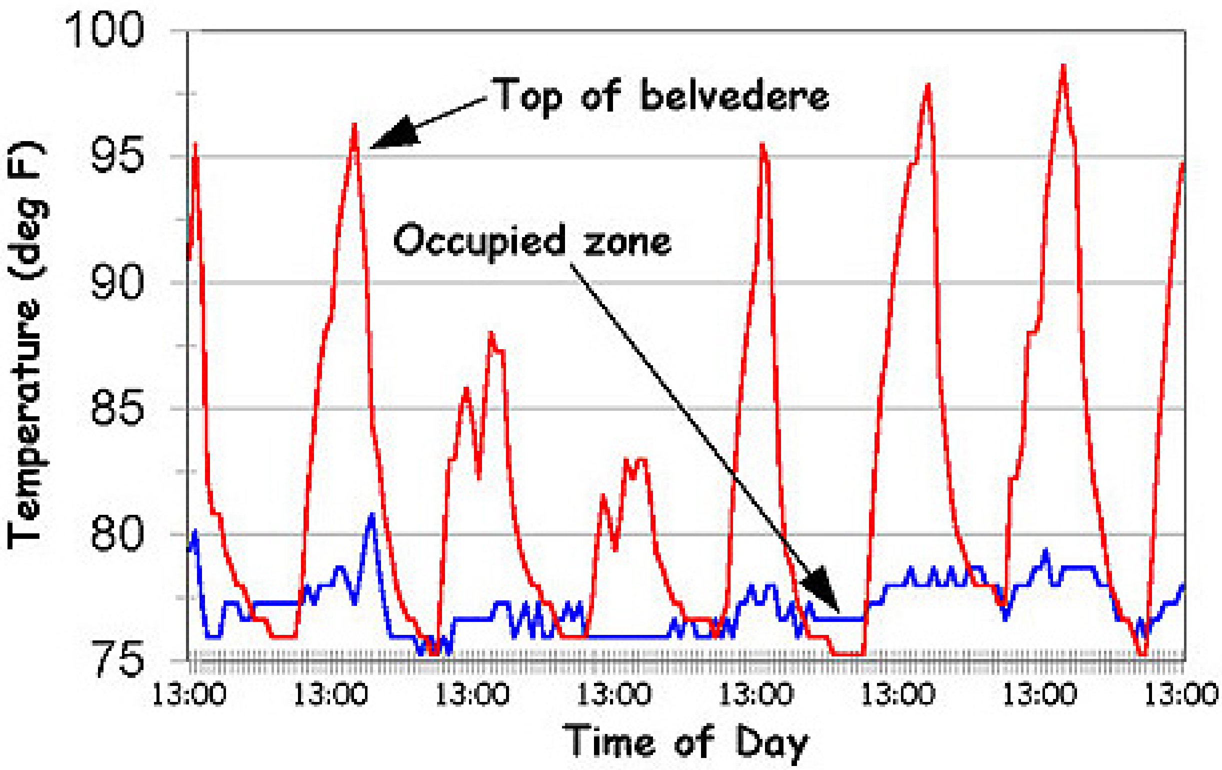

Fig. 7: Vertical temperature difference (°F) through the center of the Logan House for the week of 5-13 June 1999.