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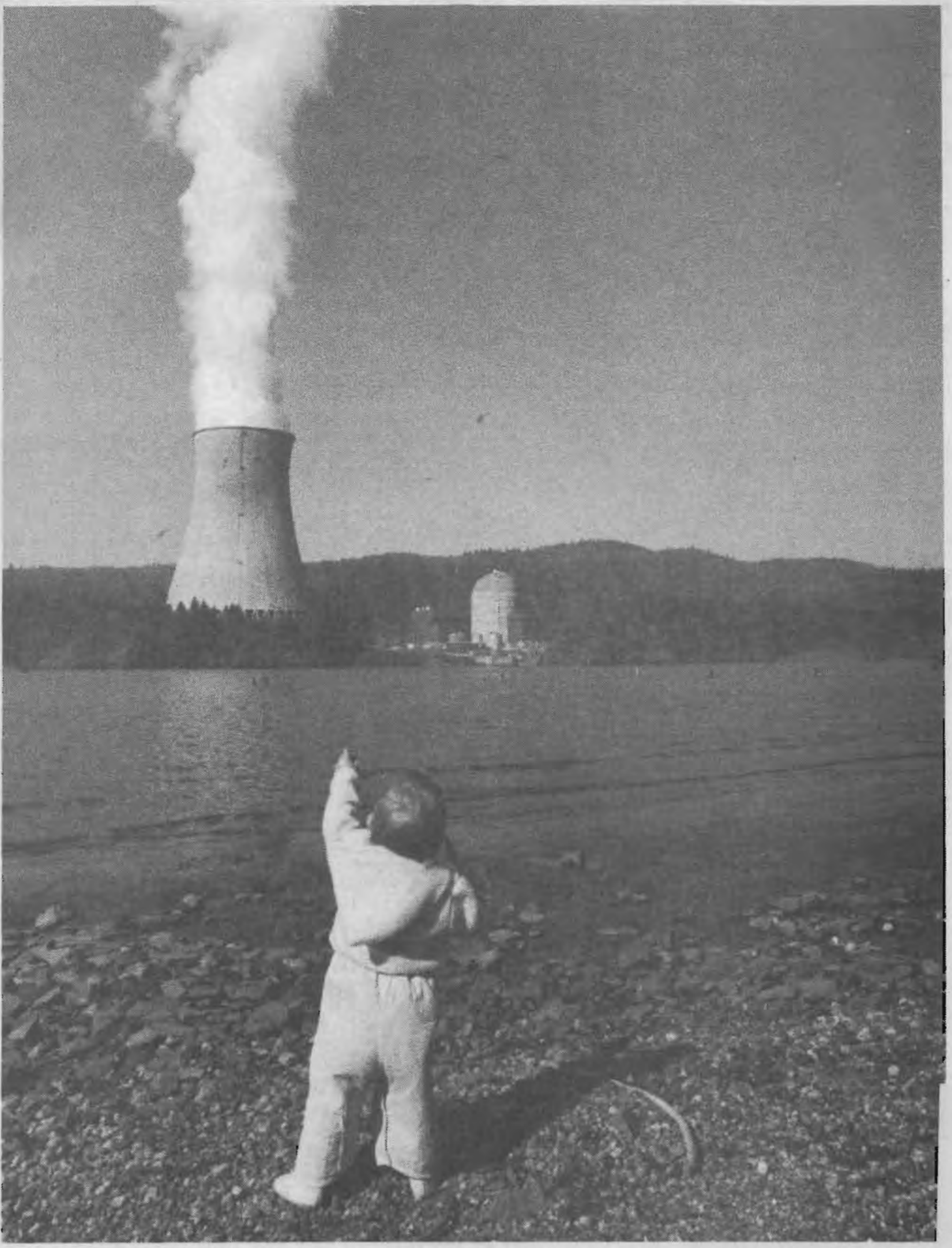


Last issue, Phil introduced us to some of the magic tricks he has observed convection air currents performing in passive solar houses and how their understanding opens up a whole new territory of passive solar design. Here he lays out some how-to principles and techniques for seeing how your own house operates. Soon we may find cadres bearing lighted incense sticks tracking down everywhere the elusive invisible airs of comfort and distress. This paper is in "ISES '78", a collection of papers from last year's gathering due to be released this month. Contact AS of ISES, c/o American Technical University, P.O. Box 1416, Killeen, TX 76541. Phil can be contacted at Box 18123, Denver, CO 80218. —TB

CONVECTION OBSERVATION FOR NATURAL CLIMATE DESIGN

by Philip Henshaw

Convection, or thermal air motion, is a rich cyclic behavior and a delicate measure of house climate. While not simple, convection is very orderly and readily observable using simple tools.

Pursuit of house climate understanding involves some largely unorthodox procedures. The heart of my study technique involves the intensive personal observation of single 34-hour periods. My equipment includes a 24-channel chart recorder, lots of thermocouples, half a dozen 'hot wire' anemometers, a couple of pyronometers, and then, very importantly, incense sticks and a refined attention to skin sensation. Smoke trails have become my best scientific tool.

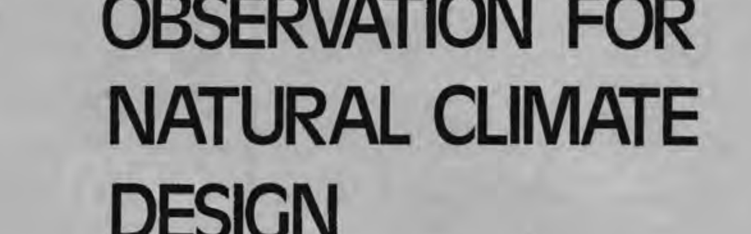
The Importance of Air Flow

Convection is a large heat mover and a very delicate indicator of the balance of remote surface temperatures, building geometries, material properties and outside influences. The complex path of a unit of energy into and then out of a home usually includes travel by means of natural air circulation. The thermal action, of solar homes especially, involves repeated internal energy flows between different parts. These radiant, conductive and convective flows are only readily observable by studying convection.

The scales of convection links in the energy flow path can be seen in the following normal case calculation: Through an open doorway to a room, in any house in winter, there might well be found a two-foot-deep cool air stream at the bottom, and its counterpart warm air stream at the top. A normal temperature difference of 3 degrees F. and a normal flow rate of 2 ft. per sec. yields a one-way mass flow rate of 3000 lb. of air per hour, and a heat flow rate of 2200 BTU per hour. That is 400 BTU per sq. ft. hour!

If one observed that this flow was the average of the day, one might conclude that the 15 cents a day in energy flow might be saved by closing the door. However, because in each situation, with the door open and with it closed, different energy flow dynamics are established, it is not likely that your prediction would be accurate.

In the case of convection on a direct gain mass wall, a significant fraction, say a third, of the incident light energy is immediately carried off by convection. At night a similar fraction of the 'stored' energy is carried off the same surface by convection. It is important to truly understand where this energy goes. Quite often both these day and night currents directly supply the cold window down drafts, thus exaggerating the heat loss. This is not necessary.



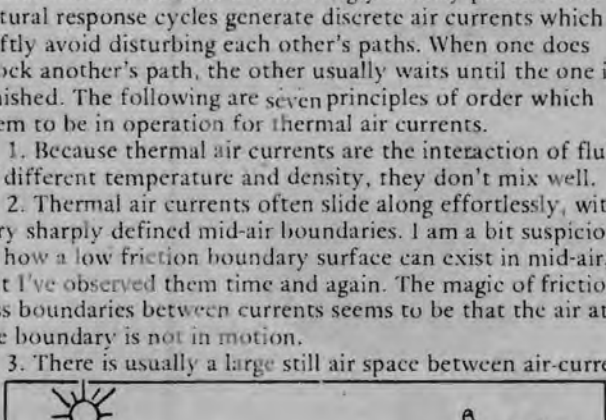
Principles of Order

With convection being such a large volume business, one would perhaps expect, but does not usually find, a large amount of turbulence. Convection is a startlingly orderly process. The natural response cycles generate discrete air currents which deftly avoid disturbing each other's paths. When one does block another's path, the other usually waits until the one is finished. The following are seven principles of order which seem to be in operation for thermal air currents.

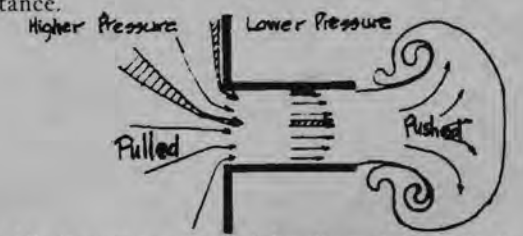
1. Because thermal air currents are the interaction of fluids of different temperature and density, they don't mix well.

2. Thermal air currents often slide along effortlessly, within very sharply defined mid-air boundaries. I am a bit suspicious of how a low friction boundary surface can exist in mid-air, but I've observed them time and again. The magic of frictionless boundaries between currents seems to be that the air at the boundary is not in motion.

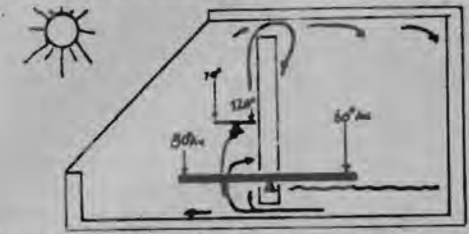
3. There is usually a large still air space between air-currents.



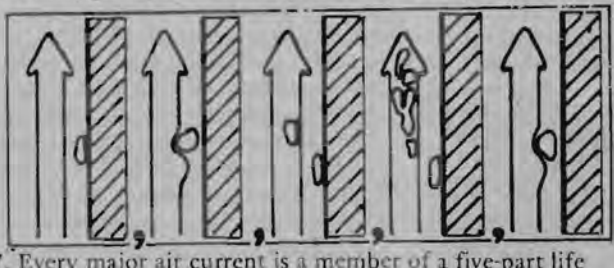
4. The type of boundary and current form depends heavily upon whether it is a 'pushing' current or being 'pulled' from a distance.



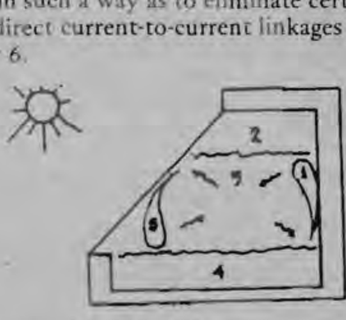
5. All air currents are both locally and distantly determined. For example, the average temperature difference between two rooms *may* determine the amount of air flow, but which of the available currents will be exchanged is determined by other interactions.



6. The observable uniformity of many currents, both large and small, is often of a uniform velocity and direction rather than temperature. Currents act like tracks for parcels of air of different temp.-density. Parcels of cooler air, moving in a current across a warm wall, for example, exchange momentum with still parcels of warmer air adjacent to the wall. This exchange takes place in a very wide range of times from very quick to a second. This still air layer I call a voluntary air layer. The small parcels of warm air introduced to the stream path mix with each other as the cooler parcels are deposited into the voluntary layer for warming. This completes a direct current to current grafting in a continuous stream. The voluntary layer ranges in thickness from very thin to feet thick and from single layered to many or continuously layered.



7. Every major air current is a member of a five-part life cycle: the rising current, the top reservoir, the falling current, the bottom reservoir and the quiet air within which the others adjust themselves. One of the tools of climate design is to arrange materials in such a way as to eliminate certain reservoirs by creating direct current-to-current linkages as described in number 6.



Convection Observation Technique

The use of incense smoke to visualize climate dynamics is a very powerful tool if benefited by a little expertise and an informed intuition. I can't convey any amount of informed intuition; that is always something you make for yourself. The following suggestions might help a bit with the expertise.

1. Carefully watch the difference between smoke rising from its own heat and smoke which has cooled and is passively following an air current. Learn how to shake off a bit of smoke to leave it hanging. Smoke often lies *between* currents, not necessarily in them. Smoke has a sketchy visual appearance, whereas the currents are always volumes. Look for what the smoke can tell you about what you can't see.

2. Wait five seconds after your own movements and five minutes after changing openings so that the natural motions may establish themselves. Stand at the side of where you expect to find a current. Notice that floor currents will often part and rejoin in passing around your legs without apparent disturbance. Note the air between currents which doesn't move.

3. Scan across openings. Draw a horizontal line of smoke across an open doorway and watch how the line bends. Scan vertically across an open doorway by starting at the bottom and raising the smoke source at the same rate which the smoke is rising from its own heat.

4. Look especially for currents near floors, walls and ceilings. Note the difference between deep slow currents and thin fast ones.

5. Scan across a current in several places from its origin to its destination. Notice if the edge is sharply defined or not.

6. Expect current patterns to change on second, minute, hour, day and season time scales.

7. Check out a room with a fireplace and check out a stairwell.

8. Measure the temperature, speed and area of opposing sides of currents (top and bottom of doors). Heat content of air is in the neighborhood of .02 BTU per cu. ft. per degree F.

9. Look for gurgling type action of air as it 'bubbles' through warmer or cooler bodies, which results from crossed flows or inversions. All pockets tend to be visited by intermittent puffs or currents. Note what geometries constitute a pocket.

10. Try to find the difference between 'push' and 'pull' currents, how a push current tends to billow out at a point and how a pull current can leave 'cracks' in the main air mass for very discrete air currents to slip into.

Then there are some suggestions for your mental process for making the observations really meaningful.

1. Develop your understanding of the basics of physics: density, momentum, balance, bounce, etc.

2. Try to develop an awareness and a habit of viewing whole cycles: ones of the moment, the day, the year, seed-organism-seed, idea-thought-idea, etc.

3. Look for what never changes as a basis for understanding and responding to what does.

4. Ask questions, develop and then refine uncertainty, draw few if any conclusions. Value uncertainty.

5. Don't expect any of the above 14 comments to be very meaningful until after you're a good observer.

Design with Air Currents

The above discussion has stemmed from my delight with the intricate order and beauty of things. This is not sufficient to make things work, though it may be one of the essential factors in letting things work. One of the basic problems in design is that it is hard enough to relate pencil lines to building materials which are visible and expected to stay put. Relating pencil lines to invisible things which change continuously is another matter entirely. While difficult to recognize, I think there is an inherent difference between arbitrary wiggling and genuinely thoughtful guesses. One of the differences is that natural air flow tends to be a sequence of straight lines and non-circular curves. All curves should contain a sense of elasticity. Drawings of air currents will often have crossing paths and use the same path for intermittent currents in different directions. In the last analysis, however, a well informed imagination is the only good key.