Fluid Mapping Table

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Introduction

This report summarizes research conducted under a cooperative funding effort by CERES and the Department of Architecture at BSU. Release time and funds were provided to support the development of environmental systems laboratory equipment for research and teaching.

As part of this effort, a Fluid Mapping Table was constructed (see figure 1). This device is used to simulate and measure windflow characteristics around and through object and building profiles. This report discusses issues concerning windflow and ventilation, the background and elementary mechanics of fluid mapping, and the opportunities and potential applications that now exist as a result of the device's presence at CERES.

Issues

Ventilation of enclosed environments has been evident throughout history. In severe climates these concerns are reflected in the materials and geometry of the architecture. For example, Seminole huts are steeply gabled and elevated above the ground with no walls to facilitate air flow. In hot, arid regions, wind scoops rise above the rooftops to capture precious breezes. In specilized industrial situations like mining, worker health and productivity are critically dependant upon a well ventilated environment. To maintain a healthy and pleasant interior environment a quantity of fresh air must be added to replace the stale air and contaminated conditions that develop as a natural product of human occupation and processes. But the need for ventilation is two-fold: health AND comfort. The cooling effect of moving air across the skin has long been recognized as an appropriate comfort goal. Again, by examining historic examples, many alternatives to the more complex and expensive methods of cooling used in contemporary buildings can be found. Conventionally, this ventilation has been achieved using mechanical methods and systems utilizing expensive equipment, electric fan powerr, and uncontrolled infiltration and exfiltration.

With the continuing focus of attention on energy utilization and conservation, some efforts have been made to develop methods of tapping "natural systems" as a means of providing ventilation - a "rediscovered" strategy utilized by earlier societies and since discarded with the advent of technology. The two natural forces available for moving air are: 1) the natural convective forces of wind, and 2) thermal stratification, or the tendancy of warmer air to rise relative to surrounding cooler air.

The success of a natural ventilation scheme in a building depends upon the correct relationship between a large number of factors including: prevailing wind direction, wind speed, air temperature, site configuration, the building envelope inlet/outlet design, directional characteristics, dimensions, and location, the location of the inlet relative to the outlet, and finally the location, size, and characteristics of interior barriers to windflow. The influence of each of these varies in importance with the situation.

For example, the orientation of the building's opening to the direction of windflow need not always be a perpendicular relationship. The speed of airflow through the building must be of the correct magnitude relative to air temperature to achieve bioclimatic comfort conditions. The configuration of the surrounding site must direct windflow to create the correct high and low air pressure areas surrounding the building. Inlets should be located in high pressure zones and outlets in low pressure zones to promote airflow through a space. A large ratio between inlet and outlet size (small inlets, large outlets) increases the speed of airflow. The

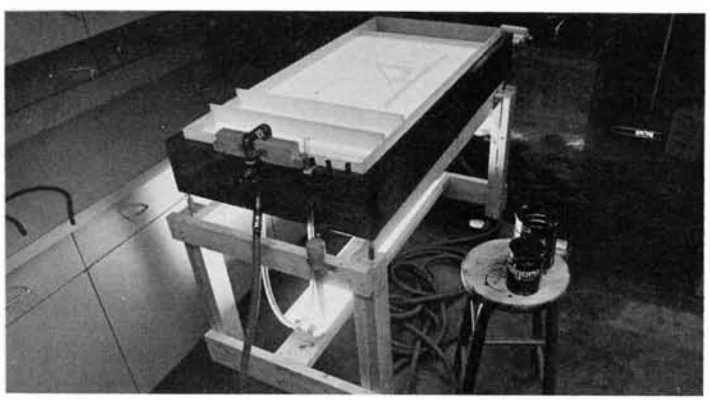

Figure 1: The CERES/CAP Fluid Mapping Table.

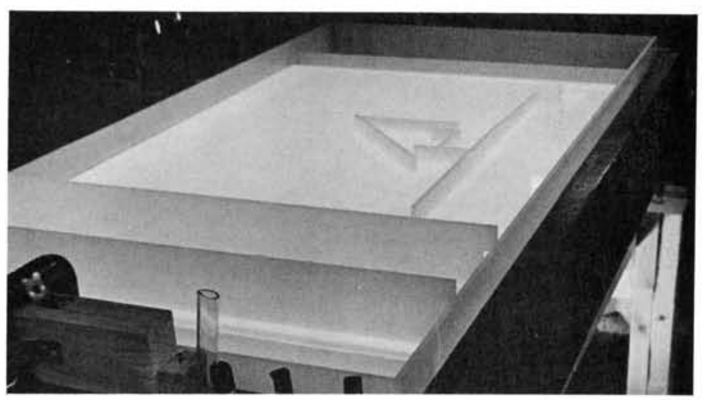

Figure 2: A typical "two-dimensional" model on tabletop.

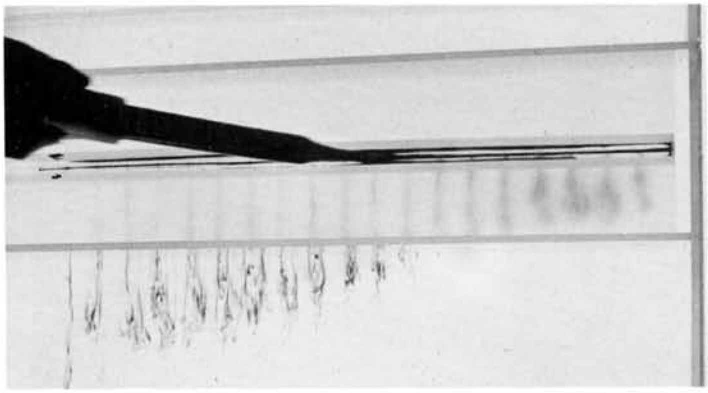

Figure 3: The dye inducer.

placement of the inlet will influence how air moves through the space in many ways. For example, an inlet placed too high on a wall may cause airflow to remain too close to the ceiling to achieve useful cooling effects. The physical characteristics of the inlet itself can also be a factor. On the exterior, certain configurations will create high pressure areas and catch wind, diverting it into the building. On the interior, the inlet design can directionally influence the path of air to flow more over the inhabited area for increased cooling effectiveness. The layout of barriers and partitions within the space can either enhance or inhibit natural ventilation tendencies. Barriers that are more or less parallel with airflow are acceptable while perpendicular barriers greatly reduce effectiveness of the scheme. Finally, the distance between the inlet and outlet locations can influence air speed which is more important than the actual volume of air that moves through the space for cooling.

Another link between energy conservation and wind flow characteristics is the concept of wind sheltering. In cold climates, wind blowing across a building's surface accelerates the rate of heat loss through the building materials due to convective heat transfer and therefore increases the energy needed to maintain interior temperatures. Sheltering building surfaces from windflow can reduce this effect. Any object placed in the path of windflow deflects it and leaves an area of low wind velocity or "wind shadow" on the down-wind side of the barrier. Wind shadows can be used to shelter building surfaces. The size and shape of these wind shadows is influenced by the size, shape and configuration of the windflow barriers.

Because of this wide array of variables it is very difficult to mathematically predict results in natural ventilation and wind sheltering schemes. Even more difficult, is the use of calculations as a design tool during the de-

Figure 4: Conducting a test.

sign of the system. While rules of thumb exist, they do not allow adjustment for the unique variations which occur within virtually every design. The time investment required and the lack of connection between understanding numerical figures and physical windflow patterns and characteristics are also deterents to the use of mathematical methods for system design.

Opportunities

As an alternative, physical modeling techniques can simulate actual conditions and can simultaneously account for the large number of variables present in every design situation. Also, modeling allows a better qualitative understanding of wind behavior through visualization with a relatively small investment of time; an asset in a design situation. In addition, some quantitative results can be obtained.

Much research has been done using wind tunnels and three-dimensional models. Knowledge about the nature of windflow and its interaction with buildings concerning structural stability and natural ventilation has been gained as a result of this research. Improved design responses have also been achieved as a result of direct testing using these devices. Wind tunnels, however, are large and expensive. In addition, the construction of appropriate test models requires more time and effort than might be desired in the important early stages of building design.

A slightly less accurate, smaller, quicker, and less expensive alternative to wind tunnel studies is fluid mapping. Fluid mapping is based upon principles of fluid mechanics and the fact that both moving air and water can be considered fluids of similar dynamic character. A fluid mapping table is a device that utilizes the flow of a thin layer of water around and through a simple model

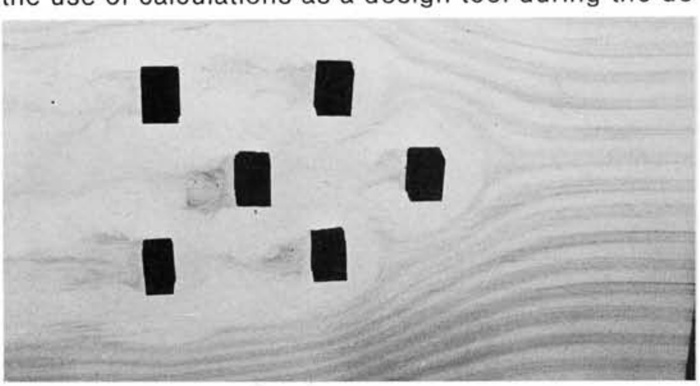

Figure 5: Site plan building configuration study -wind sheltering.

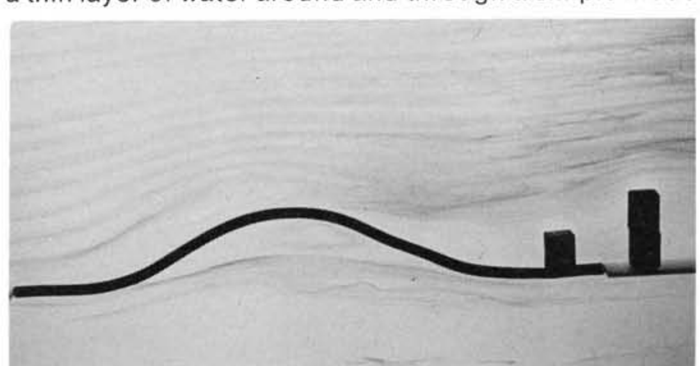

Figure 6: Wind sheltering study simulating bermed earthforms.

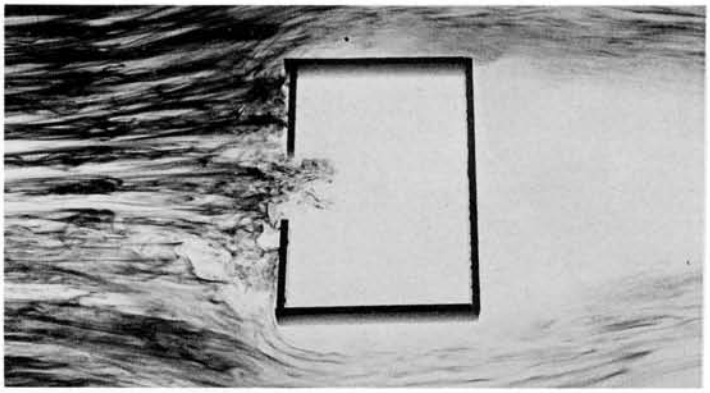

Figure 7: Wind will not enter a space without an outlet.

of a two-dimensional configuration (ie. a building plan or section, see figure 2). As this thin layer of water flows around and through the models, its path simulates the path that wind driven air would take. While the Fluid Mapping Table cannot simulate air movement as a result of thermal forces, the dynamics of wind driven turbulence and ventilation are significant elements for design consideration.

Methods

In order to reveal the path that the water is taking, dye is introduced at regular intervals along the layer of water. The resulting lines of dye move around and through the model(s). As quick adjustments are made to the model configuration or the water (wind) velocity, immediate feedback concerning changes in airflow tendencies can be obtained.

The fluid mapping table itself is constructed of a flat surface of plexiglas across which a continuous layer of water flows. Baffles at each end reduce turbulance from water entering and leaving the table surface and insure a parallel flow of water from one end of the table to the other. A dye inducing device is placed across the table and dye is poured into a groove on its surface. The dye flows through small holes in the inducer and into the water as it flows below thus creating parallel "tracer" lines. Simply constructed models of plexiglas may then be placed in the water stream and the design adjusted until the desired results are achieved (see figures 3 and 4). A light source below the table illuminates the translucent surface allowing photo documentation of test results or tests in progress using, prints, slides, film, or video techniques.

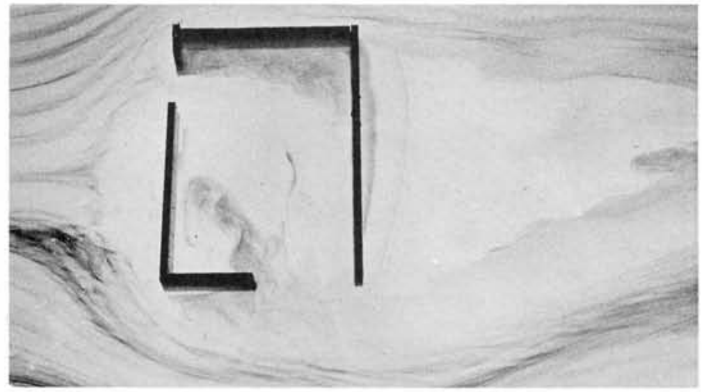

Figure 8: Typical airflow and eddy pattern through a space in plan.

Applications

The device in place at CERES has numerous applications in research, education, and service. As a research device the Fluid Mapping Table can be used to determine solutions to specific design situations as well as to broaden general knowledge concerning the interrelation of natural ventilation, wind sheltering, and energy conservation through more generic studies. As an educational device the Fluid Mapping Table gives faculty a method to physically demonstrate fundamental principles (see figures 6,7,8, and 9) as well as more complex characteristics (see figures 10,11, and 12) of windflow. In addition, it gives the student a "hands on" opportunity to experiment and learn about windflow principles, particularly in relation to conceptualizing design approaches, as well as in the refinement of specific design responses in studio projects. As a device for service, local and state professionals and communities will have access to the device: 1) as an educa tional tool for learning about windflow, wind sheltering, and natural ventilation, and 2) to gather data and solve problems specific to their particular interests. In addition, access to other research results obtained from this device will be provided.

Conclusion

The Fluid Mapping Table is now available at CERES for use by students, faculty, the profession, and the community. Its creation is part of a larger plan for an Environmental Systems Laboratory which will strengthen CERES, CAP, and BSU by enabling the provision of better quality research, education, and service in all areas pertaining to the environment, human response, and energy use.

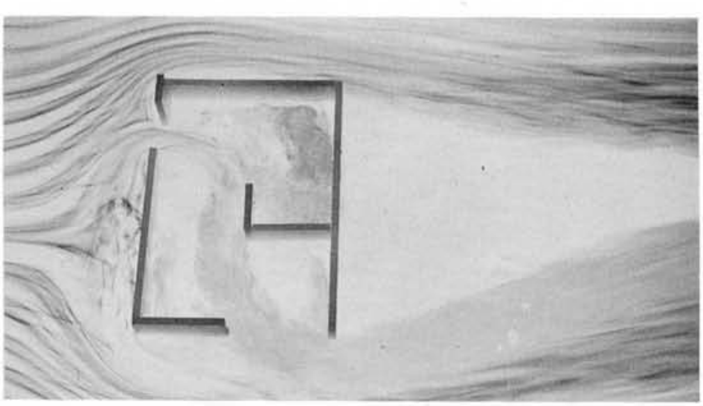

Figure 9: Improper partitioning of a space can inhibit windflow.

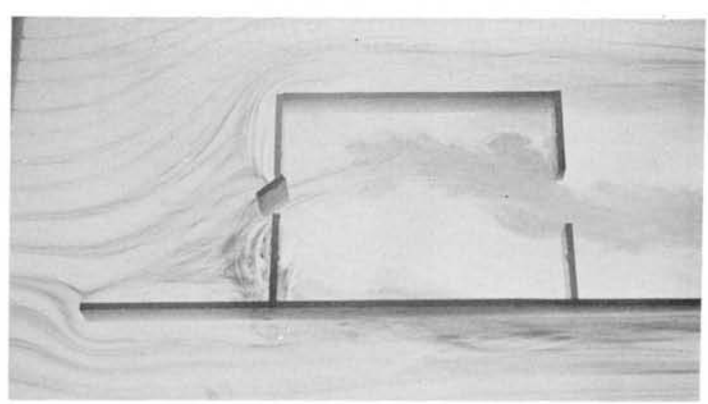

Figure 10: The characteristics of an opening can control the nature of windflow through a space.

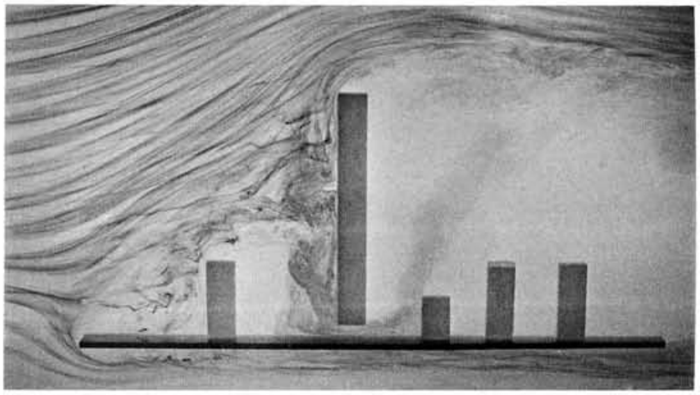

Figure 11: A study of the effects of tall buildings on windflow in an urban context.

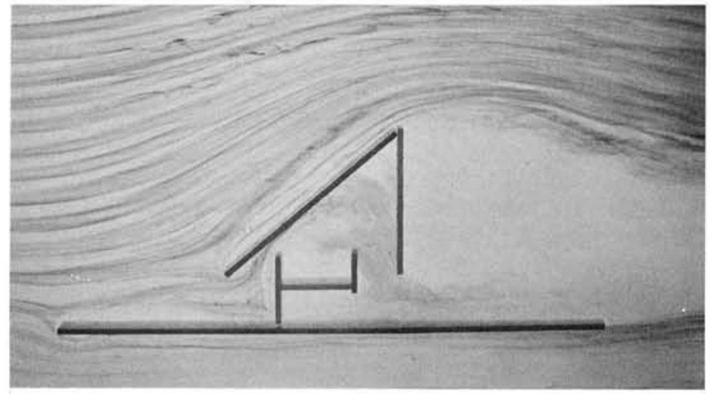

Figure 12: A study of a natural ventilation scheme.

Procedures

The following is an outline of procedures to follow for the operation of the Fluid Mapping Table. For further assistance please contact J. Culp or the CERES laboratory technician.

Set-Up

1. Move the table to a flat level surface adjacent to a sink or drain, faucet, and electric outlet.
2. Connect the garden hose from the faucet to the table's supply plumbing (see figure 1). The fixture will lift off and out of the table to facilitate connection. Make certain all connections are snug.
3. Make certain that the table's black drain hose is pointed into a sink or drain and that the clear plastic tubing at the supply end of the table is fastened so that its free end is held above the level of the table's edges (see figure 2).
4. Turn on the water slowly at the faucet. Use cold water only. Tighten connections as necessary. The water velocity should be adjusted at the faucet NOT AT THE TABLE'S VALVE.
5. After water begins to drain into the sink, level the large table surface using the adjustable legs and the levels provided. Return the levels to their holders when completed.
6. Plug in the fluorescent fixture (if desired) using an extension cord.
7. If dye is not already mixed, sprinkle A FEW crystals of potassium permanganate (KMn04) into the bottom of a container and add a moderate amount of water slowly. Experiment with the mixture. The solution should be a deep purple when mixed correctly but a few crystals will make a considerable amount of dye (BEWARE-THE DYE WILL STAIN THE SKIN AND CLOTHING-FLUSH WITH WATER IMMEADIATELY-AVOID CONTACT WITH EYES AND DO NOT TAKE INTERNALLY!).
8. After the dye is mixed, place the dye inducer across the table near the supply end. Make certain there are no bubbles under the inducer or clinging to the table surface.
9. Fill the large eyedropper provided with dye. Place its end in the dye inducer's groove and inject dye while slowly sweeping the eyedropper from one end of the inducer to the other (see figure 3).
10. The lines of dye should remain parallel to the table's edges and to each other for the full length of the table's surface. If they are not, adjust the table legs until the lines of dye are parallel.

Testing

1. The models should be made of 1 inch strips of plexiglas set on edge. The pieces may or may not be glued together.
2. Additional dye need only be induced periodically NOT continuously.
3. Velocity measurements may be taken by determining the rate of water flow ("scale feet" per unit time). Water velocity should be adjusted AT THE FAUCET.
4. For photo documentation (with light on): FOR BLACK AND WHITE PRINTS: use a SLR camera (on tripod if possible) w/Tri-X film. Set the shutter speed at 1/30 sec. (or faster if possible) and open up the aperature 1 to 2 stops from the meter reading. Use a 50mm lens. Use a dark green filter to increase contrast (important if film is to be sent in for processing). If film is to be self-processed high contrast paper may be used to increase contrast if desired. FOR COLOR SLIDES: use a SLR camera (on tripod if possible) w/400 ASA daylight film. Set the shutter speed at 1/30 sec. (or faster if possible) and open up the aperature 1 to 2 stops from the meter reading. Use a 50mm lens with a rose-colored filter.

Clean-Up

1. Unplug the fluorescent fixture.
2. With the table running, rinse the dye inducer with the eyedropper until clean. Allow the table to run until all dye has drained into the sink.
3. Shut off the table and allow it to drain (the table surface may be wiped carefully with the squeege to expedite drainage).
4. Lower the free end of the clear plastic tube into a bucket and drain the supply end of the table. Re-attach the plastic tube's free end when completed.
5. Disconnect the garden hose from the table supply fixture (beware of spillage! - disconnect while holding the fixture and hose over a sink).
6. CAREFULLY wipe excess water from the end baffle areas, the table surface, and the dye inducer with a soft, clean cloth when finished.

Development of these materials was funded through the CERES Publications Program. For further information contact: Robert J. Koester, Director, Center for Energy Research/Educational/Service, Ball State University, Muncie, IN 47306. Telephone (317) 285-1135.