ENERGY CONSERVATION WITH NATURAL AIR FLOW THROUGH WINDOWS

BENJAMIN H. EVANS

ABSTRACT

The need for optimizing energy use in buildings is drawing designers back to some of the basics of natural environmental control. Of the principal elements which govern human comfort, air temperature, humidity, and air movement, the latter is the only one which can be significantly controlled without substantial energy use.

Windows are of primary concern as vehicles for getting air into and out of buildings, and they must be chosen carefully for their air-controlling characteristics. However, windows are only part of a "system" of air-controlling features which must be used to enhance air movement through the "living zone" of a building where it can cool occupants.

Air is moved by pressure differences set up as wind strikes a building. The wind moves from high to low pressure. Wind has inertia and it causes friction as it moves.

The location and type of inlet opening (window) determines the pattern of the air entering the building. The size of the outlet opening determines the speed-- the larger the outlet, the faster the air moves.

The location and type of window directs the air as the nozzle of a hose directs water. The air tends to follow the opened window vanes.

Other elements such as overhangs, landscaping screens, trees, and shrubs can also be used in the control of air movement.

INTRODUCTION

The energy crisis and the need for optimizing energy use in buildings is forcing designers to get back to some of the basics of natural environmental control. This may be the best thing that has happened to architecture since the discovery of air conditioning. The introduction of natural air movement into habited spaces for cooling humans is almost a forgotten art after having been a significant determinant of building design for eons of time. It seems appropriate now for us to reconsider the possibilities of cooling as related to air movement and window design.

Windows in buildings are expected to respond to a variety of problems and opportunities-- to allow people a view out (and in), to collect solar energy,

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to reject solar energy, to reject rain and moisture, to reduce heat transmission, to prevent infiltration, to allow ventilation-- and they must be light-weight, rustproof, rotproof, maintenance free, easy to operate, and above all, must have a low first cost. In spite of all the accomplishments manufacturers have made in window design and production, and there are many, there seems to be an almost total lack of concern for; and understanding of, summer ventilation through windows. The emphasis has obviously been on infiltration and the prevention of "drafts." We are all painfully aware of the energy losses that acrue through the infiltration of cold air around windows and other openings. (Although when we seal our building up tightly we then have to introduce fresh air into the system and dehumidify it.) Nevertheless, more thought has gone into the design and performance of the window when it is closed than when it is open.

But let it not be implied here that air movement through windows is the solution to the world's problems. It isn't, of course. When you and I are in Houston, Texas, and the air temperature is 90F and the humidity is 65% we will want to retreat to the nearest air-conditioned building and be sure that the windows are closed. And when we are in Buffalo in January, we will be very concerned about infiltration of cold air around windows. So, there is an appropriate time and place for the effective use of natural air movement and this paper will be devoted to its application in moderate-to-warm climate conditions.

The four main variables affecting human comfort are, as we know, air temperature, radiation, humidity, and air movement. Controlling any one of these variables enables us to adjust human comfort to some extent. But the absence of temperature and humidity controls, which are the big energy users, leaves us with air movement as the only "energy free" controllable factor.

Air movements produce a cooling tendency in people by accelerating the conduction of heat from the body and by increasing the opportunity for evaporation of skin moisture which is a cooling process. Even when the air is moving where it can carry off body heat, there are some characteristic constraints. Some people have low skin moisture (they don't perspire much). People often wear clothing which prevents air movement from doing its job. (The secretaries in Houston offices sometimes wear long sleeves or sweaters to compensate for the air conditioning and then when they go out are miserable). Some house wives would rather be hot than have the cooling air currents blow their $60 permanents. And in extremely dry climates where body moisture will evaporate easily, direct wind currents are often not only unnecessary but undesirable. Still, that leaves ample opportunity for use of natural air flow in wide parts of the United States and in a variety of seasons. The problem is, people have simply gotten out of the habit of using air movement. Our buildings are not oriented properly, our windows are not selected for good air movement, our streets are not laid out with regard to wind orientation, and our buildings are not designed to take advantage of air movement. Designers of our environment must become aware of the possibilities for energy conservation, economic savings, and psychological benefits to be accrued from the proper use of windows for cooling.

Windows, however, cannot be considered in isolation from the rest of the building and from the effects even of other buildings and objects in the immediate surroundings. It might be said the windows are part of a "system" for moving air around and through buildings. The characteristics of this total ventilation system were studied at the Texas Engineering Experiment Station in the 1950's where the feasibility of using scale models to test air movement in a low speed wind tunnel was established. The author was a member of the architectural research team which did the experimental development and testing. This paper puts forth some of the findings of that research team.

CHARACTERISTICS OF AIR FLOW

Let's look at the characteristics of natural air movement. Air is moved by pressure differences and by temperature differences which result in pressure differences (Fig. 1). Air moves from high pressure to low pressure, and hot air rises. Air will sometimes flow through a low structure by temperature differences alone, but in hot weather its cooling effect is negligible compared to that caused by even a very light breeze setting up pressure differences around the structure. Studies in Australia have shown that in industrial plants with significant process heat, even slight breezes will overcome convection currents.[1]

Air has inertia and, once set in motion, will continue to move in that direction until some external force causes it to change its direction.[2]

Air movement causes friction as a result of the air coming in contact with surfaces and objects. Such friction can be caused by shrubbery in the ground, by venetian blinds, by louvers, drapes, window muttons and mullions, and so on. This phenomenon is more significant in air movement through ducts than in the less constrained environment of rooms.

PRESSURE DIFFERENTIALS

Of fundamental importance is the consideration of where the pressure difference exists when the wind envelopes a building. When the wind impinges against a building, a region of high pressure is created generally on the windward surface of the building.[3] As the air is deflected around the building (Fig. 1), it speeds up and causes relatively low pressures along the sides just behind the windward face and along the entire lee side.

Naturally, the air tends to flow into the building at the high pressure points (windows, cracks, etc.) and out at the low pressure points. The speed at which the air moves through the building is determined by the relative magnitude of the pressure areas created by the impingment of oncoming air and by the establishment of window openings-- inlets and outlets.

The greatest differentiation of pressures will be created when the air movement is perpendicular to the windward face of the building. Fig. 2 shows how the leeward eddy pattern and, hence, pressure area downwind is reduced as a rectangular building is slanted away from the incoming air.[4]

In circumstances where the building is made up of combinations of shapes, or odd shapes, or faces the wind at odd angles, the prediction of pressure differentials can be very difficult. In fact, it is safe to say that, except in very simple situations, the only way to determine pressure differences and resulting air flow patterns is through the use of wind tunnel studies of scale models.[4]

But just moving the air through windows and into (and out of) the building is not all there is to producing effective cooling of the occupants inside.[5] The air must move through the "living zone" of the space where the occupants will feel the movement of the air. (Fig.3) There is some value to moving air across the ceiling, for instance, to carry off the hot air build-up, but that air, being above the occupants, will not be very effective in causing a cooling sensation. Properly utilized windows are among the most effective elements for giving the incoming air the proper directional component.

DETERMINANTS OF AIR FLOW PATTERN

There are two main factors which determine the air pattern as it enters the building; they are the location of the inlets in the wall and the type and configuration of inlets used.[2] A third factor, usually of less significance, is the location of other objects adjacent to the inlet such as landscaping, overhangs, and louvers.

LOCATION OF THE INLET

Consider the location of the inlet. As the air impinges upon the face of the building, it builds up velocity vectors which move across the surface. If the window opening is located in the center of the wall, these vector currents will be symmetrical and the air will enter the window very much in a "straight in" pattern. (Fig.4) If the inlet opening is located off center, as in the third story wall, the air will have a tendency, because of the surface vector forces, to enter the room in an upward pattern. Or if the opening is in the first floor, the air will have a tendency to enter the opening in a downward direction, although the ground surface also has its effect on the building surface vectors. These air pattern variations, shown in Figure 4, are caused by the inequality of pressure above and below the inlet openings as a result of their location in regard to the proportion of solid wall surface around them. The same principle applies to the air patterns resulting from the location of the inlets as viewed in plan (Fig.5). As may be seen from Figure 6, the outlet opening is irrelevant to the pattern of the air entering the building. The inertia of the air entering the inlet opening causes it to flow upward and across the ceiling regardless of the location of the outlet opening and continue across the ceiling until it reaches the immediate vicinity of the outlet.

TYPES OF INLET

The configuration of the inlet itself is a major determinate of the incoming air flow pattern. Figure 7 shows what happens when a vertical projection such as a door, shutter, or a casement window is added to a simple opening. The force component (or vector) from the larger wall surface is disrupted, allowing the force component on the smaller wall surface to become dominant and the pattern of the entering air is altered dramatically. One might say that the inlet configuration acts very much as the nozzle on a hose and gives direction to the air passing through.

While there are a great variety of windows on the market, they may be classified as one or a combination of three basic types as related to air movement.(6) The three types are (1) simple opening, (2) vertical vane, and (3) horizontal vane (Fig.8).

Simple opening windows are such windows as the single hung, double hung, and horizontal sliding-- any window which does not pivot, but opens by sliding in a single plane.

Vertical vane windows are the side hinged casement, the folding casement, and the vertical pivoted or reversible window-- any window which opens by pivoting on a vertical axis.

Horizontal vane windows are the projected sash, the awning, the basement, the horizontal pivoted, and the jalousie or louvered glass window-- any window which opens by pivoting on a horizontal axis.

Air patterns resulting from typical windows and openings are shown in Figures 9, 10, and 11.(6) Typical air patterns are shown in section and plan, assuming a wind perpendicular to the plane of the window wall. Air movement through simple window types tends to be governed by the exterior wall surface conditions or force vectors (Fig.9). With vertical vane windows, the air is directed by vanes (in plan view) and generally flows along the surface of the adjusted window sash (vane), just as the flow of air follows the rudder of an airplane's tail (Fig.10). The direction of the air in section is still controlled by the force vectors of the exterior wall surfaces above and below the window. The horizontal vane window works on the same principle as the vertical vane except that the operating sash directs the air up or down rather than sideways (Fig.11).

DETERMINANTS OF AIR SPEED

As noted previously, the speed with which the air moves through the building is principally a function of the relative pressures at the inlet and outlet and the sizes of these openings. Increased air speeds within a building are acquired when the outlet is larger than the inlet. Inertia and friction will play their part to some degree in slowing air movement but their effect is relatively minor.

Theoretically, the greatest volume of air flow, or the greatest number of air changes, is acquired when the inlet and outlet are equal in size.(2) And, of course, maximum total volume, or the greatest total number of air changes, are acquired when both the inlet and the outlet are as large as possible.

But this volume or air change view of natural ventilation has little to do with summer cooling.(5) A building may have many air changes per hour, but if the air does not flow through the living zone and the air speeds are low, the occupants will not experience a cooling sensation.

Most people labor under the misapprehension that good air flow is achieved when the large openings are faced toward the breeze with the idea of "scooping" the air into the room, along with some small openings on the opposite side of the room to allow cross ventilation. Actually, the reverse situation would be better from the standpoint of summer cooling, assuming the inlet windows are properly selected and placed to direct the air into the living zone.

Figure 12 shows air speeds through typical building sections as tested in the wind tunnel.(6) The oncoming air speed is indicated as 100, and the inside air speeds are expressed in percentage of this outside speed. The diagrams clearly indicate a substantial gain in inside air speeds as the size of the outlet is increased while holding the inlet size constant.

Figure 13 points out the effect of the location of the outlet opening on air speed. Because of the air's inertia, when it is forced to change its direction of movement its speed is retarded somewhat and summer cooling energy is wasted. Changes in the direction of the air movement through a building should be kept to a minimum.

LANDSCAPING

Figures 14 and 15 show some of the effects of landscaping on the air flow through a building.(7) Figure 14 shows how high hedges may be used to create pressure differences and effectively cause air to flow through a building oriented with no window inlets facing into the wind and would otherwise be without significant air movement. This suggests that buildings do not necessarily have to be oriented perfectly to the wind to get cooling movement of the air.

Figure 15 shows the effect of variations in a hedge and tree arrangement. With the hedge located leeward of the tree as shown in the upper diagram, the air flow is deflected over the building creating a low pressure region in front which causes the air to be drawn through the building slowly in the opposite direction to the wind. But with the hedge and tree arrangement reversed as shown in the lower diagram, the air flow is directed back to the ground and through the building where its cooling effect can be felt.

SOME AIR-COOLED BUILDINGS

The impetus for the experiments in the wind tunnel at Texas A&M came at the beginning of the post World War II school building boom. Air conditioning was not yet in demand and good ventilation was a must for the Southwest area. As a result of applying wind tunnel tests to the preliminary designs of a number of architects, several excellently ventilated school buildings were built. Figure 16 shows the results of two of these school designs.

SUMMARY OF CONCLUSION

1. The type of inlet opening (window) and its location in a wall determine the initial air flow pattern through a room. However, because of the variability of the factors which make this so, air flow patterns are difficult to predict without testing, except in the simplest situations.
2. The relative size of the outlet to the inlet opening in the principal determinant of the speed with which the air moves through a building. There must be "cross ventilation" and the outlets should be larger than the inlets for best cooling results.
3. It is important for summer cooling that the inlet window direct the incoming air into the "living zone" where it can cool the occupants. Air changes mean little in regard to summer cooling.
4. Changes in direction of air flow tend to retard the speed of air movement and, therefore, should be avoided if possible.
5. Windows should be carefully selected with consideration for summer cooling as well as for winter protection.

While natural ventilation of habitable spaces is not a solution for all cooling problems, its proper use in many situations where mechanical cooling has been used in the past can do much toward providing human comfort. In addition to the fossile fuel energy saved through natural ventilation, many people find a psychological uplift as a result of the freedom from confinement and the "sameness" of the totally controlled environment.

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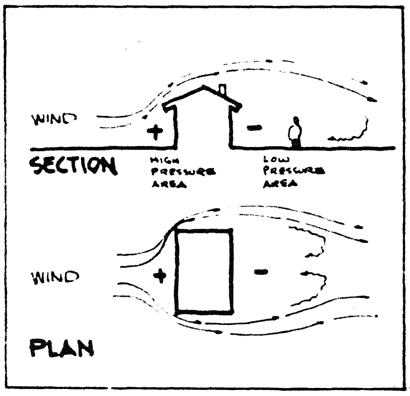

Fig. 1

Fig. 1 High and low pressure areas are established as wind blows over and around a building

Fig. 2 Highest pressure differentials will occur when the oncoming wind is perpendicular to the long axis of the building

Fig. 3 Air must move through the "living zone" of a building to provide best cooling for people

Fig. 4 The location of the inlet opening in the wall is a factor in determining air flow patterns

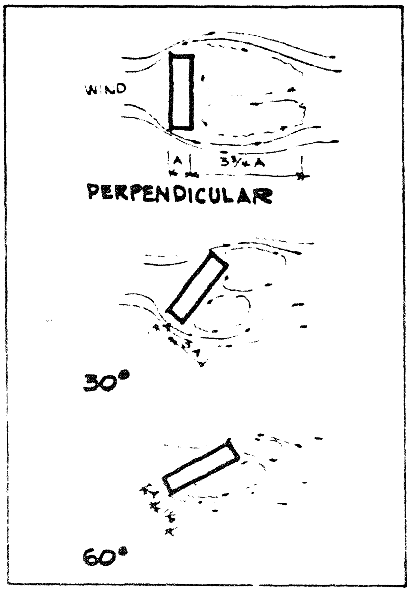

Fig. 2

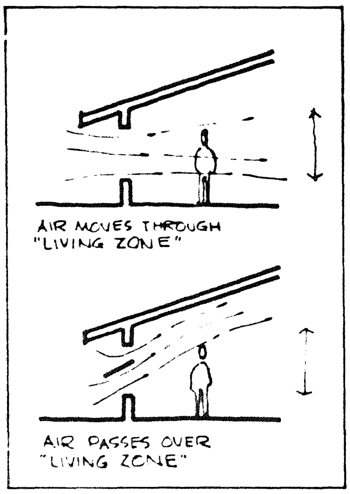

Fig. 3

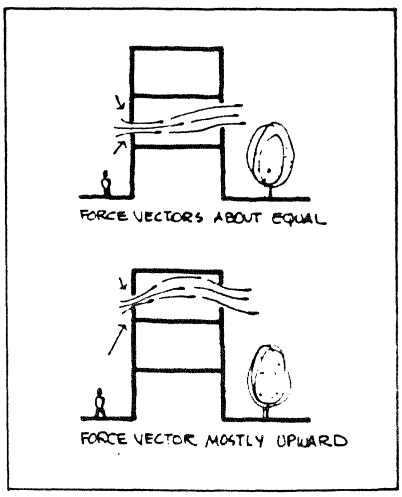

Fig. 4

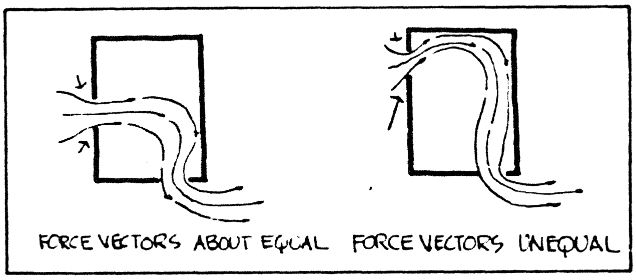

Fig. 5 The location of the inlet opening in the wall is a factor in determining air flow patterns

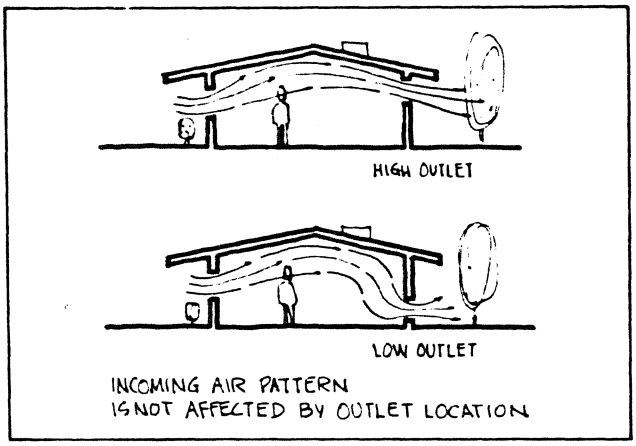

Fig. 6 The location of the outlet opening does not significantly affect the incoming air pattern

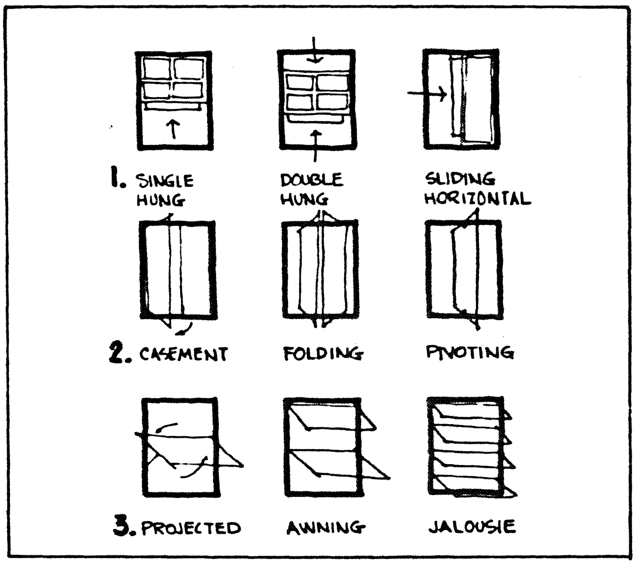

Fig. 8 The 3 basic types of windows are:
(1) Simple opening
(2) Vertical vane
(3) Horizontal vane

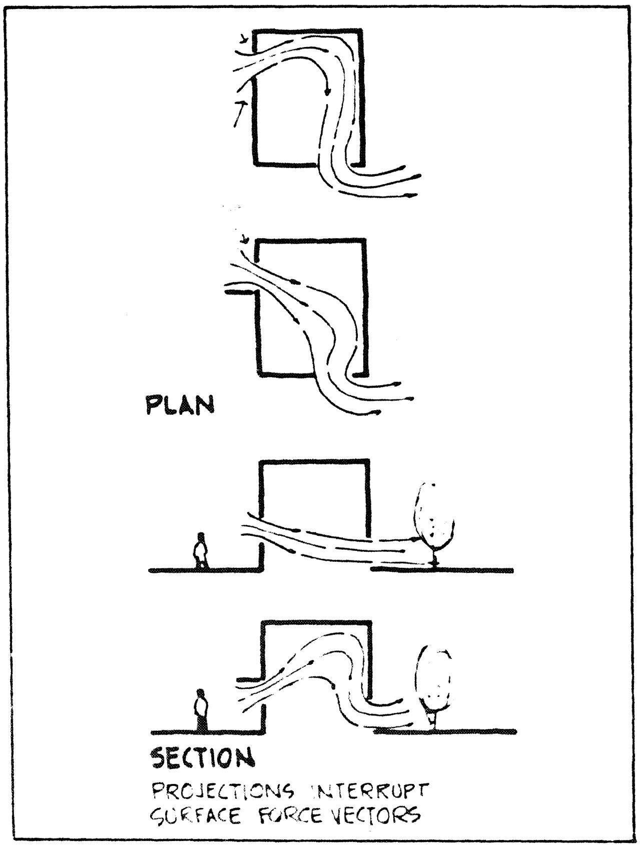

Fig. 7 Exterior projections at the inlet will effect inter or air flow patterns

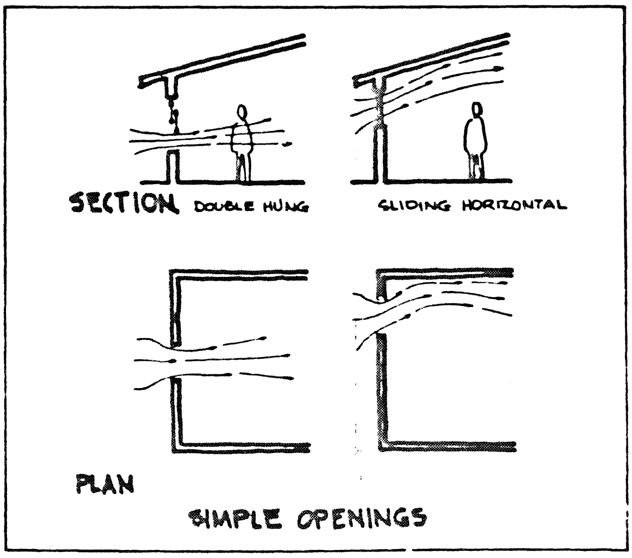

Fig. 9 With simple opening windows, the air flow pattern is determined by the location of the inlet in the wall

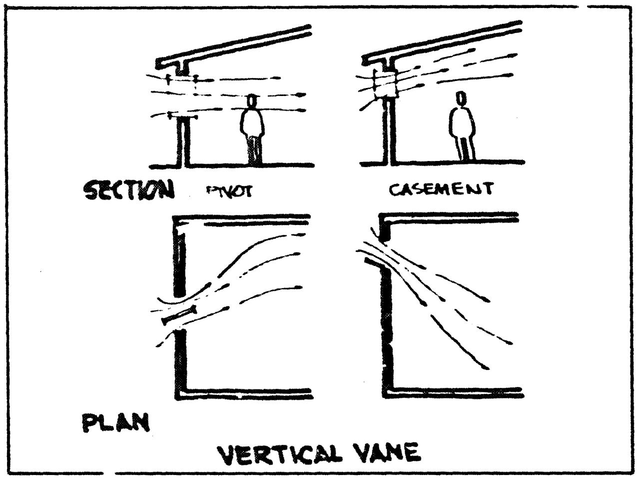

Fig. 10 With a vertical vane window, the air pattern is controlled by the vane (in plan) and by the location of the inlet (in section)

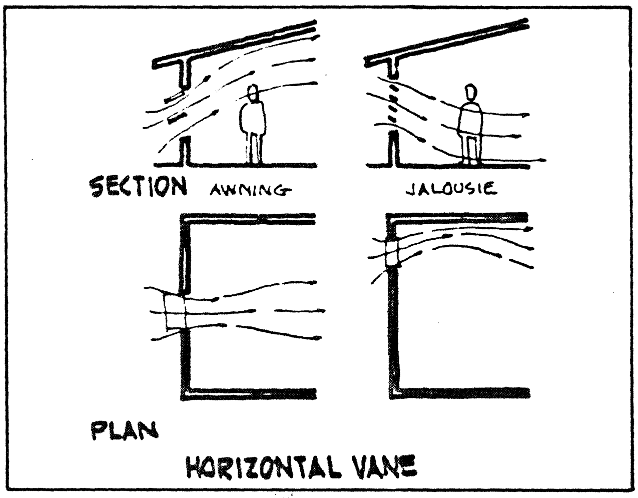

Fig. 11 With a horizontal vane window, the air pattern is controlled by the vane (in section) and by the location of the inlet (in plan)

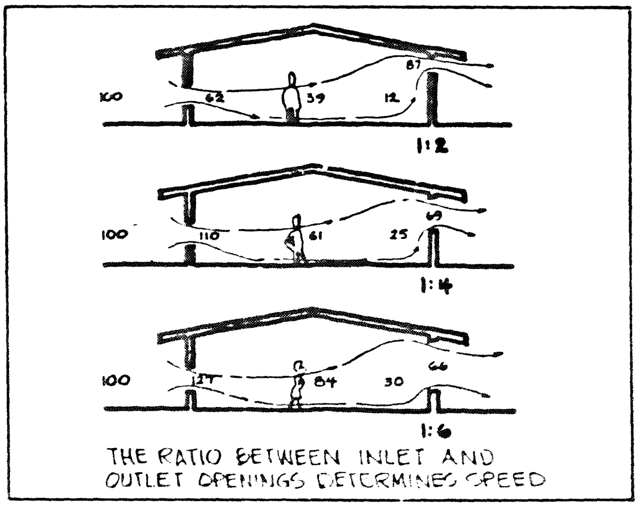

Fig. 12 Increased outlet size in relation to the inlet size, results in increased air speeds

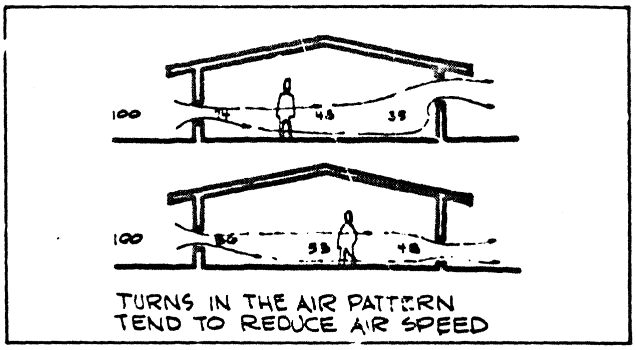

Fig. 13 Turns in the air pattern such as might be caused by the location of the outlet, tend to reduce air speed

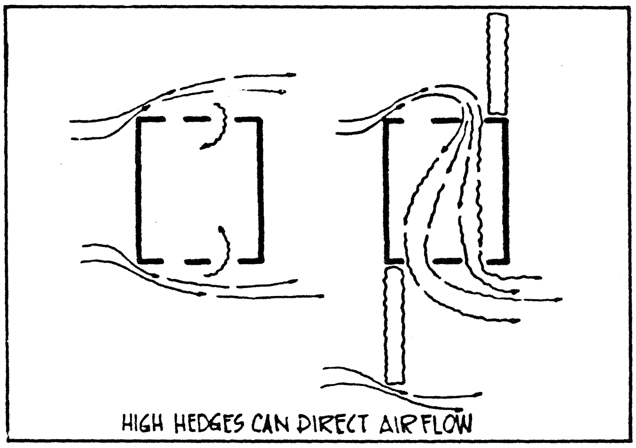

Fig. 14 High hedges (or screens) can be used to change pressure differentials and move air through a building

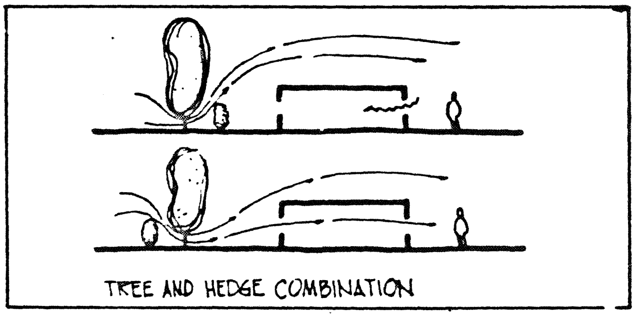

Fig. 15 Combinations of trees and hedges can be used to control air movement into buildings

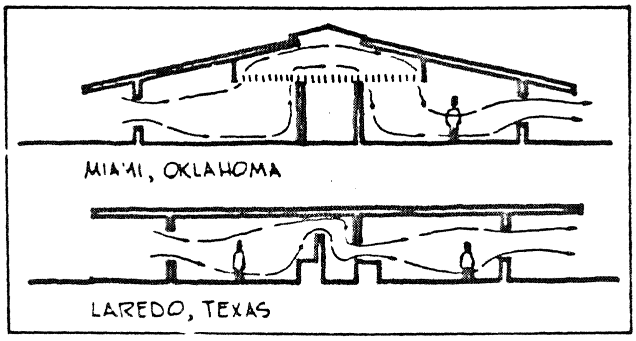

Fig. 16 Two school building designs that allow for natural air movement

DISCUSSION

D.R. WULFINGHOFF, Wulfinghoff Energy Services, Wheaton, MD: I thought your presentation was a good introduction to the basics of ventilation. However, I would take exception to two of the themes of your paper.

First, it seems obvious that merely opening windows is unsatisfactory, from the standpoints of excessive drafts on people and work objects, the entry of rain and dirt, and excessive chilling effect in cold climates. It seems equally clear that the effective approach to natural ventilation is not merely opening windows, but must lie in the development of devices, probably fairly simple in nature, that will control natural drafts and make them acceptable to occupants. For example, we have conceptualized a simple gravity damper with a dashpot and diffuser that will control gusts and compensate for changes in wind direction. This leads me to the question: How much of this more sophisticated treatment of natural ventilation is presently going on?

Second, much of your work is reported in terms of wind tunnel data, where a prevailing wind direction is assumed. However, for a majority of residential homes and commercial buildings in the U.S., there is no strongly predominant wind direction. Wind control devices or systems must be designed to effectively accomodate winds from any direction.

BENJAMIN H. EVANS: Your comments raise some good points. First, let me reiterate that I was addressing the issue of natural ventilation as an agent for directly cooling human beings by blowing across their bodies during warm weather. I noted that some people do not like to be in the direct air flow for a variety of reasons. Drafts (or unwanted air currents) can certainly be a problem during cold weather.

The development of various devices (in addition to windows) for controlling air flow would be very helpful to the field. I am not aware of any such developments in progress. I believe a successful example of the idea was embodied in the Laredo school described in my paper, in which the air entered the downwind room through a louvered grill.

Any simulation technique, such as wind tunnel studies, has limitations. We study things through simulation because we can get <u>some</u> answers and because simulation is quicker, easier, and less expensive than full-scale studies. But you are quite right, that techniques need to be developed for advantageously using the wind regardless of its direction. I am working on that.

P.O. FANGER, Technical University of Denmark, Lyngby, Denmark: I do not agree with point 3 in your conclusion: "Air changes mean little in regard to summer cooling." Cross ventilation may be useful for two reasons: (1) the increased velocity may cool the occupants, and (2) increased ventilation may cool the space. The air change is important for cooling the space when the outside air is cooler than the inside, which is often the case during the night. For centuries this has been applied in houses in Mediterranean countries, where windows were maintained open during the night and morning. Windows and shutters were then closed during the afternoon and were not opened until the outside air cooled down below internal temperature late in the evening.

EVANS: You have pointed out a serious oversight in my paper. I was so intent on discussing the value of <u>direct</u> flow across people that I neglected the value of nighttime cooling. My point was that even significant air changes can be accomplished without producing sufficient direct air movement to cool the body during warm weather. Very little mass-cooling will take place regardless of the number of air changes when the air temperature is at 90°F, for example, but that same 90 degree wind can be very useful in cooling the body.

DeGIDS: (This is a reaction to a question posed at the presentation.) In Holland we use natural ventilation in winter. In summer, large window openings cause some complaints about drafts.

EVANS: As I have already noted, my paper dealt with warm weather and the use of direct wind movement for cooling the body. There are many circumstances when this direct air flow is inappropriate.