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Pressurization, convection and air flow inside buildings

Pressurization, convection, and air flow within buildings are interrelated to such an extent with the external pressure conditions imposed by wind impingement that it is impossible to discuss one without the other.

ANALOGY

The action of the wind around a building can be compared to a shallow moving stream of water in which a deep rectangular box is held stationary to the bottom, but is only partly submerged; the water level represents static pressure head (Fig. 1). Water impinging on the flat "bow" of the box builds up in level locally (Fig. 2) until the flow at right angles to the "bow" caused by this additional head equals the volume of the impinging fluid (Fig. 3).

As the impingement head is converted to velocity head and the right angle streams sweep past the edges of the "bow" surface, fluid is aspirated into these streams from the adjacent fluid (Fig. 4). Replacement for that water joining from the upstream side is readily achieved by the onrushing stream. Replacement for water drawn from the downstream sides is not easily effected, since these areas are shielded to some extent by the right angle streams. The fluid level drops slightly. The diversionary effect of the main stream impingement, plus the d minishment of what might otherwise be a partially coun erbalancing static head on the downstream side, brin the right angle streams into curved paths which eve tually come alongside the side walls of the box and agai move with the main stream.

The virtual encirclement of the areas at the sid just aft of the "bow" surface causes a substantial lowe ing of the fluid level or static head in those areas. Rel

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Fig. 1 Water depth is analogous to external pressure

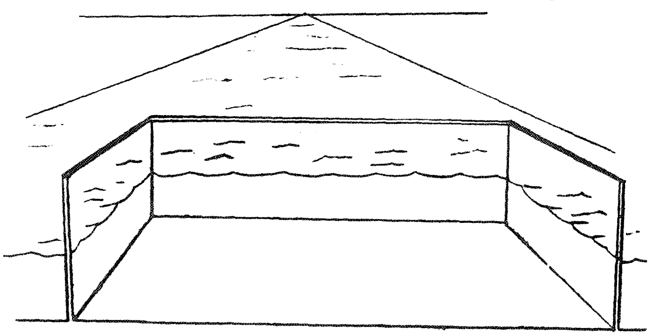
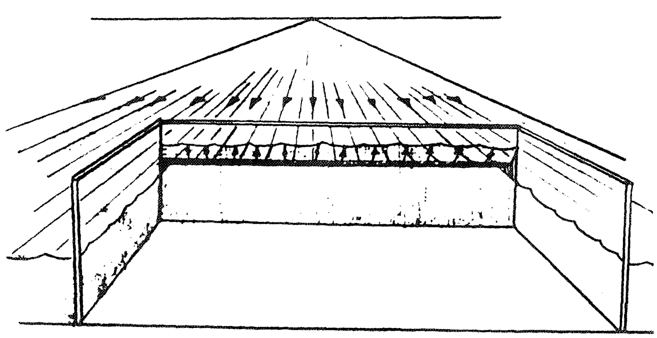


Fig. 2 As stream begins to move, impingement pre sure piles up on windward wall



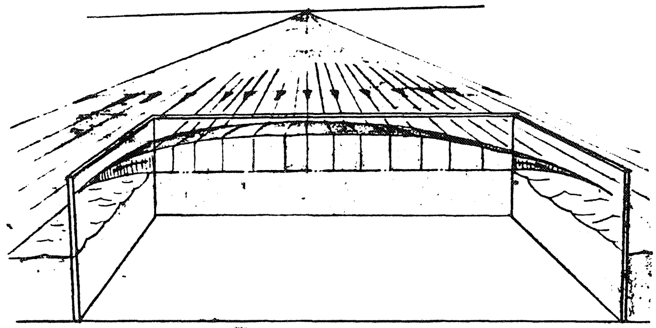


Fig. 3 Lateral flow is diverted by main stream

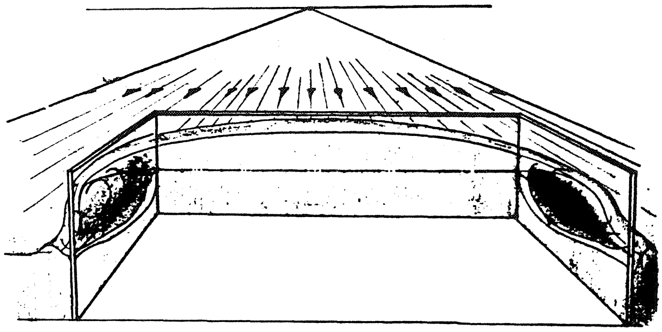


Fig. 4 Induction flow leaves low pressure pockets off corners. Note wide variation in pressures (water depths)

tive to the main stream, this is read as a negative pressure.

Application of this water analogy explains how a similar negative area is produced in the "wake" of the "stern" surface.

The obvious limitation of this analogy lies in the fact that the surrounding environment of the structure is three dimensional, and we must be concerned with the roof as well as the vertical surfaces. However this may complicate the analogy, it does not invalidate it. Further, it gives us an alternative to streamlines as indicators of air flow around the building. While these are useful in visualizing direction of air flow around a building, they are difficult to translate into pressure ideas.

Streamline visualization can lead to such erroneous conclusions as the assumption that an external screen to the windward of an entrance to a negative pressured building protects the building from impinging wind by diverting it (Fig. 5). In reality, the impinging wind produces a local head which can act in any direction available, often around the screen, causing air flow through the entrance into the building (Fig. 6). By analogy, it would seem that water could be prevented from entering a bow opening protected by a diverter screen only above some critical stream velocity.

EXAMPLES

This discussion has pointed out the complexity of the problem. It is convenient, therefore, to limit the examination to a few greatly simplified cases, the first of which is that of a partitionless structure entirely devoid of leaks. The building is hermetically sealed except when the door is open. The location of the door within its wall is such that the entire door is in the same pressure zone. That is, when the wind impinges on this wall, the entire door is within that area of the wall subjected uniformly to a built-up static head. Conversely, when the wall is to the leeward, the door is in that part of the wall which is uniformly at a static head below datum, that is, negative. A high and very long wall with a relatively small door in the middle would meet these requirements.

Under isothermal, zero-wind conditions, absolutely no movement of air takes place through the open doorway. The motion producing forces are absent. If the opening is suddenly subjected to an impinging wind, a local buildup of static pressure, potentially equal to the velocity head of the wind, will develop. In view of the pressure differential which momentarily exists between the building interior at the atmospheric datum and this local external head, air will begin to flow into the building through the opening until the internal static pressure balances the wind-imposed local external head (Fig. 7).

Only a small amount of air must be added to the hypothetical sealed building to achieve this. Boyle's law, or more familiarly

$$P_1V_1 = P_2V_2$$

Where P = absolute pressure
V = net volume
Subscripts 1 and 2 denote initial and final conditions

gives the exact relationship.

An absolute pressure of one atmosphere expressed in units common to ventilation design is about 408 in. wg. If P_2 designates the impingement head generated by a 45.5 mph wind, its value is equal to the initial atmospheric datum of 408 in. wg plus the velocity head of

Fig. 5 No wind, baffle protected opening, pressure equalized

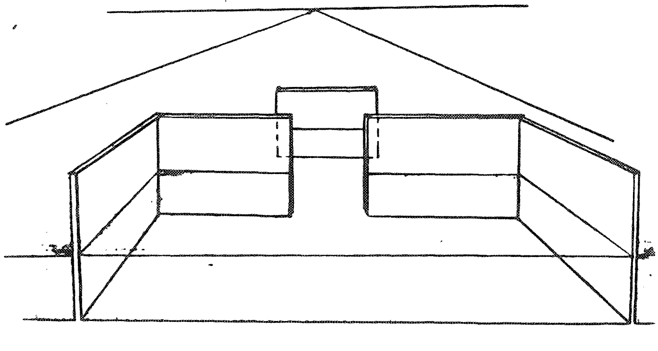
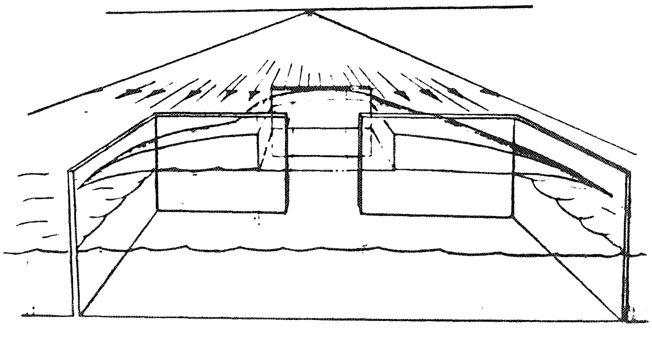


Fig. 6 Build-up, as in Fig. 3, produces an impingement head which will pour air into enclosure around baffle until equalized



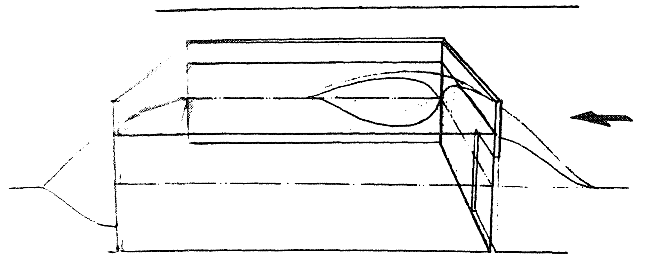


Fig. 7 Wind impingement on opening raised enclosure pressure to impingement head. Note wide variations in pressure at front, side, leeward

the wind, in this case 1 in. wg for a total absolute of 409 in. wg. Thus

$$V_2 = V_1 \times \frac{P_1}{P_2}$$
$$= V_1 \times \frac{408}{409}$$
$$= 0.9975\ V_1$$

The amount of air to be added to the structure to achieve a pressure balance is approximately

$$V_1 - V_2 = V_1 - 0.9975\ V_1 = 0.0025\ V_1$$

or an additional ¼% of the net internal volume of the building. An empty building 50 x 200 ft with a 10-ft ceiling, requires the addition of another 250 cu ft of air to achieve this condition.

Given:

Empty Building
50 x 200 x 10 ft internal
Initial wind velocity = 0
Final wind velocity = 45.5 mph
P_1 = 408 in. wg abs

Find:

Approximate volume of infiltration to balance wind impingment

Solution:

P_2 = 409 in.
$V_1 = 50 \times 200 \times 10 = 100{,}000\ ft^3$
$V_1 = 0.0025\ V_1 = 250\ ft^3$

Intermediate air velocities call for proportionately smaller volumes. By inspection, it is evident that the 250 cu ft could pass through a 3 x 7 ft doorway in a fraction of a second and achieve the new balance (Fig. 8).

Conversely, when the doorway is in the wall to leeward, a depression of the atmospheric datum in the vicinity of the doorway results in a short outflow of building air, leaving the interior at a pressure lower than atmospheric. The amount of air withdrawn to drop the pressure to that of external local conditions is similarly low.

If the door is closed and assumed to be airtight, the wind impingement has no effect, regardless of its direction or magnitude. It has been assumed that the building is airtight. The pressure level that prevailed within the building when the door was sealed will be maintained regardless of external conditions. Only a subsequent change of interior temperature, with its corresponding pressure change at constant volume, introduction of pressurizing air, or generation of gas within the structure could vary the condition.

It is interesting to note that a temperature change of 1.34 F is sufficient to raise the internal pressure of a sealed structure from the reference atmospheric pressure to the additional level required to equal the impingement head of a 45.5 mph wind.

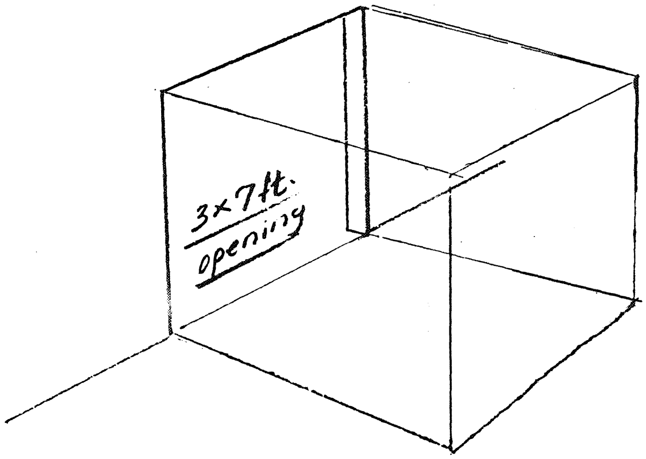


Fig. 8 Assuming steady state conditions, time required to pressurize $t = \frac{d}{Vel.} = \frac{12\ ft}{45.5\ mph} \cong \frac{1}{5}$ *sec*

Complications arise when leakage is introduced in the above structure. As before, only a fraction of a second is required to raise the internal pressure by admission of outside air through the open doorway to a level which will balance the wind inpingement head.

However, the pressure differential across the leeward wall now equals the sum of the impingement head which has been communicated to the building interior plus the negative pressure in the "wake" of the building. If the leak opening is introduced at this point, the internal building pressure will drop to some intermediate point, so that the pressure differential across the doorway acting over the area of the opening and through its coefficient of discharge will equal the volumetric flow induced by the differential across the leak opening area and through its coefficient of discharge.

The structure will attain a new pressure equilibrium characterized by continuous flow of outside air through the building.

A question arises as to whether it is possible to offset the undesirable inflow at the door by forced introduction of outside air through a blower means. In the case of the sealed building, the total additional volume, ¼% of the net internal structure volume, was so low as to be readily attainable. When the leak opening is introduced, sufficient air must be provided to elevate the internal pressure to that of the impingement head, while continuously replenishing the leak losses. The net effect at the leak opening is a substantial increase in differential over the non-pressurized equilibrium condition, with a subsequent proportionately increased outflow. If the differential is 1 in. wg and the aggregate leak area 1 sq ft with a coefficient of discharge of 0.61, the leakage rate will be

$$Q = C_d \times A \times V = 0.61 \times 1 \times 4005 \times (1)^{1/2}$$
$$= 2803\ cfm$$

It should be noted that, while the pressurizing increment for the sealed building depends on the volume of the building and is a fixed one time addition, as it were, the pressurizing increment for the leaky building depends on the leak orifice and must be continuously replenished. It is evident that tight construction of the building offers the only practical means of controlling the adverse effects of wind impingement on the building.

When the open door is to the leeward and the leak in the windward wall, essentially the same conditions result. The equilibrium pressure within the building will depend on the relative sizes and discharge coefficients of the door and aggregate of the leak openings.

The larger the door in relationship to the leak, the nearer the internal pressure will approach the impingement head. Conversely, as the door size diminishes in relation to the leak opening, the internal pressure will approach the leeward low pressure level.

The closed door represents an easily recognized special case of either of the foregoing examples. If the door is airtight, the only openings left in the building are the leak openings, which can be treated as the open doorway of the airtight building. A leaky door is treated as an open doorway of the smaller magnitude equivalent to the leak area around the closed door.

What happens when an airtight partition is introduced into the airtight building at right angles to wind flow, in such a way as to segregate the windward and leeward exterior walls? By this definition, one of the compartments will be totally sealed and remain at the pressure level existing at the moment it was sealed. It will remain unaffected by subsequent pressure changes except for those which might be introduced internally, such as a temperature change. The airtight partition will leave the other half, the windward side, a virtual separate building fitting into one of the previously discussed cases.

An actual building will leak and will be partitioned by a structure through which leakage will also take place. Under no wind, isothermal conditions, and with leaky door open or closed, no air flow will take place since the flow inducing factors are absent.

If a wind begins to impinge on the open doorway (Fig. 9), the pressure will tend to rise in the windward compartment, its upper limit being the static equivalent of the inpingement head. This limit is not reached, however, because the increasing pressure simultaneously produces flow through the leak openings in the partition into the leeward compartment. In turn, the rising pressure in the leeward compartment, together with the depressed pressure along the exterior of the lee wall, results in flow out of that compartment. An equilibrium results, with the pressure levels attained in the two compartments being a function of the leak coefficients and cross-sectional areas for a given wind direction and velocity. If the door is closed and relatively tight, the leeward leak openings quite small, and the partition doorways large and open, the difference in pressures between the two compartments tends to be infinitesimal. On the other hand, if the partition is closed and the exterior openings are large, the tendency is toward the maximal pressure differential between the compartments.

PRESSURE DIFFERENTIALS

How great is the pressure differential which can be achieved between compartments in free communication with each other? If our hypothetical building, 50 x 200 x 10 ft high, is to be ventilated at the rate of six air changes per hr or at 1 cfm/sq ft, the ventilating system will require a capacity of 10,000 cfm. We will further assume that all of this volume is to be introduced into

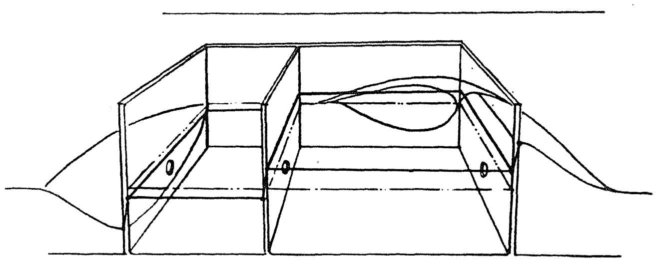


Fig. 9 Descending order of pressure through leaky walls and partition

one part of the building separated by a partition, having a 3 x 7-ft doorway in it, from the other part in which the return air registers are located. Such a situation might arise in the attempt to prevent contamination of the atmosphere in the first compartment.

Since $Q = C_d \times A \times 4005\ (\Delta P)^{1/2}$

it follows that $(\Delta P) = \left(\dfrac{Q}{C_d \times A \times 4005} \right)^2$

Substituting $\Delta P = \left(\dfrac{10{,}000}{0.61 \times 21 \times 4005} \right)^2$

$\Delta P = 0.04$ in. wg

The differential would be minor. Additionally, when the magnitude of wind effects is taken into consideration, it is immediately evident that any leakage which allows this wind effect to be transmitted to the building interior will offset the small differentials possible by attempted pressurization of compartments having large openings.

It should be noted that if the air supply bias in favor of the first compartment is held to exhaust air in the amount of 10% or 1,000 cfm, the differential falls to an almost unmeasurable 0.0004 in. wg.

If the interior doorway is closed and the leak area reduced to 1/10 of the full opening, as when the peripheral clearance is ⅛ in., the pressure differential possible can be increased a hundred fold to 0.04 in. wg when biased.

The pressure differential can fall off rapidly by an increased opening or decreased bias. It can easily become so small as to be readily offset by buoyancy effects generated by temperature differentials.

For example, if the exhaust compartment of the example is at a higher temperature than the supply compartment, as might be the case in the situation described above, warm air will tend to spill up over the header of the opening into the cooler room. As it cools, it will again return to the warm room, so that the net flow into the exhausted room will be the original 1,000 cfm plus an amount of flow induced by the gravity effect. Whereas the designer intends to prevent contamination of the first compartment by extraordinary pressurization, this is offset by the air density difference, which is sufficient to partially overcome the small pressure differential developed by delivering all the fresh air to the one compartment.

A similar situation prevails at the open exterior doorway under non-isothermal conditions, with or without wind impingement. Whatever the equilibrium pressure profile from windward to leeward through the building, when the building interior is heated, the gravity flow vectors must be superimposed. Under what is commonly regarded as the most severe condition, direct impingement of the wind against a heated building, pressures reach an equilibrium point in fractions of a second. The only unbalanced vector is the air density difference between the heated interior air and the cold atmosphere. Even though this gravity head may be slight, it can cause considerable flow out of the building seemingly into the wind because, in the case of a tight building, this force is really unbalanced, that is, unopposed.

If the building is airtight, a suitable air barrier comprising a moving air stream across the opening from top to floor return can be very effective in controlling this flow.

SUMMARY

A rectangular box with various openings held motionless in a moving stream of water serves as a useful analogy to conditions which develop within an enclosure subjected to wind pressures.

The internal static pressures may rise by as much as the value of the impinging air velocity pressure.

There is no practical substitute for airtight construction as a means of controlling interior pressures.

Tight interior partitions have tended to result in a series of descending pressure zones from windward to leeward.

POLLEN EFFICIENCY OF FILTERS

(Continued from page 64)

Q_1 = infiltration volume flow rate, cfm
Q_2 = air conditioner volume flow rate, cfm
E = filter efficiency, as a decimal fraction

Integrating and using the boundary condition that $C_t = C_o$ at $t = 0$,

$$C_t = \frac{C_o Q_1}{Q_2 E + Q_1}\left[1 - e^{\left(\frac{(Q_2E + Q_1)\,t}{V}\right)}\right] + C_o e^{\left(\frac{(Q_2E + Q_1)\,t}{V}\right)}$$

The equilibrium condition, which corresponds to $t = \infty$, yields

$$C = \frac{C_o}{\frac{Q_2}{Q_1}E + 1}$$

Table II gives examples of effects of filter efficiency and time on room pollen concentration in a typical situation where C_o = 1000 grains/cu yd, Q_1 = 15 cfm, Q_2 = 150 cfm, and V = 900 cu ft.

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2. Evaluation of Air Cleaners for Occupied Spaces, K. T. Whitby, D. A. Lundgren, A. R. McFarland, and R. C. Jordan, Air Pollution Control Assoc. Jr., 11: 503-15, 1961.
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TOXICOLOGY CENTER ESTABLISHED AT THE UNIVERSITY OF CALIFORNIA

George F. Stewart, formerly Chairman of the Department of Food Science and Technology at the University of California, Davis, has been named director of the Toxicology Center at the University.

The research and training Center, established recently at Davis through a grant from the U.S. Public Health Service, will investigate the chemical and microbial hazards associated with agricultural production, food processing, and food preservation. The highly specialized Center is a joint undertaking of the University and the U.S. Public Health Service.

Training will be an important function of the new Center, which is basically concerned with environmental health. The Davis campus now has a wide offering of health-related graduate and postdoctoral training programs. Under Center sponsorship, new graduate and postgraduate programs will be organized to serve its specific interests, together with specialized training courses for practicing analysts and toxicologists. The Center will also sponsor seminars and conferences.

An information and documentation service will serve as a clearinghouse for queries concerning the environmental sciences and will prepare bibliographies, abstracts and summaries of the technical literature in this field.

The research programs of the Center initially will be concerned with four general areas of investigation.

The Analytical Methods and Instrumentation program will cover a wide spectrum of chemicals and deals with the development and application of advanced automated instrumental and colorimetric methods to the residue detection of pesticides and feed and food additives.

The Methods for Assessment of Chronic Toxicity program will involve the development of rapid, sensitive, and reliable tests for detecting and measuring small amounts of toxicants in lower aquatic animals, and their correlation with tests using mammals.

The Morphological, Physiological, and Biochemical Aspects of Chronic Toxicity program will include research into the storage and elimination of toxic chemicals in mammals, their action on embryos, as well as on young and adult birds, and the comparative effects of herbicides on proliferating plant and animal tissues.

The Environmental Fate Program will be designed to survey the decomposition of pesticides by temperature, light and air; identify chemically the breakdown products and determine the toxicity of the decomposition products; and devise analytical methods for estimation of these compounds and application of these methods to treated crops.