The Cave Airflow Bible

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To comprehend the movement of air through caves, one must acquire an appreciation for the techniques of studying air movement. A few terms need to be defined first.

Terminology:

Air – the atmosphere that surrounds the earth, is a mixture of gases. *Air movement* is a change in position of air regardless of the cause or degree.

Wind – the natural form of air movement; usually but not always the movement is horizontal.

Ventilation – the process of supplying air and removing it from a given space by any method.

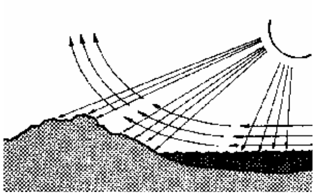
Buoyancy – a force that creates air movement, is the tendency of air to rise because of thermal differentials. It is positive, neutral, or negative.

Pressure – a force that creates air movement, is the shifting of air caused by force differentials.

Air Movement Systems – The Big Picture

A movement is created by uneven heating of the atmosphere. As the sun heats it, the air expands, rises, and is replaced by cooler air. The exchange of air creates a cycle known as the general circulation, the major wind system of the earth.

The general circulation creates prevailing air movement. It is affected by differences in heating qualities of land and sea and by the position of the sun. Land is heated by the sun quicker than water; water retains more heat for longer periods of time. Consequently, the land and water almost always differ in temperature, and that causes the air masses over them to move. The sun constantly changes its position, and so the angle of its rays varies through the year. The effect of variation is to heat the earth unevenly and at varying rates.



Mathematics can be used to study air flow. Ventilation by pressure forces is influenced by the actual air movement velocity, prevailing direction, variations in intensity and patterns, and local obstructions.

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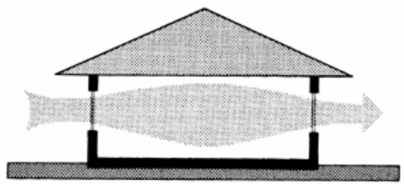
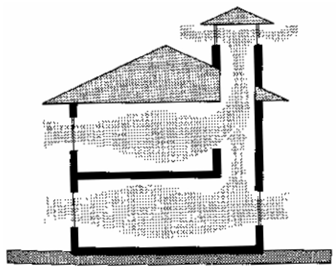


If the inlet and outlet openings are equal in size then there will be a constant airflow. Should the outlet opening be greater in size than the inlet opening, the air movement will be greater; similarly, if the outlet opening is smaller than the inlet opening, the air movement will be smaller.



Ventilation through buoyancy can be hindered only by the caves internal resistance to air movement if the thermal conditions for buoyancy to occur are correct. For the forces of buoyancy to act, there has to be a significant temperature differential between the interior of the cave and the outdoors. The following equation can be used to calculate the quantity of air through the openings due to buoyancy.

$Q = cf\ A[h(Ti-To)/Ti]^{1/2}$

Where Q = airflow, cu ft per min

A = free area of opening(inlet), sq ft

h = half the height between inlet and outlet

Ti = average indoor air temperature at height h, °F + 460

To = outside air temperature, °F + 460

Cf = conversion factor

Usually, ventilation is due to both pressure and buoyancy forces causing air movement through a given space greater than either force could if it were acting alone. However, the new air movement is not the sum of the two forces; it is the square root of the sum.

Ratio of inlet area to outlet area	Multiplier of cf
1:1	313
1:2	394
1:3	417
1:4	429
1:5	432
2:1	197
4:1	107
4:3	264

$Q = \mathrm{sqrt}(Qp + Qb)$

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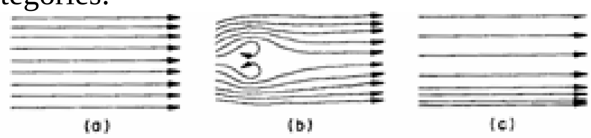
General Principles:

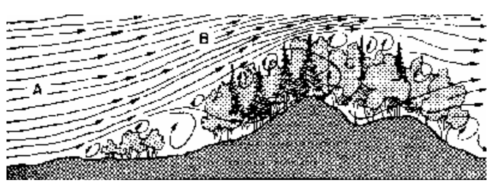
Internally, air flow is driven by buoyancy and pressure differentials and modified by inertia and friction. Externally, landforms, vegetation, and buildings influence air movement by altering the velocity and pattern of the airflow. The environmental factors of a given climate affect the movement of air, and in turn, air movement affects the climate.

As air circulates in its 3d sphere, it follows specific laws of nature. These assist and drive the movement of air in a relatively orderly and predictable fashion. Air movement is a cause-and-effect phenomenon. The flow patterns of air movement fall into three categories:

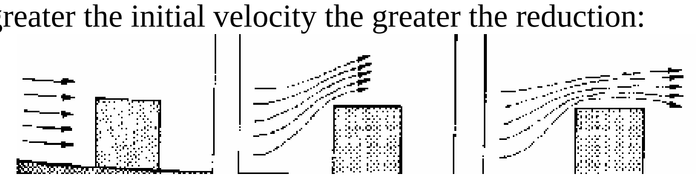


Air movement patterns are classified as (a) laminar, (b) turbulent, and (c) separated.

In laminar air movement, which occurs quite frequently, airstreams flow on top of or beside one another in a relatively parallel and predictable pattern because of low internal turbulence. As external elements increase the internal turbulence, the pattern of the airstreams becomes random and unpredictable. The main path, however, occurs in one major direction and creates turbulent air movement. Then friction may decrease the velocity of certain airstreams while maintaining a parallel pattern without internal turbulence. The result is separated air movement. Air movement may change from one category to another over a period of time or distance. Laminar air movement, for example, may become turbulent air movement if the topographical roughness becomes greater:

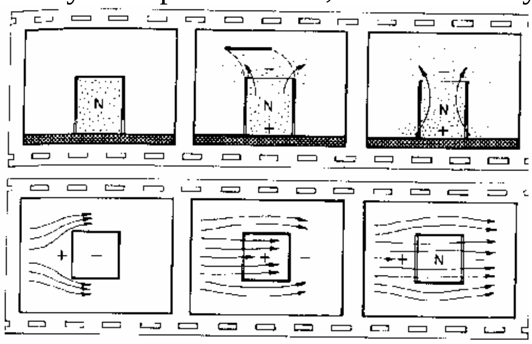


As air flows from one location to another, inertia, friction, and differential affect the movement. First, moving air has inertia: once it is set into motion, it tends to continue in the same direction until it is diverted from its original path. Elements that divert the flow are topography, trees, and large rocks. A change in direction will reduce the velocity of the airflow; the greater the initial velocity the greater the reduction:

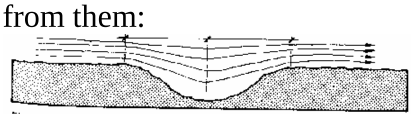


Second, moving air creates friction as it moves along such bodies as land, water, and such. Friction reduces the velocity of air movement and may even alter airflow patterns. In addition, the friction between the air and the revolving earth produces a gradation of air velocities from low to high altitudes. The speed of air movement increases with height as the frictional effect of the earth's surface reduces in its intensity.

Third, air movement is created by differentials. The forces of buoyancy and pressure may work separately or cooperatively in developing differentials. As air passes from positive to negative buoyancy zones and/or from positive to negative pressure zones, air movement is created. The gradients of buoyancy consist of variations in air density, and differences in air force action develop the gradients of pressure. Air movement is not a steady-state phenomenon; it involves a dynamic interchange of equalizing forces.

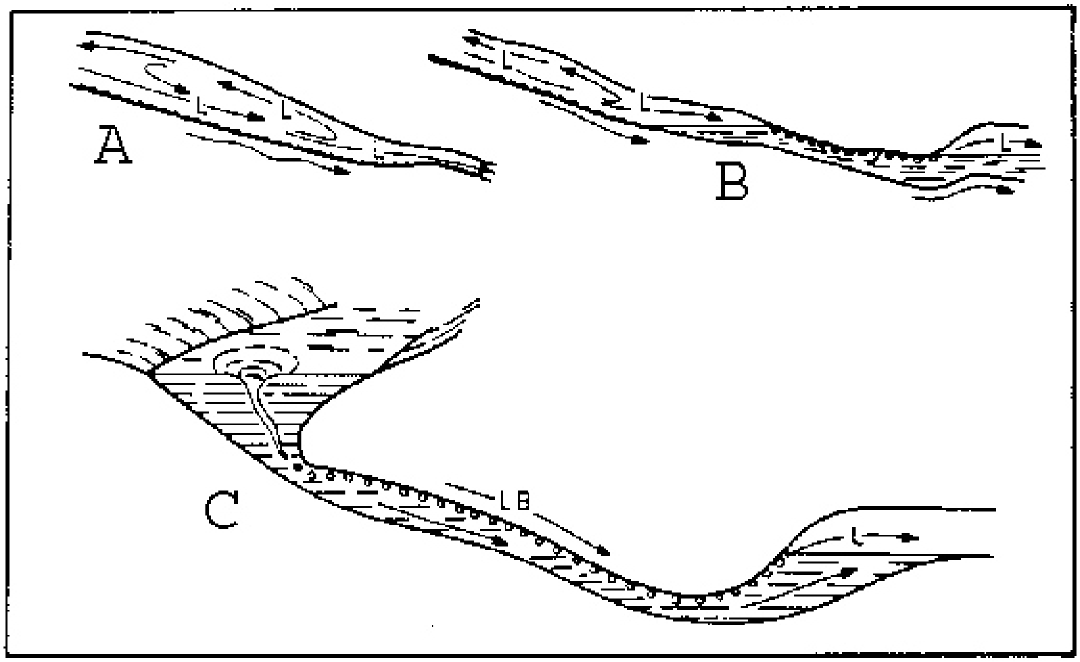


As air move across the surface of the cave it encounters a multitude of natural obstacles. These deflect and impede the airflow; they change its pattern and reduce its velocity while influencing its quality and quantity. The velocity of air movement is altered by changes in topography. The apparent movement varies with such concave and convex surfaces. Concave surfaces attract airflow into them; convex surfaces deflect airflow from them:



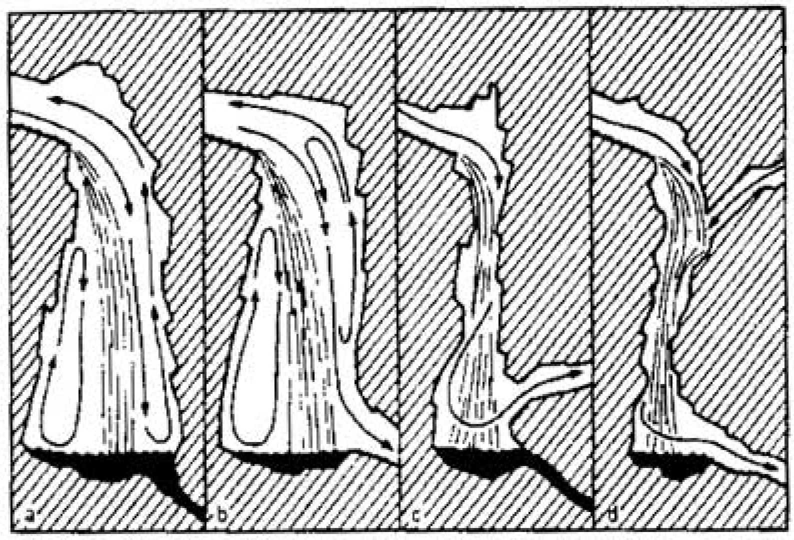
Airflow Due To Water

In an active cave the most obvious agent promoting the circulation of the air is the freely running stream. As a result of friction with flowing water, air is moved forward. If the water course has narrow passes or siphons inserted in it, local air circulation takes place in front of them(A), the air then skims back along the ceiling to the point of departure. Rapidly flowing water sweeps air along with it at the transition to a pressure flow (B), or sucks it into the center of the whirl(C).



Because of it’s buoyancy the air swept along is carried under the ceiling. The steeper the passage, the higher the velocity of flow necessary to be able to move the air downward against its buoyancy. This supplies sumped passages with air on the other side of the sump where there may or may not be a connection to the outside. Air carried in this way in narrow passages under phreatic conditions effects an air movement by means of suction before the swallowing point; when the water re-emerges air movement is caused by an increase in pressure. Even this air movement is too slow as a rule for it to be perceived by the senses but the evidence can easily be found by the movement of swaths of smoke.

Waterfalls are especially effective, above all those in narrow shafts where the water touches the walls. In this case the effect of a water-jet air pump occurs with the suction at the upper end and a considerable increase in pressure in the air at the lower end. Closed circulation of air happens when a waterfall pours down a wide shaft which is closed at the bottom(A). Partly closed circulation of air occurs when a waterfall pours down a fairly wide shaft which is open at the bottom(B), cave wind is in the direction of water flowing away. When a waterfall falls down a narrow shaft, especially when the water touches the cave walls, a stronger cave wind is created in the side passage shown(C). Waterfalls in a narrow shaft with an infeeder side passage suck air through the waterfall from both the main and side passage and is blown away as a much stronger cave wind(D).



Cave Airflow Basics

The airflow in Indiana Caves is dependent on the interaction of outside air temperature with the temperature of cave air. Cave airflow is mostly dictated by the principle that hot air rises and cold air sets. Since cave air remains the same temperature all year round (about 52 degrees Fahrenheit) the airflow changes when the outside air temperature passes above or below this threshold.

In the winter time when the outside air temperature is colder than the cave air, the hot air (relative to the outside temperature) in the cave rises and exits the upper-most entrance or entrances in the cave. In the summer when the outside air temperature is hotter than the cave air the cold cave air sets and flows out the lowest entrance or entrances of the cave.

I will address the conditions when the air is hotter outside than in the cave as summer and when the air outside the cave is colder as winter from now on. It is important to realize that the airflow is not dependent on the season but the temperature variation between the cave and the outside air. Also the cave air temperature will be described relative to the outside air temperature.

The hot or cold air exiting the cave causes suction creating airflow through the cave. When the air exits the lower or upper entrance or entrances of the cave it will be sucked in from the entrance or entrances at the opposite elevation. For example, in the winter time the warm cave air exits the upper entrances causing the outside air to enter through the lower entrances creating a draft through the cave. The opposite is true during the summer. In the summer time the cold cave air exits the lower entrance or entrances of the cave pulling the outside air into the cave through the upper entrances.

The size of the cave passage affects the rate of airflow. When the passage is larger it holds more air and therefore heats up or cools down more air. The increased amount of warm or cool air increases the speed that the air exits and enters the cave because the added air provides more force to push the air out of the cave. When the air is exiting or entering multiple entrances the airflow will be less than if it were entering a single entrance. When exiting or entering the cave the smaller the opening the greater the airflow will be. Would the airflow into or out of each entrance or exit be noticibly affected by the entrance size, shape, and obstacles as well as the passage size, shape, and obstacles? The same amount of air should exit the cave as enters the cave because lost air would be replaced.

How to use airflow to find cave:
When trying to find a new cave if a hole is blowing or sucking a lot of air then there is a cave there. The more air the better though remember if multiple entrances may cause the air intake or outtake to be less. How much does the temperature variation affect the airflow? Do greater temperature variations between the cave and outside air cause more airflow? If you know the outside air temperature how should you judge how much airflow differentiates a big cave from a nerd hole?

Inside the cave you will have to determine which way the air should be going, up or down. If it's cold outside then the hot air should be rising and following the uppermost route from where the outside air enters to where the cave air exits. The air would not necessarily travel the length of the cave. It would follow the length of the cave if that's the lowest or highest route from entrance to exit. If it's warm outside the cold air would follow the lowest routes to the lowest exit or exits of the cave.

Inside the cave you're less likely to feel the air in larger passages because the airflow isn't as concentrated. There's also a lot more room for the air to slip by in large passages. In large passages smoke bombs should be used. Your face is the best part of your body to feel for air. Inside the cave good airflow often indicates more cave though it would be difficult to differentiate whether the air is going into more cave or exiting outside if you weren't near enough the exit to feel the affects of the outside temperature.   In this case you can look at the overlay or ridge walk above the cave and see if any sink holes are producing a similar amount of air near where your cave is losing air. Since the size of the passage should affect the airflow. If the air isn't exiting nearby above ground then you know there's probably more cave there.

Big rooms connected by smaller passages could refuel or briefly increase the airflow because the room holds more air and the additional air provides more push out of the room subsequently causing more suction into the room. Also, if the passage leading out of the room is of greater size than the passage leading in the air would come in at a faster rate than it goes out.

Since Indiana Caves are formed by water drainage and in valdose caves the water would be affected by gravity there are more likely to be more upper air entrances than lower air exits because the cave is providing drainage; taking water in from various locations and releasing it. In valdose caves the water obeys gravity and descends the lowest route. Because gravity often centralizes the water and the water eats away the floor the cave exit or exits are often few or nearby each other. There will usually be more infeeders than springs.

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