# Contaminant reduction: general vs. local exhaust ventilation



*Local exhaust ventilation is a more effective system for reducing contaminants in the workplace*

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**Local exhaust ventilation** has been successfully used by industrial hygiene engineers for many, many years to reduce contaminant concentrations in the workplace and reduce the exposure of workers. Some of the elements and the factors that constitute local exhaust ventilation are enumerated in this article.

Contaminant sources should be enclosed as fully as possible. If the contaminant sources cannot be fully enclosed, then exhaust connections should be located as close to the contaminant source as possible. In this respect, the governing principle was developed long ago by J. M. DallaValle.[1] He showed that the air velocity at contaminant source falls off as the square of the distance to the exhaust point. Thus, exhaust hoods and exhaust ducts must be placed as close to the contaminant source as possible to increase their effectiveness.

Based on the design of the hood enclosing the contaminant source or the distance of the exhaust opening from the contaminant source, proper quantities of air must be exhausted from each hood. These air quantities are mainly determined by experience although there are some governing principles that allow designs to be made.

Each exhaust opening is connected to a carefully and appropriately designed duct system. The duct system, in turn, is connected to a central exhaust fan that generates the pressures required to induce flows from each of the openings near the contaminant sources. Contaminants are frequently removed from the air stream with filters.

Local exhaust systems are quite effective. They can often reduce the contaminant concentration by 90 to 95 percent of what it would be if there were no local exhaust systems installed.

The air from a local exhaust system is frequently exhausted to the outdoors. Sometimes, if the contaminant concentration in the air from the filter is well within allowable limits, the air may be returned to the workplace. In some cases, heat exchangers have been used to remove heat from the exhaust air and to heat clean, outdoor air supplied to the workplace.

Air exhausted to the outdoors must be made up by means of a heated outdoor air supply to retain the efficiency of the exhaust system (avoiding the development of negative pressures in the building) and to prevent cold, uncomfortable working conditions. The makeup of air exhausted by local exhaust systems is a cause of part of the considerable cost of installing and operating local exhaust systems.

## General ventilation

General ventilation is the introduction of clean, outside air into a workspace for the purpose of reducing contaminant concentration by dilution. The clean air required for general ventilation may be introduced by supply air systems or by exhaust systems. If the air is introduced by supply systems, the building must have openings or exhaust systems to provide a means for the air to escape from the buildings. No air can be introduced into a hermetically sealed space. Similarly, if the air is to be introduced by exhaust, the building must have openings to allow the entry of outside air, or it must have supplied air systems. In the winter, of course, the air supply from outdoors must be heated to prevent the building from becoming uncomfortably cold.

If the quantity of contaminant being generated is known and if the allowable concentration in the workplace is also known, then the amount of dilution air required to maintain allowable concentrations can be readily calculated. In that event, two implicit assumptions are made:

- The amount of contaminant is instantaneously, continuously, and uniformly dispersed throughout the space.
- The air required for dilution of the contaminant is also uniformly dispersed throughout the space.

Neither premise is justified in reality. Ventilating air moves from building openings toward roof ventilators, from supply air systems to leaks in the building, or toward exhaust system openings. Some air volumes of a plant will have higher

[1]*Footnotes refer to numbered references at end of article.*

air movement than others.

The second premise is even further removed from reality than the first. Dust sources are not uniformly distributed throughout a plant. The contaminant sources are frequently located at work stations. In the vicinity of a contaminant source, the concentration is maximum. Until one moves to some substantial distance from the dust generating point, it cannot be postulated that there is a uniform concentration of contaminant in the ventilating air. This latter premise will cause the calculation of average concentration in the plant to be lower than the actual level to which workers will be exposed.

### Ventilation advantages

One advantage of general ventilation is that very little knowledge of the discipline of industrial hygiene engineering is required to apply it. In contrast, local exhaust ventilation requires a detailed knowledge of the process, a familiarity with hood design, avoiding interference with both the process and the operator, a knowledge of appropriate volumes to be exhausted, and a detailed knowledge of duct design, fans, and filters. In contrast, general ventilation is deceptively easy to apply.

Over the years, the author has seen numerous instances where general ventilation has been proposed to control or reduce contaminant concentration. Large central filters have been proposed for reducing the fumes in welding shops. These filters behave by filtering and recirculating large quantities of air in the welding shop.

In machine shops, it has been proposed that appropriate filters be placed in the general vicinity of machines that use oil lubrication while machining parts. The oil mist would be handled by diluting the air being filtered near the machine instead of through filters and duct systems. In steel mills, monitors frequently have been used to exhaust fumes from furnaces rather than installing appropriately designed hoods, ducts, and fan systems.

Most recently, extensive studies have proposed general ventilation rates of four and ten air changes per hr to reduce the level of dangerous contaminants in plants to extremely low levels.

Air changes per hr are frequently used as a convenient method of defining the level of general ventilation rates. Air changes per hr are defined by the following equation:

$$\text{Air changes per hr} = \frac{\text{cfm ventilation air} \times 60}{\text{space volume, cu ft}}$$

Air changes per hr must be used with discretion when determining dilution requirements for contaminants in a workplace. It has validity as a criterion for relative dilution rates. For example, it is fair to reason theoretically that if the dilution rate is changed from three to nine air changes per hr, then the contaminant concentration should be reduced by a factor of three. (Data will be presented later in this article that will cast doubt on that conclusion.)

Air changes per hr produce different air volumes based on the size of the building. In large buildings, air changes per hr represent larger volumes than in small buildings. As mentioned previously, larger volumes will produce lower average concentrations since only the volume of dilution air and the quantity of contaminant being generated determine the average concentration. Nevertheless, air changes per hr are very useful in determining relative effects on concentration reduction in a workplace. In this article, air changes per hr will be used for that purpose.

### Ventilation effectiveness

General ventilation and local exhaust ventilation are compared from several different points of view:

- The degree of air movement produced.
- The general ventilation rate produced by local exhaust openings placed in the center of hypothetical 3 and 6 ft radius spherical spaces surrounding those local exhaust openings.
- The reduction of intermittent sources of contaminant concentration in 3 ft radius spheres surrounding both the contaminant source and the local exhaust opening at that source.
- A study that presents contrasting large numbers of dust counts made in a plant in both winter and summer.
- A carefully controlled test that describes where in a plant dust counts were taken either with or without large additional general ventilation systems in operation.

### Air movement

Hoods designed for local exhaust may have control velocities of 100 to 1500 fpm or more. General ventilation produces levels of air movement in the vicinity of dust sources that are so low as to be almost negligible.

Table 1—Air changes caused by dust pipes in center of 3 and 6 ft radius spheres.

| Dust pipe size, in. | Air volume, cfm at 4000 fpm | Air changes per hr, 3 ft sphere | Air changes per hr, 6 ft sphere |
|---|---|---|---|
| — | — | 4 | 4.0 |
| — | — | 10 | 10.0 |
| 4 | 350 | 186 | 23.0 |
| 5 | 550 | 292 | 36.5 |
| 6 | 800 | 425 | 53.0 |
| 7 | 1100 | 584 | 73.0 |
| 8 | 1400 | 743 | 93.0 |
| 9 | 1800 | 956 | 119.0 |

Consider a space in a production plant that is 10 by 10 ft. If the ceiling height is 25 ft, then the space volume is 10 × 10 × 25 or 2500 cu ft. A ventilation rate of 4 air changes per hr (15 min air change) will cause an air movement of 167 cfm dispersed through that volume. A ventilation rate of 10 air changes per hr (6 min air change) will cause an air movement of about 400 cfm throughout the same volume.

If the clean air volume is introduced into the base of the 10 sq ft column, the most favorable condition, then an upward air movement of 1.7 fpm (4 air changes per hr) or 4 fpm (for 10 air changes per hr) will be produced. The air volumes will travel sideways through the column or through an area of 25 by 10 ft, which is equal to 250 sq ft.

Air movements of this magnitude are so low that it is extremely difficult to conceive that—especially in the vicinity of contaminant sources—any appreciable effect can take place that will reduce the exposure of workers. Local exhaust connections produce high levels of air movements that draw the contaminants out of the workspace and away from the breathing zones of the operators with a high degree of efficiency. General ventilation rates of relatively high orders of magnitude cause exceedingly small air movements in that same vicinity and do not remove the contaminants from either the workspace or necessarily from the breathing zone of the operator.

## Local exhaust

Compare the ventilation rates of 4 air changes per hr and 10 air changes per hr. These rates are proposed for general ventilation with those produced by local exhaust openings located as close as possible to contaminant sources.

Two cases are studied. In one, the air movement produced in a 3 ft radius sphere surrounding the local exhaust connection is calculated. In the other, the air movement produced in a 6 ft radius sphere is calculated. The 3 and 6 ft distances from the local exhaust opening were chosen because it is believed that in most instances contaminant sources will be at work stations and that the worker will be located within 3 or 6 ft distances from that source. Table 1 shows the results of these studies.

The first two lines of Table 1 record the general ventilation rate proposed for plants to reduce contaminant levels. The other lines show the air changes produced by exhaust pipe connections 4, 5, 6, 7, 8, and 9 in. in diameter with volumes produced as a result of velocities of 4000 fpm in the pipes.

It is obvious that the air changes produced in the vicinity of local exhaust connections are considerably greater than those proposed for general plant ventilation. In a 3 ft sphere surrounding a 4 in. exhaust opening, 186 air changes per hr are generated. The air change rate increases to a considerable 956, which is 95 times as great as the highest proposed for general pipe ventilation in the 3 ft radius sphere surrounding a 9 in. exhaust pipe.

Even in spheres of 6 ft radius, at the center of which is a 4 in. diameter exhaust opening, 23 air changes per hr of general ventilation are produced. This ranges up to 119 air changes per hr in a 6 ft radius sphere surrounding 9 in. diameter exhaust connections.

In the vicinity of a contaminant emitting source, local exhaust has several advantages over general ventilation. These include:

- The general ventilation rate in the vicinity of the contaminant source, where the operator is probably located, is many times greater than the rates proposed for general ventilation of overall plants.
- A properly designed local exhaust connection will remove 90 to 99 percent of the contaminant. General ventilation will merely stir it around.
- The local exhaust and the general ventilation volumes produced in the vicinity of the contaminant source are removed by duct from the plant, filtered, and blown outdoors. General plant ventilation merely disperses the contaminant without filtering it and sends it outdoors.

Table 2—Reduction of concentration due to general ventilation in 3 ft radius sphere that surrounds exhaust duct.

| Dust pipe size, in. | Air volume, cfm at 4000 fpm | Air changes per hr, 3 ft sphere | $\left(1 - \frac{C_f}{C_i}\right)$ 100, percent reduction | | |
|---|---|---|---|---|---|
| | | | 30 sec | 1 min | 2 min |
| — | — | 4 | 3.0 | 6.0 | 12.0 |
| — | — | 10 | 8.0 | 15.0 | 28.0 |
| 4 | 350 | 186 | 79.0 | 96.0 | 99.8 |
| 5 | 550 | 292 | 92.0 | 99.2 | (Inf) |
| 6 | 800 | 425 | 97.0 | 99.92 | (Inf) |
| 7 | 1100 | 584 | 99.2 | (Inf) | (Inf) |
| 8 | 1400 | 743 | 99.8 | (Inf) | (Inf) |
| 9 | 1800 | 956 | 99.97 | (Inf) | (Inf) |

## Contaminant reduction

The reduction of the concentration by dilution ventilation of a contaminant that is intermittently generated is given by the following expression:

$$\frac{C_f}{C_i} = \frac{(-\text{cfm})\,(t)}{V}$$

where

$C_f$ = final concentration
$C_i$ = initial concentration
$e$ = 2.72 (natural logarithm base)
cfm = diluting ventilating air, cfm
$t$ = time after start of dilution process, min
$V$ = volume of space being ventilated, cu ft

The equation assumes that a contaminant fills a volume ($V$) with a concentration ($C_i$). The dilution ventilation (cfm) is equal to the diluting air that is uniformly dispersed through the space $V$. The ratio of $C_f/C_i$ is dependent on the time ($t$) after the start of ventilation.[2]

Table 2 was constructed by using the ventilation rate produced in a 3 ft radius sphere that surrounds an exhaust duct opening, presumably, is the source of the contaminant. The assumption was made that the contaminant was dispersed in the 3 ft radius sphere and the ventilation volume was started subsequent to the dispersal. The first column shows the dilution volume induced in the 3 ft radius sphere surrounding the dust pipe. Obviously, the first three columns of Table 2 are identical to those of Table 1. The last three columns are derived from the above equation. Instead of $C_f/C_i$ being recorded, the value of $(1 - C_f/C_i) \times 100$, or the percent reduction in concentration after the start of general ventilation, is shown. The percent reductions in the table are 30 sec, 1 min, and 2 min following the start of dilution ventilation.

In the first two lines of Table 2, the concentration reductions caused by dilution rates of 4 and 10 air changes per hr are recorded. After 30 sec, at 4 air changes per hr, the concentration reduction is only 3 percent. At 10 air changes per hr and 30 sec after the start of general ventilation, the reduction of the contaminant concentration in a 3 ft radius sphere is only 8 percent. Even after 2 min, the concentration reductions are only 12 and 28 percent, respectively.

Contrast these reductions with those shown for a 4 in. diameter exhaust opening of 79 percent after 30 sec and 99.8 percent after 2 min. For a 9 in. diameter duct opening, the reduction in concentration in the 3 ft radius sphere is 99.97 percent after 30 sec of general ventilation.

Where percentage reductions have risen to such high values as to render them difficult to understand, the expression *Inf.* has been inserted to show a reduction of final concentrations to infinitesimal values.

The conclusion is that local exhaust ducts (4 to 9 in. in diameter) located within 3 ft of intermittent dust sources are far more efficient in reducing dust concentrations than general ventilation systems with air change rates of up to 10 per hr or greater.

## Dust counts

In a plant that was studied for the effect of general ventilation, 41 dust stations were regularly sampled from October 1969 to July 1978. The samples were operator samples, *i.e.*, the operators wore the sampling apparatus. The samples were divided into two parts: those taken between the months of October through March and those taken in the warmer months of April through September. Roof ventilators increased the exhaust rate from the plant from 2.8 air changes in one portion of the plant to 8.5 air changes—a threefold increase. Similarly, in another portion of the plant roof, ventilators increased the general ventilation rate from 1.4 air changes per hr to 12.9 air changes per hr—a ninefold increase.

In this study, it was assumed that the roof ventilators would more likely be turned on during the milder months of April through September than the colder ones of October through March.

Over 600 dust samples had been taken at the 41 dust sampling stations. Of these, 180 pairs of readings were compared. Each pair was taken in the same year and at the same station. One reading of the pair was taken during October through March and the other during April through September.

In 102 pairs, the reading in the warmer months was actually higher than in the cooler months. In 78 pairs the reverse was true—the readings in cooler weather were higher than in the warmer weather.

We must conclude that what must have been substantially higher general ventilation rates in warm weather did not translate into lower sample readings for samples taken in the breathing zone of plant workers.

## General ventilation test

A carefully controlled study of the effects of general ventilation was conducted in a relatively large plant. This was the same one in which the previous analysis of dust counts taken in warm and cold weather was made. One portion of the plant is 300 ft wide by 360 ft long and is known as the finishing end. Thirty machines in this area are applied to finishing pipe products. Table 3 shows the finishing end having a volume of 2,279,000 cu ft with 105,000 cfm of dust. Fume exhausts provide 2.8 air changes per hr of general ventilation. In the finishing end, there are seven roof ventilators with the capacity of 31,000 cfm each for a total of 217,000 cfm. When the roof ventilators are in operation, they provide 5.7 air changes per hr of general ventilation. The total of both roof ventilators and local exhaust provides a ventilation rate of 8.5 air changes per hr.

Similarly, the wet end of the plant, which is adjacent to and not separated from the finishing end, is 200 ft wide by 240 ft long. From Table 3, the wet end has a volume of 1,937,000 cu ft. Dust and fume system exhaust has a capacity of 44,000 cfm, providing 1.4 air changes per hr of general ventilation capacity. Twelve roof ventilators with a total capacity of 372,000 cfm can provide 11.5 air changes per hr of general ventilation capacity. The total of the two is 12.9 air changes per hr.

On February 14 and 15, 1979, four

Table 3—General ventilation air changes produced by exhaust systems and roof ventilators.

| Location | Space volume, cu ft | Dust and fume exhaust, cfm | Air changes | Roof ventilators, cfm | Air changes | Total air changes |
|---|---|---|---|---|---|---|
| Finishing end | 2,279,000 | 105,000 | 2.8 | 217,000 | 5.7 | 8.5 |
| Wet end | 1,937,000 | 44,000 | 1.4 | 372,000 | 11.5 | 12.9 |

Table 4—Ventilation rate (air change ratio) compared to dust count ratio (fans off/fans on).

| Location | Dust counts with fans off/ dust counts with fans on, average | Ventilation rate ratio, fans on/ fans off | Ventilation ratio/count ratio |
|---|---|---|---|
| First three stations, (finishing end) | 2.3 | 3.0 | 1.3 |
| Six readings, (finishing end machines) | 1.6 | 3.0 | 1.9 |
| Four readings, (wet end) | 1.8 | 9.0 | 5.0 |
| Five readings, (near wet end machines) | 2.6 | 9.0 | 3.5 |
| | | Average | 3.0 |

sets of readings were taken at 21 sampling stations. After running the roof ventilators for several hours, they were turned off for about 1 hr before the start of sampling at 7:30 AM. Sampling proceeded from 7:30 to 10:30 AM. All roof ventilators were turned on at 11:00 AM, and sampling was repeated from 12:00 noon until 2:30 PM with the fans on. On the 15th, the process was reversed. Fans were off from 1:00 AM until 6:30 AM, when they were turned on. Sampling proceeded from 7:30 until 10:00 AM. Fans were turned off by 10:30 AM, and samples were collected with fans off from 12:00 noon until 2:30 PM. All the samples taken were area samples. Sampling equipment was stationary and not worn by operators. The results of the tests are shown in Table 4.

The ratios of counts with fans off to those taken with fans on ranged from 1.6 to 2.6. The average was about 2. The ventilation rate ratio of air changes provided with fans on vs. roof fans off is 3 in the finishing end and 9 in the wet end. The last column shows the ratio of ventilation rate changes divided by the ratio of dust count changes. This last ratio ranges from 1.3 to 5 with an average of 3.

It can be concluded that increasing general ventilation did indeed reduce the dust count level. However, the reduction in dust count level was about one-third of the increased general ventilation rate.

Dust control of the plant was so effective that readings taken were generally both close to the ultimate sensitivity of the test method and also close to the background levels that could be obtained at some distance from dust sources. It would be extremely interesting to repeat tests of the type reported in plants where the contaminant control was not so effective.

## Ventilation costs

The costs of general ventilation can vary greatly. Supply of heated makeup air is probably the single most costly factor. However, the use of steam vs. direct gas heating is certainly another, as is the use of extensive duct systems to improve air distribution. Table 5 shows some rough costs associated with general ventilation and with local exhaust systems.

Table 5—Relative costs of general ventilation and local exhaust.

| | 830,000 cfm makeup air, 830,000 cfm exhaust | 150,000 cfm dust control, 150,000 cfm makeup air |
|---|---|---|
| First cost makeup air | $1,600,000 | $300,000 |
| First cost roof ventilators | $500,000 | — |
| Makeup air, hp | 300 | 60 |
| Roof exhaust, hp | 270 | — |
| Dust control, hp | — | 340 |
| Heating fuel | $350,000 | $63,000 |
| Yearly power cost | $177,000 | $124,000 |

The general ventilating system cost is based on supplying 10 air changes per hr of heated air to a plant of 5,000,000 cu ft or 830,000 cfm. Roof ventilators of the same capacity are required to exhaust the supply air. The local exhaust systems in the plant total about 150,000 cfm in capacity. Costs are based on makeup air of 150,000 cfm in this alternative.

Makeup air systems were priced at $2.00 per cfm. Roof ventilators were estimated to cost $0.60 per cfm. The heating fuel was assumed to be gas at $5.00 per MMBtu. The yearly operating cost was based on an average winter temperature of 45 F, 70 F supply air, 6 months heating season, 5 days per week, 24 hr per day operation.

Power costs are based on $0.07 per KWH, 24 hr per day, 5 days per week, 52 weeks per yr of operation. It is estimated that the local exhaust system could be replaced for a cost of $1,000,000.

By examining the data in Table 5, it is rather obvious that local exhaust systems are much less expensive to buy, install, and operate than are general ventilating systems that require heated makeup air to be supplied to the plant.

## Conclusion

Local exhaust ventilation is more effective than general ventilation in the vicinity of contaminant sources for reducing contaminant concentration by a factor of ten.

The general ventilation dilution effect caused by local exhaust connections in the vicinity of contaminant sources greatly exceeds that produced by general plant ventilation rates of even 10 air changes per hr. The reduction in contaminant concentration is only about one-third of the ratio of increase in general ventilation rates.

General ventilation, with rates of 10 air changes per hr, especially where heated supply air must be provided, is much more expensive to install and operate than local exhaust ventilation, which is much more effective in reducing contaminant concentration. Ω

## References


1) DallaValle, J. M., *Exhaust Hoods*, Industrial Press, 1952.

2) Goldfield, J., "Contaminant Concentration Reduction: General Ventilation vs. Local Exhaust Ventilation," *American Industrial Hygiene Association Journal*, November 1980.

3) Hemeon, W. C. L., *Plant and Process Ventilation*, Industrial Press, 1955.