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PRINCIPLES OF SOURCE CAPTURING AND GENERAL VENTILATION DESIGN FOR WELDING PREMISES

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ABSTRACT

Workers are commonly exposed to fumes and gases emitted as byproducts of welding operations and workers are potentially exposed to all these agents. Contaminant control and comfort conditions in welding shops can be achieved by using properly designed ventilation systems.

This paper presents different types of local exhaust systems: portable, mobile, flexible fume extraction arms (for small, medium, and large welding operations), built-in fume extractors in stationary or turning welding tables, and push-pull hoods applied to welding robots. The paper also discusses efficient methods of general ventilation and air cleaning from welding fumes. Advantages and disadvantages of these systems for different applications are discussed.

INTRODUCTION

Welding operations are often used at different types of manufacturing facilities (mechanical, aircraft and aerospace, ship-building, maintenance, etc.). When welding, workers are potentially exposed to fumes and gases arising primarily from the filler metals, electrode coating, or cores. The potential exposure varies with the process and welding conditions employed. Hand welding and semiautomatic, automatic, spot, joint contact, robot, and gas welding are the most common welding processes used in manufacturing and construction industries.

Hygienic and sanitary aspects of the welding process depend upon the method and regime of welding, as well as welding materials used. The most common method of welding (about 65% to 70% of all welding work in industry or about 33% of all welding work) is semiautomatic, CO_2-shielded and gas mixture welding. About 10% of welding is manual arc welding, 15% to 20% is submerged arc welding, and about 5% is other welding methods, such as spot, laser, plasma, etc.

Welding fumes and gases are chemically very complex. The most common particles in welding fumes are iron oxide, cadmium oxide, zinc oxide, magnesium oxide, nickel, chromium, and copper. Common effects from welding fumes are eye and respiratory tract irritations, metal fume fever, headaches, systemic poisoning, chest pain, loss of memory, and cancer. The data on specific emissions produced by different welding processes are usually available from electrode manufacturers.

Clean, fresh air at welding operations is provided by ventilation systems, which as a rule consist of local exhaust systems and general supply and exhaust systems. The most efficient method of contaminant control in the occupied zone of the welding shop, particularly in the breathing zone of the welder, is using local exhaust systems to capture the contaminants at or near their source.

Measurements taken by the Swedish Foundation for Working Environment Protection show that using fume extraction at the source can achieve up to a 60% reduction in energy costs. Investigations made in Canada show that after installing local exhaust, productivity will increase 10% to 20%. In other words, there is a lot of money to be saved by using fume extraction at the source.

No local exhaust ventilation system is 100% effective in capturing fumes. There will be circumstances, because of a short duration or an awkward place for welding work, where installation of local exhaust ventilation systems may not be practicable. In such situations, general ventilation is used to dilute contaminants not captured by the local ventilation system. Air supplied by general ventilation will replace air extracted by the local and general exhaust systems, as well as improve comfort conditions in the occupied zone.

LOCAL EXHAUST VENTILATION SYSTEMS

Local exhaust ventilation systems consist of the following basic elements: the hood, the duct system, the air-cleaning device, the fan, and the duct on the fan outlet to discharge the air to the atmosphere.

As a rule, the amount of fresh air to be supplied by a general ventilation system into a welding shop to dilute contaminants not captured by local exhausts exceeds the air exhausted by local ventilation systems. Local exhaust systems can evacuate some of this amount and the rest can be evacuated from the building by the general exhaust system. Most air cleaners used in welding premises remove only dust particles and do not clean the gas pollutants from the air, concentrations of which may exceed the contami-

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nant's TLV. These are some reasons why returning cleaned air from local exhausts back into the building may not be a solution. Of course, exhausted air must conform to the tolerable limits of local air pollution codes and, if required, objectionable pollutants removed prior to discharge outside of the building.

The type of local ventilation system depends on the method and conditions of welding, type of welding equipment, size of the welded details, and other factors, such as

- small gun-mounted exhaust hood incorporated directly in a gun of the welding semiautomat, automat, or robot (Figure 1);
- cross-draft (Figure 2) or downdraft (Figure 3) welding table or extraction panel with a circular nozzle (Figure 4) for a welding table or workbench with small and medium size details;
- flexible fume extraction arms for small, medium, and large workplaces (Figure 5);
- fume extractors built into stationary or turnover welding tables;
- push-pull hoods over welding robots (Figure 6).

Gun-mounted exhaust hoods vary in design, capture efficiency, and volume of extracted air, which can be within 50 to 100 m^3/h (29 to 59 cfm). This type of system is of particular value for semi-automatic MIG welding guns with continuous electrodes but at present is not widely used.

A cross-draft table is an open hood used in conjunction with a welding table. The table can be enclosed at the sides and top to form an open-front box, and air is extracted through slots, grilles, or a circular nozzle. The exhaust volume depends upon the design of the hood and the bench. It can vary from 3300 to 5000 m^3/h per m^2(181 to 273 cfm per ft^2) of the table for the open-type table, from 2500 to 3000 m^3/h (1470 to 1764 cfm) for the panel with the circular nozzle, and at least 2200 m^3/h (1294 cfm) for the exhausted bench with enclosed sides and top.

For workpieces that are too large to fit on a bench but can be moved, exhausted booths can provide effective fume control. Booths can also be used for assembly-line work. Here the workpieces are moved into and out of the booth on overhead conveyors. Exhausted booths operate in the same way as benches—but on a larger scale—and exhaust considerably greater quantities of air (face velocities of at least 0.5 m/s [100 fpm] are required). So, for the booth with an open frontal area 2.5 m wide by 2 m high (82 ft by

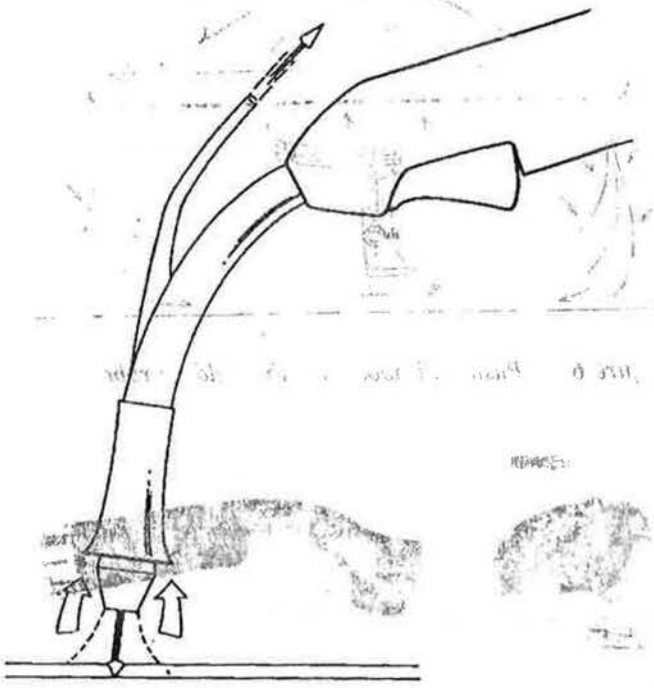

Figure 1 Gun-mounted exhaust hood.

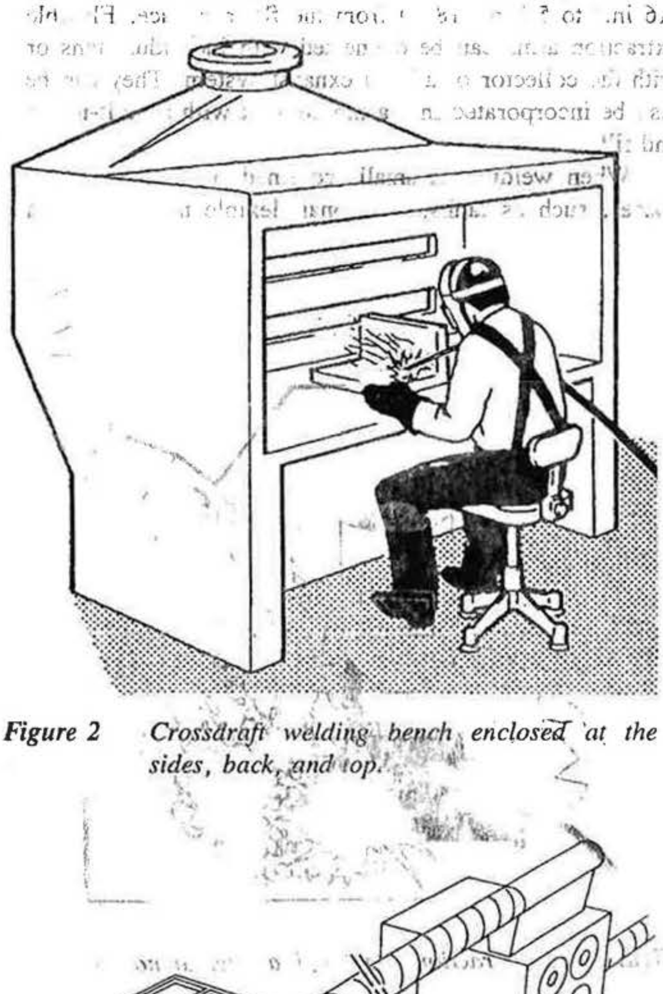

Figure 2 Crossdraft welding bench enclosed at the sides, back, and top.

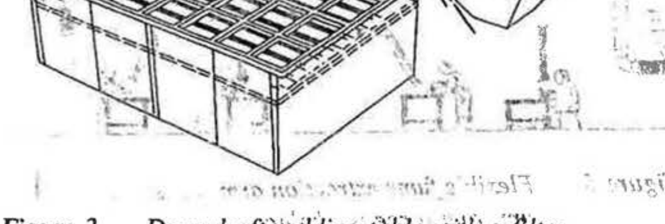

Figure 3 Downdraft welding table with a filter.

66 ft), a total volume flow rate of at least 9000 m³/h (5821 cfm) is needed.

The minimum face velocity for the downdraft table also depends on the hood design and should be equal to or greater than 0.75 m/s (150 fpm) (exhaust volume 2700 m³/h per m² [137 cfm per ft²] of the table). Cross-draft and downdraft tables can be also equipped with built-in filters and a fan.

Flexible fume extraction arms usually have a hood connected with a duct 140 to 160 mm (5 to 6 in.) in diameter. High capturing efficiency is reached on the area of about 500 mm (20 in.) in diameter (with a hood at the distance of about 400 mm (16 in.) from the surface) with an airflow through the hood from 900 to 1400 m³/h (529 cfm to 823 cfm). The hood can be positioned anywhere within the area up to 9 m (30 ft) in radius on a height of 400 mm (16 in.) to 5.5 m (18 ft) from the floor surface. Flexible extraction arms can be connected with individual fans or with the collector of a local exhaust system. They can be also be incorporated into a mobile unit with a built-in fan and filter.

When welding in small, confined, poorly ventilated spaces, such as tanks, additional flexible hose extension with a hood and magnetic foot (Figure 7) can be hooked on the fume extraction arms instead of the standard hood.

Flexible hose 45 mm (1¾ in.) in diameter with a nozzle on magnetic foot extracting from 150 to 300 m³/h (88 to 176 cfm) is also a commonly used solution for fume extraction from confined spaces. It can also be used by the maintenance team in combination with the portable fume extractor with built-in fan and filter.

When gun-mounted exhaust hoods cannot be used with welding robots, the alternative is often large hoods above the working area capable of capturing welding fumes at any position of the welding gun. To reduce the amount of air supplied by a general ventilation system for replacing exhausted air, the exhaust hood might be combined with a filter and circular slot air diffuser (Figure 4) creating an air curtain around the welding area (push-pull system). When the air curtain reaches the floor surface, it turns and is evacuated by the hood. Polluted air, after being partially filtrated (about 1000 m³/h [588 cfm]), is evacuated outside the building and partially returns to the air supply slot. The amount of recirculating air depends upon the welding area and the type of air supply slot.

GENERAL VENTILATION

Supply systems can be mechanical or natural. When there are no special demands for comfort conditions in the

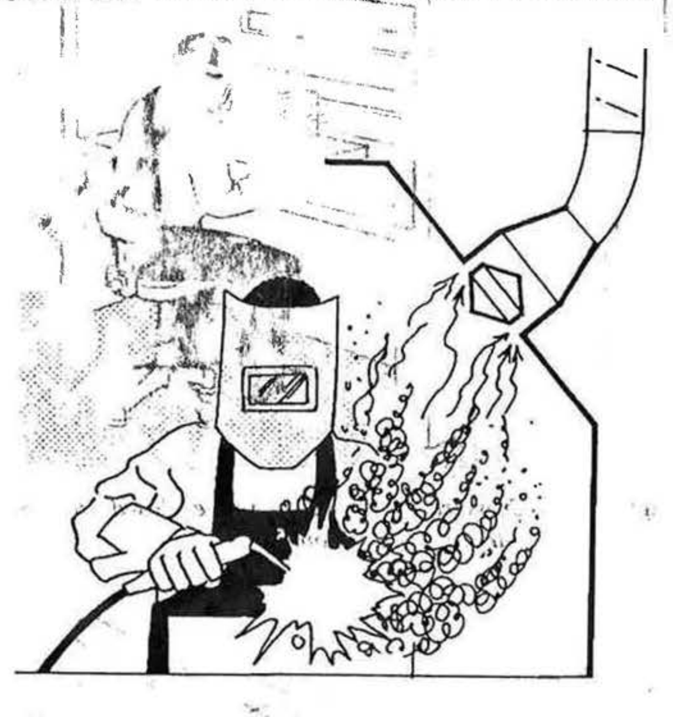

Figure 4 Extraction panel with a circular nozzle.

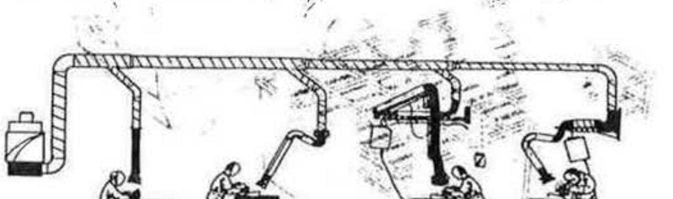

Figure 5 Flexible fume extraction arms for small, medium, and large workplaces.

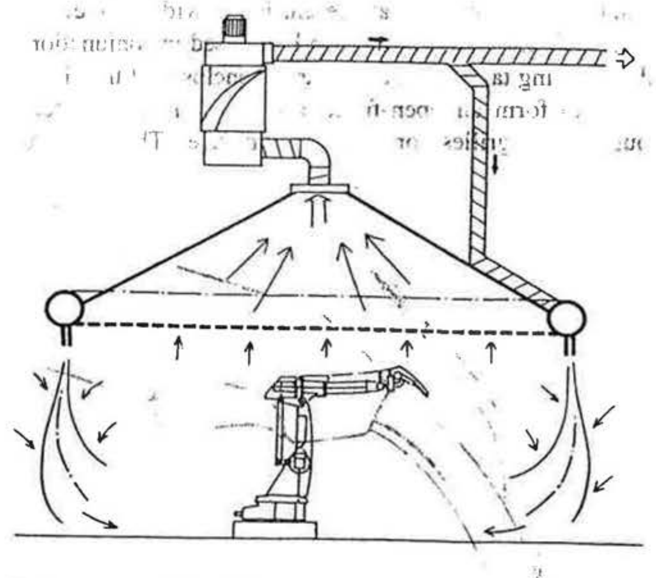

Figure 6 Push-pull hood over the welding robot.

Figure 7 Flexible hose with a hood and magnetic foot.

building during the cooling season, natural ventilation through the windows, doors, or fixed air vents is used.

As a rule, for contaminant control and to create a comfortable environment, mechanical supply systems are used. They consist of inlet sections, a filter, heating and/or cooling equipment, a fan, ducts, and air diffusers for distributing air within the premises. When toxic gases and particles are not present, it may be possible to recirculate back into the room part of the air cleaned in the general exhaust system, which will have the advantage of reducing heating costs in winter. In this case, a return duct is used to bring the air to the supply unit or air is cleaned in free-hanging air filter units.

To remove air contaminated by fumes, gases, or particles not captured by local exhausts, a general exhaust system is used. It usually consists of inlets, ducts, an air cleaner, and a fan. In welding shops, this amount of air is evacuated from the upper zone. After passing through filters, cleaned air is discharged outside or part of it returns back to the building.

The degree of cleaning efficiency of the filter should be enough to follow the regulations of environmental agencies and depends on the plant location, background concentration in the atmosphere, nature of contaminants, height, and velocity of air discharge, etc. In some cases, for example, when the industrial zone is located away from residential areas, the air-cleaning device may be excluded from the general exhaust system.

The rate for general ventilation should be calculated for each of the contaminants, as well as considering surplus heat produced and not captured by the local ventilation system. The ventilation rate needed to maintain a concentration of a contaminant in the occupied zone within the TLV can be obtained from the following equation, based on material balance in the premises:

$$Q_o = Q_{exh} + \frac{G(1 - \varepsilon) - Q_{exh}(TLV - C_o)}{K_g(TLV - C_o)} \quad (1)$$

where

Q_o = air supply rate;
Q_{exh} = local ventilation exhaust rate;
G = rate of pollutant generation;
ε = local ventilation capturing efficiency;
TLV = threshold limit value contaminating fume, gas, particles;
C_o = concentration of fume, gas, particles in the supplied air;
K_g = ventilation efficiency coefficient:

$$K_g = \frac{C_{u.z.} - C_o}{TLV - C_o};$$

$C_{u.z.}$ = concentration of fume, gas, particles in the upper zone of the premises (if air is evacuated from this zone), or in the exhausted air.

When evaluating the rate of pollutant generation, G, one can consider the amount of contaminants produced by burning 1 kg (2.2 lb) of welding materials from the manufacturer's data and the amount of burned material as follows:

manual welding with stick electrodes—1 kg/h (2.2 lb/h);
semiautomatic welding—4 kg/h (8.8 lb/h);
robot welding—4 to 6 kg/h (8.8 to 13.2 lb/h).

Capturing efficiency of the local ventilation system, ε, can be evaluated as 70% to 75% if no other information is available.

Concentration of fume, gas, or particles in the supplied air depends upon the ratio between the outside and return air ratio and the efficiency of recirculated air cleaning.

TABLE 1
Approximate Values for Ventilation Efficiency Coefficients

Air Supply Method	Heating Period	Cooling Period
Mixing Ventilation (Fig. 8c,d,e)	$K_g = 1$, $K_t = 0.9$	$K_g = 1$, $K_t = 0.9$
By Inclined Air Jets (Fig. 8a,b)	$K_g = 1$, $K_t = 1$	$K_g = 1.1$, $K_t = 1$
Displacement Ventilation (Fig. 8f)	$K_g = 1.1$, $K_t = 1$ (heating by recirculating warm air heating units installed in the upper zone)	$K_g = 1.4$-1.7, $K_t = 1.2$-1.4

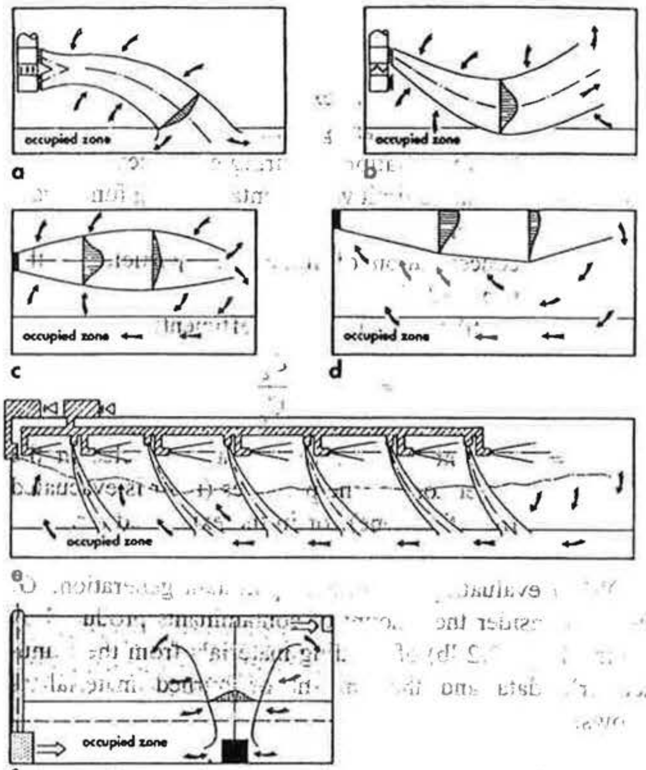

Figure 8 *Methods of air distribution: air is supply with inclined jets (cooled air—a, heated air—b); air supplied with concentrated air jets and ventilation of occupied zone is provided by the reverse flow (nonattached jets—c, attached to the ceiling jets—d); air is supplied with concentrated air jets and vertical and/or horizontal directing jets and ventilation of occupied zone is provided by the reverse flow and the vertical directing jets—e; displacement ventilation—f.*

The ventilation rate needed to assimilate the surplus heat can be obtained from the following equation based on the heat balance in the premises:

$$Q = Q_{exh} + \frac{W - C_p Q_{exh}(t_{o.z.} - t_o)}{C_p K_t (t_{o.z.} - t_o)}, \qquad (2)$$

where

W = surplus heat transferred or generated in the premises;

C_p = specific heat;

$t_{o.z.}$, t_o = air temperature in the occupied zone and supplied air accordingly;

K_t = ventilation efficiency coefficient (for heat assimilation):

$$K_t = \frac{t_{u.z} - t_o}{t_{o.z} - t_o};$$

$t_{u.z}$ = air temperature in the upper zone of the premises (if air is evacuated from this zone) or of the exhausted air.

Ventilation efficiency coefficient values (K_g and K_t) depend on the air supply method (Table 1).

When possible, air supplied by the general ventilation system is used for heating the building in the wintertime. Airflow of the supply unit and duct system is designed for the maximum ventilation rate needed for dilution ventilation and heat assimilation at designed parameters in the summer period.

If the maximum comfort ventilation rate exceeds the one for the dilution ventilation rate for some period in the day, it is economically expedient to use a VAV system. Analyses of different welding operations where local ventilation is used shows that the air exchange rate in the winter can be reduced by 70% from the designed value.

For large spaces housing welding operations with heights over 6 m, the following methods of air distribution are recommended:

- air supply by inclined jets (Figures 8a and 8b);
- concentrated air distribution with ventilating of occupied zone by return airflow (Figures 8c and 8d);
- concentrated air distribution with horizontal and vertical or only vertical directing jets (Figure 8e);
- displacement ventilation method (Figure 8f).

For the spaces with obstructions higher than 3 m (10 ft), displacement ventilation and air distribution with directing jets or air distribution by inclined jets into the corridors between obstructions are recommended.

If there are significant surplus heat gains, the ventilation methods shown in Figure 8f and Figures 8a and 8b should be used. The air diffusers should be installed lower than 4 m (13 ft) to supply conditioned air closer to the workers and to take advantage of thermal stratification.

In VAV ventilation systems, to avoid formation of areas with abnormal air motion and poorly ventilated zones, the methods shown in Figures 8a, 8b, and 8e are recom-

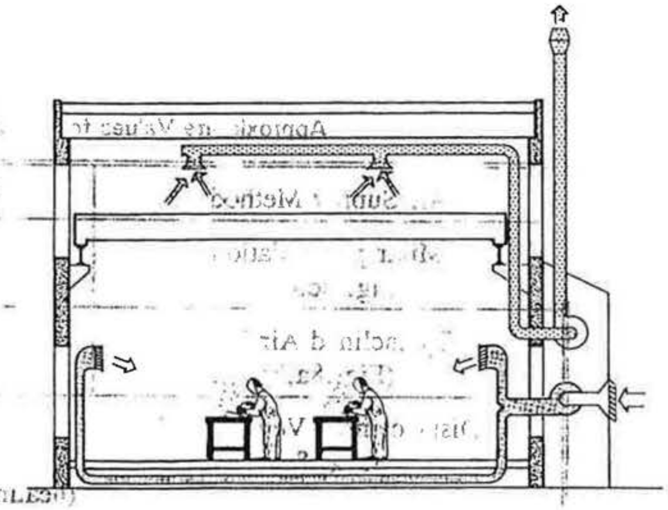

Figure 9 *General ventilation supply and exhaust systems.*

mended. These methods guarantee rather uniform air distribution in the occupied zone at an air exchange rate reduced by 75% to 85% from the designed maximum value.

Air distribution systems should be designed to follow technological and comfort demands to the air parameters (velocity, temperature) in the occupied zone.

The technological limitations on air velocity at the arc area are:

- for manual stick welding—1.2 m/s (240 fpm);
- for semiautomatic CO_2-shielded welding, powder wire, and submerged arc welding—0.5 m/s (100 fpm);
- for semiautomatic inert-shielded gas welding—0.3 m/s (60 fpm).

SEVERAL CASES OF VENTILATION SYSTEMS

Case 1. Natural ventilation system. Air is supplied through the fixed air vents and evacuated through deflectors on the top of the roof.

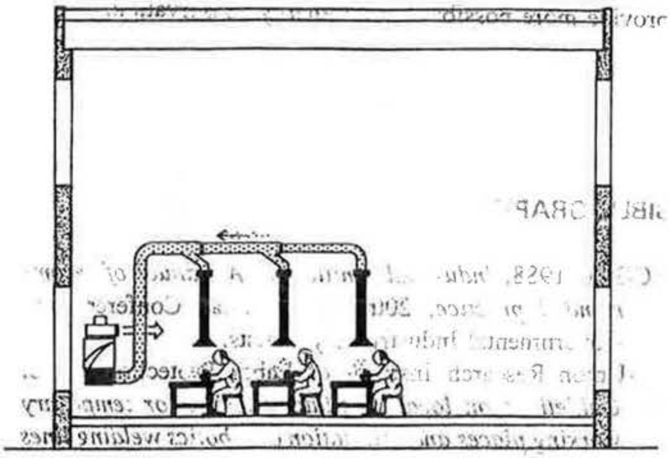

Figure 10 Wall-mounted fume extractors with a filter.

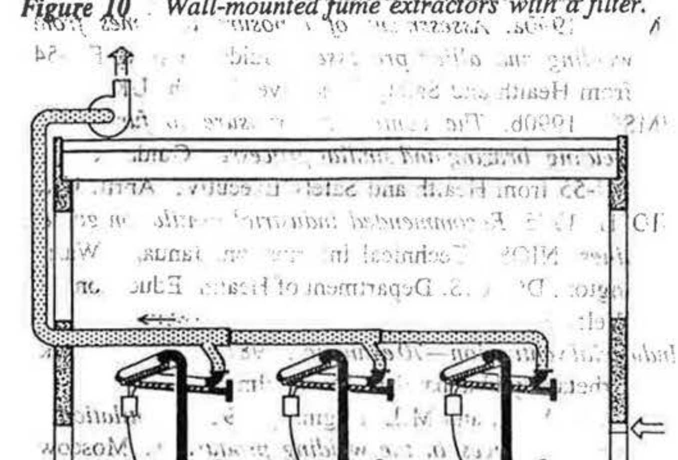

Figure 11 Wall-mounted fume extractors connected to the central fan with air discharged outside the building.

Advantages: Low initial cost.

Disadvantages: Does not solve the problem of high concentration of pollutants in the breathing zone of the welder; high air velocities in the arc zone reduce the quality of welding; inefficient in large buildings; cannot solve air pollution problem.

Case 2. General ventilation supply and exhaust systems (Figure 9). Air treated (filtrated and heated/chilled) in the air supply unit is distributed in the building through a number of air diffusers. Contaminated air is evacuated from the upper zone of the building by a general exhaust system or axial fans placed on the roof.

Advantages: Low initial costs.

Disadvantages: High operating costs of heating/cooling system and air transportation due to high air exchange rate; does not solve the problem of high concentration of pollutants in the breathing zone of the welder; does not solve problem of air pollution.

Case 3. Wall-mounted flexible fume extractors connected to the collector of the local exhaust ventilation system with electrostatic or mechanical filter. After being cleaned in the filter, air returns back into the premises (Figure 10).

Advantages: Low energy costs. No air pollution.

Disadvantages: Extraction hood must be positioned within 250 to 500 mm (10 to 20 in.) of the source; high background concentration of welding fume not captured by local exhaust ventilation system and gaseous contaminants left in filtrated air.

Case 4. Wall-mounted flexible fume extractors connected to the central fan with air discharged outside the building (Figure 11).

Advantages: Efficient removal of pollutants from the breathing zone of welders.

Disadvantages: Extraction hood must be positioned within 250 and 500 mm (10 and 20 in.) of the source; there are drafts and low-temperature zones in the working area due to infiltration; air pollution problem is not solved.

Case 5. Local ventilation system with wall-mounted flexible fume extractors connected to central fan with filter and air discharge outside the building, combined with general supply and exhaust systems. Air exhausted by general ventilation system is cleaned before discharged outside the building (Figure 12).

Advantages: Efficient removal of pollutants from the breathing zone of welders. Contaminant control and comfort conditions in the occupied zone; no air pollution; low energy costs.

Disadvantages: Extractor hood must be positioned within 250 and 500 mm (10 and 20 in.) of the source; high initial cost.

Case 6. Local ventilation system with mobile fume extractor with built-in filter and fan and wall-mounted flexible fume extractors, connected to central fan with a filter and air discharge outside the building, combined with general supply and exhaust systems. Air exhausted by general ventilation system is cleaned before discharging outside the building (Figure 13).

Advantages: Efficient removal of pollutants from the breathing zone of welders; contaminant control and comfort conditions in the occupied zone; no air pollution; reduced energy costs for general ventilation system due to using mobile fume extractors at temporary working places.

Disadvantages: Extractor hood must be positioned within 250 and 500 mm (10 and 20 in.) of source; high initial costs.

SUMMARY

Welding processes emit fumes and gases dangerous to the welders. Efficient ventilation systems not only create a pleasant and healthy working environment but also reduce energy costs and increase productivity.

General ventilation and/or free-hanging filtering units, when used separately, do not reduce the concentration of fumes in the operator's breathing zone. The best results can be achieved by using both local and general ventilation systems. The choice of a local ventilation system depends on method and conditions of welding, type of the welding equipment, size of the welded workpieces, and other factors.

This paper describes the most commonly used local exhaust systems for the welding industry and provides information helpful in making proper choices for specific applications. Efficient local ventilation solves the problem of high concentration of pollutants in the breathing zone of the welder and saves up to 70% of total energy costs.

The heating, cooling, and electrical energy consumption of the general ventilation system depends on its operating modes and method of air supply. In most common cases, VAV systems and air distribution with thermal stratification provide more possibilities for energy conservation.

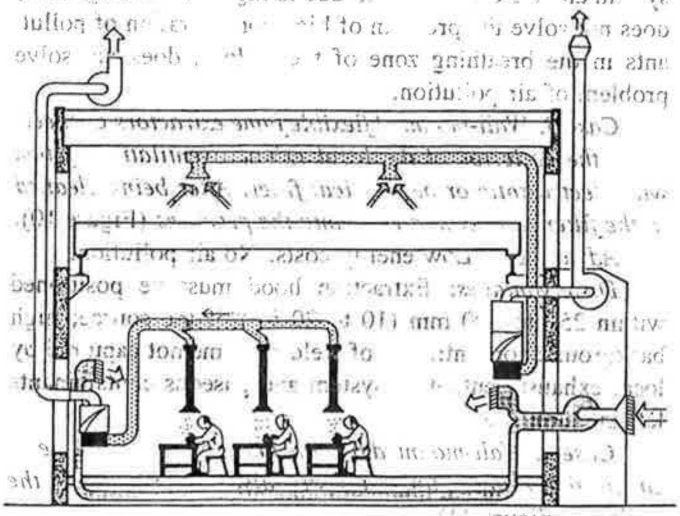

Figure 12 General supply and exhaust systems, wall-mounted fume extractors with a filter and air discharge outside the building.

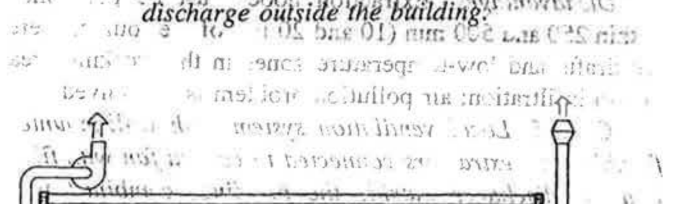

Figure 13 General supply and exhaust systems, wall-mounted fume extractors with a filter and air discharge outside the building, mobile fume extractor with a built-in filter.

BIBLIOGRAPHY

ACGIH. 1988. *Industrial ventilation. A manual of recommended practice*, 20th ed. American Conference of Governmental Industrial Hygienists.

All-Union Research Institute of Labor Protection. 1988. *Guidelines on local ventilation design for temporary working places and ventilation of robotics welding lines in welding industry*. Leningrad (in Russian).

HMSO. 1990a. *Assessment of exposure to fumes from welding and allied processes*. Guidance Note EN-54 from Health and Safety Executive. March. UK.

HMSO. 1990b. *The control of exposure to fume from welding, brazing and similar processes*. Guidance Note EN-55 from Health and Safety Executive. April. UK.

NIOSH. 1976. *Recommended industrial ventilation guidelines*. NIOSH Technical Information. January. Washington, DC: U.S. Department of Health, Education and Welfare.

Industrial ventilation—70 examples. 1987. Bengtsson-Back. Arbetarskyddnamanden. Stockholm (in Swedish).

Pisarenko, V.L., and M.L. Roginsky. 1981. *Ventilation of working places in the welding production*. Moscow: Mashinostroyeniye (in Russian).

Zhivov, A.M. 1990. Variable-air-volume ventilation systems for industrial buildings. *ASHRAE Transactions* 96(2).

Zhivov, A.M. 1993. Selection of general ventilation method for industrial spaces. *ASHRAE Transactions*.