Design of energy-efficient air distribution systems for industrial buildings

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Initial situation

Various air distribution systems are available for industrial production plants.

Important selection criteria are personal safety against air pollutants, thermal conditions in the working environment and last but not least energetic expenditure.

By choosing the right air distribution system with the efficient use of supply air, high potentials for improvement and savings are the result.

During design stage it is necessary to determine at first place the thermal loads and pollutant loads that have to be expected. Because of financial reasons thermal loads in industrial halls are often removed by free cooling with outdoor air. But at high outdoor air temperatures the cooling capacity drops to zero. It is even possible that an unwanted 'summer heating mode' occurs, if the temperature of the outdoor air supplied to the industrial hall is higher than the indoor air temperature. This case will be dealt with in a later chapter.

Pollutant loads do not appear in all industrial halls. As a rule there are no or only very low emissions in final assembly, shipment or stock. In other mechanical manufacturing processes where cooling lubricants are used during welding processes or in foundries it is different. Although the first target during design stage should be the collection of air pollutants at their source, it is rarely possible to completely avoid pollution of the workspace of persons.

(1) Turbulent mixing ventilation via twist outlet

(2) Low-turbulence displacement ventilation with built-in thermostatic control unit

Variants of air distribution systems

A distinction of ventilation systems for industrial application is made between turbulent mixing ventilation, displacement ventilation at a height of 3 m above the ground and displacement ventilation at the floor, also called stratified ventilation. All three systems have reasonable cases of application.

The **turbulent mixing ventilation** is frequently realised with radial and twist outlets (1) or jet nozzles. Characteristic features of the turbulent mixing ventilation are the assembly of the air outlets in the ceiling area or at the top part of the wall and air discharge velocities of 4 to 6 m/s with twist outlets or 8 to 12 m/s with nozzles. Because of the high induction effect of the supply air the 20- to 30-fold air volume is circulated in relation to the supply air volume flow rate and by this the temperature difference between supply air and indoor air is reduced rapidly. With turbulent mixing ventilation, heat and pollutant loads are evenly distributed over the entire room. Consequently the use of mixing ventilation is less suited in cases where air pollutants enter the indoor air because of manufacture processes.

Displacement ventilation offers a better solution in such cases. Here the air outlets are arranged at a height between 3 and 4 m, mostly at the columns in the industrial hall (2) + (3).

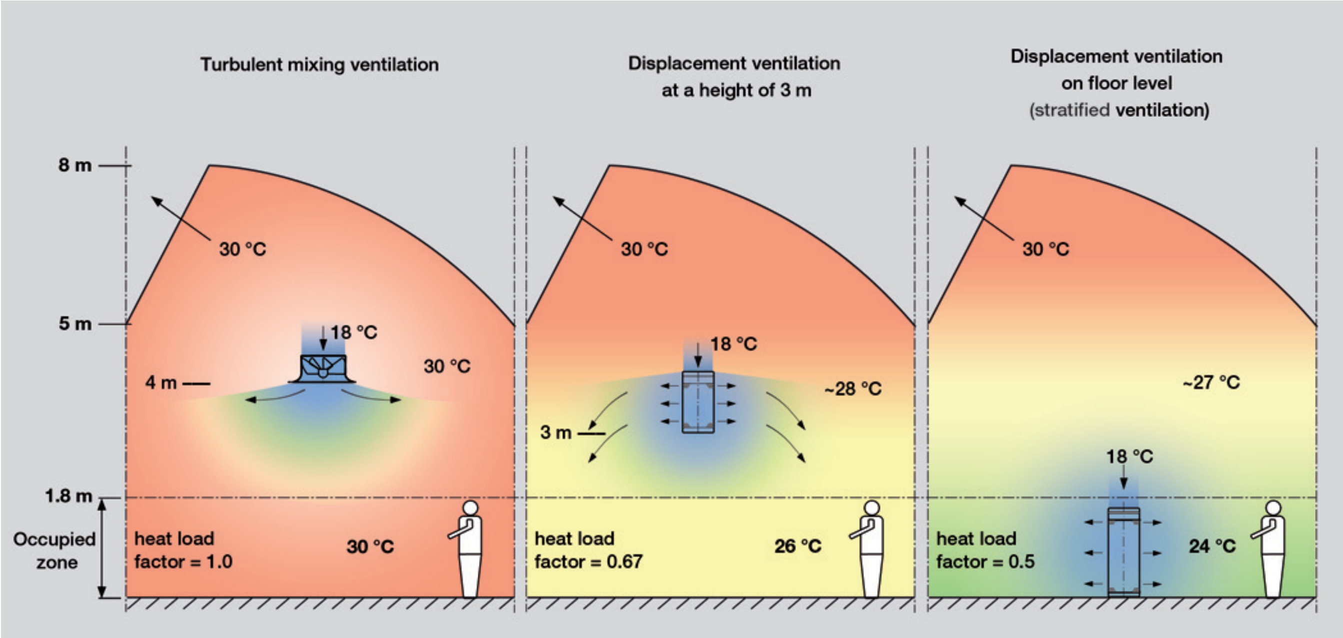
The discharge velocity of 0.6 – 0.9 m/s of the supply air is essentially lower than the velocity achieved by turbulent mixing ventilation. Consequently less indoor air is induced into the supply air. By this, there are lower temperatures and pollutant loads in the occupied zone than in higher zones of the building. The proximity of the air outlets to the working zone furthermore allows the installation of manual adjusting devices at the columns. This increases the acceptance of the employees, because they are able to regulate the intensity of air movement at their workplaces by themselves.

Displacement ventilation (stratified ventilation)

Having high heat and pollutant loads, the air outlets should be positioned on the floor. By this it is possible to achieve highest efficiency with the merest possible supply air volume flow rate. This stratified ventilation is achieved by displacing supply air with low air velocities of 0.3 to 0.4 m/s in the proximity of the workplaces (4). So the spread of the pollutants is not hindered because of the displacement effect and the thermal buoyancy and they are transported to higher regions of the hall, where they will be removed with the exhaust air.

(3) Low-turbulence displacement ventilation at a height of 3 m

(4) Stratified ventilation with air outlets positioned on the floor



5 Comparison of the heat load factors of the three air distribution systems

Comparison of the systems

When comparing the systems, two essential parameters have to be considered: on the one hand the heat load factor and on the other hand the pollutant load factor. The heat load factor μ_h results from the following equation:

$$\mu_h = \frac{\vartheta_{in} - \vartheta_{su}}{\vartheta_{ex} - \vartheta_{su}}$$

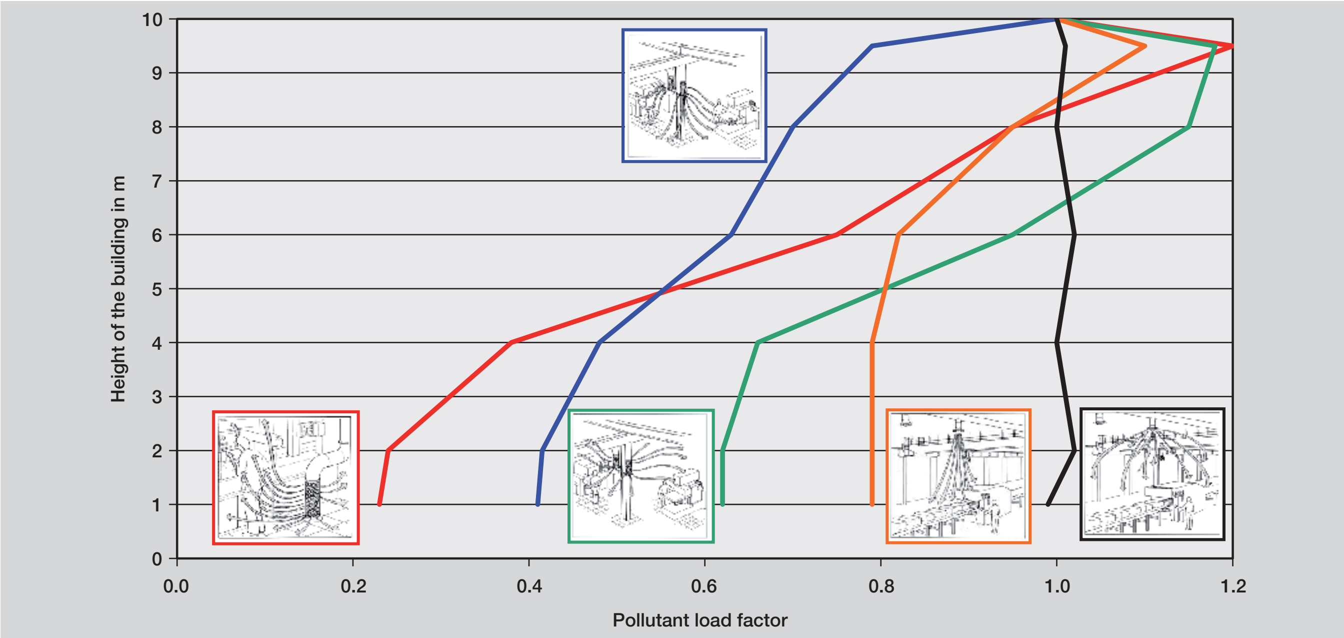
ϑ_{in} = indoor air temperature (°C)
ϑ_{su} = supply air temperature (°C)
ϑ_{ex} = exhaust air temperature (°C)

Figur 5 presents an overview of the systems. Due to high induction the turbulent mixing ventilation produces more or less the same temperatures in the entire industrial hall and in the exhaust air. Here the heat load factor amounts to 1.0. This load drops to 0.67 with displacement ventilation at a height of 3 m and having displacement ventilation with air distribution on floor level, the thermal load drops to 0.5. Consequently about 50% of the released heat does not take effect on the temperature rise in the occupied zone using stratified ventilation.

Alternatively it is possible to compare the three air distribution systems on the basis of the supply air volume flow rates that are necessary for the required equal indoor air temperatures in the occupied zone. Resulting from this are the relations listed in Table 1 at a specific cooling load of 120 W/m² and a required temperature in the occupied zone of 26 °C. One can see that the supply air volume flow rate of the displacement ventilation can be reduced by 30% and with stratified ventilation even by 50% compared to the mixing ventilation system.

System	Supply air temperature °C	Temperature in the occupied zone °C	Heat load factor –	Exhaust air temperature °C	Specific supply air volume flow rate l/s·m² [m³/(h·m²)]
Turbulent mixing ventilation	18	26	1.0	26	12.4 [44.6]
Displacement ventilation	18	26	0.67	30	8.3 [29.8]
Stratified ventilation	18	26	0.5	34	6.2 [22.3]

Table 1: Comparison of the systems with the necessary specific supply air volume flow rates



6 The local pollutant load factors of the three air distribution systems in comparison

Comparison of the systems

The second important criterion is the local pollutant load factor which is defined as follows:

$$\mu_p = \frac{c_{oz}}{c_{ex}}$$

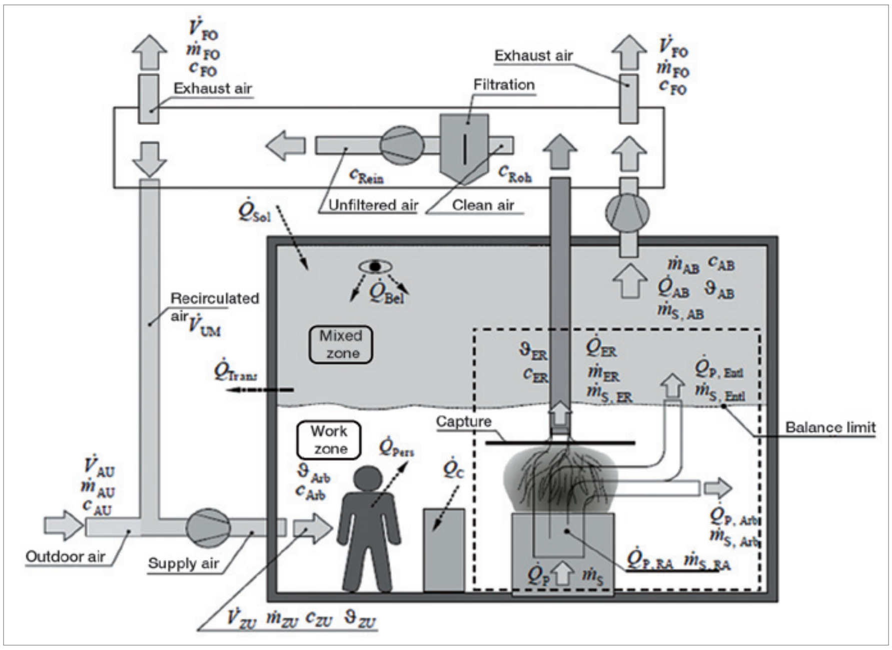
c_{oz} = pollutant concentration in the occupied zone

c_{ex} = pollutant concentration in the exhaust air

With the turbulent mixing ventilation a pollutant load factor of 1 develops in the entire room because of the high induction effect. The two systems of displacement ventilation are essentially more effective 6.

In general the pollutant load rises from the bottom (floor) to the top (ceiling) with these systems. The exhaust air is always extracted below the ceiling of the industrial hall. Depending on the adjustment of the air outlets, the displacement ventilation positioned at a height of 3 m achieves a value of the pollutant load factor between 0.4 and 0.6. Using the displacement ventilation with air outlets standing on the floor, values of 0.25 can be achieved.

This means that the same air quality can be achieved in the occupied zone with only a quarter of the outdoor air volume flow rate compared with the turbulent mixing ventilation. However, two further aspects, which will be dealt with in the next chapters, have to be considered.



7 Volume flows and pollutant flows in industrial buildings with extraction systems (from VDI 2262/3/draft, 12/2009)

Air balance between supply and return air volume flow rate

An essential target of the design is the collection and extraction of air pollutants directly at their source. This is the case when using cooling lubricants during the processing of workpieces or at the release of welding fumes in particular. The air flow that replaces the extracted air usually comes from the occupied zone in the factory building. The sum of decentralised extractions can absolutely reach the volume of the supply air and can even be higher because of later installations of extraction systems. Resulting from this is a negative pressure, so that outdoor air or indoor air flows in from other connected industrial halls.

If the proportion of the decentralized machine exhaust air to the total exhaust air in the lower zone of the building is too high, not enough exhaust air is extracted below the ceiling of the industrial hall. Consequently there are backflows of polluted air from the upper parts to the occupied zone. Therefore it is important to make sure that 50% of the amount of the supply air can be removed as exhaust air in the higher parts of the industrial hall.

Unfortunately the exact equipment with machines and the corresponding decentralized machine extractions are not fixed during the design stage. In order to avoid the above described problems in this case and for later modifications, it is recommended to equip the HVAC system with a reserve regarding the supply air flow rate. Since today it is state-of-the-art technology to use speed controlled fans, the plant can be adapted to the local requirements during operation.

8 Displacement ventilation (stratified ventilation) while cooling

9 Displacement ventilation (stratified ventilation) while heating

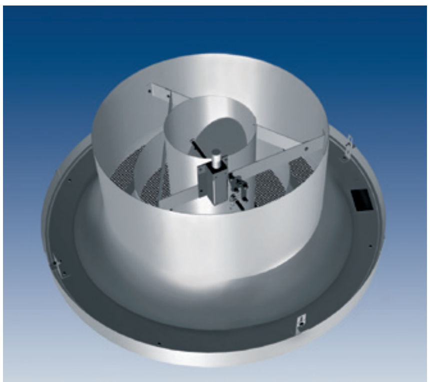
Adjustment to thermal load

The adjustment to thermal load, i.e. the heating or cooling needs, can take place in different ways. Different mechanisms are installed in the air outlets by the manufacturers of the components. In the cooling mode it is necessary to lead the supply air with an indoor air velocity as low as possible to the working zones **8**. The heating mode needs a stronger impulse of the warm supply air downwards that is directed against buoyancy **9**.

The adjustment of the air outlet to heating or cooling mode is made either manually or automatically. At manual adjustment, e.g. with control lever **10**, it is the responsibility of the employee, who works in the area affected by the outlet, to change the adjustment. Surely this will increase the acceptance of the employees. However, with regard to an optimum use of energy, especially when heating, automatic adjustment is recommended.

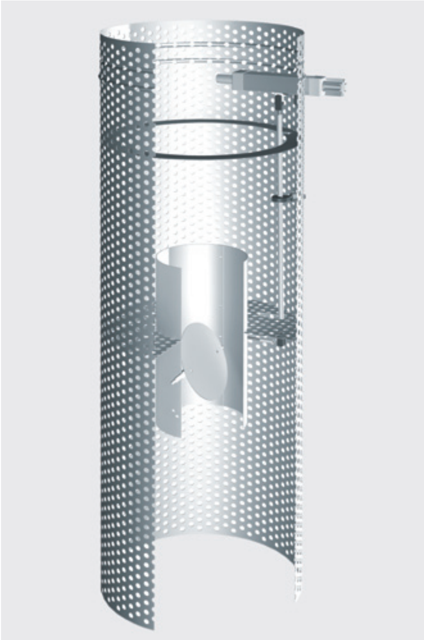
Automatic adjustment can be carried out by electric servomotor or by self-acting thermostatic control unit. The advantage of the adjustment with thermal control is that there is no need of electric wiring and controllers. It receives the operating energy directly from the supply air and a special wax mixture (expandable material) adapted to the required temperature range delivers the adjustment mechanism for the piston stroke. Here, either only the supply air temperature **11** or the supply and indoor air temperature (arrow in **2**, page 2) can be used as a real temperature difference control unit. The latter has advantages if the indoor air temperature may fluctuate in a larger temperature range, in particular if there is no mechanic chiller.

10 Air outlet with manual adjustment for stratified ventilation



11 Thermostatic control unit, Example: Radial displacement outlet

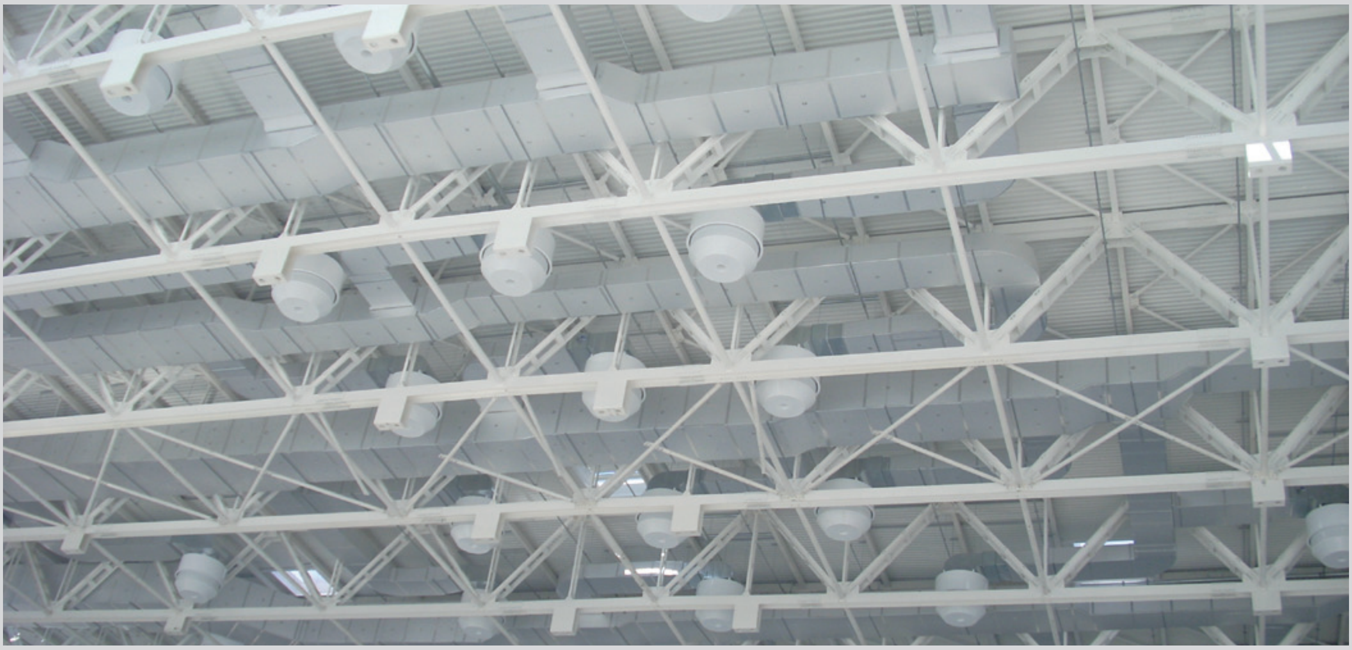
⓬ Non-adjustable textile air outlet while heating



⓭ Schematic representation of an air outlet with thermostatic control unit, basing on temperature difference

Adjustment to thermal load

Sometimes air outlets without adjustment are used in displacement ventilation (stratified ventilation). But this is only possible if an additional chiller guarantees that the supply air temperature is always lower than the indoor air temperature. Furthermore it must be sure that no heating mode occurs. Since this constellation is very rare, the displacement ventilation systems should be equipped with a device to adjust the air flow pattern. These stratified displacement systems react very negative, if there is no reinforcement of the supply air momentum downwards, in case of a supply air temperature that is higher than the indoor air temperature. Because of the low air discharge velocity, the warmer supply air would directly rise towards the ceiling of the industrial hall and would be extracted by the exhaust air system. The advantage of the low pollutant load factor would turn into negative. If there is no chiller for the cooling of the air, in summer it may occur that the supply air temperature lies above indoor air temperature. This is the case, if for example an industrial hall is cooled down in the night with outdoor air, in the morning it is still quite cool in the hall and then the outdoor air temperature rises fast. The heat of the fans is added with about 2 K to the supply air temperature. Here as well the thermal adjustment would ensure that the supply air would be displaced rather into the occupied zone than to rise early to the top.



14 Conical displacement outlets in an aircraft painting hangar

Summary

For the selection of a ventilation system for industrial halls, the heat load and the pollutant load have to be considered in the first place. Further to this the balance between supply air and exhaust air, especially with decentralized extraction systems, must be guaranteed. The adjustment of the supply air flow to the different thermal loads can be made by economic thermostatic control units that use the supply air temperature and do not need auxiliary power. Work areas can be provided effectively and energy-saving with the necessary outside air, thanks to a project design that considers the best suited ventilation system for the respective application.

For further information about the radial displacement outlet VA-PV click here!

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