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Implementation of an algorithm for determining the effectiveness of ventilation and energy efficiency in industrial ventilation systems

Marius Adam[1,*], *Olga* Bancea[1], *Ioan* Aschilean[2]

[1] Universitatea Politehnica Timisoara, Facultatea de Construcţii, Departamentul CCI
2 Universitatea Tehnică Cluj, Facultatea de Instalaţii, Cluj-Napoca

ABSTRACT. The requirements for good indoor air quality and energy efficiency have often been considered to conflict with each other, however, buildings with low energy consumption in Europe seem to have also a lower rate of building related health symptoms. The paper aims to develop a succession of necessary operations, an algorithm, for the determination of ventilation efficiency and energy efficiency in industrial ventilation systems, starting from a general model that will be developed according to the particularities of the industrial ventilation system. These systems are important as they are related both to energy cost and indoor climate management as well as to the health of the occupants. The stages of algorithm development will include: source control and efficient removal of contaminants, proper location of fresh air intakes, cleaning of intake air, efficient air distribution in rooms with improved ventilation efficiency, heat recovery from exhaust air, night time ventilation cooling, ventilation rates control by air quality, correct balancing of air flows and controlling the indoor climate locally.

1. Introduction

Ventilation plays an important role in maintaining good indoor air quality. Ventilation air transfers the internal pollutants efficiently from a building. When ventilation rates are reduced, energy is saved, but at the same time indoor air quality deteriorates, therefore it is important to use heat recovery systems to increase energy efficiency.

Industrial ventilation is imposed by law so that besides ensuring the necessary conditions for the technological processes, the conditions of the safety and the labor protection technique are ensured and fulfilled. According to the Environmental Law, exhaust air from industrial ventilation facilities must be cleaned before being discharged into the atmosphere to limit environmental pollution.

All these industrial ventilation systems have to be chosen depending on the location of the sources of pollution and the type of pollutants, so as to achieve a high ventilation effectiveness.

In order to design a proper ventilation system in terms of ventilation efficiency and energy efficiency we need to develop an algorithm that will meet the particular requirements of each application.

2. The structure of the algorithm

The algorithm is shown in figure 1 and will include 4 phases:

- the particularities of the environmental factors in the industrial field;
- experimental measurements in the case of an existing building or analytical calculations and simulation of values for newly designed buildings, both for indoor air and for exhaust air;
- determination of the flow rate, selection of the ventilation system (local, general, overpressure, depression, equal pressure, mixed ventilation or displacement) and determination of ventilation effectiveness;
- choosing heat recovery and determining the energy efficiency.

* Corresponding author: marius.adam@upt.ro

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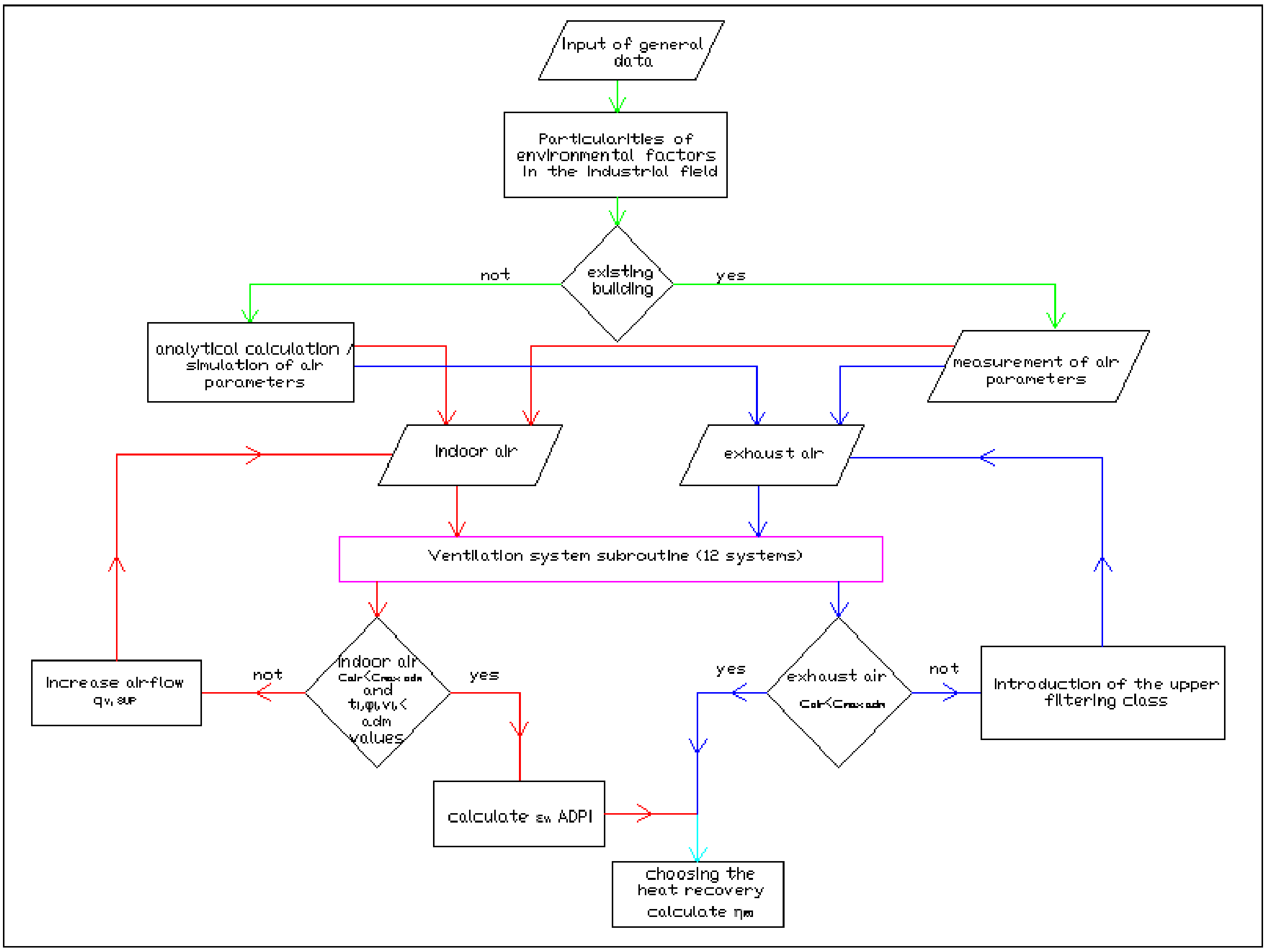

Fig. 1 The logic scheme of the algorithm for choosing the optimal industrial ventilation system

2.1 Particularities of environmental factors in the industrial field

The microclimate of a room involves maintaining at certain values the factors of thermal comfort (air temperature, relative humidity, air velocity, average temperature of radiation) and indoor air quality, by reducing the pollutants [1]. The thermal limits admitted to the workplaces, respectively the correlation between the minimum temperature and the maximum speed of indoor air according to the working category, are presented below:

Table 1. Values for air velocity and indoor air temperature

Work category	**t_i (°C)**	**v_i (m/s)**
static activities	18 - 20	0,2
light physical work	16	0,3
average physical work	15	0,4
hard physical work	12	0,5

The relative humidity of the indoor air correlates with the indoor air temperature and the work category during the hot season of the year and is limited to 65% during the cold season of the year.

Indoor air quality - technological processes in the electrotechnical, mechanical, pharmaceutical, and other industries impose restrictions on dust concentration and particle diameter. In addition to outdoor air filtration operations, a special system for the retention and neutralization of various pollutants is provided on the fresh air circuit.

2.2 Experimental measurements / analytical calculations

In the case of existing buildings, experimental measurements will be made to determine the current situation and how the ventilation system can be improved if necessary. Measurements will be made according to a certain plan, and the sensors will be mounted respecting the distances by EN ISO 7726 (EN 12599), namely 3 different planes (0,1m, 1,1m, 1,7m for standing persons, respectively, 0.1m, 0.6m, 1.1m for seated persons). For new buildings, the values of the indoor air and evaporative air parameters will be calculated and simulated and compared to the maximum permissible values.

2.3 Effectiveness of ventilation

Depending on the measurements or the simulations, the value of the calculation flow rate will be determined as the maximum value between the relations (1) and (2).

The ventilation rate needed for the emission rate and the allowed concentration level in the room give the dilution of a known emission, as follows [2]:

$$q_{v,SUP} = \frac{q_{m,E}}{c_{IDA} - c_{SUP}} \tag{1}$$

where: $q_{v,SUP}$ - volume flow rate of supply air in m^3/s; $q_{m,E}$ – mass flow rate of emission in the room in mg/s; c_{IDA} – allowed concentration in the room in mg/m^3; c_{SUP} – the concentration in the supply air in mg/m^3.
In case of different pollutants, it is necessary to check all relevant pollutants in order to determine the most critical one [2]. To determine the air flow that takes into account the thermal balance and the moisture balance, the relation (2) is applied:

$$q_{v,SUP} = \frac{\Delta Q}{h_{IDA} - h_{SUP}} \tag{2}$$

where: $q_{v,SUP}$ - volume flow rate of supply air in kg/s; ΔQ - thermal load in kW; h_{IDA} – the enthalpy of the indoor air in kJ/kg; h_{SUP} – the enthalpy of the supply air in kJ/kg.
The ventilation effectiveness describes the relation between the pollution concentrations in the supply air, the extract air and the indoor air in the breathing zone (within the occupied zone). It is defined as:

$$\varepsilon_v = \frac{c_{ETA} - c_{SUP}}{c_{IDA} - c_{SUP}} \tag{3}$$

where, ε_v is the ventilation effectiveness; c_{ETA} – the pollution concentration in the extract air; c_{IDA} – the pollution concentration in the indoor air; c_{SUP} – the pollution concentration in the supply air.
The ventilation effectiveness depends on the air distribution and the kind and location of the air pollution sources in the space. It may therefore have different values for different pollutants. If there is complete mixing of air and pollutants, the ventilation effectiveness is one.
The assessment of the effectiveness of the existing ventilation facilities will be determined by measurements: "air distribution performance index" ADPI [3], based on actual air temperature t_{ef} [°C] values, depending on t_x - air temperature at a point of the working area [°C], t_m - the average air temperature in the working zone [°C], v_x - the velocity of the air flow at a point in the working area [m/s], v_m - the average speed of the air in the working area [m/s]. The t_x and v_x values are measured in as many points in the working area and t_m and v_m are calculated as the average of the measured values. To determine the effective temperature, t_{ef} [°C] of the air flow, the relationship will be used:

$$t_{ef} = (t_x - t_m) - 7 * (v_x - v_m) \tag{4}$$

The actual temperature values are calculated for each point. A satisfactory thermal comfort is considered to be:

$$1{,}7\ °C < t_{ef} < 1{,}1\ °C \tag{5}$$

The ADPI performance index is established as a ratio of the number of points N_{cf} in which t_{ef} satisfies the comfort condition and the total number of points N_t in which the measurements were made. It is considered that the ADPI index proves a satisfactory choice of ventilation system and the type and location of the air devices if the ADPI value approaches 100%. The ventilation effectiveness will be determined in the algorithm subroutine for each of the 12 possible systems (figure.2).

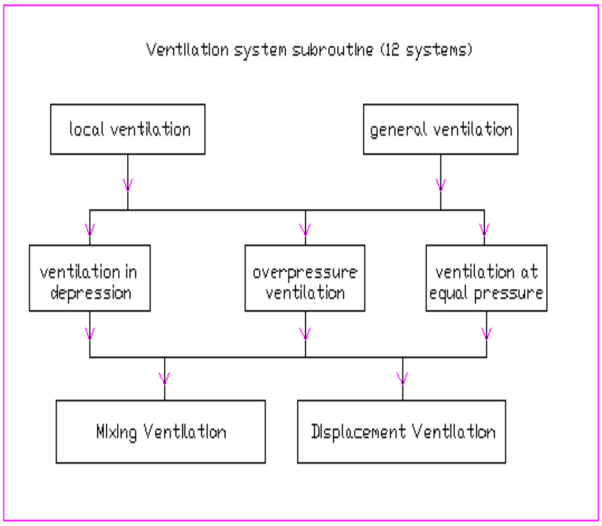

Fig. 2 Ventilation system subroutine

The efficiency of ventilation depends on certain factors such as: avoiding and limiting recirculation areas and avoiding the by-pass areas [4]. Recirculation areas can be avoided or limited by increasing the jet trajectory by using the wall effect (ceiling jet bonding) by providing the exhaust air devices on the same side with the supply air devices (subject to comfort conditions) by changing the temperature of the jet air jet , in accordance with the thermal load and the air flow rate.

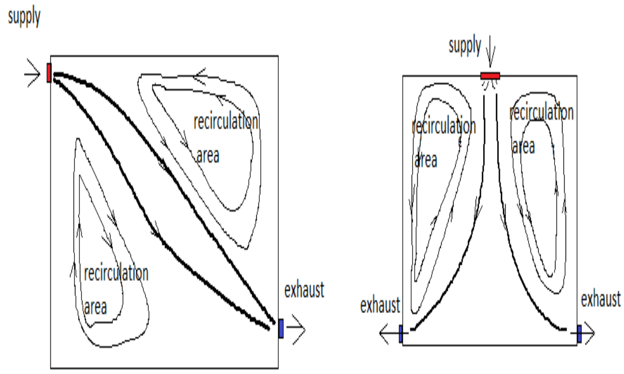

Fig. 3 Creating recirculation zones in the case of air supply up and exhaust air at the lower part, in the working area (mixed ventilation, top-down)

Recirculation areas may also occur due to temperature differences between supply air temperature and indoor air temperature, Δt_0. It is defined criteria *Ar* (Arhimede):

$$Ar = 3{,}6^2 10^6 \frac{g \Delta t_0 L}{T_i H n} \tag{6}$$

where n – air changes per hour [h^{-1}], T_i – indoor air temperature [K], L, H - length and height of the room[m], g - gravitational acceleration [m/s].
It is believed that the air jet will provide ventilation over the entire length of the room if Ar = 1300 - 1500. If Ar =

2800-3000 the jet blows the room 2/3 of its length and if *Ar*> 3400 the jet reaches only 1/3 of the length room. It is therefore advisable to avoid strong non-isothermal jets.
By-passing the supply air can occur during the summer when the supply air devices are placed on the same wall as the exhaust air devices [5]. In the winter situation, the by-pass between the supply air and the exhaust air occurs if the supply and exhaust devices are placed at the top of the room on the same or opposite sides of the room.

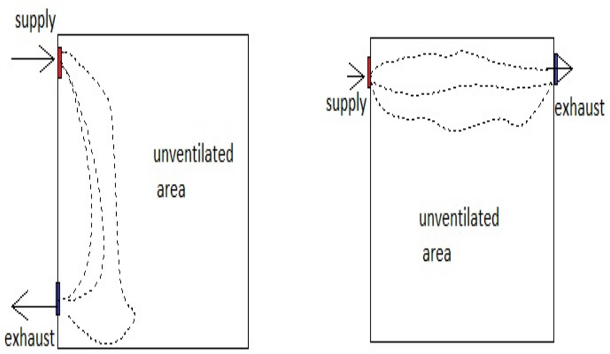

Fig. 4 By –passing zone in ventilated room

To avoid that cold air jets fall on the floor and the hot one remains at the ceiling, it is recommended that the value of the Archimedes criterion, calculated with the characteristic size of the supply air device:

$$|Ar| < 5 * 10^{-3} \tag{7}$$

2.4 Energy efficiency

Depending on the level of pollution in the rooms, the quality of the air extracted from the rooms is classified into four categories (ETA1 - ETA4). Constructively, heat recovery devices are rotary, plate-shaped, heat-conducting and intermediate fluid. These are of several types, namely:
– regenerative systems using a heat accumulating material that can store its sensitive heat, latent or both. This category includes rotary regenerators with regeneration.
– recovery systems, which use an area for heat transfer exchange, sending only sensitive heat, this category includes plate recovery with heat pipes, with intermediate fluid;
– heat pump systems using a refrigerant to transmit heat from a low potential source.
The efficiency of sensitive heat exchange in %, in the case of plate exchangers is defined as [6]:

$$\eta_{RC} = \frac{t_1'' - t_1'}{t_2' - t_1'} * 100 \tag{8}$$

where: t_1', t_1'' are the fresh air temperatures in the initial and final state; t_2' – the exhaust air temperature in the initial state.

3. Conclusions

After developing this algorithm using a programming language, it will result in an industrial ventilation system optimization software for which ventilation efficiency will be obtained by taking and evacuating the hazards on the shortest way by avoiding the recirculation and short circuit areas. Also, a high energy efficiency of the entire ventilation system will be achieved by choosing the optimum heat recovery system. This software will determine a supply air flow, $q_{v,SUP}$, with a minimum value, or which the value of ε_v and IPDA to be as close to 1 and the value of η_{RC} to be maximum.

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