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Adaptive fan control

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Abstract. The paper presents the possibility of management the fan performance in dependence on CO_2 concentration. A mathematical calculation is made from the prediction of the electric energy consumption for a variant control algorithm. The most advantageous algorithm is programmed into the actual fan control system, and its power consumption is shown in graph. Finally, the saving of the adaptive control is compared to the classical control over time. To program the control algorithm, the CO_2 mass balance equation is used. The equation depends on the input values, namely the number of CO_2 sources, the room volume and the supply air. Due to the infinitely variable of fan control, it is possible to adjust the power setting depending on the expected development of the logarithmic rise of CO_2 concentration in the room. This prediction is programmed with the Visual Basic code and program code can be used to the Arduino control unit, which controls the EC fan power with a 0-10 V signal. Although significant savings over a short period of time can not be expected, the ventilation system where the fan runs for a significant part of the year will be substantial. Therefore, the result will be presented by graphical diagrams of different ways of controlling the fan per year of operation.

1. Introduction

Energy consumption during ventilation operation can be significantly reduced by designing efficient HVAC systems with low fan input. The efficiency of ventilation systems is generally relatively low so far, but the savings potential can be increased by a suitable fan control algorithm.

The energy consumption of fans can be significantly reduced by following these three steps.

The first step is to reasonably dimension the air exchange intensity by reducing as much air as possible and by using efficient air distribution. Efficient air ducts reduce unnecessary over-ventilation due to the use of air-tight ducts, respect for air flow principles and air flow control.

Perhaps the most important thing is to reduce the flow resistance and therefore the fan pressure. This is achievable through aerodynamic piping design (including optimum engine room and riser placement to reduce piping length), more generous dimensioning of piping elements, and increased unit size, but without overall oversizing of the HVAC system.

It is necessary to optimize the efficiency of the HVAC system (including fan, drive, motor and variable speed drive, to minimize overall losses in ensuring the necessary air flow and pressure conditions). Oversizing should be avoided, as the efficiency of the fan may decrease significantly if the combination of air flow and delivery pressure is not close to the combination achieving the highest

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efficiency. The efficiency of the motor and drive can also drop significantly at low loads. Therefore, oversizing and variable loads are key factors affecting system efficiency.

These three measures are much more important in climates where there is a need to heat or cool than some use of natural driving forces. The article focuses on the first of these points, especially on the control of fan operation.

2. Description of the room model and the selected fan type

In the mathematical model, the calculation of ventilation is made for the school classroom. Dimensional characteristics are room width 21.0 m, room length 13.3 m, room height 3.8 m. Room volume is 1061 m3, maximum number of persons is forty.

To introduce a variable rate of people in the room, the percentage of people was distributed according to the distribution shown on Figure 1.

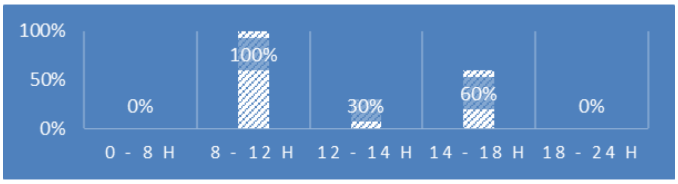

Figure 1. Percentage distribution of people in the room

Natural ventilation of the room by windows infiltration was considered. However, this part of the ventilation component is minimal.

A radial fan is considered. Traditionally, the impeller is embedded in a spiral casing that provides an energy efficient conversion of the kinetic energy of the flowing air into a pressurized air. In connection with the application of new EC motors, we can observe the expansion of radial fans with “free impeller”, where the spiral box is replaced directly by the air-handling unit chamber. This modification of the fan-motor set significantly reduces and cheaper, but at the cost of aerodynamic properties. The air flow in the spiral housing is shown on Figure 2. [1]

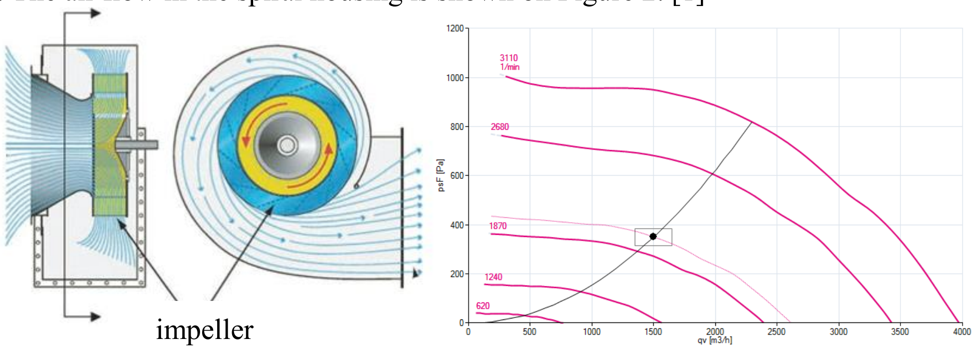

Figure 2. Air flow through radial fan with spiral housing [1]

3. Computational model and description of variants

The computational model of the room is considered as an analytical model. [2]

$$\dot{V} \cdot k_e d\tau + \dot{M}_s d\tau - \dot{V} \cdot k_i d_\tau = O dk_i \tag{1}$$

Where:

$\dot{V} \cdot k_e d\tau$ is the mass of the pollutant introduced into the room by the air required for ventilation over time dτ

$\dot{M}_s d\tau$ is the mass of the pollutant from the source in the room over time dτ

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$\dot{V} \cdot k_i d_\tau$ is the mass of the pollutant taken from the room by the air required for ventilation over time dτ
$O dk_i$ is the weight gain of the pollutant in the room air

$$k_{int_i} = k_{ext} + (k_{int_{i-1}} - k_{ext}) \cdot \exp\left(\frac{-V_{(i-1)} \cdot \Delta\tau_i}{O}\right) + \left(\frac{M_{s_i}}{V_{(i-1)}}\right) \cdot \left(1 - \exp\left(\frac{-V_{(i-1)} \cdot \Delta\tau_i}{O}\right)\right) \quad (2)$$

Where:
k_{ext} is outdoor CO_2 concentration
k_{int_i} is maximum CO_2 concentration
$\dot{M}_s$ is the mass of the pollutant (CO_2)
$V_{(i-1)}$ is forced ventilation (estimated)
O is the volume of the room
$\Delta\tau$ is calculation time interval

Description of individual fan control variants:

Variant 1 - minimum fan start interval is **5 min**, the fan is switched on at a measured of CO_2 concentration 900 ppm, **type of regulation: on / off**.

Variant 2 - minimum fan start interval is **30 min**, the fan is switched on at a measured of CO_2 concentration 900 ppm, **type of regulation: on / off**

Variant 3 - minimum fan start interval is **5 min**, the fan is switched on at a measured of CO_2 concentration 900 ppm and switched off only after reaching a CO_2 concentration of 600 ppm, **type of regulation: on / off**

Variant 4 - minimum fan start interval is **5 min**, the fan is switched on at a measured of CO_2 concentration 900 ppm and switched off only after reaching a CO_2 concentration of 600 ppm, type of control: **stepping (2 fans regulated on / off)**

Variant 5 - minimum fan start interval is 5 min, the fan is switched on at a measured of CO_2 concentration 900 ppm and only switched off after reaching a CO_2 concentration of 600 ppm, type of regulation: **continuous regulation** (air flow is controlled **linearly** according to CO_2 concentration)

Variant 6 - minimum fan start interval is 5 min, the fan is switched on at a measured of CO_2 concentration 900 ppm and turns off after reaching a CO_2 concentration of 600 ppm, type of regulation: **continuous regulation** (air flow is controlled **quadratically - convex** according to CO_2 concentration)

Variant 7 - minimum fan start interval is 5 min, the fan is switched on at a measured of CO_2 concentration 900 ppm and switched off only after reaching a CO_2 concentration of 600 ppm, type of regulation: **continuous regulation** (air flow is controlled **quadratically - concave** according to CO_2 concentration)

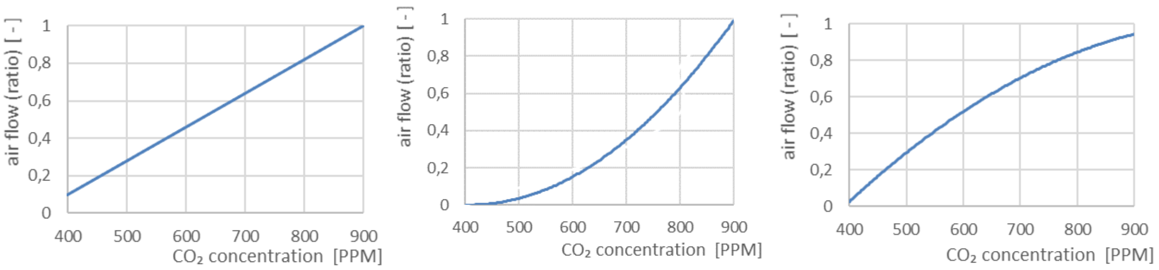

Figure 3. Graphical dependence of fan power control, from left: linear, quadratic - convex, quadratic – concave

Figure 3 shows the air flow dependencies on CO_2 concentration which are used in the calculation of variants 5, 6 and 7. These dependencies affect the start-up of the fan operation and they significantly influence the fan power output.

4. Results

The results are presented by using the graphs. On figure 4 there is a graph of increasing CO_2 concentration the fan operation variant 1.

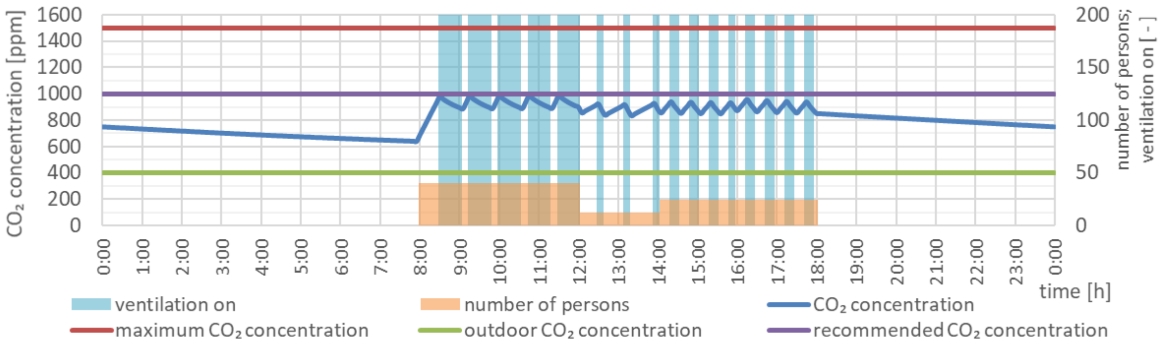

Figure 4. Graphical representation of the course of CO_2 concentration reduction, with the fan operation variant 1

When the concentration rises above 900 ppm, a fan is triggered (light blue color). The results shown represent an on/off control variant with a minimum operating interval of 5 min. The graph shows frequent switching of ventilation.

Graph on the figure 5 represents the adaptation of the fan power to the quadratic dependence on the CO_2 concentration. The ventilator is operating continuously, but the power adapts to the actual CO_2 concentration.

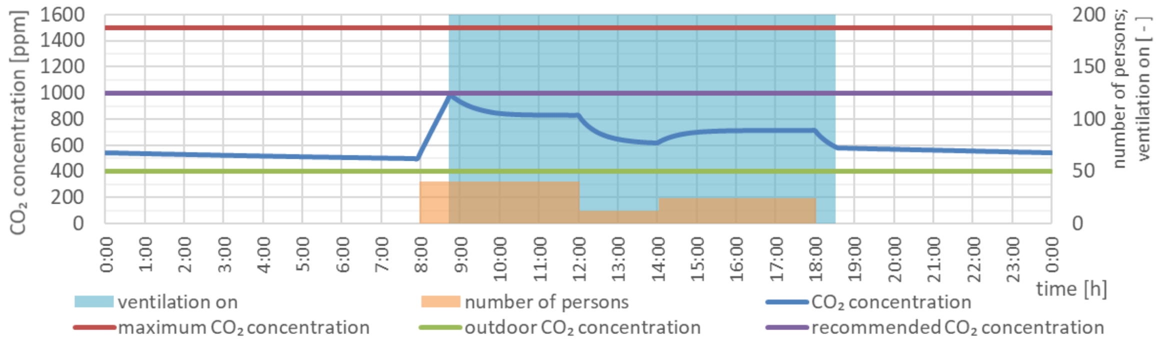

Figure 5. Graphical representation of the course of CO_2 concentration reduction, with the fan operation variant 7

On the figure 6 there are results for the cumulative CO_2 concentrations for the fan control variants 1-7.

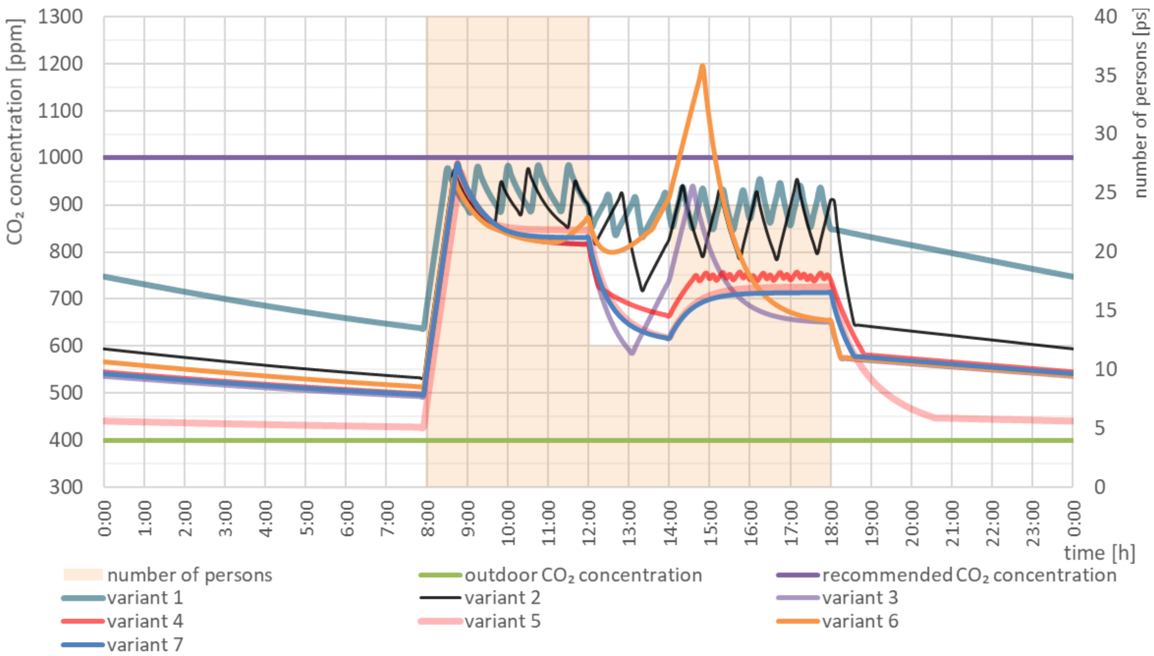

Figure 6. Graphical representation of the course of CO_2 concentration reduction, with the fan operation variant 1-7

The overall results of the fan operation per day, month and year according to the model above are shown in the figure 7.

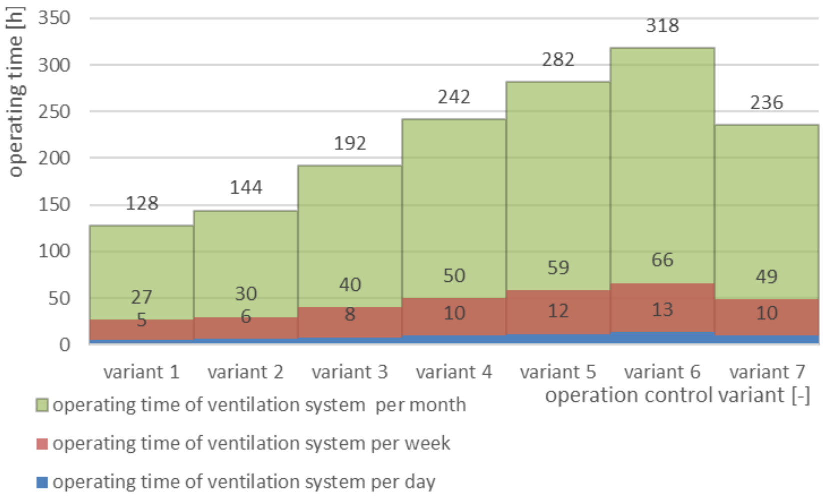

Figure 7. Fan operating time for operating variants 1-7

The economic evaluation is shown on figure 8. The price of 0.17 EUR for kWh of electricity was considered in the preparation of this chart.

The power input of the fans was determined from the characteristics of the fan manufacturer.

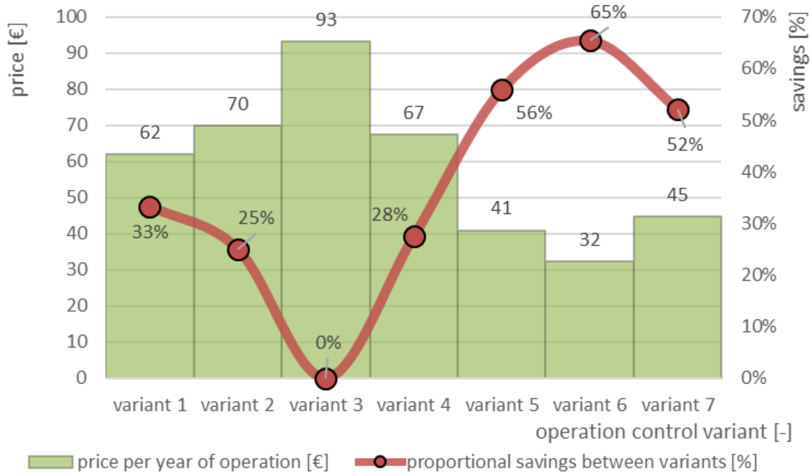

Figure 8. Price per year of fan operation for each variant and percentage savings compared to the most expensive variant

5. Conclusion

The results show that the greatest savings are achieved in variant 6, which is the control of the fan according to the quadratic dependence in the convex shape. However, it should be added that this method was the only method to exceed the recommended CO_2 concentration. This is because the fan's start-up is very slow in nature and the fan starts to run at higher CO_2 concentrations at higher power. The compromise between performance, savings and CO_2 concentration results from variant 7, fan control according to quadratic dependence in concave shape. In this case, the ventilator can effectively ventilate the room and the cost of running the fan is only 13% higher than the most economical option 7.

The conclusion is made for one situation (occurrence of people, room size, etc.). Given the nature of the problem of increasing concentration and reaction of the HVAC system, it can be assumed that even if the fan operating hours will vary, the ratio between the different variants will also change. The total cost per year of fan operation considered in the calculation is not very high. This situation is due to the fact that only one fan with a relatively low flow rate per room is considered. For buildings such as schools, hospitals, etc., the savings would be much more significant in the sum of all fans.

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