On-Demand Ventilation Energy Saving in Industrial Applications

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ABSTRACT

The purpose of this paper is to describe innovative on-demand industrial ventilation. These on-demand systems are already being used in the chemical, metal, and woodworking industries, achieving average electricity savings of 68% over unregulated, classical systems.

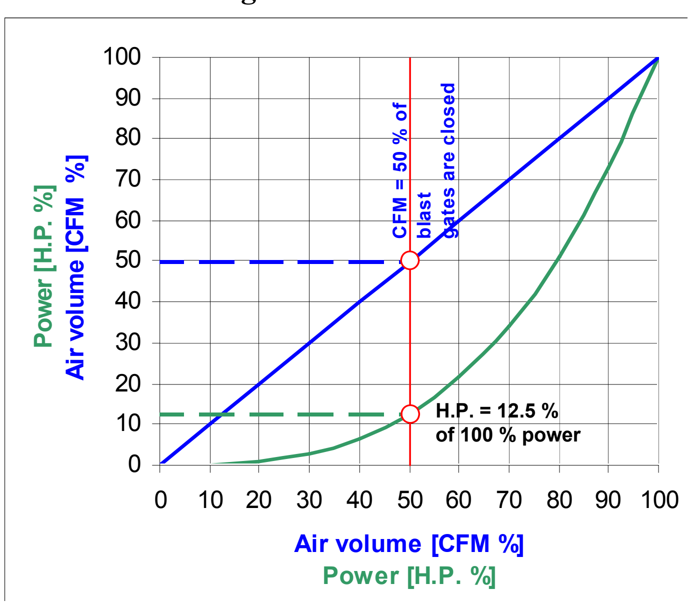
Industrial Ventilation – Classical Design

Classically designed industrial ventilation systems utilize a large central fan and a system of ducts connecting each workstation to the fan (Fig 2). The typical fan motor size is between 50 and 350 HP, based on the number of connected workstations and the length of the duct system (losses). Larger factories use multiple systems that operate continuously for the whole shift time.

Industrial ventilation is used everywhere where dust, fumes, or mist is created, such as the woodworking, metal working, food processing, and pharmaceutical industries. Systems are designed in a way that enables ventilation from all installed machines at the same time. Correspondingly, the appropriate size of the fan motor is chosen. However, data from real factories show that, typically, less than 50 % of machinery is working at any given time; therefore, 50% of machinery is not producing dust (fume, mist); despite this fact, suction continues from all machines.

The "Fan Law" shows why electricity savings can be high. This law of physics says that at 50% reduction of air-flow which is achieved by automatically closing gates on non-operating machinery, fan motor will consume only 12.5% of electricity (an 87.5% saving) of what is required when suction is running at all workstations.

Figure 1: Fan Law



If the air volume is reduced by 50 %, then the electricity consumption of the fan motor will be reduced to 12.5% of the original power - an 87.5% saving. The laws of physics are on our side this time.

The basic idea is simple: Let's equip each workstation with a sensor that detects when ventilation is necessary, and let's use a motorized gate to close the ventilation duct when ventilation is not necessary. Then the RPM of the fan can be adjusted to achieve proper air volume in the ducting (Fig. 3).

However, there is a problem with this simple idea: if dust or other material is to be transported through the ducting, then it is necessary to maintain a set minimum velocity in the ducting to prevent the material from settling in ducts; also, minimum negative pressure should be maintained to overcome pressure losses in the duct system[1]. When gates at non-working workstations are closed, air volume and, subsequently, air velocity in the main duct will drop and dust could settle. An on-demand dust collecting system solves this problem by using a PLC (industrial computer) that calculates the necessary air volume and the necessary negative pressure based on information from the sensors. The PLC adjusts the RPM of the fan accordingly, and it also opens additional gates at non-working machinery if this is necessary for maintaining proper air velocity. Duct diameters are smaller because they are optimized for example for 70% of air volume. The Duct Optimizer software (for Windows PC) is available to simulate and optimize the duct system for any given application.

How the On-Demand System Works

Each workstation is equipped with a sensor that detects when ventilation is necessary (Fig. 3). A motor-operated gate closes the ventilation duct when suction is not needed at a particular outlet. Both the sensors and the gates are connected to a central computer (industrial PLC). As a result, the computer continually receives information from the sensors and uses a software model of the ducting and fan to calculate the proper RPM (speed) of the fan and to determine the number and position of additional gates to be open whenever necessary for maintaining proper air velocity and negative pressure in the duct system. A serial line is used to communicate with the variable speed drive to adjust fan speed. Additional information for the computer is provided by a negative pressure sensor installed in the main duct. Every five minutes, the computer records the following: consumption of the fan motor, times when each workstation was switched on or off, system warnings, and errors. This data can be downloaded to any computer by a modem or via an Internet connection. Data are collected in an SQL database from which many different reports can be generated. Energy saving reports can be used for financing – the "Pay-by-Electricity-Savings" program. Customers pay for such a system in monthly payments that do not exceed the measured cost of saved electricity.

[1] This minimum negative pressure is not a constant value; it is a variable dependent on the number and position of open gates. An extreme example is when just one gate next to the fan is open: in this case, the losses in ducting are minimal, and the necessary negative pressure must exceed just the losses in the dust collector and fan. On the other hand, when the open gate is located at the far end of a long duct system, the minimum necessary negative pressure is substantially higher because it has to overcome the additional losses in a long duct system.

Figure 2: Unregulated (Classical) Ventilation System with Duct System Connected to each Work-Station, Central Dust Collector, Fan and Fan AC Motor

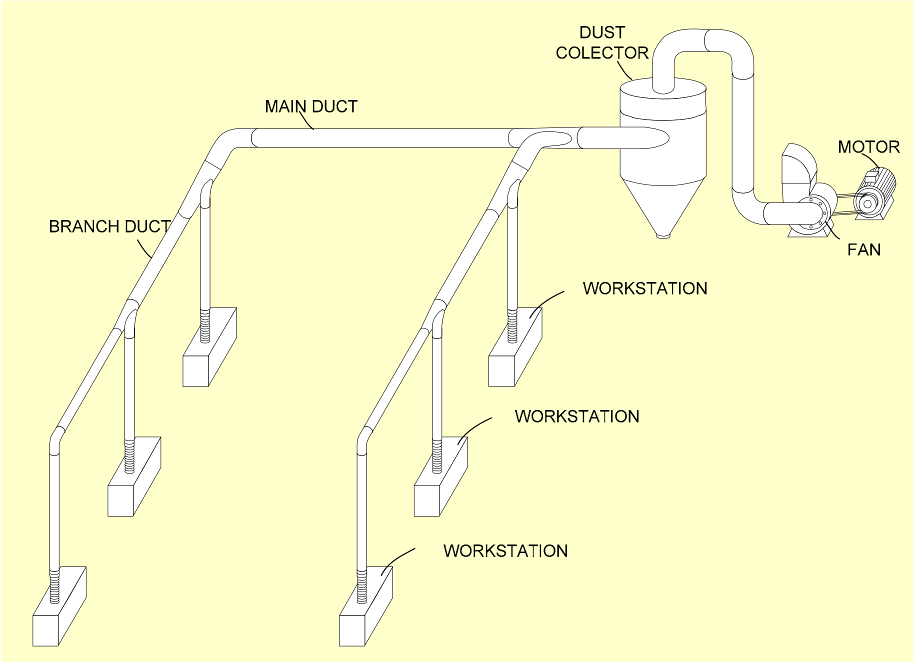
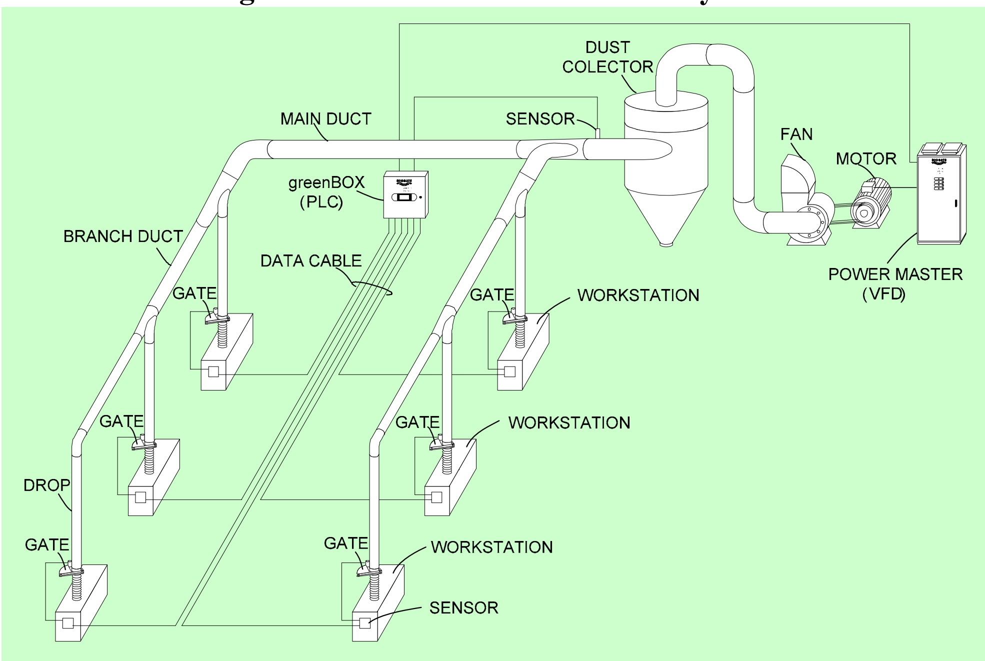


Figure 3: On-Demand Ventilation System



Note: each workstation is equipped with a sensor and a gate to close the ventilation duct when necessary. Both the sensors and the gates are connected to a central computer (PLC) that calculates the proper RPM (speed) of the fan and determines the number and position of additional gates to be open whenever necessary for maintaining proper air velocity and negative pressure in the duct system.

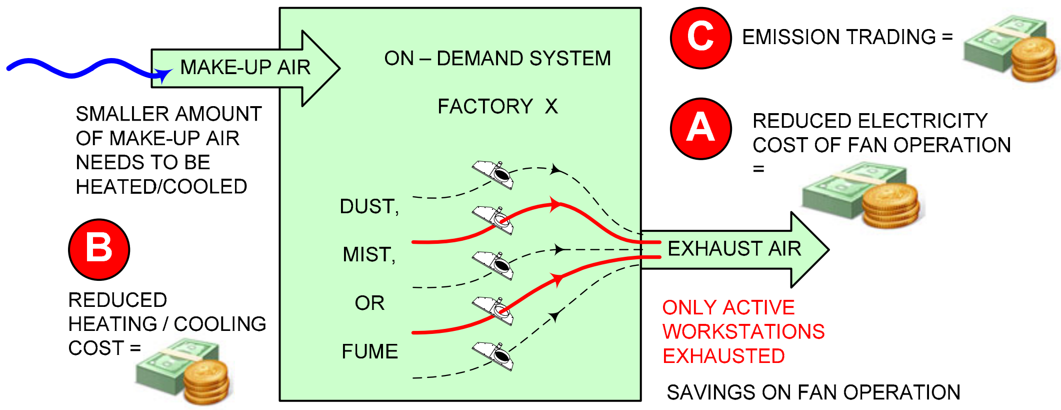
Figure 4: Motorized Gates for Different Duct Diameters Are Used to Close Ventilation on Non-Working Machinery

Table 1: Cost of the Fan Operation at 3 Shifts and Electricity Cost $0.07-$0.20 per kWh

Cost of Fan Operation Per Year 3 Shifts (24 hr. day / 7 days per week), 100% fan load						
$ per kWh → Sys. Size↓	$0.07	$0.12	$0.14	$0.16	$0.18	$0.20
50 HP	$21,168	$36,288	$42,336	$48,384	$54,432	$60,480
100 HP	$44,272	$75,895	$88,544	$101,194	$113,843	$126,492
200 HP	$88,405	$151,551	$176,810	$202,068	$227,327	$252,585
300 HP	$124,161	$212,847	$248,322	$283,796	$319,271	$354,745
500 HP	$221,372	$379,495	$442,744	$505,993	$569,243	$632,492
1000 HP	$442,744	$758,990	$885,488	$1,011,987	$1,138,485	$1,264,984

By using an on-demand ventilation system, 50 to 80% of the fan operating cost can be saved. If air-conditioning or heating is used in a plant, then, in addition to the fan operation cost savings, additional savings are achieved because less air is ventilated outside the building, i.e. it is necessary to cool /heat less make-up air. Air conditioning/heating savings are typically two times higher than fan electricity savings (depending on geographical location, operating hours and energy cost).

Figure 5: Savings by On-Demand Ventilation Systems



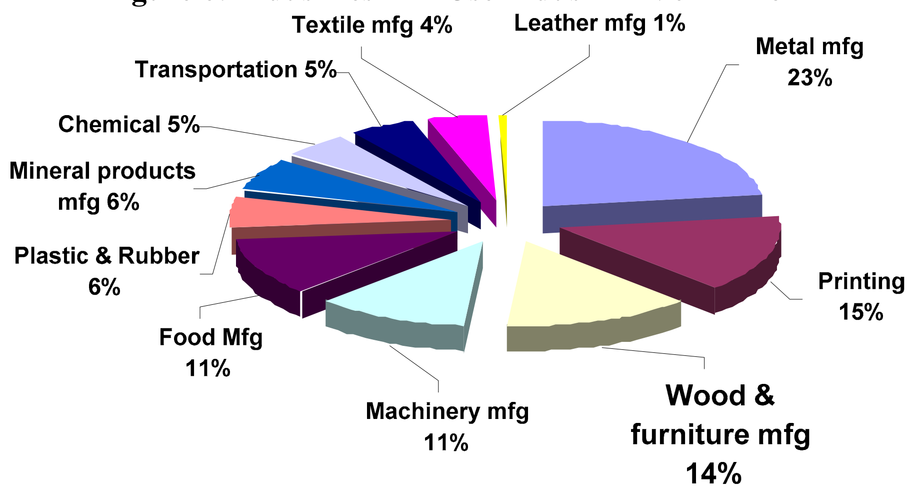
Note: A. Fan operation electricity savings, B. air conditioning/heating savings (if used), and C. emission trading (where available).

- Heating/air conditioning cost depends on geographic location and natural gas prices
- Typically, 2x higher savings (than fan operation cost savings) can be achieved by reducing make-up air volume

Where Is Ventilation Used?

Among industries using industrial ventilation are the automobile manufacturing, printing, food processing (flour, milk powder, salt, sugar, spices), chemical (solids, fumes), petrochemical & pharmaceutical industries, the woodworking industry, the metalworking industry, dental labs.

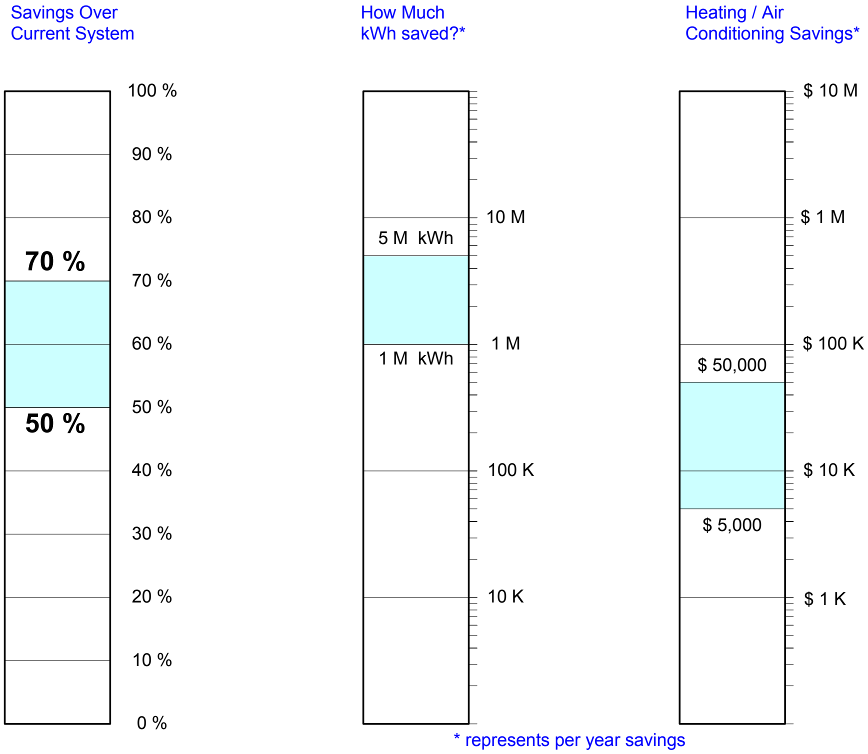
Figure 6: Industries that Use Industrial Ventilation



Example 1: Chemical Industry – Battery Producer

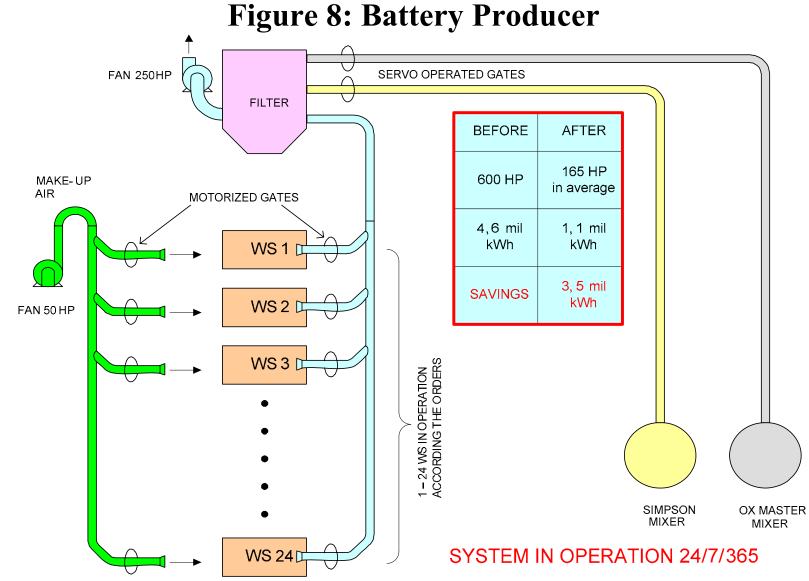
This example describes the system being used by a car/boat battery producer. This factory uses 24 workstations that produce lead battery grids. Production is planned in one-week intervals, based on the orders from dealers, seasonal changes, etc. Using this information, the factory makes a decision on how many workstations it will run during the different shifts of that one-week period. Any number out of those workstations (0-24) are then planned to be used during any particular shift. Each workstation uses supply-air as well as the ventilation system. Currently, both the supply-air and the ventilation system work for all workstations even if they are not in use. Implementing an on-demand air-supply and ventilation system could significantly reduce energy use. In our example, the factory was using 600 HP to operate the fan without the on-demand system. After installation of the on-demand system, only and average of 150 HP is required to run the fan, a 450 HP reduction.

Figure 7: Chemical Industry



Note: typical fan operation savings by on-demand systems compared to an unregulated design (left column), typical fan operation annual kWh savings (middle column) and how much can be saved on make-up air cost per year. (Heating/air conditioning is typically not used in the chemical industry.)

Figure 8: Battery Producer

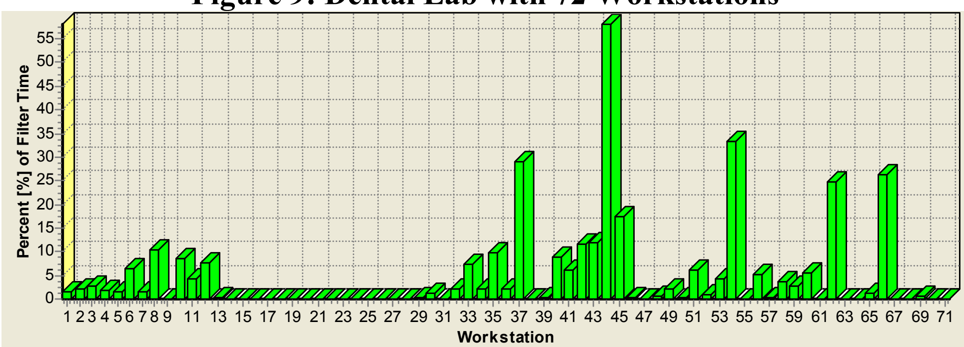


Note: one large unregulated 600 HP system running 24/7/365 was used originally; the new system is divided into three sections that work on-demand (not all three sec-tions are working all the time; two sections and all workstations 1...24 are equipped with gates; the fan is equipped with a variable speed drive.

Example 2: Dental Lab

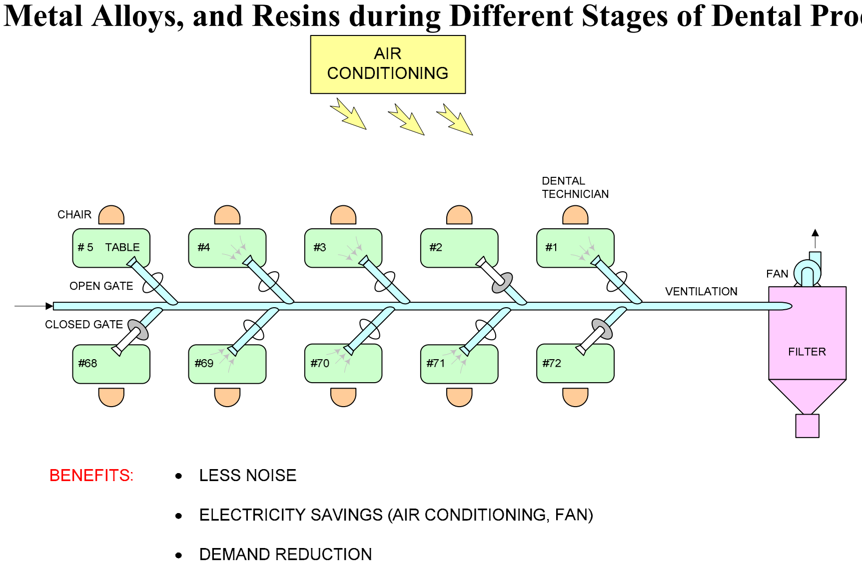
Dental labs use industrial ventilation to collect dust during stages of making dental crowns, bridges and dentures. The company in this example runs 72 operating workplaces in their facility. Each workplace is equipped with a motorized gate and a sensor; in this application the sensor senses current to the hand-held tool used by dental technicians. A variable speed drive controls the fan motor (40 HP). The ventilation system is open only for workstations that are in use. The ventilation system significantly reduced noise and the amount of air ventilated outside of the building. Because the whole building is air-conditioned and less air is ventilated outside of the building, air conditioning costs have been significantly reduced.

Figure 9: Dental Lab with 72 Workstations



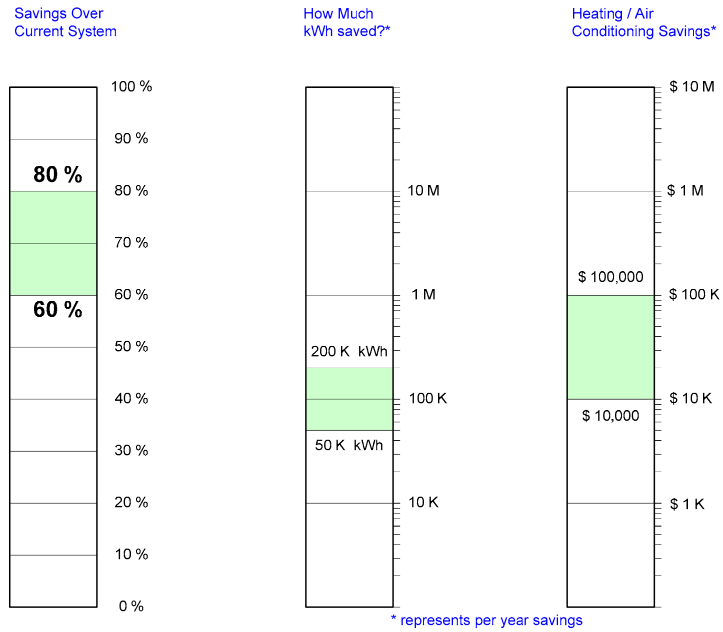
Note: the chart shows activity time of individual work-stations as a percent of total shift time; workstation 44 is used max 55% of the shift time, several other workstations about 30% of the time, but the overall average is less than 10% of total shift time.

Figure 10: Dental Labs Use Industrial Ventilation to Collect Dust Particles of Plaster, Metal Alloys, and Resins during Different Stages of Dental Production



Note: the company in this example runs 72 operating workplaces in their facility.

Figure 11: Dental Lab

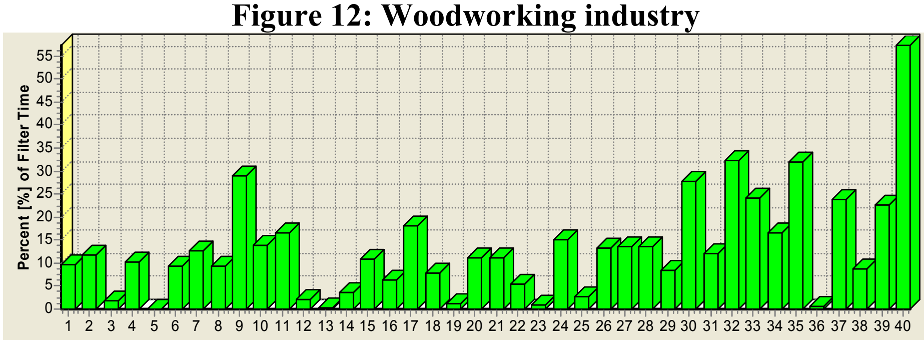


Note: typical fan operation savings by on-demand systems over unregulated design (left column), typical fan operation annual kWh savings (middle column) and how much can be saved on heating/air conditioning annually.

Example 3: Woodworking Industry

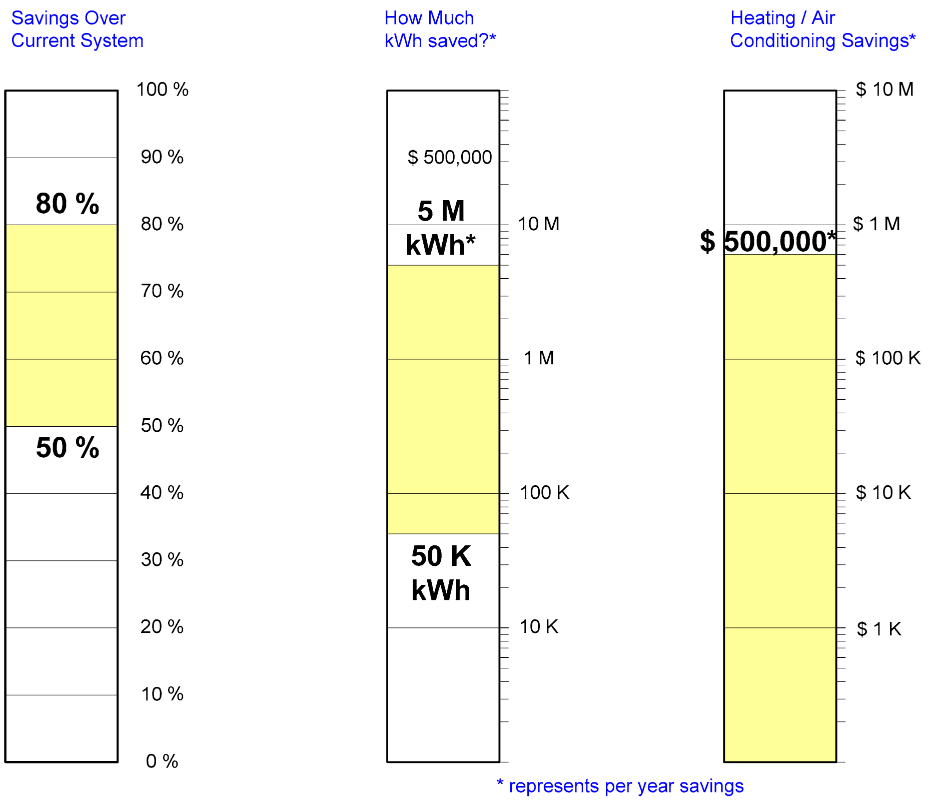
Ventilation systems are commonly used in the woodworking industry (sawdust collecting). The amount of ventilated air is relatively high. For this example, a total of 900HP was required for the ventilating systems in one factory. It has a total of seven ventilation systems in the range from 100-200 HP in fan size. Woodworking machines are not cutting material all the time. According to our measurements, cutting time represents less than 50 percent of the total shift time. Average electricity savings in this particular installation are 67% compared to an unregulated system, with annual savings of $250,000 (fan operation savings).

Figure 12: Woodworking industry



Note: 200 HP dust collecting system with a total of 40 work-stations; chart shows percentage of shift time each workstation is active; the overall average is about 10% - a substantial opportunity to save on fan operation by using an on-demand ventilation system.

Figure 13: Woodworking Industry

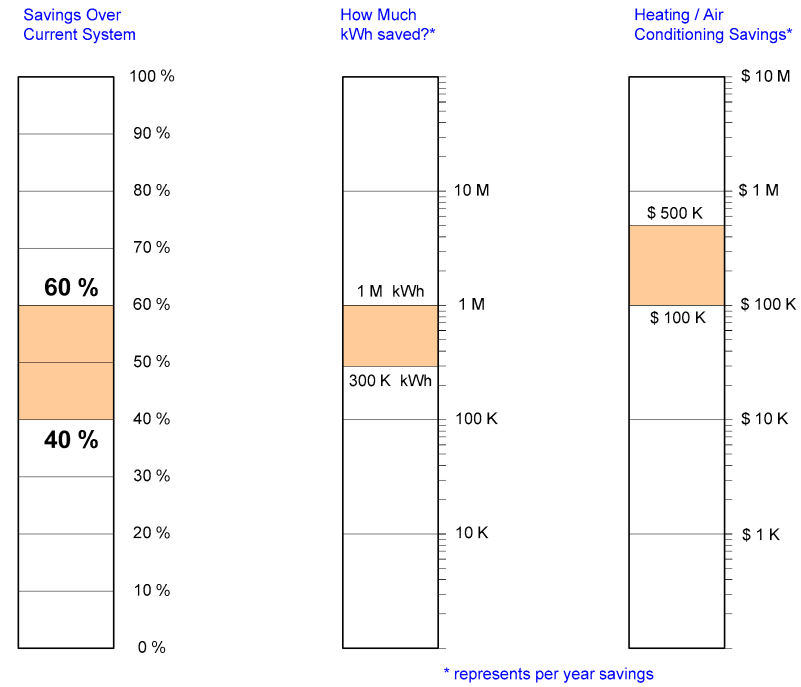


Note: a typical fan operation saving by on-demand systems over unregulated design (left column); a typical fan operation annual kWh saving (middle column); how much can be saved on heating/ air conditioning when used (right column).

Example 4: Exhaust Ventilation Systems in Car Manufacturing

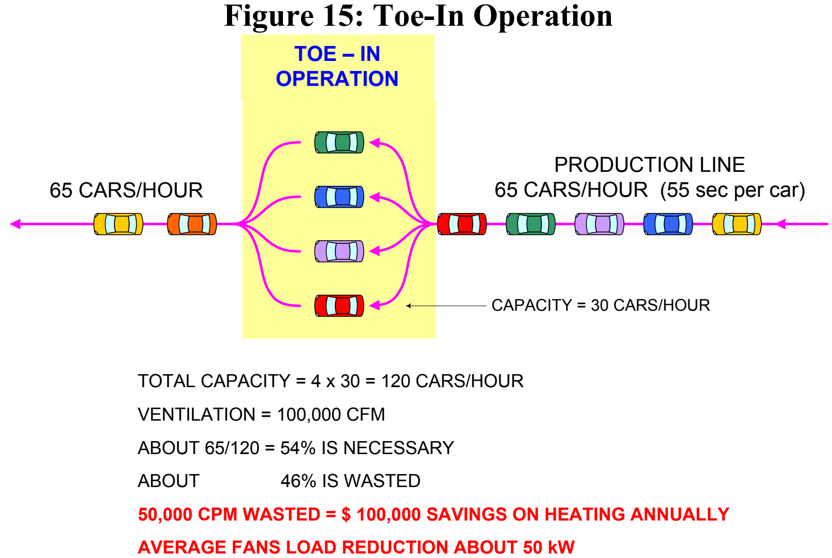
After analyzing the performance and effectiveness of industrial ventilation systems in automobile manufacturing plants, we have identified several areas where ventilation systems are running even without a car present (see Fig 15). To optimize the efficiency of ventilation, we propose that an on-demand systems be implemented (at Toe-In operation and Dynamic Vehicle Testing) to prevent exhaust fan activity in workplaces without a car present, and to ensure optimum ventilation. (Note: other opportunities to implement on-demand ventilation in car manufacturing are in foundries, paint spray repair booths, assembly line, care lines, etc.).

Figure 14: Automobile Manufacturing



Note: typical fan operation savings by on-demand systems over unregulated systems (left column); typical fan operation annual kWh savings (middle column); how much can be saved on heating/air conditioning annually per one factory annually (right column). Heating/air conditioning savings represent majority of savings achieved.

Figure 15: Toe-In Operation



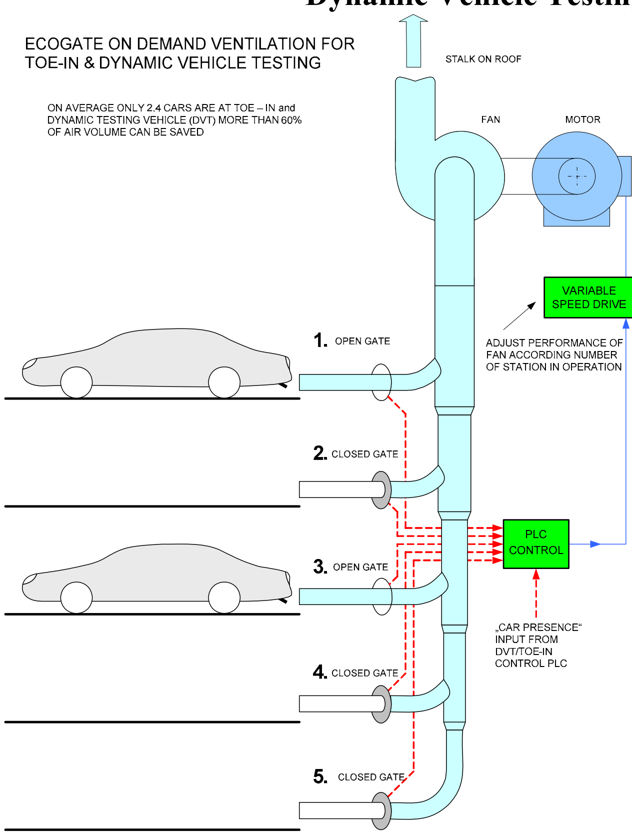
Note: Toe-In operation uses four workplaces in parallel with a total capacity of 120 cars per hour; production line runs at 65 cars per hour, i.e. 46% of the time a car cannot be present but ventilation still runs; A substantial opportunity for an on-demand system because more than 50% of the air volume is wasted.

Let's assume for this example that there are 65 cars coming on the conveyor to the Toe-In per hour. The Toe-In adjustment takes approximately 90-120 seconds (30 -40 cars per hour; a conservative number of 30 cars per hour is used for the savings calculation at toe-in), so there must be several "toe-in" places working in parallel. Under ideal conditions, two working places would be enough, but in real life there are four Toe-In working places for each plant (each conveyor) to compensate for possible equipment malfunction or various small delays. Nevertheless, it is obvious that the average use of these four working places is approximately 50%, and we therefore recommend that the "on-demand" ventilation system be implemented here because there is a substantial saving opportunity.

Dynamic Vehicle Testing (DVT)

Let's assume in this example that there are 65 cars coming to the DVT from the production line each hour. The DVT adjustment takes approximately 120-150 seconds (24-30 cars per hour; conservative number of 24 cars per hour is used for the savings calculation at DVT), so there are several DVT places working in parallel. Optimally, 2-3 working places would be enough, but in real life there would be five workplaces here on each production line (conveyor) to compensate for possible disruptions or equipment malfunction. Nevertheless, it is obvious that the average use of these five working places is approximately 50%. We therefore recommend that the on-demand system be implemented here because there is a substantial saving opportunity.

Figure 16: Block Diagram of the On-Demand Ventilation System for "Toe-In" and "Dynamic Vehicle Testing"



- On-demand ventilation system for Toe-in and DVT operations
- Inputs (car presence obtained from Toe-In or DVT control systems) and gates are connected to a central computer (industrial PLC)
- The computer also regulates the speed of the fan via a variable speed drive unit

Conclusion

Based on our studies over 100 factories average workstation use is 30-50% of total shift time. Because workstation utilization is low ventilation can be designed 50-80% more efficiently if an on-demand system is implemented. Potential energy savings in the USA is 26 billion kWh per year with potential savings of electricity cost $ 1.8 billion per year; pollution offset $ 33 billion Lb CO_2 per year.

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