Savings Through CO_2 Based Ventilation

According to one study in the U.S.,[1] infiltration of outdoor air accounted for 55% of the total heating load and for 42% of the total cooling load. Another survey[2] showed that 75% of fuel oil consumed in New York City schools was devoted to heating ventilated air. Because building conditioning accounts for nearly 20% of all the energy consumed in the U.S.,[3] optimized admission of outdoor air can make a major contribution to reducing our national energy budget. The purpose of this paper is to describe the available control techniques for optimizing the admission of outdoor air.

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DURING periods when free cooling is not available, outdoor air is admitted for ventilation and pressurization purposes in order to:

- Make up the oxygen that was consumed by the occupants;
- Minimize contamination and dilute odors;
- Minimize infiltration by maintaining a positive building pressure.

In conventional installations, the amount of outdoor air admitted is usually based on one of the following criteria:

- 0.1 to 0.25 cfm/ft^2 of floor area;
- 10% to 25% of total air supply rates;
- About 5 cfm volumetric rate per person.

These criteria have all originated at a time when energy conservation was no serious consideration and therefore, their aim was to provide simple, easily enforceable, rules which will guarantee that the outdoor air intake always exceeds the required minimum. Today the goal is just the op posite. It is to make sure that the minimum requirement is *not* exceeded.

ASHRAE has recognized this[4] by permitting minimum ventilation air quantities to be reduced to *one third* of the specified minimum in Section 6 of ASHRAE Ventilation Standard 62-73, if the air quality is maintained. This can result in substantial savings.

METHODOLOGY

There is a direct relationship between savings in building operating costs and reduction in outdoor air admitted into the building. The following steps can be exploited to accomplish such savings:

- Outdoor air damper should be completely closed at all times except when the building is occupied. If, for example, the HVAC system is operated from 7 am to 6 pm, but the building is occupied only from 8:30 am to 5 pm, the damper should be fully closed from 5 pm to 8:30 am. This alone will reduce the daily quantity of minimum outdoor air which needs to be conditioned by 25%.
- Dampers must give tight shutoff. This is an important hardware selection and maintenance criterion. In testing a building in Rochester, Minnesota, the author has measured as

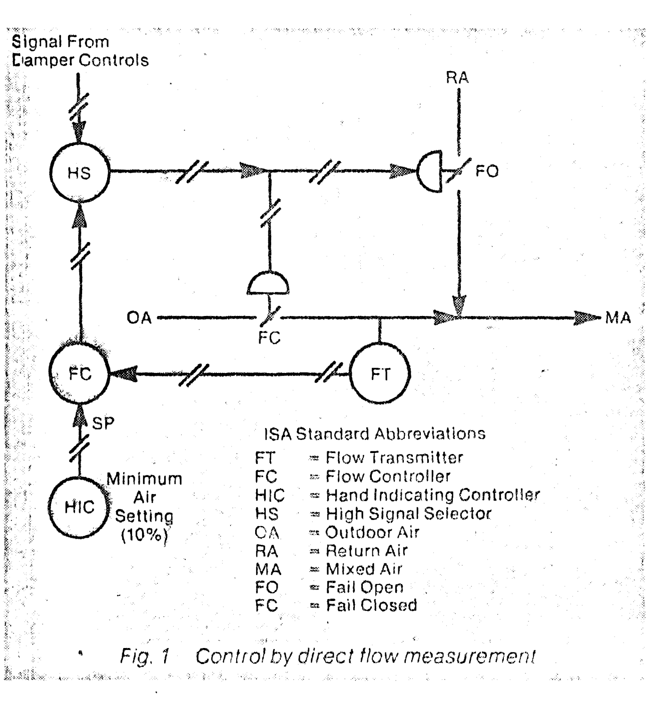

Fig. 1 Control by direct flow measurement

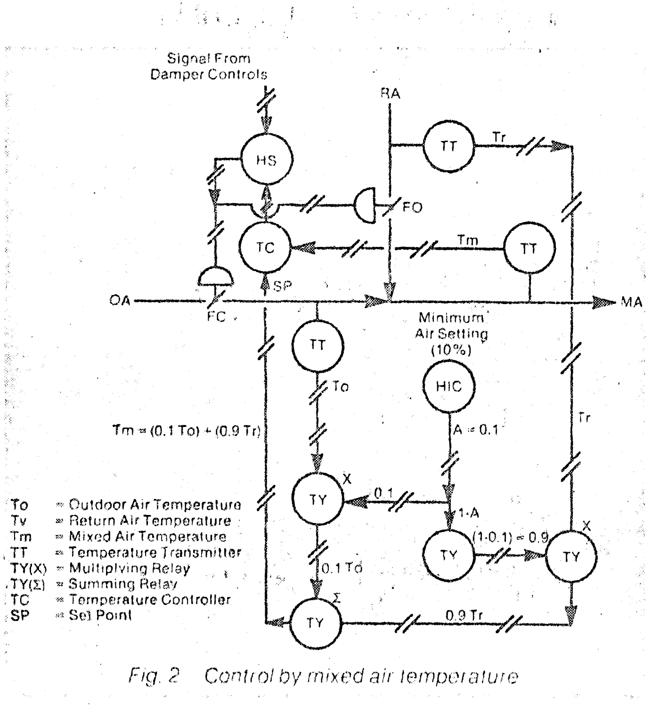

Fig. 2 Control by mixed air temperature

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much as 16% air flow, through "closed" outdoor air dampers.

- If fans are cycled and the dampers are closed when the fans are off, the resulting savings will be in direct proportion to the ratio between "on" and "off" periods.
- During occupied periods, optimization is achieved by measuring the minimum air flow and controlling it at the desired level. It is very important to measure the minimum air flow. The conventional scheme of opening a minimum air damper and assuming that the resulting air flow is what it should be, is unacceptable. In testing a building in Armonk, New York, the author has measured actual minimum outdoor air flows of 46% instead of the "assumed" 10%.
- The minimum outdoor air can be directly measured by an airflow monitoring traverse section as illustrated in Fig. 1.
- If the purpose of the measurement is only to determine the percentage ratio of outdoor air in the total mixed air, this can be done through temperature measurements only, as illustrated in Fig. 2, because:

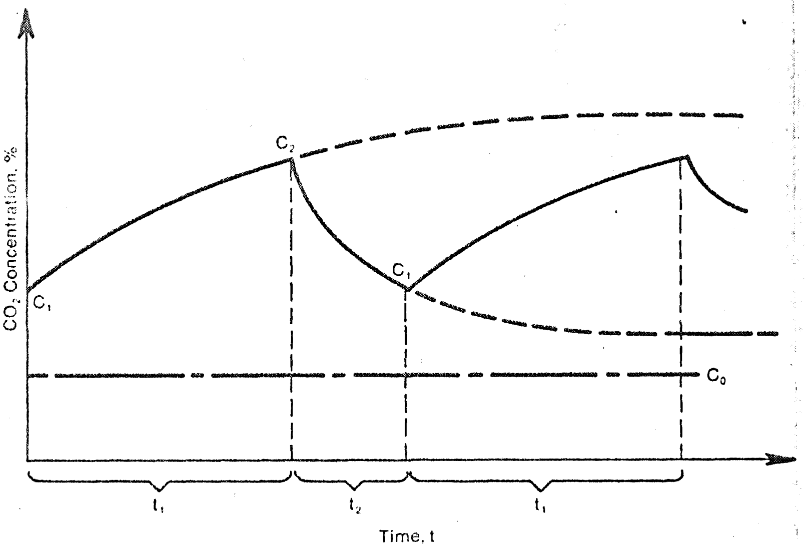
% Outdoor Air = (Tr − Tm)/(Tr − To)

This approach is limited not only because it cannot yield absolute flow information, but also because it becomes inaccurate when the detected temperatures are near to each other.

- In variable volume airhandling systems,[5] it is important to realize that the same damper opening will result in different flows at different times. This is because flow is a function of not only the area of the opening, but also of the pressure drop across it. In VAV systems, the damper ΔP can vary by several fold as a function of total air circulation rate. For this reason, in the more recently designed VAV systems, the use of two separate outdoor air dampers (minimum and maximum), has been replaced by the use of a single damper, provided with a pneumatically set minimum limit. This is desirable, not only because it makes optimization easier, but also because the cost savings resulting from the elimination of the extra damper, can pay for the addition of the flow transmitter shown in Fig. 1.

CO_2 BASED OPTIMIZATION

ASHRAE has recognized[4] that the purpose of ventilation is *not* to meet some arbitrary criteria, but to maintain a certain *air quality* in the conditioned space. Smoke, odors, and other air contaminant parameters can all be correlated to the CO_2 content of the return air.[6] This then becomes a very powerful tool of optimization, because the amount of outdoor air required for



C_0 = Outdoor CO_2 in NYC = 0.05%
t_1 = Elapsed time = 50 minutes
C_1 = Lower CO_2 gap limit = 0.07%
C_2 = Upper CO_2 gap limit = 0.11%

Fig. 3 CO_2 based oa optimization.

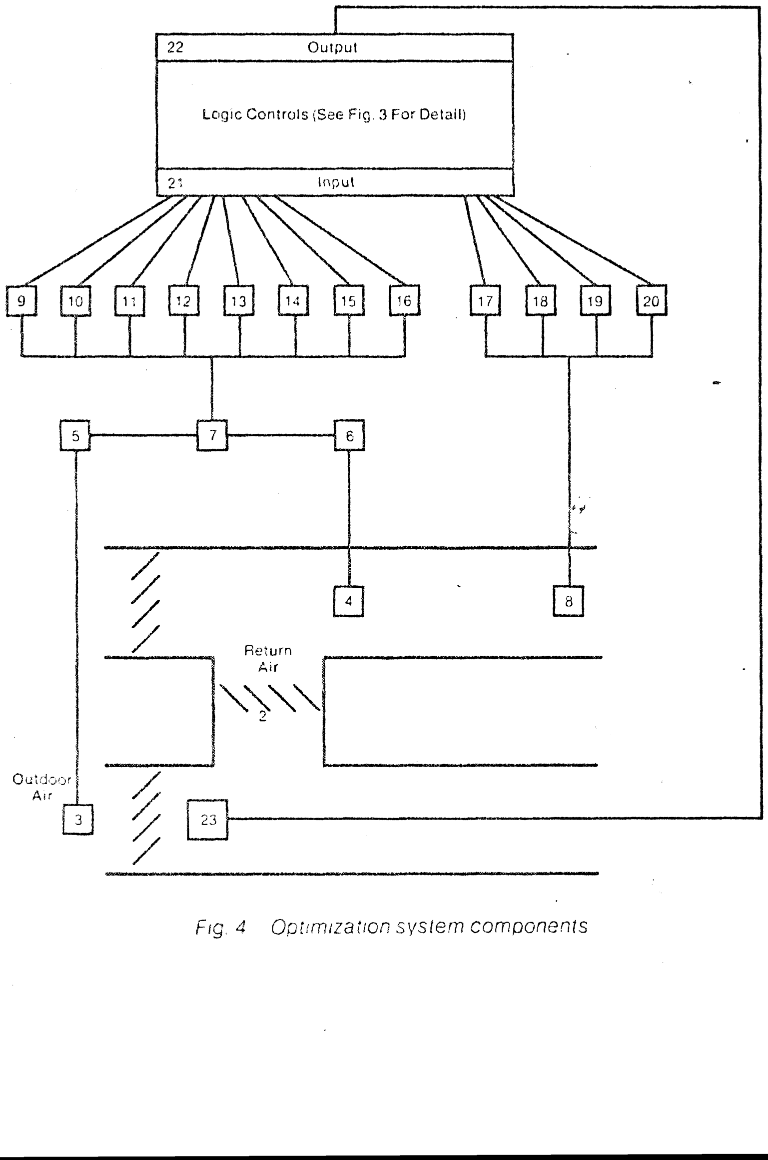


Fig. 4 Optimization system components

ventilation purposes can be determined on the basis of CO_2 measurement,[7] while the time of admitting this air can be so selected that the air addition will also be energy efficient. With this technique,[8] the health and energy considerations will no longer be in conflict, but will complement each other.

CO_2 based ventilation controls can easily be integrated with the economizer cycle and can be implemented by use of conventional or computerized control systems. Because the rate of CO_2 generation by a sedentary adult is 0.75 cfh, control by CO_2 concentration will automatically reflect the level of building occupancy.[9] Energy savings of 40% have been reported[10] by converting conventional ventilation systems to intermittent CO_2 based operation. Fig. 3 illustrates some actual readings[10] that were collected during testing of New York City schools.

Table 1

Output Signal (psig)	Corresponding Enthalpy Difference (Btu)
3	Outdoor air is 20 Btu's *below* indoor
6	Outdoor air is 10 Btu's *below* indoor
9	Outdoor air has the *same* Btu as indoor
12	Outdoor air is 10 Btu's *above* indoor
15	Outdoor air is 20 Btu's *above* indoor

Table 2

Pressure Switch Number	Actuates on Pressure	Settings in psig	Settings in Btu Differential
9	Rise	15.0	+20
10	Rise	12.0	+10
11	Rise	10.5	+5
12	Rise	9.5	+1
13	Drop	8.5	-1
14	Drop	7.5	-5
15	Drop	6.0	-10
16	Drop	3.0	-20

CONVENTIONAL INSTRUMENTS

CO_2 based optimization of building ventilation can be implemented with computers[8] or with conventional controls. Described below is a simple and inexpensive implementation of this powerful optimization technique.

Fig. 4 shows part of a typical air conditioning system wherein outdoor air is drawn into the building through outdoor air damper *1* and is mixed with return air drawn through return air damper 2. Carbon dioxide analyzer *8* continuously measures the air quality while the Btu difference calculator *7* continuously detects the enthalpy difference between the indoor and outdoor air, which is a direct indication of the energy cost of conditioning. The system minimizes energy cost while maintaining air quality in the following manner:

Wet bulb temperature detectors *3* and *4* respectively measure the wet bulb temperatures of the outdoor and return air. These are pneumatic transmitters with 3-15 psig output signals.

The outputs from the wet bulb temperature transmitters are received by the characterized cam relays *5* and *6*. These are pneumatic devices with cams that are cut to reproduce the curve in Fig. 5. Thereby the output signals from the characterized cam relays *5* and *6* are linearly related to the enthalpy of the air, having the units of Btu/lb.

The dual subtracting relay *7* serves to determine the difference between the two enthalpy signals. This is also a pneumatic device which has a full output range of 3 to 15 psig. The linear relationship between the enthalpy values and the output signal appears in Table 1.

The output signal is simultaneously received by eight pressure switches (9, 10, 11, 12, 13, 14, 15, 16). Each of these switches has a different setting, corresponding to a different Btu differential. These values are listed in Table 2.

Therefore, the most energy demanding condition in the summer is indicated when pressure switch *9* is actuated, because in that case at least 20 Btu's will need to be removed from each pound of outdoor air as it is admitted. Similarly, the highest energy cost in the winter will occur when pressure switch *16* is actuated, because it will require the addition of at least 20 Btu's for each pound of admitted air.

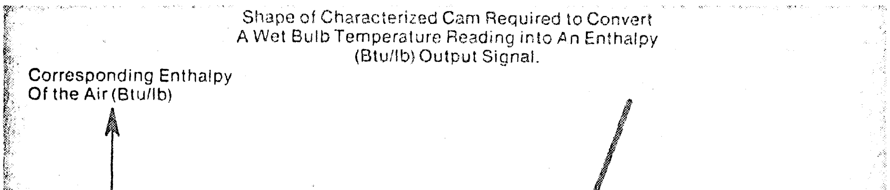


Fig. 5 Shape of characterized cam required to convert a wet-bulb temperature reading into an enthalpy (Btu/pound) output signal

Consequently, the cost of conditioning outdoor air is indicated by the number of pressure switches that are actuated; this can be used as part of the logic input *21*, which is described in more detail in Fig. 6. When a pressure switch is actuated, its contact #1 is closed and its contact #2 is opened.

The output signal from the carbon dioxide analyzer *8* is also received by pressure switches (17, 18, 19, 20). The settings of these pressure switches are so selected as to correspond to predetermined and acceptable levels of air quality. In other words, even the setting of pressure switch *20* is still below the maximum allowable CO_2 concentration that corresponds to acceptable air quality. The actual settings are shown in Table 3.

Table 3

Pressure Switch Number	Actuates on Pressure	Settings in Units of CO_2 Concentration
17	Rise	Very Low
18	Rise	Low
19	Rise	Medium
20	Rise	High

Table 4

Path No.	System State Causing Damper to Open
#1	High CO_2 concentration
#2	Free cooling available
#3	Medium CO_2 concentration when conditioning cost is not high
#4	Low CO_2 concentration when conditioning cost is minimal

Therefore, the quality of the air inside the building is indicated by the number of pressure switches that are actuated (setting exceeded). When a pressure switch is actuated its contact #1 is closed and contact #2 is opened. This information is used as part of the logic input *21*, which is shown in more detail in Fig. 6.

Depending on the air quality (switches 17 to 20) and on the cost of conditioning the outdoor air (switches 9 to 16), it is decided if outdoor air damper *1* should be opened or closed. Whenever the logic output *22* is electrically energized (closed) the operator of the outside air damper *23* will open the damper. Whenever this circuit is deenergized (open) the outdoor air damper is closed.

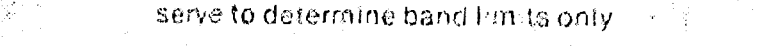


Fig. 6 *Simplified optimization logic diagram*

Fig. 5 shows the relationship between the wet bulb temperature and the enthalpy content of air. This is the relationship which the characterized cams of the relays 5 and 6 in Fig. 4 will reproduce so as to obtain a 3-15 psig linear output signal corresponding to an enthalpy range of 0-60 Btu/lb.

Fig. 6 shows the actual logic relating the various levels of air quality at the optimized decision concerning the opening or closing of the outdoor air damper. As shown, summer/winter selector switch *24* activates the applicable half of the logic network. If it is a "summer" period, there are four combinations of conditions which will cause the energizing of damper actuator *23*. These are identified as path #1 to #4. The conditions corresponding to each of the paths are listed in Table 4. The logic of initiating the opening of the outdoor air damper *1* is similar for a winter condition.

It should be understood that Fig. 6 is a simplified logic diagram identifying only those conditions which will *initiate* the opening of the damper. In addition to these functions, a detailed logic diagram will also include latching and timing functions. An example of the latching function can be: that, if pressure switch *20* is actuated, indicating that the CO_2 concentration is high, path #1 in Figure 6 will not be broken (damper deenergized) until the CO_2 concentration is lowered all the way down to the setting of switch *#19*.

An example of the timing function is that if pressure switch *20* is actuated, path #1 will be kept energized for a set time period, regardless if the CO_2 concentration has dropped below the setting of switch *20* in the meanwhile. Addition of timing and latching functions will define the limits within which certain conditions are maintained without cycling. The pressure switch contacts that are not presently shown in Fig. 6 are provided to give flexibility in determining the limits of each of the bands. These requirements are a function of the type of building served and therefore are not detailed in Fig. 6.

REFERENCES

1. Kovach, Eugene G. "Technology of Efficient Energy Utilization: The Report of a NATO Science Committee Conference Held at Les Arcs., France, 8-12 October, 1973, Scientific Affairs Division, NATO, Brussels, Belgium.
2. Liu, S.T. et al "Research, Design, Construction and Evaluating an Energy Conservation School Building in New York City", NBSIR (under review).
3. Stanford Research Institute "Patterns of Energy Consumption in the United States", Prepared for the Office of Science and Technology, Washington, D.C.
4. ASHRAE Standard 90-75, Section 5.3.2.3.
5. Daryanani, S. "Design Engineers Guide to Variable Air Volume Systems", Actual Specifying Engineers, July, 1974.
6. Nomura, G., and Yamada, Y. "CO_2 respiration rate for the ventilation calculation", Transactions of Japanese Architectural Society Meetings, October, 1969.
7. Lipták, B.G. (ed) "Carbon Dioxide Sensors, Environmental Engineers' Handbook", Volume II, Section 4.6, Chilton Book Co., 1975.
8. Lipták, B.G. "Reducing the Operating Cost of Buildings by the Use of Computers", ASHRAE Transactions 1977, Volume 83, Part 1.
9. "Environmental Engineering for Shelters" TR-20-Vol 3, Department of Defense, Office of Civil Defense, May, 1969.
10. Kusuda, T. "Intermittent Ventilation for Energy Conservation" NBS report of ASHRAE Symposium in Dallas, Texas, February, 1976. □□