The History of Ventilation and Temperature Control

The results of a 10-year study of schools in New York provided guidance on ventilation to schools throughout the United States.

The First Century of Air Conditioning

This is the eleventh article in a special series that commemorates a century of innovation in the HVAC&R arts and sciences.

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When man brought fire into his abode, he discovered the need to have an opening in the roof to let out the smoke and to supply air to keep the fire burning. Control of combustion provided the first incentive for the ventilation of a space. Because the fire warmed the space to a more comfortable temperature, thermal comfort was intimately linked to ventilation.

The ancient Egyptians observed that stone carvers working indoors had a higher incidence of respiratory distress than those working outdoors did. They attributed this to a higher level of dust in the indoor workspace. Thus, control of dust was the second recognized need for ventilation.[1]

The Romans negated the need for indoor fires when they invented radiant heating. Hollow tiles under the floors of their buildings ducted hot combustion products from "stoves" around the periphery of the buildings, through the floor tiles to a smokestack.

They developed a preferred ratio of window to floor area for daylighting. Oiled parchment over the window openings led to high infiltration. Later, the Venetians devised a method for making flat glass for windows.

In the Middle Ages, people began to realize that air in a building could somehow transmit disease among people in crowded rooms. Homes and small buildings were heated with open fires in fireplaces. Smoke often spilled into the room and poisoned the air. King Charles I of England in 1600 decreed that no building should be built with a ceiling height of less than 10 ft (3 m), and that windows had to be higher than they were wide. The objective was to improve smoke removal.

Research began to address the question, "What constitutes bad air?" In the 17th century, Mayow (cited by Michael Foster, 1902) placed small animals in a confined bottle with a burning candle.[3] The candle flame was extinguished before the animal was asphyxiated. An animal survived about half again as long without the candle. He concluded that the "igneo-aerial particles of the air" were the cause of the animals' demise.

One hundred years later (1775) Lavoisier, the father of gaseous chemistry, identified Mayow's igneo-aerial particles as carbon dioxide (CO_2). Lavoisier began his study of oxygen and carbon dioxide in the air of crowded rooms in 1777. He concluded that excess CO_2—rather than a reduction of oxygen—caused the sensations of stuffiness and bad air. The hypothesis was that excess CO_2 in the lungs interfered with their ability to absorb CO_2 from the blood. The argument as to whether "bad air" was caused by oxygen depletion or excess carbon dioxide continued for many years. Pettenkofer (1862) concluded that neither oxygen nor carbon dioxide were responsible for bad air. Rather, biological contaminants were responsible for vitiation of the air.[4] He believed, as did Saeltzer (1872) and others, that CO_2 was a useful surrogate for vitiated air.[5]

About the Author

John E. Janssen chaired Standards Project Committee (SPC) 62, which developed ANSI/ASHRAE Standard 62–1989, *Ventilation for Acceptable Indoor Air Qualtiy* and also served on the SPC that wrote Standard 62–1981. Until his retirement, he was a principal research fellow at Honeywell. Janssen has authored several Journal articles, including "The V in ASHRAE, An Historical Perspective" as part of ASHRAE's Centennial series.

Minimum Ventilation

According to Klaus (1970), a Cornish mining engineer, T. Tredgold (1836) published the first estimate of the minimum quantity of ventilating air needed. He calculated from the breathing rate that a subject needed 800 in.^{3}/min. of unvitiated air to purge the CO_2 from his lungs.[4] He also calculated 5,184 in.^{3}/min. for body moisture removal and 432 in.^{3}/min. for the miner's candle giving a total of 6,415 in.^{3}/min or about 4 cfm (2 L/s). These calculations, based on measured flow rates, did not consider the CO_2 or moisture concentration exhaled by the occupants. Tredgold's estimate was intended to satisfy metabolic needs, but it erred on the side of too little ventilation for comfort.[5]

Thomas Tredgold published the first estimate of the minimum quantity of ventilating air needed.

Subsequent efforts to provide quantitative guidance for ventilation of buildings have ranged from Tredgold's estimate to more than 30 cfm (14 L/s) per occupant as shown in *Figure 1*. There was a growing dichotomy in the objectives for ventilation. Should the objective be based on physiological needs or on comfort factors?

Klaus states that the most authoritative American work just before the turn of the century was *Ventilation and Heating* by J. Billings (1893).[6] Billings, a physician, believed that CO_2 was an accurate measure of impurity emissions from the human body. He calculated that 50 cfm of ventilating air would be needed to keep the room CO_2 level to 550 ppm if the exhaled respiration was limited to a concentration of 200 ppm.

Some people believed that 10 cfm (4.7 L/s) of ventilation air was sufficient. Billings argued for a 30 cfm (14 L/s) minimum and recommended 60 cfm (28 L/s). He was concerned with the spread of disease, especially tuberculosis. According to Klauss, ASHVE in 1895, "adopted the view that engineers were ready to accept the ideas of hygienists and physiologists." They recommended 30 cfm (14 L/s) per person as the minimum ventilating rate. This required mechanical ventilation and placed responsibility for system design and construction on the engineers.

For several centuries, there had been two schools of thought with respect to ventilation. Architects and engineers were concerned with providing comfort and freedom from noxious odors and the debilitating effects of oxygen depletion and/or carbon dioxide accumulation. Physicians, on the other hand, were concerned with minimizing the spread of disease. During the Crimean War, 1853–55, and a few years later in the U.S. Civil War, it was observed that there was a greater and faster spread of disease among wounded soldiers in crowded hospitals with poor ventilation. Wounded soldiers fared better when they were housed in tents or barns. Physicians wanted more ventilation to reduce the spread of disease. Thus, Billings based his recommendation of 60 cfm (28 L/s) of ventilation air per person on his concern for disease; whereas 30 cfm (14 L/s) was adequate for comfort. Thirty cfm of outdoor air per person was written into Massachusetts law in the 1880s. ASHVE adopted a minimum ventilation rate of 30 cfm (14 L/s) per occupant in 1895 and proposed a model law with this rate in 1914.

Steam heating systems were developed after the Civil War. Ventilation to control odors and reduce disease became an integral part of heating equipment. It was becoming clear that overheating was a key part of the sense of poor ventilation. Although desired ventilation rates were being debated, suitable equipment was not yet available to provide the rate needed.

Temperature Effects

The report of the New York State Commission on Ventilation (1923) found that work by Hermans (1893) in Amsterdam had concluded that the negative reaction to poorly ventilated rooms was probably caused by thermal effects, i.e., temperature and humidity. Hermans appears to be the first to blame poor indoor air quality on thermal effects. His hypothesis was that excess temperature interfered with body heat loss and produced physiological effects on a person confined in a poorly ventilated room. This hypothesis was not widely endorsed, but Billings, et. al (l898) did find that the "two great causes of discomfort, though not the only ones, are excessive temperature and unpleasant odors."[7]

Flugge (1905) and his pupils, Heyman, Paul and Ercklentz at the Institute for Hygiene in Breslau, Germany confirmed these hypotheses through a series of experiments. This work was confirmed later in England by Hill and Haldane (1905, 1907, 1913).[8]

Flugge's endorsement of Billings' recommendation of 30 cfm (14 L/s) per occupant of outdoor air was soon adopted by state building codes. Massachusetts had already promulgated such a code in the 1880s. By 1925, 22 states required a minimum of 30 cfm (14 L/s) per occupant of outdoor air. This necessitated mechanical ventilation, which was made possible by the development of the electric power industry.

Some investigators experimented with recirculated air for part of the supply.

There was a growing resistance to heating large quantities of outdoor air for ventilation. Recommended ventilation rates sometimes failed to discriminate between the outdoor airflow rate and the total supply.

Arguments persisted as to whether the effects of poor air quality came from excess carbon dioxide, excessive temperature or biological emissions. The *Department Committee Appointed to Enquire into the Ventilation of Factories and Workshops Report* (1907) in England reported on the effects of restricted ventilation.

Seventeen subjects were kept—for periods of two hours to 13 days—in small, 189 ft^3 (5 m^3) chambers. Air was circulated slowly while temperature was controlled externally. Carbon dioxide was usually more than 3,500 ppm (0.35%). During the daytime when the subject was active, the CO_2 was more than 10,000 ppm (1.0%), and at one time it reached 23,100 ppm (2.3%).[2] Subjects felt comfortable as long as the chamber was kept adequately cool.

Other tests reported by the Departmental Committee on Humidity and Ventilation in Cotton Weaving Sheds (1909, 1911) confined subjects in an uncooled chamber of 106 ft^3 (3 m^3).[9] Carbon dioxide reached 3% to 4%, oxygen fell to 17%, and the wet-bulb temperature rose to 80°F to 85°F (27°C to 29°C). Breathing was deepened by the high CO_2. These rather bar-

baric experiments exonerated CO_2 as a contaminant of concern. However, the fact is that CO_2 is dangerous at concentrations of 3% to 4%, and it is lethal above 5%.

Chicago/ASHVE

The Chicago Department of Health succeeded, in 1910, in having a commission appointed to study ventilation of school buildings. The commission included ASHVE, the Chicago Public School System and the Chicago Department of Health. Their report (1914) concluded that carbon dioxide was "not the harmful agent of major importance in expired air or air otherwise contaminated;" that the temperature of 68°F (20°C) with proper humidity control is desired in artificially heated living rooms; that the then current state of knowledge was insufficient to designate all harmful factors; and, "that from the standpoint of health, relative humidity is one of the important factors in ventilation." ASHVE wrote a model code in 1914 with a minimum ventilation rate of 30 cfm (14 L/s) per occupant of outdoor air.[10]

New York Study of Schools

A study by the New York State Commission of Ventilation in schools began in 1913. During the next ten years various ventilation systems, occupant response and incidence of disease and fuel consumption were studied in 216 classrooms in schools in New York, Springfield, Mass., Fairfield, Conn., and Minneapolis, Minn.

The ventilating systems in two rooms in PS51, Bronx, N.Y. were modified to experiment with various methods of circulating the ventilating air. The resulting report (1923) concluded that overheating was the single most annoying factor in the indoor environment. A window-ventilated room with a natural draft (gravity) exhaust from near the ceiling of an inside wall was the preferred method. It produced substantially less than the recommended ventilation rate of 30 cfm (14 L/s) per occupant. Fan ventilation with supply at the ceiling and exhaust at the floor was the next best. Window-ventilated rooms at a temperature from 59°F to 67°F (15°C to 19°C) had the lowest rate of respiratory illness. Fan ventilation with a temperature of 70°F (21°C) produced 18% more absences and 70% more respiratory illnesses. It was postulated that the more uniform air conditions (i.e., better mixing) with fan-induced circulation increased the rate of the spread of airborne disease. Sixty-eight degrees Fahrenheit (20°C) was believed the ideal temperature for comfort and minimizing the spread of disease.

Ventilation through open windows had to be constrained by outdoor conditions. Noise, dirt, odors or other emissions from the streets could make window ventilation unattractive. Fan ventilation was preferred. In addition, window-ventilated rooms required radiation under the windows and deflectors to prevent cold drafts.

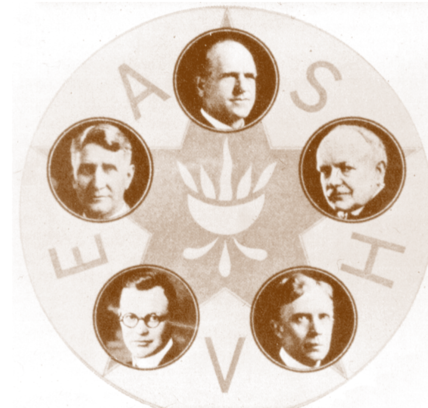
Recirculation was unacceptable because of odors, even when the recirculated air passed through an air washer. This conclusion appears to have been based on 100% recirculation. The possibility of partial recirculation with air washing was suggested as possibly acceptable.

The results of this project became a guide for schools throughout the United States. Using proper temperature control meant that the ventilating rate could be reduced below 30 cfm (14 L/s) of outdoor air per occupant. Yet in 1922, 22 states had building codes requiring 30 cfm (14 L/s).

The ASHVE Laboratory

Heating and Ventilating Magazine, April 1917, stated that, "ASHVE President Lyle appointed a committee to investigate the matter of establishing a bureau of research to be conducted under the auspices of the society," John Bartlett Pierce, a founder and vice president of the American Radiator Co. provided funds to establish the John B. Pierce Foundation for technical research in heating, ventilating and sanitation, "to the end that the general hygiene and comfort of human beings and their habitations may be advanced." These funds provided the initial support for the ASHVE Bureau of Research. The John B. Pierce Laboratory was established later at Yale University.

The ASHVE Bureau of Research was established in January 1919 at the U.S. Bureau of Mines Laboratory in Pittsburgh. At that time, some government laboratories were available for privately funded work. John R. Allen, dean of the college of engineering at the University of Minnesota, was the first director of research. He acquired a research staff and began research to establish heat transfer from radiators, heat transfer and air leakage rates through building wall sections and components, and studies of outdoor air quality in various cities, Allen died suddenly in 1920, so Dean Scipio continued as acting director for one year. F. Paul Anderson, dean of engineering at the University of Kentucky, took a leave of absence to become director of the ASHVE laboratory from 1921 to 1925.



The founders Group for ASHVE Research (from an early Society publication). Starting at the top (clockwise) John R. Allen, F. Paul Anderson, A.C. Willard, F.C. Houghten and L.A. Scipio.

He hired several outstanding research people to continue and extend the work underway. Among these was a former student from Kentucky, Margaret Ingels. She was one of the first female members of ASHVE, and one of the first American women to receive a degree in mechanical engineering.

Margaret Ingels was one of the first women to join ASHVE research.

Ingels had wanted to study architecture, but the University of Kentucky offered no courses in this field. Instead, she opted for mechanical engineering, and graduated with a bachelor's degree in 1916. She joined Carrier Engineering in Newark, N.J.

They were pioneering the air conditioning of buildings. Carrier was developing the technology of humid air and had air conditioned a printing plant in 1902. Carrier had published a pioneering ASME paper on psychometrics in 1911. Ingels received a master's degree in 1920 on the basis of her experience and a thesis. One of the main air contaminants of concern was dust. Ingels worked on filtration of dust from air. She left the ASHVE Laboratory and joined her old boss at Carrier in 1929. There she worked on the marketing of air conditioning. This was directed at home air conditioning after World War II.

The laboratory, under the direction of John Allen, had hired F.C. Houghten, O.W. Armspach, Louis Ebin and Percy Nichols. Houghten went on to become a director of the lab. Armspach helped develop the dust spot meter and measured human body heat loss rates. Ebin published tables on heat transfer rates for radiators and also determined steam flow rates in one- and two-pipe steam heating systems. Allen contracted with F.B. Rowley and A.B. Algren, professors at the University of Minnesota, to measure wall heat transfer factors and air leakage rates through walls and building components. A heat flow meter invented by Percy Nichols was used in this work. These data that were published in the ASHVE Guide and Handbook are still used today. From 1921 to 1925, C.P. Yaglou worked at the lab on problems of ventilating spaces and the interaction of human occupants with their environment. He continued his work as instructor in ventilation and illumination at the Harvard School of Public Health.

Lemberg/Yaglou Research

In a laboratory environment, W.H. Lemberg, et. al. (1935), under contract from ASHVE, measured the minimum ventilation requirement using the human nose as the sensor. The olfactory nerves of the nose are exceedingly sensitive.[11] Pierce (1935) reported that a concentration of 5×10^{-7} mg of oil of rose per cm^3 of air can be distinctly smelled.[12] The odor of butyric acid can be detected at a concentration of 9×10^{-6} mg/cm^3 of air. When exposed to an odor, the olfactory sensors rapidly become saturated and lose sensitivity. It is necessary, therefore, to precondition the judge in clean air before he briefly sniffed the unknown atmosphere to be measured. Under these conditions, human judges using their sense of smell became reliable instruments for measuring odor level. The response to odor was found to be logarithmic—as is the response of the human ear and eye.

Lemberg, Brandt and Morse, all graduate students at Harvard devised an odor intensity scale ranging from zero—no perceptible odor to five—overpowering (nauseating). An index number of two was defined as a moderate odor and was deemed to be acceptable.

A box 20 in. by 20 in. by 6 ft long (0.5 by 0.5 by 1.8 m) long was used as a test chamber. It was ventilated by temperature controlled air entering at one end and exiting at the other end. Judges sampled the odor through holes in the exhaust pipe.

Ten subjects were placed in the box, one at a time, and 15 trained judges performed experiments at ventilating rates ranging from 1 cfm to 50 cfm (0.47 L/s to 24 L/s) per occupant. They found the odor to be acceptable (index no. 2) at 65°F to 72°F (18°C to 22°C) and 20 cfm (9 L/s) per person. When the temperature was raised from 79°F to 86°F (26°C to 30°C), the ventilation had to be increased to 30 cfm (14 L/s).

Yaglou, Riley and Coggins (1936) continued a more exhaustive study at Harvard.[13] A room having a floor area of 155 ft^2 (14 m^2) and a ceiling height of 9 ft, 2.5 in. (2.8 m) was used. An adjoining room of identical dimensions was used as a judge's control room. All windows were weather stripped and cracks were sealed. The judge's room was ventilated at a rate of 50 cfm (24 L/s) per occupant to precondition the judges' sense of smell. A judge entered the test room with a "clean" nose, sniff the air in the test room to measure its odor, render a judgment, and return to the odor-free preconditioning room where his sense of smell was restored.

The test room was occupied by 3, 7 or 14 subjects giving an air space of 470 ft^3, 200 ft^3 or 100 ft^3 (13 m^3, 6 m^3, 3 m^3) per occupant respectively. The ventilation airflow was varied from 2 cfm to 30 cfm (0.9 L/s to 14 L/s) per occupant. The temperature and humidity of the two rooms were kept the same, but it was necessary to keep the ventilation rate of the preconditioning room at 50 cfm (24 L/s) per occupant to approximate a zero odor condition.

Men and women within an age range of 16 to 60 years, grade school children 7 to 14 years of age, laborers, school children of lower socioeconomic class and children of a higher class comprised the groups studied.

Yaglou and his associates found a strong correlation between the required ventilation rate and the net air space per occupant. For example, at 150 ft^3 (4 m^3) per person, 20 cfm (9 L/s) of outdoor was needed to control the perceived body odor to an acceptable level of 2 on Lemberg's scale. If the occupant density was reduced to the equivalent of an air space of 300 ft^3 (8 m^3) per occupant, ventilation was reduced to 12 cfm per occupant for sedentary adults. Grade school children required 25 cfm (12 L/s) at 150 ft^3 (4 m^3) per child and 17 cfm (8 L/s) at 300 ft^3 (8 m^3) per child. Fifty percent more ventilation was required if children had gone 6.5 days without a bath and change of underwear. Only a 33% increase in ventilation was required for adults a week after a bath.

Untreated recirculated air was found to have no effect on odor density, but washing, humidifying, cooling and dehumidifying recirculated air were all beneficial in reducing the outdoor air requirement. Twelve cfm of outdoor air in the total supply of 30 cfm (14 L/s) was acceptable for sedentary adults if there was at least 200 ft^3 (6 m^3) of air space per person. There were significant differences due to children vs. adults, socioeconomic class, and air space per occupant. Subsequent research by Cain, et. al. (1983)[14] and Berg-Munch, et. al. (1984)[15] confirmed most of Yaglou's work except for the effect of air space per occupant. This difference has not been fully explained.

Ventilation Code

W.H. Carrier's work in building air conditioning, beginning in 1902, generated a need for thermal comfort and ventilation requirements by 1920. Measurements of occupant response to their environment by Yaglou, Houghton, Riley, Coggins and others provided a growing body of knowledge. A code of "Minimum Requirements for Heating and Ventilation of Buildings" was published in the ASHVE Guide in 1925. The code was updated as new data became available, especially in 1938. Yaglou began to develop the comfort chart in 1925. The code provided a minimum ventilating rate of 10 cfm (4.7 L/s) per person for the 1946 American Standards Association (ASA) lighting standard.

ASHRAE Standards

The ASHVE research yielded a body of knowledge that led to ASHRAE Standard 55 for thermal comfort and Standard 62 for ventilation. The first, ANSI/ASHRAE Standard 62-1973, *Standards for Natural and Mechanical Ventilation,* presented minimum and recommended ventilation rates for 266 applications and became the basis for most state codes. The standard was updated in 1981 and again in 1989. A conflict with the Tobacco Institute and the Formaldehyde Institute concerning the way the standard treated tobacco smoke and formaldehyde vapor prevented its adoption. Subsequent research on odor made it necessary to raise the minimum ventilation rate so that these conflicts disappeared in the 1989 issue. Standard 62-1989, *Ventilation for Acceptable Indoor Air Quality* is widely used.

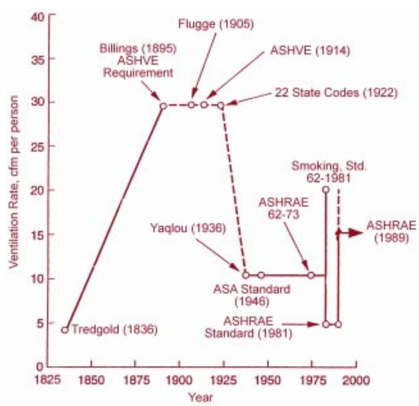


Figure 1: Minimum ventilating rate history.

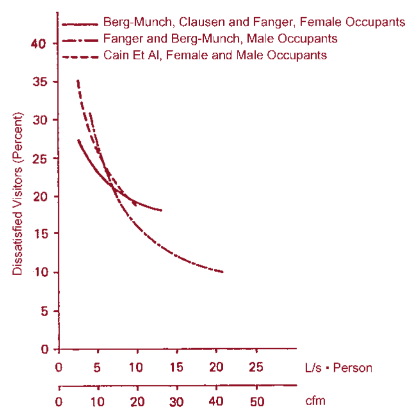


Figure 2: Odor acceptance.

ASHVE research led to a comfort chart that correlated temperature, humidity and comfort response. It was first published in the *ASHVE Guide* in 1924, and it continued to be published in the guide until 1974 when ASHRAE published Standard 55-1974, *Thermal Comfort*. Subsequent editions of that standard were published in 1981 and 1992. The comfort chart has been modified to reflect the response due to clothing, heating/cooling system designs, and living habits.

Many papers have argued the cost/benefit of outdoor air for ventilation. T.R. Tiller (1973) of Kohloss and Tiller argued this point from an Australian point of view.[16] A high dust content in desert climates sometimes makes return air preferable to outdoor air. Indeed, Standard 62-1989 says that the outdoor air should meet the U.S. Outdoor Air Quality Standard or be treated to do so. The standard mainly is concerned with dilution of indoor-generated contaminants.

W. Cain, et. al (1983) and P.O. Fanger, et. al, (1983) published results of new studies that generally confirmed Yaglou's early results. Cain working at Yale University and Fanger at the Technical University of Denmark both agreed that 15 cfm (7.5 L/s) of outdoor air was needed to dilute occupant odors to a concentration acceptable to 80% (20% dissatisfied) of the "visitors" entering an occupied space. These new data did not, however confirm Yaglou's dependence on air space. Thus, Standard 62-1989 adopted 15 cfm (7.5 L/s) per occupant of outdoor air as the minimum (see *Figure 2*).

Janssen (1986)[17] found, based on work by Leaderer and Cain (1983) [18] and Thayer (1982) [19] that 15 cfm (7.5 L/s) of outdoor air per occupant was sufficient to reduce the concentration of tobacco smoke to a level acceptable to 80% of the population at today's reduced smoking rate. Thus, Standard 62-1989 did not discriminate between smoking allowed and smoking prohibited. The new standard did, however, require more ventilation for applications such as bars, cocktail lounges, and smoking lounges where smoking activity is expected to produce higher levels of tobacco smoke.

Whether or not carbon dioxide is a surrogate for occupant odor, a health risk, or of no concern is not adequately answered today. Should the CO_2 level be limited by comfort or only by health risk? Early investigators thought CO_2 was a useful surrogate but not a health risk. Yaglou thought it was a poor indicator because of its non-linear response with odor. Ernest B. Sangree, M.D. (1894) reported that when out walking on a cold day he restored warmth to his body, his hands, and his feet by breathing deeply and holding his breath as long as possible. One may speculate that this increased the CO_2 in his lungs. Carbon dioxide is known to influence metabolic rate and is a vasodilator that dilates the capillaries in the skin. Thus, it increases the heat available and circulate it to the extremities.

Janssen, et. al (1984) studied the response of school children to CO_2-controlled ventilation. A polarized questionnaire devised by Woods, et. al (1982) was used.[20] When the CO_2 in the room rose to 1,600 ppm (0.16%) the children (ages 12 to 15) voted the air more "stuffy," more stagnant, about 2°C (3.6°) warmer, and their hands and feet warmer with respect to their bodies. No correlation existed at 1,000 ppm (0.1%) when the outdoor air was raised to 15 cfm per student. Standard 62-1989 accepted 15 cfm (7.5 L/s) as the lowest permissible ventilation rate under the Ventilation Rate Procedure. Some believe (ASHRAE/ANSI Standard 62-1989) that carbon dioxide is a useful surrogate for occupant-generated biological contaminants. Some stress may exist in concentrations of 1500 ppm (0.15%), but it is not known if this is harmful.

One problem not yet adequately solved, is the ventilation of schools in warm, humid climates. The high latent load on cooling systems poses a cost penalty. Efforts are under way to determine what degradation of the indoor environment occurs if the ventilating rates are reduced.

Kansas State Laboratory

The ASHRAE Board of Directors decided (1961) that it would be more economical to move the research lab to Kansas State University and contract for work at Kansas State or other laboratories. The temperature-controlled room was moved from Cleveland to Manhattan, Kan. and placed under the direction of Professor Ralph G. Nevins. Technical management of projects was placed under a new society Research and Technical committee. This has worked well.

Summary

Natural ventilation through operable windows was the only means of ventilating buildings prior to the development of the electric power industry in the late 19th century. The B.F. Sturtevent Co. of Boston did develop a steam engine-powered centrifugal blower in the 1880s, but this was useful only during the heating season. Overheating of buildings was recognized as the single most critical problem. Proper distribution of heating and ventilating air exacerbated the overheating problem.

Thermostatic controls were invented in the 1880s, but these also suffered from the lack of a power source. Thus, it was not until electric power became generally available early in the 20th century that the desired ventilating rates and temperature control could be achieved. As late as 1920, the relative location of open windows and room exhausts were still studied. The expansion of air conditioning in the 1930s made natural ventilation obsolete.

We now have a good idea of what ventilation rates should be and what the desired temperature and humidity conditions are. The oil embargo of 1974 has brought attention energy use. Today systems must be designed and operated to achieve a proper balance among therma1 comfort, air quality and energy consumption.

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