A PERSPECTIVE OF VENTILATION FOR HEALTH CARE AND RELATED FACILITES

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INTRODUCTION

Perhaps it all started much earlier when Mrs. Neanderthal scolded her mate "The stench in this cave is making us sick!"

Certainly we can extract from biblical reports dating back 4000 years evidence of an acute need for ventilation—Noah's Ark. As early as 1500 BC, the ancient Egyptians identified silicate dust produced by the cutting of construction stone as a cause of respiratory disease (Lord 1986).

Windows for residences were decreed by Charles I of England as a defense against plague and other diseases. However, the outdoor air was often so foul as to be unsuitable for ventilation. The air in London was so bad that the year of 1357 was designated "The Year of the Great Stink." Even in 1661 London's air was characterized as "an impure and thick mist, accompanied with a fulginous and filthy vapour, corrupting the lungs and disordering the entire habits of the inhabitants' bodies."

Ben Franklin was considered deranged by his advocacy, contrary to prevailing medical opinion, of opening windows at night in order "to have a constant supply of fresh air in your bedchamber as a means of preserving health" (Franklin 1780).

The nineteenth century was the occasion of some significant research and hypothecation regarding the value of ventilation. Perhaps the most pertinent was that of J. S. Billings, an American physician, who in 1893 expounded on the connection between ventilation and the prevalence of pulmonary tuberculosis, and recommended 60 cubic feet per minute (cfm) of outdoor air per person for continuously occupied space, and that less than 30 cfm was inadequate. The American Society of Heating and Ventilation Engineers (an American Society of Heating, Refrigeration, and Air Conditioning Engineers predecessor society) with strong support from hygienists and physiologists, adopted the 30 cfm value as the minimum standard. This necessitated mechanical ventilation. The rate was subsequently considered excessive and we engineers were held responsible for overdesign of ventilation systems and wasting money (Klauss, et al., 1970).

Subsequent reevaluation of the health effects focused upon ventilation air quality and consideration of body odor as the controlling factor. This led to reductions in the recommended outdoor air ventilation rate and the substitutionary use of treated recirculated air.

Currently, ASHRAE Standard 62-1989, *Ventilation for Acceptable Air Quality* (ASHRAE, 1989) prescribes a minimum outdoor ventilation rate of 15 cfm per person with higher values for some occupancy classifications.

VENTILATION OF HEALTH FACILITIES

The ASHRAE Standard prescribes ventilation rates for hospitals and nursing and convalescent homes based upon cfm of outdoor air per person for five space classifications and one (autopsy) based on cfm per ft^2 of floor area. The sources for these values were the Guidelines (1983/1984) and the Minimum Requirements

(1979) for Construction and Equipment of Hospital and Medical Facilities, Public Health Service (PHS). The outdoor air ventilation rates in these publications are presented in air changes per hour (ach). Conversion to cfm per person for the ASHRAE Standard was accomplished using the stated occupancy per 1000 ft^2 of floor space and an unstated estimate of nine feet ceiling height. The earlier PHS publication became the source if the more recent one prescribed no outdoor air rates. Unlike the federal guidelines the ASHRAE Standard does not prescribe total air change rates. The PHS publications call for high efficiency filtration of the air supplied to spaces employed in patient treatment and care, thus recognizing the value of particulate removal and resulting reduced concentration of particulates within the occupied space to the health of both patients and staff.

In 1987 (and recently reaffirmed) the American Institute of Architects (AIA) published guidelines with ventilation rates similar to the PHS Guidelines except for operating rooms. For these rooms both outdoor air and total air changes were reduced from 4 and 20 ach to 3 and 15 ach. The 1991 ASHRAE Applications Handbook recommends both outdoor and total air change rates for hospital spaces extracted from the PHS Minimum Requirements published in 1979. For operating rooms, these sources advocate 5 and 25 ach for outdoor and total air.

It is interesting to note that following World War II, eight ach of 100% outdoor air (no recirculation) was commonly applied for operating room ventilation. This was then increased to 12 ach in 1963 (Gaulin, 1963). In 1969, the outdoor air component was reduced to 5 ach by the Public Health Service (PHS, 1969).

For operating rooms, there can be perceived two changes in ventilation practice over the last half of the century. One, reducing the outdoor air rate. This can be attributed to several factors: improvements and greater reliability of filtration of recirculated air, improvements in anesthesia, scavenger ventilation, and the imperative for energy conservation. An increase in total air circulation was followed by a reduction, as represented by the

AIA values. Reasons for this are more obscure, but may reflect recognition that airborne surgical infections are more the consequence of air contamination in the micro-environment of the surgical procedure than the average concentration of viable particulates within the operating room. Total air change has bearing on the latter whereas room air distribution has more effect on the former.

Research Reports

Major emphasis on study and research into ventilation of medical care facilities has centered chiefly on the operating room. A number of studies reported upon total and outdoor air change rates, room air distribution techniques (both of supply and return air), quality of air filtration and anesthetics control. A study (Woods, et al., 1986) primarily directed toward energy and economic considerations recommended further investigation into control of the micro-environment.

Galson and Goddard (1968) proposed ventilation rates for most hospital spaces based on pre-established criteria of the maximum number of bacterial colonies per ft^3 in the room air. The rates proffered were frequently higher than applied in common practice by HVAC system designers. However, they were based on a rational, albeit stereotyped, analysis of the protection of occupants. With the exception of the risk to operating room personnel from anesthetic gases, the primary objective of ventilation study and design for medical facilities is protection of the patients, who are considered to be more vulnerable than the medical and support staff. The acknowledged risk of airborne infection by *M. tuberculosis* to medical-workers has altered the picture (Riley, Nardell, 1993).

Air Filtration

It is known that some microbial diseases can be transmitted through the indoor air (National Research Council 1987). Tuberculosis, influenza, staphylococcal infections, measles, mumps, the common cold and legionellosis are among those diseases identified (Stowlwijk, 1983). In addition, airborne fungi spores and fungi produced toxins are agents for hypersensitivity pneumonitis, common allergies and more serious disease. Toxins produced by several species of fungus, such as *aspergillus versicolor*, are believed to be carcinogenic to humans (Morey, 1992).

Droplet nuclei, containing pathogenic organisms, can be carried and dispersed on air currents. The typical size range has been estimated at one to five microns (Kuehn, 1991), but extending both above and below this range, with the average size about three microns (Riley, Nardell, 1993). Particles of this size are respirable and can remain in suspension for days. Some require a large concentration to cause infection (Burge, 1990) whereas for TB a single mycobacterium deposited in the lungs is sufficient. Micro-organisms may also be transmitted through the air on host particles and even as single organisms (Kuehn, 1991).

The significance of the size of these infectious particles is that they are respirable yet most can be removed from the air by medium to high efficiency filters, thus reducing the probability of infection transmission. Typically fungi spores are similarly characterized in size between two and five microns. Their removal can reduce allergic response.

A standardized performance test procedure for predicting particulate removal efficiencies is still on the way. However, such efficiencies have been published for extended surface air filters by several sources (Ensor, et al., 1988). There is substantial agreement that filters with an ASHRAE dust spot efficiency of 90-95% (ASHRAE Standard 52.1-1992) will remove approximately 99% of particles in the one to five micron range. Even 60-65% medium efficiency filter as could be used in the HVAC system serving administrative and other non-medical space have a removal capability in the order of 75%. Bacterial removal efficiencies have been determined (Luciano, 1984) showing even more effective performance. HEPA filters, rated at 99.97% efficiency for 0.3 micron particles, offer little improvement in effectiveness over the 90-95% dust spot for the preponderance of pathogenic and allergenic particles. The higher efficiency HEPA filters are more costly and difficult to apply; consequently it is best to limit their use—especially in HVAC system— to highly critical situations.

Even well filtered recirculated air will contain noxious gases and vapors. The outdoor air ventilation component is necessary to dilute such contaminants unless gas adsorbers or oxidizers are employed. The outdoor air is not regarded as devoid of microorganisms and should be filtered along with recirculated air (Bernard, Cole, Claywell 1961). Providing substantial total air changes utilizing well-filtered supply air is, as Galson and Goddard (1968) proposed, an important factor in safeguarding both patients and staff.

Infection Risk

Health risks can be incurred from airborne pollutants generated within the inhabited areas of the facility by the occupants, processes or building materials. Pollutants may be introduced with the outdoor air through entrainment of effluent. They can also be produced within the ventilation systems themselves through the accumulations of biological material and organic nutrient. Toxic chemicals are occasionally unwittingly introduced as a biocide. Ventilation is countereffective if it introduces contaminants.

Dilution of contaminants generated within the spaces is secondary to source control as a health safeguard. Accordingly, ventilation is primarily intended to limit the concentration of those contaminants that cannot otherwise be controlled.

The ASHRAE ventilation standard includes an analysis procedure for predicting the concentration of space contaminants or determining the amount of air necessary to maintain concentration limits. However, its application in assessing health risk is sorely limited by lack of necessary situational data. At best such solutions are stereotyped and realistic predictions of results are going to be few. Even so the technique can prove useful in comparing system performance capabilities, such as the significance of total ventilation rates in operating rooms and isolation rooms.

Nardell, in an extension of earlier studies, evaluated the role of dilution ventilation as a control for the spread of tuberculosis demonstrating both its effectiveness and limitations (Nardell et al., 1991). If relevant situational parameters are known the incidence of cross infection is predictable.

Predictions are obtainable through the application of the Wells-Riley equation to evaluate risk from inhalation of infectious droplet nuclei based on steady state conditions, uniform distribution of droplet nuclei and dilution ventilation throughout the space.

$$C=S(1-e^{-Iqpt/Q})$$

The terms of this equation are:

- **C**: the number of new infections predicted
- **S**: the number of susceptible persons in the exposed environment.
- ***I***: the number of infectors
- ***q***: the number of "quanta" of infection added to the air per unit of time, quanta per hour(qph). The value is derived from data relative to a specific episode. It is then employed to predict the number of infections under altered circumstances, e.g., increased ventilation rate. The value is influenced by a number of factors such as the concentration of airborne droplet nuclei and the virulence of the microorganism genus and species. The range in values for various situations involving tuberculosis was reported by Nardell to be 1.25 to 250qph. In contrast, a measles case in a school produced an estimated 5480qph.
- ***p***: the respiration rate (air sampled) per occupant,cfm.
- ***t***: exposure time, hours.
- ***Q***: the ventilation rate in cfm. Only outdoor air was considered as the means of dilution in the cited study.

It is perceived that the usefulness of this predictive technique extends beyond application to tuberculosis to other airborne diseases and response to allergenic organisms produced within the space. Application of the equation circumscribes the limits of effectiveness of reasonable ventilation rates in disease control. Beyond those limits, source control, irradiation, protective safeguards or other alternatives are going to be required for protection of exposed individuals.

The use of the Wells-Riley equation is extended a further step to enable performance comparisons of alternative dilution ventilation rates, air conditioning system performance and filter efficiencies. Simply stated, a rate of infection incidence (C_b) is established for a base ventilation rate produced by a selected HVAC system. This rate is equal to the outdoor air (presumed to be free of the infectious organisms) plus the recirculated air, discounted to account for the inefficiency of the filtration in removal of the infectious particle (droplet nuclei). A second rate of infection incidence (C) can be calculated for an alternative condition and then divided by the base rate to establish a performance or infection risk index ($I = C/C_b$).

This technique is submitted for more complete presentation at ASHRAE IAQ 93 Conference this autumn. A preview of the index application to a school classroom is shown on one of the visuals. Several observations of the classroom analysis can be transposed to health care situations. If a risk reduction in the order of 10 to 1 is desired, as might be to protect medical personnel from TB infection, dilution ventilation alone is not a solution. If the virility or concentration of the infectious agent is very high, source control (total isolation) or exposed person protection are the only apparent solutions.

Health Risk Effects of HVAC Systems

Intake locations: It seems axiomatic that intakes to air supply systems should be located away from the discharge of exhaust, combustion stacks and cooling towers. Yet this has proved deceptively difficult. Physical placement of mechanical equipment rooms in a manner that can predictably avoid entrainment of noxious materials is a challenge. Better to design the points of discharge of effluent away from intakes. The more flagrant violations of the separation principle often occur when supply or exhaust systems are added to existing buildings.

Factory built air conditioning units: Common features of such equipment, especially popular over the last two decades, that increase the probability of the HVAC system becoming a source of contamination are:

- Inaccessible access to components.
- Flat condensate pans with side drain connections.
- Low efficiency filters.
- Mineral wool insulation exposed to the air stream.
- Inadequate provision for humidity control.

Better equipment is now becoming available as manufacturers react to indoor air quality concerns of their customers; but only through owner and designer recognition of its value will it be selected for our medical facilities.

Humidity control: Many older systems maintain humidity by recirculating water sprays. These are recognized amplifiers of bioaerosols and causes of heat transfer equipment depredation. Maintenance is so burdensome their use is usually terminated and wintertime humidification discontinued. Steam, free of boiler treatment chemicals and applied in a manner that will avoid wetting duct linings and downstream filters, is the preferred method of humidification.

Terminal humidifiers are sometimes installed in the individual supply air ducts fed by a common operating suite system. The range of design temperature and humidity conditions prescribed for operating rooms can be met by a single central humidifier control providing a moisture content of approximately 60 grains per pound of dry air. For specific operational procedures the temperature range may be stretched beyond normal design parameters. Even then the resultant relative humidity hardly represents a health risk or comfort compromise. Neglected maintenance of terminal humidifiers and their controls can, on the other hand, have serious consequences, which can be compounded if filters are placed downstream of the humidifiers. Wet (or dirty and wet) filters will reduce supply airflow—with the probability of creating a negative pressure within the operating room. For more reliable control and to avoid cross contamination between operating rooms, an individual air conditioning system for each is preferred, but this is frequently not feasible.

Space pressurization: A positive or negative space pressure relative to adjacent spaces is generally achieved by a deliberate imbalance of supply and exhaust airflows. The actual pressure differential created is extremely small and virtually unpredictable during design unless the room is of special sealed construction (ASHRAE 1991). Pressure relationships can be completely upset, even reversed, by door and window openings. Such relationships can also be compromised simply by depredations over time of the adjustments of airflow regulating devices throughout the system serving the critical rooms. Over reliance upon the protection provided by imbalance of airflows incurs a risk. Anterooms with independent air supply and/or exhaust as well as sealing of all openings are proven techniques. In existing hospitals, the need arises to convert ordinary patient rooms into isolation rooms (positive or negative). What then?

Variable Air Volume (VAV) Systems

VAV systems are one of the most popular concepts of air conditioning. Room temperature control is accomplished by regulating the supply airflow. Its use has been extended to patient care space, where formerly constant supply air flow with the room's temperature controlled by changing the supply air temperature had been considered essential. Accepting the energy use and cost benefits of VAV, usually involves compromise with indoor air quality objectives. Most VAV systems operating today are controlled in a manner that reduces outdoor airflow in proportion to the reduction in total system supply airflow. Moreover, if exhaust airflow is constant, a shift from positive to negative pressure may occur in individual spaces or the entire building causing infiltration of potentially contaminated air.

Considerations for the Future

Shifting populations will continue to create a need for new medical facilities. However, with the pressure to contain medical costs, there is likely to be increased emphasis on the more effective use of those now existing. Many of today's air conditioning systems are old, less able to perform as they once could. At their best they would hardly meet current indoor air quality and medical treatment criteria. Upgrading or replacement must occur. Replacement concepts for desired improvement are not always easy or obvious.

Reductions in health risk to building occupants from airborne infection are likely to involve improved source control through isolation and containment, elimination of known reservoir and amplifiers of microorganisms, and better ventilation techniques. Weakness in the housekeeping, maintenance and operation of HVAC equipment is a reality, but many past design and construction practices have made these functions hard to accomplish.

Improved design for better component access has been mentioned. Upgrading filters for higher efficiency can often be accomplished through new filter cell designs at favorable cost and reduced maintenance. Dirt collecting room units can be replaced with more cleanable designs (now coming on the market) or, better yet, with all air systems. Ultra low temperature all-air systems take less space and may even cost-justify replacement through operational savings. Isolation of infected patients may be facilitated by application of displacement ventilation principles coupled with local exhaust near the patient's head as a means of source control. The use of air curtains at patient room doorways offers the opportunity for improved isolation where anterooms are impracticable. The expanded use of high total air change rate room ventilating systems now being employed for protection of immuno-suppressed or -compromised patients and ultra violet irradiation or both, may also be applied to protect staff and visitors.

Twin duct air system concepts combining the desirable features of VAV and constant volume air conditioning can augment or replace existing VAV systems to upgrade indoor air quality and comfort control.

It is hoped that this limited list of suggestions may stimulate the discussions of the workshops toward the achievement of the goals of the conference.

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