VENTILATION DESIGNS

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HISTORY

On October 22, 1947, rules required under Title 42 Chapter 1 — Public Health Service, Federal Security Agency, Part 53 Grants for Survey, Planning and Construction of Hospitals were published in the Federal Register. In this rule, specific requirements for the Ventilation of General Hospitals, Mental and Psychiatric Hospitals, and Tuberculosis Hospitals were described. Among these were the following:

> *Ventilation.* Rooms which do not have outside windows and which are used by hospital personnel, such as Utility rooms, Toilets, Bed pan rooms, and Baths, and Sterilizer rooms, shall be provided with forced or suitable ventilation to change the air at least once every six minutes.

> Kitchens, morgues and laundries which are located inside the hospital building shall be ventilated by exhaust systems which will discharge the air above the main roof or 50'-0" from any window. The ventilation of these spaces shall comply with the State or Local Codes but if no code governs, the air in the work spaces shall be exhausted at least once every six minutes with the greater part of the air being taken from the flat work ironer and ranges. Rooms used for the storage of inflammable material shall be ventilated to the outside air with intake and discharge ducts.
>
> The operating and delivery rooms shall be provided with a supply ventilating system with heaters and humidifiers which will change the air at least eight times per hour by supplying fresh filtered air humidified to prevent static. No recirculation will be permitted. The air shall be removed from these rooms by forced system of exhaust. The sterilizing rooms adjoining these rooms shall be furnished with an exhaust ventilating system.

The significance of this rule was considerable in that compliance was required in order to obtain Federal Grant money to build these health care facilities. At least one state department of health continues to use some of the language in this rule today. Notice that the interior rooms of these buildings were required to have 10 air changes per hour (ACH) and that the operating rooms only eight ACH of outside air. The beginnings of pressure relationships were also spelled out regarding the OR and sterilizer rooms.

With this rule, there began a systematic attempt to standardize the performance of health care facility ventilation systems across the country. The idea of infectious disease passing through the air from one person to one or more other people did not begin in 1947.

In his paper entitled "Historical Background," Dr. Richard L. Riley reported on the history of airborne contagion for a conference on that topic sponsored by the New York Academy of Sciences (Riley, 1980). A quick synopsis of the history as described by Riley follows:

- 1862 Pasteur published "Memoir on the Organized Corpuscles that Exist in the Atmosphere."

- 1876 John Tyndall quote:

> "I have spoken of the floating dust of the air, of the means of rendering it visible (the Tyndall beam), and of the perfect immunity from putrefaction which accompanies the contact of germless infusions and moteless air."

- 1910 Charles V. Chapin quote:

> "Bacteriology teaches that former ideas in regard to the manner in which diseases may be airborne are entirely erroneous; that most diseases are not likely to be dust-borne, and that they are spray-borne, only for 2 or 3 feet, a phenomenon which after all resembles contact infection more than it does aerial infection as ordinarily understood."

- 1931 William F. Wells develops the Wells centrifuge for the examination of bacteria in the air.

- 1934 Wells publishes "On Airborne Infection. Study II: Droplets and Droplet Nuclei."

- 1935 Wells and G.M.Fair publish work on the effect of UV radiation on sterilizing air.

- 1941 Robertson et al. publish work on use of aerosol glycols to sterilize air.

- 1957 & 1962 R.L.Riley et al. demonstrate spread of TB by air in a Baltimore Veterans Hospital.

- 1968 Schulman demonstrates natural airborne transmission of influenza in mice.

- 1970 A single small pox patient in a West German hospital infects 19 others whom he had never seen.

- 1978 E.C.Riley reports on a measle epidemic in an elementary school where the ventilation system is implicated.

Commenting on the development of the technique of air disinfection Riley closes his 1980 historical perspective with:

> "Failure of cooperation between architects, engineers, microbiologists and the people developing the technique of air disinfection has held back progress. The medical profession remains confused and, by and large, has not given its blessing to air disinfection in hospitals."

Indeed, it seems as if the engineering community and the health care community has with rare exceptions worked independently not only on disinfection of air but also on all other aspects of its conditioning and delivery.

Two of the more notable exceptions are The Department of Health and Human Services (DHHS), (including all of its ancestors), and the American Society of Heating, Refrigerating, and Air Conditioning Engineers, Inc (ASHRAE). DHHS, which has had an intimate involvement since 1947, today has enlisted the services of the American Institute of Architects to continue the evolution and publishing of guidelines for health care facility construction. ASHRAE continues to edit and publish its own design guide in the form of a chapter of the popular ASHRAE handbook series. These handbooks are entitled *Fundamentals, Refrigeration, HVAC Sysytems and Equipment, and Applications*. Chapter 7 of the *1991 Applications Handbook* contains the most recent health facilities

design guidelines. This chapter is presently under revisions by the Healthcare Facilities Subcommittee of Technical Committee 9.8 Large Building Air Conditioning Applications and is to be published in the *1995 Applications Handbook*. The history of this chapter shows the evolution of the industry and of some of the politics which shape that evolution.

ASHRAE AND HEALTH CARE FACILITY DESIGN GUIDELINES

In the 1959 ASHRAE Guide Chapter 8 was entitled "Air Conditioning in the Prevention and Treatment of Disease." The opening paragraphs described the effects of knowledge gained from World War II regarding the importance of the control of airborne infection. It also described the benefits of air conditioning in aiding the convalescence of patients. Another interesting topic in those opening remarks was the unique air conditioning problems in civil defense shelters, a topic which later moved into a separate section of the Guide book. The text describes the effects of a surface or subsurface blast of about 20 kilotons. Given the politics of the time it is little wonder how such a topic could find its way into a discussion about health care facilities.

Other topics in the 1959 Guide Chapter 8 included:

> Sanitary Ventilation, Control of Airborne Infection, Value of Air Cooling under Tropical Conditions, Treatment of Disease, Operating Rooms (including a subheading on reducing explosion hazard), Nurseries for Premature Infants, Fever Therapy, Cold Therapy, Allergic Disorders, Oxygen Therapy, and General Hospital Air Conditioning.

The *1962 Guide and Data Book* contained a Chapter 28 entitled "Hospital Air Conditioning." Topics included:

> The Infection Problem, Air Quality, Air Cleaning, Air Movement, Zoning, Air Conditioning Systems, Design Criteria.

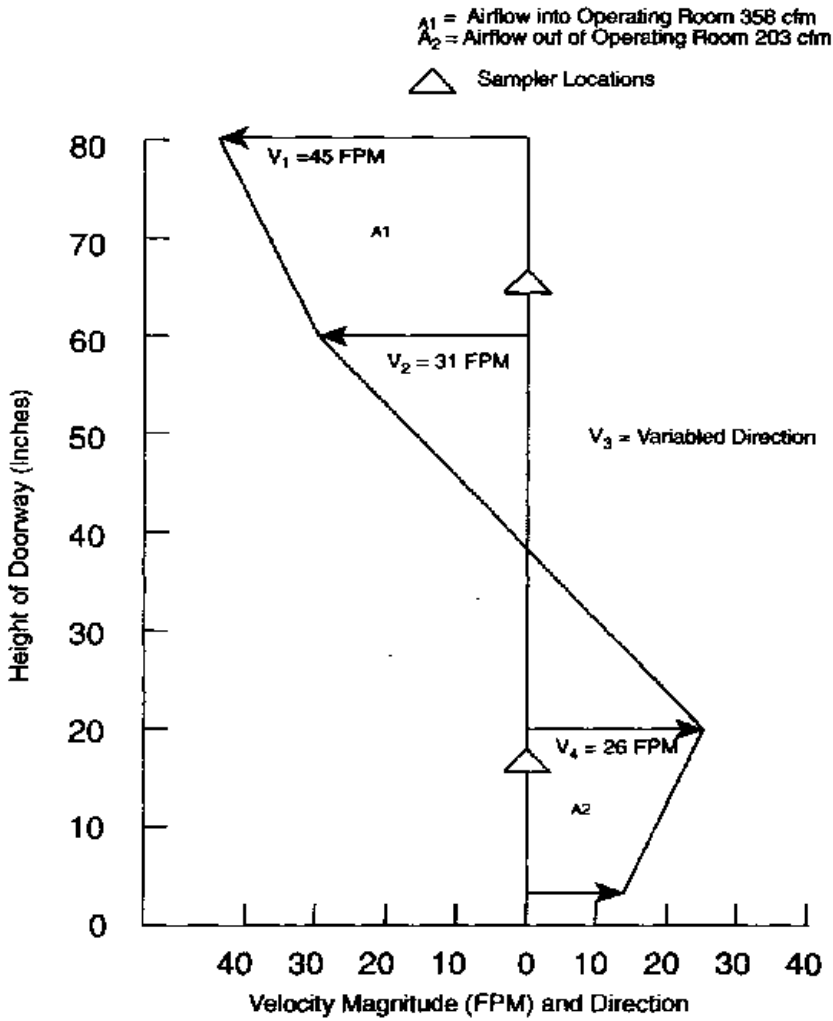
This year also published Tables on Airborne Bacterial Counts and filter efficiencies for removing biological particulates.

The 1964 chapter was renumbered to 29 and renamed to simply "Hospitals" but otherwise the text remained virtually unchanged. At this time the editing of the chapter was indicated to be assigned to Technical Committee TC 6.2 "Large Building Air Conditioning." In 1966 and 1967 the first topic title (The Infection Problem) was dropped but otherwise there were no textual changes.

The 1968 chapter, now numbered 14, dropped the table on filter efficiencies and replaced it with text describing NBS dust spot testing, protection of filters during construction, and some applications of various filters. The Air Movement section was expanded this year introducing the concept of ceiling supplies and floor returns in clean areas. In addition, a new figure and accompanying text introduced an important issue which will appear in our recommendations. The text reads, "The opening of a door or closure between two such areas instantaneously reduces any existing pressure between them to such a degree as to nullify the effectiveness of the pressure" (ASHRAE, 1968). Figure 1 shows the air velocity vectors in an elevation of an open door.

The *1968 Guide and Data Book* also introduced the now familiar Table 3 with the following text "Table 3 gives the recommended minimum ventilation rates for the various areas of the hospital." The table has the format used to this day showing pressure relationships, minimum outside air changes, minimum total air changes, air exhausted and air recirculated with the room allowances for various spaces. The first such *Guide Book* table has some changes from air changed rates recommended in the previous year's guide book. A comparison of the air change rate values over the years is in the Tables section of this paper.

Between 1968 and 1971 the chapter underwent significant change. By 1971 it was numbered Chapter 15 and entitled "Hospitals and Related Health Facilities." The first major title in the chapter



Velocity Distribution through Operating Room Doorway (Room Not in Use)

Figure 1

became Air Conditioning in the Prevention and Treatment of Disease. This was a return to the title of the entire 1959 chapter. In this section was a well-documented and scholarly description of the effects of humidity and temperature on respiration and body heat loss. Figures were added to show, among other things, heat and water exchange during respiration. The topic of Application

of Air Conditioning to Health Facilities reintroduced The Infection Problem which had been previously eliminated. The primary contagion discussed under this topic was *Staphylococcus aureus* but many of the basic principles for infection control described then are still relevant today for other infectious agents. The remaining two main topics were Air Conditioning Systems and Design Criteria, the latter then becoming the permanent home to Table 3 on air change rates.

The 1974 edition of the chapter appeared in the *Applications Handbook* and began a pattern of occurring every 4 or 5 years. It became Chapter 7 and was entitled simply "Health Facilities" a title and number which has with one exception in 1987 remained the same to this day. This year also marked the reassignment of the chapter editing to TC 9.8 "Large Building Air Conditioning Applications," a shift foretold by the previous editions topic on application of air conditioning to health facilities.

The *1978 Applications* Chapter 7 was the product of some severe editing which reduced the length from 14 pages to 10 and the references from 42 to 10. For the first time and forever since, one of the references was the US Dept.of HEW 1974 "Minimum Requirements of Construction & Equipment for Hospital and Medical Facilities," now more commonly referred to as the "AIA Guidelines." In this year the figures on respiration were removed along with most of the text surrounding them. Table 1 which had been titled "Airborne Bacterial Counts Found in Hospital Environments" was now replaced with a new Table 1 on the recommended minimum filter efficiencies and their applications which, with some modification, had appeared in previous editions of the chapter as text, and then was dropped. Beginning with this year, Table 3 divided the operating room air change rates into recirculating and all-outside air values. There were also several significant reductions in the amount of outside air recommended in spaces such as recovery, delivery, patient rooms, intensive care, isolation, anterooms, X-ray, laboratories, autopsy, and especially food preparation which had been previously listed at twenty air changes of outside air. These changes were undoubtedly due to

major energy conservation efforts occurring in the industry at that time. A new major topic was added to the end of the chapter entitled "Energy Conservation."

The 1982 chapter marked the beginning of the subdivision of the text into parts. This year had two parts labeled Hospitals and Nursing Homes and although the hospital section had most of the text, the section on nursing homes repeated smaller versions of the tables on air change rates and filter efficiencies. The number of references dropped to nine.

The 1987 chapter, temporarily numbered 23, marked the end of the subheading labeled "The Infection Problem" in favor of a more upbeat "Infection Sources and Control Measures." The text was more useful and specifically mentioned tuberculosis, varicella, rubella, and introduced legionella. The first mention of bone marrow transplant rooms requiring special filtration was mentioned. Ultraviolet sterilizing lamps went from being not recommended in the previous edition to not being mentioned at all. The topic of Design Criteria was divided into "Design Criteria for Principal Areas of an Acute General Hospital" and "Specific Design Criteria by Department." There were no changes to the air change rates in Table 3, but several new spaces were added including an X-ray treatment room and several different variations of laboratory. A new major topic called "Continuity of Service and Energy Concepts" was added and several subtopics like Zoning and Energy were grouped under this heading. A third major part to the chapter was added entitled "Outpatient Surgical Facilities ." This part was added due to the demand for the construction of these facilities. The text under this part mostly referred back to the part on Hospitals. The numbers on the references disappeared and the number of references increased to 14.

The current (1992) edition of the chapter, once again listed as Chapter 7, contains new data about the role of air conditioning in special clinical treatment spaces. For example, in Table 1, a new filter has been added with 99.97 per cent efficiency to be used in orthopedic surgery, bone marrow transplant, and organ transplant

operating room applications. A new section in infection sources states that *Aspergillus* species can cause an untreatable and often fatal disease. The topic title "Design Criteria for Principal Areas of an Acute General Hospital" was dropped but most of the text remains the same as 1987. This edition, like the previous, makes reference in the text to DHHS pressure relationships and air change rates in health care spaces by saying that it is not intended for the two guidelines to agree completely. The guidelines also state that, in those few cases where ASHRAE Standard 62-1989 requires higher outside air quantities, Standard 62 should be followed. Reference is made to NFPA 90A, 92A, and 101. Table 3 added a recommendation for Delivery rooms using 100 per cent outside air and a new line for Labor, Delivery, Recovery and Postpartum (LDRP) rooms. The typical patient room total ventilation was changed from 2 ACH to 4 ACH. Another Standard referred to for the first time is the Safety Code for Mechanical Refrigeration (52-1989). Table 5, the pressure relationships and air change rates for nursing homes, is dropped in this edition.

The current chapter contains several ideas that date back to as far as the 1962 chapter and have survived the repeated edits of various TCs over those years. Table 2 and Figure 1 date from 1962 as well as Specific Design Criteria regarding Nurseries, Radiology, Laboratories, Pathology, Autopsy, and Pharmacy.

In some ways paralleling the work of ASHRAE, the DHHS has developed, first *General Standards in 1947*, then *Minimum Requirements* in 1973, and finally *Guidelines for Construction* in 1984. These documents, like the original Federal Register publication, containe information which pertains to all aspects of health care design including architecture and equipment as well as engineering. The latest edition of the *Guidelines* (1992) has just been released and for the remainder of this paper it will be referred to as AIA.

Although these two guidelines have been available since 1947, designers historically have had only to adhere to what a local building code and State Department of Health rule required by law.

Ventilation designs in hospitals therefore, followed original construction specifications and ongoing maintenance according to the period of construction and/or renovation. The quality of the design often was contingent on the funding source for construction. Early construction used designs which included neutral air pressure relationships for isolation rooms. Subsequent design guidelines were explicit with respect to pressure controls and filtration requirements in isolation rooms construction from about 1962 on. The ventilation design before that time depended upon the hospital planning awareness towards the control of infectious disease. Such efforts to cohort and isolate patients have been a clinical practice for years extending back to the days of Florence Nightingale. Historical efforts to contain patients with infectious disease have occurred in the time of increasing sophistication in ventilation systems. The plumbing codes providing for bathroom exhaust were probably the initiation of ventilation control in patient rooms. The engineering premise to supply air for makeup to the exhaust system then initiated the need to bring in outside air. Because of the variation in designs over the history of health care facility construction the importance of understanding the current concepts for airborne spread of infectious disease and the role of ventilation in the control of that spread is important.

EXISTING DESIGNS—NEW BUILDINGS

Ventilation Systems

General Ventilation

In many ways, the modern hospital has many of the same design needs of any typical air conditioned space. Air is introduced for the dual purpose of absorbing heat within the space and resupplying oxygen. Air is removed from the space with the absorbed heat and carbon dioxide generated by occupants. There are a number of techniques employed to accomplish these tasks, most of which are applicable to the hospital. For the purposes of this section, we will direct our attention to the design applications which pertain to the movement of air within spaces. Later on we will discuss

airflow rates, airflow distribution, intake and exhaust issues, outside air rates and general maintenance concerns.

Patient Rooms

Most modern hospital construction utilizes central air handling systems with ducted supply and return air to each room. These rooms generally are provided with individual temperature controls which operate some type of heating or cooling modulation for that room. The distribution system may be single duct, constant volume with reheat; single duct, variable volume, with or without reheat; dual duct with individual room mixing boxes; or single duct primary air to individual fan-powered boxes. Air can be distributed to the room through diffusers set in the ceiling or a sidewall. Air removed from the room may be taken up by return grills set in the ceiling or sidewall. Often special purpose rooms will use low sidewall return systems. If the quantity of air supplied to the room is low, all of the air may be removed through the patient toilet exhaust. This has the benefit of a low first cost but does not allow for upgrading the room to a more ventilation intensive specialized purpose in the future. When air is purposefully delivered at a low volume, such as the minimum AIA guideline of two ACH, the excess heat present in the room can be removed through a water based system such as a valance or radiant panel. Such systems can become difficult to maintain and are prone to condense moisture if the chilled water temperature is below the dew point of the room air. In this event the panel or valance fin tube is more of a liability than a benefit. Systems which have fallen out of favor include through-the-wall unit ventilators; all-air induction ventilators; two-pipe and four-pipe fan coils; and window air conditioners. Some states discourage or ban altogether the use of variable air volume systems.

Isolation Rooms

As a special case of the general patient room, the isolation room receives particular attention during the design of the modern health care facility. The current situation in hospital isolation rooms has been away from cohorting persons with similar diseases. Isolation rooms have been often moved to a specific patient care

service or are further isolated in some remote area of respective patient care units. The room configuration usually includes an attached complete toilet and shower or bath facility the door of which opens into the patient room. Some rooms are also equipped with an ante-room or airlock through which attendant personnel must proceed. Regardless of the concept for constructing the isolation room the importance of having a room with mechanical ventilation is primary. Because of this the design engineer usually provides air in one of a number of ways depending on the guidelines followed. If no guidelines were followed then the need for comfort control of the temperature and humidity are the primary consideration. The ventilation to the patient room most often supplies air from a diffuser in the ceiling or wall. Exhaust ventilation removes air from the room most often from the ceiling in both the toilet and the patient room. Some special purpose rooms use low sidewall exhaust grills. This exhaust air is generally moved directly to the outside of the building and not allowed to be recirculated. The ante-room ventilation is varied with the potential for no ventilation, supply only, exhaust only, or both supply and exhaust. Both AIA and ASHRAE describe the distinction between infectious and protective isolation ventilation. Both guidelines recommend a minimum of six ACH of total air volume in the patient room. In practice, the volume of air supplied is more often dictated by cooling/heating requirements for those systems that are all-air. In larger institutions, the infection control practioner may set larger air volumes for specific infection control reasons such as fungal spore control. The isolation rooms generally are constant volume with reheat to ensure that the specified pressure relationships are maintained. The design may call for a sensing device to control the volume of the air entering the room to favor the exhaust over the supply. Exhaust air is usually removed through grills rather than diffusers partly because of the cost but more so because grills are less likely to clog with debris and are easier to clean. The lack of efforts to keep grills clean often results in the oversupply of air to the room creating an effect opposite to that of containing infectious disease.

Radiology

Modern radiology departments are areas of frequent change in the type and quantity of equipment used and the resulting impact on the building systems they require. All too often, it is only after new equipment is installed and running that the inadequacy of the ventilation to maintain an appropriate environment is discovered. For this reason, the ventilation in these department spaces receive more than the normal level of interest and attention. The attention, however, is generally due to comfort rather than infection control issues. That may be changing now that patients who are being transported from their rooms to the radiology department for diagnosis and treatment (D/T) are increasingly themselves at risk or place others at risk of infection. The diagnostic and treatment procedures within medical imaging and theraputic radiology are becoming of longer duration and more invasive. Both guidelines are recognizing these changes by recommending air change rates separately for D/T and surgery. When the X-ray power equipment is located with the treatment room there generally is adequate ventilation to control heat gain. When the power equipment is in separate rooms the designer will usually follow the minimum recommended volumes in the guidelines. Air distribution in the treatment room will be similar to the patient room.

Waiting Rooms, Admitting, and the Emergency Department

In the 1962 ASHRAE Guide and Data Book a simple statement is found regarding these types of spaces: "This area requires no unusual air treatment and should be conditioned for comfort of the occupants." This language remains in ASHRAE up to the latest edition. AIA does not address these spaces. These spaces should not be overlooked. The emergency room waiting and admitting area in which ASHRAE recommends 10 ACH and negative pressure should be considered for local ventilation.

Local Ventilation

Local ventilation, usually exhaust systems, have historically been used for a variety of purposes including infection control. Scavenger exhaust of respirated anesthetic gases have been common as have laboratory hoods for chemical fumes, biological research and testing, and radioisotope labeling.

Special Procedure Rooms

Special exhaust systems used in gastroenterology and endoscopy are becoming more common. There is a growing use of local patient hoods which recirculate air through HEPA filters during medicated aerosol treatment of HIV patients. These hoods are generally not of any standard construction and may have been designed in-house and built in the hospital shops. Because the very nature of their use (sputum induction, bronchoscopies, or aerosolized pentamidine administration) generates large quantities of sputum droplet nuclei there is an inherent risk of spreading infection. At present, the design guidelines do not address this consideration of health care ventilation. Research is needed in both the area of effective design of these patient hoods and of the general ventilation in the room where they are used.

Operating Rooms

The entire operating room in some cases is considered a local ventilation system. Depending upon the type of surgery done in the room the ventilation can vary from vaned ceiling diffusers or sidewall diffusers which ensure complete mixing of air, to highly specialized systems with over one hundred ACH through HEPA filters in a near laminar flow distribution. There is no consensus on the appropriate system for these rooms and so designs as well as opinions vary widely. What is agreed upon universally is the desire to prevent infection of the open wound. To that end most systems employ a combination of displacement and local ventilation. The locale however, is considered only the wound site and not the room at large. Nor do most designs consider how an infectious disease (airborne) might affect the operating team. Here is an example of a potential application of the patient hood for this purpose. The patient is immobile and may already have some sort of respiratory control. A local exhaust system which removes the respirations directly to the outside even for patients under local anesthesia could be effective.

Air Cleaning

General ventilation is completely dependent upon clean air from the central ventilation system. While building codes and state department of health rules still recognize open windows as an

equivalent ventilation system in the health care facility modern design has all but eliminated the practice. Both AIA and ASHRAE are very specific in the recommendations for filter efficiencies for various applications. Recently, the guidelines have adopted the use of 99.97% (HEPA) filters in certain applications such as protective isolation and orthopedic surgery. There is some evidence that a design which includes filter efficiencies of 90-95% throughout the entire hospital has a beneficial effect on the incidence of *Aspergillus* nosocomial infection (Streifel, 1993).

The Centers for Disease Control and Prevention (CDC) has recommended that air potentially contaminated with infectious disease be HEPA filtered prior to being recirculated. In practice, this is seldom designed even though the recommendation dates from 1990. There are two reasons for this: 1) Air that is not exhausted directly outside is not identified as potentially containing infectious disease by the health care institution. Design professionals also do not make such a designation for this air. 2) Filters are not located in recirculated air streams. The accepted design for filter location place them in the supply air systems only. This means the mixture of outside air and recirculated air (called mixed air), is conditioned, and then is filtered before being distributed throughout the building. Figure 2 shows this concept of filtering supply air as opposed to recirculated air in central air handling systems.

Research is needed in determining the optimal efficiency of filtration to prevent the spread of respective airborne infectious disease. Since the airborne particle size of one infectious disease may be different from that of another, the filtration would need to be established for the worst case. However, if the worst case particle size was a virus, the efficacy of filtration would be in doubt. Also, the probability of infection by the airborne virus varies with the virus concentration in the air and the generation rate of virus in the space. In this case, outside air would be preferable to filtration as a dilution air source. Filtration may best be used for the fungi and bacteria particles (>1.0 microns). Filtration efficiencies have been evaluated and the 90-95% effi-

cient filters have been shown to remove > 99.9% of the > 1.0 micron viable fungal particles (Rhame, 1990).

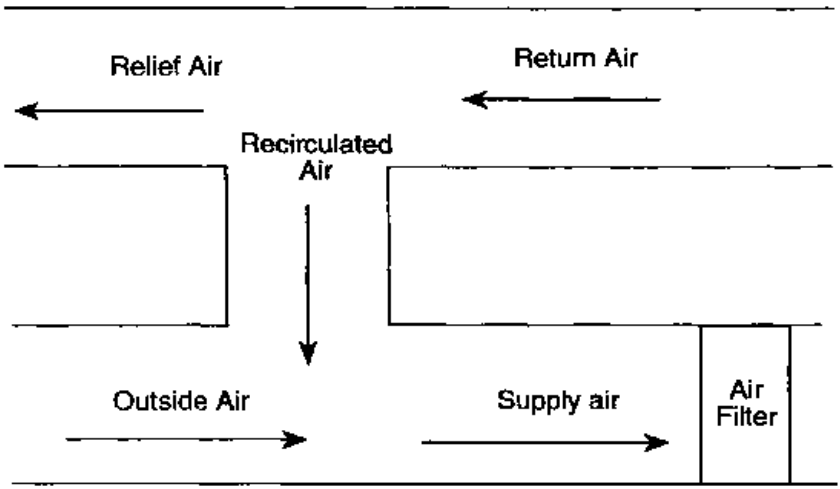


Figure 2.

Retrofit

When one of the model code making bodies produce a new or revised building code, it is usually in response to input from the various authorities having jurisdiction around the country. An incident or a series of incidents prompt a review of the model code and new language is drafted, debated, and ultimately voted on in open meetings. Once adopted, individual states who subscribe to the model code will review the language and either adopt it by reference or perhaps write an amended version. Then the new proposed state code undergoes the rulemaking process which includes public hearings. All of this takes a lot of time to implement. It is not unusual to have several years pass between the first draft of the model code and the completion of the state rulemaking process. During the entire process, buildings continue to be designed and constructed under the existing code. When the new code becomes law it has an effective date which pertains only to new designs which are reviewed and not to any

previous. All existing construction is also "grandfathered." This concept is important to the issue of retrofitting existing health care facilities to new standards. If the authority having jurisdiction has a rule which sets the conditions under which retrofit falls under the new codes and not the old, health care institutions planning a retrofit may consider this when deciding how much work to accomplish at once. This, along with each particular institution's financial status, has much to do with the condition of the physical plant in the hospital industry. Therefore, the types of retrofit which have the most impact on improving infection control and have the best chance of being implemented are those which:

- Are driven by the institution's clinical staff and supported by the administration.
- Are located in states with either strong state rules or a very competitive marketplace.
- Are driven by an identified source of an epidemic of nosocomial infections. In our case those implicating the ventilation system.
- Are easy enough and inexpensive enough to be accomplished by any institution in a short time.
- Are logical and easily understood by the average ventilation design engineer.
- Are backed by creditable research for their efficacy.
- Are endorsed by CDC and NIOSH.

It is a wonder how any retrofitting happens at all.

In any discussion of what is happening in the industry today we must first describe the condition of the existing space and the new use to which the space is being modified. Since there are uncountable variables in describing the existing spaces we will choose a few examples of hypothetical patient rooms, isolation rooms, including protective isolation, and special procedure rooms. In each case we will choose the type of ventilation design with the greatest potential for a successful retrofit. The recommendations will describe those ventilation systems which for one reason or another are not good candidates for retrofit.

Patient Rooms

A patient care unit designed and built in the 50s or early 60s is served by medium pressure all-air induction units each with about 50 cfm of primary air which is 100% outside air. The induction units are either four pipe or two pipe with a summer/winter change over. There is a drip pan under the coil and no air filter.

These units are typical of the period and were popular designs. The problem is the drip pan and the coil collect dirt and are often wet from cooling. They are maintenance headaches and potential sites for microbial growth. Buildings using this design frequently have low floor to floor heights and relatively high room ceiling heights. Windows are openable and are quite tall. The toilet room, if there is one, has an exhaust equal to the quantity of the primary air to the induction unit.

Just about any retrofit of this system is expensive. The space available for ductwork is generally the ruling factor. If space is available, a totally new ducted low pressure air supply system is often suggested. However, since the quantity of outside air delivered is adequate to satisfy the newly released AIA guideline new ductwork may not be indicated. By focusing on two primary problems 1) the age and location of the induction coils, and 2) the control of the cooling, a less expensive solution often is suggested: removing all induction units, ducting the medium pressure primary air to new ceiling-mounted fan-powered boxes hidden above a dropped ceiling, and replacing the temperature controls to limit the temperature of the cooling to stay above the highest expected dew point temperature of the room. The fan-powered box is installed with 90-95% efficiency filters (generally a custom modification). Often in buildings of this age new windows are suggested to help reduce the cooling and heating load and the air infiltration.

Infectious Isolation Rooms

A patient care unit built in the late 60s or early 70s has a central air handling unit supplying four ACH to the patient rooms. There is no isolation room on the unit and one room is to be converted. It is to be designated as an acid fast bacillus (AFB) isolation room.

There is no anteroom. This retrofit will form two broad categories, architectural modifications and, ventilation modifications.

Architecture

Architecturally, the room receives a new sheet rock or plaster ceiling; either surface mounted light fixtures or recessed without air vents and sealed to the ceiling; seamless vinyl flooring; vinyl wallpaper walls; a headwall for medical gases and power-sealed to the ceiling; no plumbing fixtures in the room to provide an opening through the walls; a slow opening and fast closing door opener on the inward swinging door; a relatively loose fitting door, i.e., one which will allow a good volume of air to pass under it from the corridor into the room; and the same type of door on the toilet room which opens into the room. If the patient room is without a toilet room one should be added. The toilet room should have similar floor, ceiling, and wall finishes. The plumbing pipe openings should be sealed to the wall.

Ventilation

The return air ductwork to the room is cut and capped. The return grill to the room is either connected to a nearby isolation exhaust duct system or the room toilet exhaust. The grill is relocated to one of two places, either low along the wall between the patient bed and the outside wall, or in the ceiling somewhere between the bed and the outside wall. The supply air is rebalanced to provide at least 6 ACH, and the total exhaust from the toilet and patient room combined is increased to between 50 and 75 CFM, more than the supply needed for cooling or 6 ACH, whichever is higher. The room may or may not receive a air pressure monitor which will continuously monitor the relative pressure between the room and the corridor. This monitor will contain an alarm indicating an adverse condition. It may also have some control capability which would attempt to correct the adverse pressure by reducing the flow of supply air to the room. Obviously, if the control becomes too severe, the room comfort will suffer. Some alarm condition can be used to indicate the limit of the control functions ability to correct pressure problems.

into service without much in the way of ventilation modification. Yet these procedures generate some of the highest levels of airborne infectious particles (Catanzaro, 1982). Little is being done to standardize these types of rooms partly due to the rapid appearance of their use and the general slowness of the guideline modifications.

Building Air Intake and Exhaust

Few topics of building engineering design solicit more grisly tales of horror than that of air intakes and exhausts. Carl W. Walter cited several examples in a 1980 publication (Walter,1980).

A state university hospital was designed with a below grade air intake plenum whose walls extended 8 feet above grade. This plenum was common to all air handlers in the hospital. After numerous infection outbreaks an investigation revealed "that the screen behind the ground level intake louvers was choked with trash, leaves and wood chips from manure that had been spread over the unplanted courtyard." Similar debris had accumulated on the floor of the intake plenum. The air handling units had recirculation water spray air scrubbers. The water as well as the cooling coils were respectively murky and slimy.

A second example, this time a Veterans Administration Hospital, experienced mixed clostridial and gram negative wound infections. "Inspection revealed pigeons roosting in the intake plenum of the air conditioning system. Eight inches of guano and the decomposed carcasses of a half dozen birds littered the floor. The filters, laden with molding dust, had dropped out of their frames and the refrigerating coils were a confluent mass of slime and mold."

A third example is of a university hospital's cardiac catheterization laboratory. Air samples showed heavy contamination of *aspergillus* and *S. epidermidis*. "It was air conditioned by a domestic type window unit that projected over a trash compactor. Its filter was moldy. Its refrigeration coils and fan were slimy." Obviously, lack of proper maintenance played a major part in each of

these examples. In most cases however, a design sensitive to the needs of clean air will prevent or minimize these sort of problems. Examples of good practice include the following designs:

- Exhaust fans are located at the discharge end of the distribution system with pressurized ducts run only in mechanical rooms.
- Outside air intakes are located at least 25-30 feet from exhaust outlets, combustion stacks, medical vacuum exhaust, plumbing vents, or any other noxious fumes, (such as trash dumpsters).
- Outside air louvers are placed as high as possible but at least six feet above grade or at least 3 feet above a roof. The prevailing wind and site conditions around the building are considered and may increase these minimum distances.
- Bird screens are no smaller than one-quarter inch mesh.
- Intake plenums are adequately drained.

In certain settings, outside air may not be the best source for clean air used in dilution ventilation. Although criteria exists to determine the acceptability of outside air for general indoor air quality purposes (ASHRAE, 1989), specific health care facility requirements have not been published. There appears to be a gap in the literature regarding any special needs the health care community may have to pretreat outside air before it is admitted. Traditionally, air which is recirculated is not conditioned independently from outside air. Independent conditioning processes such as filtering may be useful in locations where the outside air is particularly polluted.

Airflow Rates

Among the most controversial aspects of the engineering control of airborne infection are airflow rates. Existing guidelines are specific in prescribing the relative quantities of total air movement in various

health care spaces and of that portion of the total air which must come from outside. Much confusion develops over these prescriptive requirements because neither AIA nor ASHRAE describe their basis or origin. As we have seen in the history, airflow rate prescriptions go back at least to 1947 when ventilation systems in all buildings including hospitals were strictly intended for human comfort. Sometimes even that design criteria was poorly met. Today, health care space designs are constrained by forces which include liability and costs of construction as well as energy. The new or inexperienced health care ventilation engineer is met with a bewildering array of sometimes conflicting requirements, guidelines, hearsay, and prejudice which try to influence the design. Frequently, long established engineering firms with traditions of service to this industry will follow one or a very small set of design criteria, forsaking all others in order to bring some sense to the chaos. This also serves to limit the time spent on research of alternate designs.

Since the mandatory requirements for construction needed to obtain construction grants under the Hill-Burton act became merely guidelines it has been up to either the State Department of Health or the health care organization itself to establish minimum criteria for design including airflow rates. On occasion the health care organization will employ the services of the epidemiologist or orthopedic surgeon to assist the ventilation engineer in establishing criteria for air change rates. Facilities with active research in such areas as transplant surgery, orthopedic surgery, bone marrow transplants, tuberculosis, or HIV Clinics may have requirements for specific rooms which may not be covered in the design guidelines.

Medical centers of excellence are frequent across the country and many very good designs are in place which never are shared in the literature. By the same token, some gruesome designs are in place which barely serve their present function, sometimes because of poor design, but more frequently because the space was never designed for the present function it serves. It is sometimes amazing to see the number of otherwise ordinary patient rooms, which may date back to the early Hill-Burton construction designs that are pressed into service as isolation rooms, often with little or

no modification to the ventilation system. The section on retrofit addresses some of the ways in which these conversions are accomplished with mixed success.

Table 6 lists the air change rates presently published in the AIA and ASHRAE documents. Various states have adopted, or modified these, usually upwards, and other states have published entirely separate requirements. Some states have no requirements beyond the original Hill-Burton language of the late 40s or early 50s.

It has largely been the influence of third party payers such as Medicare and Medicade as well as the private insurance industry which has driven health care organizations to adopt ever more stringent standards for minimizing the spread of airborne infectious disease by ventilation systems. On the other hand, it has been the desire of limiting the rising cost of health care construction and building operation which has prevented universal acceptance of guidelines where they are not backed with the force of law.

The health care facility design community is at best not unanimous and is often divided on the issue of increasing minimum airflow rates, especially in isolation rooms and operating rooms, for the purpose of minimizing the spread of infection. At even greater discord is the issue of differential pressure between spaces for the same purpose.

It can be safely said that although there has been much published about the spread of infectious disease and the possible implication of the ventilation system in epidemics, little research in how ventilation systems effectively control airborne diseases within spaces is apparent. Research is needed in this area. Such research, although obviously in need of careful input from the medical community, is best conducted from the ventilation engineering viewpoint.

Air change rates, such as those listed in Table 6 are the result of many years of practical and often empirical study. Some space airflow rates listed have had more scientific research than others. Some have been handed down from revision to revision and swapped between one guideline to another, having lost in the

process the original research which was their basis. To challenge them now could be likened to closing the gate on an empty corral. To stretch the metaphor, we, like the farmer, need livestock in the barnyard in order to be creditable.

Airflow Distribution

The primary role played by mechanical ventilation is that of maintaining a comfortable environment in the space ventilated. This is as true in health care settings as much as in other general buildings. The role of moving air in a space being used for infection control is not often used and very little understood. The most notable exception is the so-called laminar flow system for operating rooms, so-called because true laminar flow spaces, the sort used in computer chip manufacturing, require elaborate floor or wall plenums to receive the parallel airflows without restriction. Today the operating suites which contain banks of HEPA filters in the ceiling or a wall generally have more conventional return/exhaust grills. Still the concept of using air as a mechanical force to direct particles to behave in a predictable fashion has been used in several health care settings including fume hoods, scavenger exhaust, and of course operating rooms. The entire concept of local ventilation depends upon the velocity of air directing fumes or particles to be captured and either trapped in a filter or simply exhausted outside. Dilution ventilation has as its basic premise a dependence on complete mixing of air and contaminants. The air distribution in a room becomes at least as important as the quality and quantity of that air.

Fortunately, diffusers which distribute air with the intent to provide a comfortable temperature also do a fairly good job of mixing contaminants with the clean incoming air. There are still pockets of stagnant air present in just about any diffuser layout which could create areas of static infectious particles. These stagnant areas need to be minimized in the design which is considered infection control. ASHRAE has developed a standard which evaluates the performance of room air diffusion. The standard is a method of testing temperatures and velocities at various locations in a room and from the measurements calculat-

ing an effective draft temperature. From this an Air Diffusion Performance Index (ADPI) for the room is determined (ASHRAE, 1990). This index could be used as an indication of good air diffusion for complete mixing of contaminants. This is an important aspect of dilution ventilation.

Most common among the designs for distribution of air in spaces is the ceiling delivery through vaned diffusers and ceiling removal through grills. The factors which influence the ADPI are location of the supply diffusers; their size relative to the quantity of air delivered; the distance the air travels before the velocity decays to less than 50 feet per minute (commonly referred to as the throw); the total quantity and temperature of the supply air; and the location of the return grill relative to the location of the supply. The value of the ADPI is to measure the ability of the air diffusion system to produce an acceptable thermal environment. It could be said that it may also measure the ability of the diffusion system to evenly mix airborne contaminants in the air. The contaminants mixed are those which would otherwise be suspended and not fall to the floor in still air such as droplet nuclei. Research is needed to establish the connection between the homogeneous concentration of infectious particles and the air diffusion systems' ADPI.

Outside Air Rates

One of the more confusing aspects to the guideline recommendations for ventilation is the reference to outside air rates. This is partly due to the fact that the numbers listed in the tables are reported in ACH for both outside air and total air volume. When the standard for acceptable indoor air quality was published, the values listed for outside air quantities were in cubic feet per minute per person (CFM/P) (ASHRAE, 1989). To add to the confusion, both guidelines referenced this standard for minimum volumes of air.

Since most central air handling systems and their distribution ductwork do not generally separate the outside air from the recirculated air, it is not obvious how to comply with delivering ratios of outside air which change from room to room. Central air

handling systems provide only one ratio of outside air. This is also a valid argument against variable air volume systems which tend to favor recirculated air when total volumes are reduced.

Since the ACH values listed are only minimums it becomes necessary to increase the total volume of air to each room until the correct minimum quantity of outside air present in the supply air is reached. Therefore, AHUs with higher outside air ratios may supply lower total air volumes to satisfy the minimum outside air. For example, the 1991 ASHRAE recommendation for patient rooms is 4 ACH with 2 ACH of outside air. If the typical 1000 cubic foot single patient room received 4 ACH of fifty percent outside air both minimums would be met with about 66 CFM of total air. However, if the air delivered were 30 percent outside air then in order to meet the 2 ACH the total air delivered needs to be about 110 CFM (33/0.3). Both minimums are still met but more total air is delivered if the ratio of outside air is less. In this way each space of the facility can meet the intent of the guideline with air delivered by a central air handling unit of a fixed outside air percentage. Establishing what the fixed outside percentage will be is and should remain the decision of the ventilation design engineer. In practice, the modern health care facility usually requires more than the minimum total air in order to meet the comfort requirements.

Maintenance

The previous discussion regarding outside air intakes and exhaust systems establishes the critical need to properly maintain the health care ventilation system. Although these examples are particularly dramatic the more common situation is one of generally good care. The typical hospital engineering department is well aware of the need to replace filters, clean air intakes and exhaust plenums, and monitor general operation of the ventilation system. It is true that the larger institutions have somewhat more flexibility to program preventive maintenance due to larger staff sizes but this is changing due to cutting of department budgets. Much good has been done by the Joint Commission for the Accreditation of

Healthcare Organizations to lift the awareness of both maintenance and administrative staffs to the importance of maintenance planning and record keeping. Often the infection control department will work with the maintenance department to combat some problem which may have manifested in a nosocomial infection outbreak associated with the environment. On these occasions awareness of maintenance of the ventilation system becomes apparent and if necessary greater attention to operational efficiency is required.

Routine regular cleanings of patient room supply and exhaust grills are the best method of preventing air balance problems caused by clogging. Rooms with low sidewall exhaust grills are particularly susceptible to dust and lint from the floor. Operating rooms as a rule collect scrub lint in their returns. Special care is often given to humidifiers within duct systems. When any direct water injection, either by steam or cold water, is made into the air stream a potential for biological growth exists. Certain areas of the country still use evaporative cooling even in health care settings. These devices are particularly prone to harboring microbes which could grow to a point where they become entrained into the air. Maintenance procedures for these types of water/air mixtures generally are repeated more frequently to minimize such growth.

The availability and acceptance of computerized scheduled maintenance has allowed the modern hospital engineering staff to plan more effectively the necessary resources to accomplish the difficult task of maintaining today's highly technological mechanical and electrical systems. Some institutions are moving beyond preventive maintenance into predictive maintenance which will with some accuracy predict failures to critical building systems before they happen. This allows scheduled shutdowns to make repairs or replacements without the stress of the emergency outage.

RECOMMENDATIONS

Short Term recommendations

We must do whatever is economically possible in the short term to bring all health care facilities up to a minimum level of protection against the spread of some airborne infectious diseases, namely tuberculosis. That minimum level should include:

- At least one isolation room with an anteroom in each facility which meets the minimum requirements for AFB isolation described below.
- A program of minimum maintenance on the mixed air dampers, the filters and coils, and the air balance in the isolation room(s).
- A plan which outlines the timetable to bring the entire facility up to the present guideline recommendations for air filtration, outside air volumes, and total air volumes.

Minimum requirements for AFB isolation

The minimum requirements for a completely sealed single patient room are the following:

- Plaster or sheet rock ceilings, either surface mounted light fixtures or fixtures without vents caulked to the ceiling. Horizontal surfaces should be cleanable with no penetrations other than sealed electrical outlets.
- Headwalls for medical gases sealed to the ceiling.
- Air supply diffusers which have an Air Diffusion Performance Index (ADPI) of 80 percent or more.
- Low sidewall returns in the patient room between the outside wall and the patient bed.
- At least 12 air changes per hour of 90 percent filtered air.[1]
- All air exhausted out of the room through a fan system dedicated for isolation exhaust.

[1] Variables are a 1 in 20 chance of infection for a stay of 30 minutes; 60 qph, 210 CFM, a 1000 cubic foot room.

- The exhaust fan mounted on the roof or in a penthouse with a minimum of positive pressure duct.
- An ante room containing a sink and storage.
- At least 20 ACH in the ante room of exhaust going to the same isolation exhaust fan system and no supply for makeup air with both doors opening into the ante room arranged so that the swings intersect.
- Both doors on automatic door closers with slow open and quick close mechanism and no weatherstripping on the doors to allow air to flow through them.
- An electronic or pneumatic monitor to constantly measure the differential pressure of the patient room with respect to the corridor and alarm when the relationship changes.

This suite of rooms (patient, toilet, and ante room) should be left in infectious isolation condition at all times, even when used for non-infectious patients. Emergency room facilities should provide rooms with the same criteria for isolating a suspect emergency patient with an infectious disease.

Maintenance for air handling systems

The CDC and NIOSH should commission the American Society of Hospital Engineers (ASHE) and ASHRAE to develop and publish minimum required maintenance procedures for filter changing, as well as coil, diffuser and duct cleaning. These requirements should include maintenance of mixed air damper operation and their controls. At least semi-annually, each air handling unit (AHU) should be stopped and its interior inspected for filter integrity. The mixed air dampers should be operated through their full range of motion, the coils should be measured for pressure drop due to dirt. When the fan is operating, the mixed air, outside air and return air temperature should be measured as a means to determine the percentage of outside air being admitted. The volume of air entering and leaving the isolation room(s) should be measured. All of the above should be recorded. Routinely a smoke stick should be used to verify airflow movement in the designated ventilation controlled isolation rooms.

Long Term Recommendations

Outside Air

Since outdoor air is not always the best source for clean air used in dilution ventilation, pretreatment to remove particulates and gases should be installed. In new design, the outside air intakes should be above the roof. If mechanical equipment rooms are not in penthouses then outside air shafts communicating with the roof should be provided. Exhausts for removal of infectious air should be designed for minimum effective stack heights of 35 feet. The fan should be mounted outside on the roof with a vertical discharge of 3000 feet per minute or more.

Airflow Rates

The volume of outside air to a space which contains a source or a potential source of airborne infectious disease should be designed for controlling the concentration of infectious doses present in the air. The design then becomes based on the concept of assumed risk. It can be shown that the probability of an infection in a ventilated room is dependent on the variables found in the Reed-Frost equation (Riley, 1989).

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

where:

- C = number of susceptibles S who become infected
- S = number of susceptibles
- I = number of sources (already infected)
- p = pulmonary ventilation in volume per unit time
- t = exposure time (minutes)
- Q = removal rate by fresh air (CFM)
- q = number of doses of airborne infection added to the air per unit time by a case in the infectious state

If the quanta (q) can be determined for each disease in each type of room or each procedure then the design parameters of the ventilation system will depend only on the level of risk allowed and the time a susceptible person spends in the room.

Assume for the moment that a 1 in 10 chance of infection is acceptable. An isolation room with an active TB patient could be ventilated such that a person entering without a mask could stay in the room for a length of time dependent upon the ventilation rate in the room. The longer the stay the higher the risk of infection. If long stays are needed the ventilation could possibly be increased for the duration of the stay then be returned to some base line level.

In a modern isolation room of about 120 square feet and 6 ACH of 95 percent filtered air Q would equal about 100 cfm, however, since the filter efficiency is 95% only 95 cfm can be considered clean. This assumes that the filter can stop 95% of the particles needed for infection. If the particles are virus size the filtration dilution volume would default to the volume of outside air. A quanta calculation of a tuberculosis patient in a hospital setting set q at 60 qph (Riley, 1962).

Solving for t:

$$t = -Q/Ipq * \ln[1-(C/S)]$$

where: **I** = 1
p = 0.352 cfm
C = 1
S = 10

With these variables, the time (t) becomes a little less than 30 minutes.

Using this logic a table can be developed listing the airflow rate along one axis, the time spent in the room along the other and the probabilities of infection for each cfm at each length of stay (Tables 1 through 5). Such a table would be specific for each infectious disease and each type of ventilation system. The ventilation system is important because of the assumed air mixing in the formula.

The obvious need for research is to establish standard quanta (q) for each disease. The quanta also will vary by the ability of the susceptible to fight off the infection before symptoms occur. Therefore, the quanta will depend upon who is being threatened

with infection, e.g., immunosuppressed patients or staff. Quanta have been estimated by calculating from epidemics the effect of the index case and the successive generations of susceptibles who became infected.

- Intubation and bronchoscopy of a TB patient: 249 qph (Catanzaro, 1982).
- Laryngeal tuberculosis in a hospital: 60 qph (Catanzaro, 1982).
- Tuberculosis spread in an office building:13 qph (Nardell, 1987).
- Tuberculosis patient receiving chemotherapy: 1.25 qph (Riley, 1962).
- Measles in an elementary school: 93 qph (Riley EC, 1978).

Any research to establish these quanta should also recommend those values which would be used for the purpose of designing ventilation systems. The quanta so used may be higher than the actual generation rates discovered in research. Room design for infectious particle control should be studied to provide for supply diffuser types and locations along with exhaust locations which would effectively remove airborne infectious quanta. The air change rate and airflow pattern should work in concert to control the release of patient derived infectious airborne particles.

Since undiagnosed TB is a danger anywhere in the health care facility setting, minimum filtration of air everywhere in the building should be set at 90-95%. Outside air rates for every AHU should be set to provide an adequate dilution ventilation for infectious particles too small to filter. Policy should be set for the acceptable calculated risk of infection and the maximum length of stay (unmasked) in the presence of an active TB case.

By establishing these parameters and using the concept of designing to the maximum allowed risk the ventilation engineer can design the ventilation system to the specific requirements of each institution. The minimum recommended ventilation design guidelines should not also be considered the maximum ventilation for everyone.

TABLES

PROBABILITIES OF INFECTION

Table 1

QUANTA = 1.25

TIME IN MINUTES						CFM
10	20	30	40	50	60	
0.001	0.003	0.004	0.006	0.007	0.009	50
0.001	0.002	0.003	0.004	0.005	0.006	75
0.001	0.001	0.002	0.003	0.004	0.004	100
0.001	0.001	0.002	0.002	0.003	0.004	125
0.000	0.001	0.001	0.002	0.002	0.003	150
0.000	0.001	0.001	0.002	0.002	0.003	175
0.000	0.001	0.001	0.001	0.002	0.002	200
0.000	0.001	0.001	0.001	0.002	0.002	225
0.000	0.001	0.001	0.001	0.001	0.002	250
0.000	0.001	0.001	0.001	0.001	0.002	275
0.000	0.000	0.001	0.001	0.001	0.001	300

Table 2

QUANTA = 13

TIME IN MINUTES						CFM
10	20	30	40	50	60	
0.015	0.030	0.045	0.059	0.074	0.088	50
0.010	0.020	0.030	0.040	0.050	0.059	75
0.008	0.015	0.023	0.030	0.038	0.045	100
0.006	0.012	0.018	0.024	0.030	0.036	125
0.005	0.010	0.015	0.020	0.025	0.030	150
0.004	0.009	0.013	0.017	0.022	0.026	175
0.004	0.008	0.011	0.015	0.019	0.023	200
0.003	0.007	0.010	0.014	0.017	0.020	225
0.003	0.006	0.009	0.012	0.015	0.018	250
0.003	0.006	0.008	0.011	0.014	0.017	275
0.003	0.005	0.008	0.010	0.013	0.015	300

Table 3

QUANTA = 60

TIME IN MINUTES						CFM
10	20	30	40	50	60	
0.068	0.132	0.191	0.246	0.297	0.345	50
0.046	0.090	0.132	0.172	0.210	0.246	75
0.035	0.068	0.100	0.132	0.162	0.191	100
0.028	0.055	0.081	0.107	0.132	0.156	125
0.023	0.046	0.068	0.090	0.111	0.132	150
0.020	0.040	0.059	0.078	0.096	0.114	175
0.017	0.035	0.052	0.068	0.084	0.100	200
0.016	0.031	0.046	0.061	0.075	0.090	225
0.014	0.028	0.041	0.055	0.068	0.081	250
0.013	0.025	0.038	0.050	0.062	0.074	275
0.012	0.023	0.035	0.046	0.057	0.068	300

Table 4

QUANTA = 93

TIME IN MINUTES						CFM
10	20	30	40	50	60	
0.104	0.197	0.280	0.354	0.421	0.481	50
0.070	0.136	0.197	0.253	0.306	0.354	75
0.053	0.104	0.151	0.197	0.239	0.280	100
0.043	0.084	0.123	0.161	0.197	0.231	125
0.036	0.070	0.104	0.136	0.167	0.197	150
0.031	0.061	0.090	0.118	0.145	0.171	175
0.027	0.053	0.079	0.104	0.128	0.151	200
0.024	0.047	0.070	0.093	0.114	0.136	225
0.022	0.043	0.064	0.084	0.104	0.123	250
0.020	0.039	0.058	0.077	0.095	0.113	275
0.018	0.036	0.053	0.070	0.087	0.104	300

Table 5

QUANTA = 249

TIME IN MINUTES						CFM
10	20	30	40	50	60	
0.254	0.443	0.585	0.690	0.769	0.828	50
0.177	0.323	0.443	0.542	0.623	0.690	75
0.136	0.254	0.356	0.443	0.519	0.585	100
0.111	0.209	0.296	0.374	0.443	0.505	125
0.093	0.177	0.254	0.323	0.386	0.443	150
0.080	0.154	0.222	0.285	0.342	0.395	175
0.071	0.136	0.197	0.254	0.307	0.356	200
0.063	0.122	0.177	0.229	0.278	0.323	225
0.057	0.111	0.161	0.209	0.254	0.296	250
0.052	0.101	0.148	0.192	0.234	0.274	275
0.048	0.093	0.136	0.177	0.217	0.254	300

Table 6

ASHRAE AIR CHANGE RATES OVER THE YEARS

(TOTAL AIR/OUTSIDE AIR)

	1959	1962	1964	1966	1968	1971	1974	1978	1982	1987	1991
OR											
100% OA	8-12	15	15	15				15	15	15	15
RECIRC					25/5	25/5	25/5	25/5	25/5	25/5	25/5
DELIVERY											
100% OA		15	15	15							15
RECIRC					25/5	25/5	25/5	12/5	12/5	12/5	12/5
RECOVERY		4	4	4	15/6	15/6	15/6	6/2	6/2	6/2	6/2
NURSERY	8-12	12	12	12	15/5	15/5	15/5	12/5	12/5	12/5	12/5
TRAMA RM					25/5	25/5	25/5	12/5	12/5	12/5	12/5
ANESTH STO	2	2	8	8/8	8/8	8/8	8	8	8	8	
PATIENT RM	1.5	1.5	2	4/2	4/2	4/2	2/2	2/2	2/2	4/2	
TOILET RM					10	10	10	10	10	10	10
INTEN. CARE				6/6	6/6	6/6	6/2	6/2	6/2	6/2	
ISOLATION		4	4	6	12/12	12/12	12/12	6/2	6/2	6/2	6/2
ANTEROOM					6/6	6/6	6/6	10/2	10/2	10/2	10/2
LDRP											4/2

(TOTAL AIR/OUTSIDE AIR)

	1959	1962	1964	1966	1968	1971	1974	1978	1982	1987	1991
PATIENT CORR					4/4	4/4	4/4	4/2	4/2	4/2	4/2
RADIOLOGY											
X-RAY SURGERY										15/3	15/3
X-RAY D&T		6	6	10	6/6	6/6	6/6	6/2	6/2	6/2	6/2
DARKROOM		10	10	12	15/6	15/6	15/6	10/2	10/2	10/2	10/2
LABORATORY											
GENERAL					6/6	6/6	6/6	6/2	6/2	6/2	6/2
BACTERIOLOGY		10	10	10						6/2	6/2
BIOCHEMISTRY										6/2	6/2
CYTOLOGY										6/2	6/2
GLASSWASH									10/2	10	
HISTOLOGY										6/2	6/2
NUC MED										6/2	6/2
PATHOLOGY									6/2	6/2	
SEROLOGY										6/2	6/2
STERILIZATION									10	10	10
MEDIA TRANS				4/4	4/4	4/4	4/2	4/2	4/2	4/2	
AUTOPSY		10	10	15	15/6	15/6	15/6	12/2	12/2	12/2	12/2
BODY HOLD (NO FRIG)							10	10	10	10	
PHARMACY								4/2	4/2	4/2	4/2

(TOTAL AIR/OUTSIDE AIR)

	1959	1962	1964	1966	1968	1971	1974	1978	1982	1987	1991
D&T											
EXAM		4	4	4	12/6	12/6	12/6	6/2	6/2	6/2	6/2
MED ROOM								4/2	4/2	4/2	4/2
TREATMENT	4	4	4	12/6	12/6	12/6	6/2	6/2	6/2	6/2	
PHYS TRPY					4/4	4/4	4/4	6/2	6/2	6/2	6/2
SOILED HLD		3	3	4	12/4	12/4	12/4	10/2	10/2	10/2	10/2
CLEAN HLD				3	12/4	12/4	12/4	4/2	4/2	4/2	4/2
SERVICE											
FOOD PREP		20	20	20	20/20	20/20	20/20	10/2	10/2	10/2	10/2
WAREWASH					10	10	10	10	10	10	10
DIETARY					2	2	2	2	2	2	2
LAUNDRY		10	10	10	10/10	10/10	10/10	10/2	10/2	10/2	10/2
SOILED LIN		8	8	8	10	10	10	10	10	10	10
CLEAN LIN		8	8	8	2/2	2/2	2/2	2	2	2	2
TRASH CHUTE				10/2	10/2	10/2	10	10	10	10	
BEDPAN RM					10	10	10	10	10	10	10
BATHROOM					10	10	10	10	10	10	10
JANITORS CLO				10	10	10	10	10	10	10	

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