**James E. Woods, Ph.D., P.E.**
250 Pantops Mountain Road, Suite 5221, Charlottesville, VA 22911
☐ Telephone: (434) 972-2575 ☐ Mobile Phone (703) 593-5009 ☐ Fax: (434) 972-2576
e-mail: jewoods3@aol.com

Thank you for the opportunity to provide this testimony. I am testifying today as an independent consultant on indoor environmental quality and reside in Charlottesville, Virginia.[1] Since 1960, I have been involved in servicing, designing, teaching, researching, diagnosing, and testifying on heating, ventilating, and air conditioning (HVAC) systems performance in commercial buildings.

The objective of my testimony is to comment and provide opinions regarding proposed changes to California Mechanical Code and California Plumbing Code of Regulations, Title 24, Parts 4 and 5, Sections 217.0, 407.2.1, 407.4.1.4 (2), Table 4-B, 602.1, 602.3.1 and 906.2.1. My comments and opinions are based on my research and practical experience regarding environmental control in health care facilities, and upon a current literature review pertaining to the specific Sections upon which I am testifying.

## Credentials

During my 50 year professional career, I have focused on advancing the designs and operations of indoor environmental control systems to enhance the health, safety, and well-being of occupants, energy efficiently and cost-effectively.

My early professional practice (1962-68) was in designing and servicing automatic control systems for existing buildings and developing applications of laminar flow cleanroom technologies for health care and industrial processes. This work led to my recruitment into the Bioenvironmental Engineering Traineeship Program at Kansas State University, which was sponsored by the National Institutes of Health.

My research at KSU (1968-1974) focused on the interactions of physiological responses of humans and laboratory animals to thermal, lighting, and acoustic exposures. As Professor of Mechanical Engineering and Architecture at Iowa State University (1974-1983), I taught undergraduate and graduate courses in thermal, lighting, and acoustic principles and design, and established the Building Energy Utilization Laboratory and the Center for Advancement of Building Technologies. My research during that period focused on the relationships between indoor environmental control for occupant needs and building energy utilization. From 1977-1983, I was Principle Investigator for an ASHRAE sponsored project: RP-202: Ventilation Requirements in Hospital Operating Rooms.

As Senior Staff Scientist and Senior Engineering Manager at Honeywell, where I was responsible for scientific development of a multi-divisional and international

[1] My contact information is jewoods3@aol.com.

program in indoor air quality (1983-1989), I focused on the development and application of scientific methodologies for diagnosing building performance that had discomforting and deleterious effects on occupants, which became known as "*Sick Building Syndrome*" (SBS) and "*Building Related Illness*" (BRI). Many of the cases we investigated resulted from over-aggressive energy conservation efforts. During the period (1983-1989) I was Principle Investigator on a project sponsored by the American Hospital Association: "Hospital Ventilation Requirements."

As Professor of Building Construction in the College of Architecture at Virginia Polytechnic Institute and State University (1989-1997), I was responsible for undergraduate and graduate instruction in mechanical and electrical systems and for research pertaining to human responses and control of indoor environments. During that time, I focused on research to improve the accuracy of building diagnostic procedures through adaptation of medical and other diagnostic paradigms.

Since I retired from Virginia Tech in 1997, I have focused on applying building diagnostic procedures for evaluating the interactions of human responses, indoor exposures, and building performance in terms of energy utilization (e.g., zero net energy mandates and goals) and protection during extraordinary conditions (e.g., resiliency) in federal buildings, other public buildings (e.g., schools and hospitals), and privately owned buildings.

This body of work has resulted in the publication of forty invited papers, fifty-five peer reviewed papers, fifty-one other articles and presentations, and six books that address the interactions between environmental control, system performance, and economic performance of buildings. This work has also resulted in five appearances before congressional committees, six testimonies at trial as an expert witness, and twenty-five depositions and administrative hearings that addressed the performance of buildings regarding their effects on health and safety.

ASHRAE

I became an Associate Member of ASHRAE in 1962 and a Full Member in 1967. I have served on Technical Committees since 1967, was elected an ASHRAE Fellow in 1992, became a Life Member in 2005 and received my Distinguished 50 year Life Membership this year. I served as a Member of the Board of Directors from 1997 – 2000. My first involvement with ASHRAE Standards was as a Graduate Student at Kansas State University, where I helped prepare drafts of ASHRAE Standards 55-74: *Thermal Environmental Conditions for Human Occupancy*, and ASHRAE Standard 62-73: *Standards for Natural and Mechanical Ventilation*. As Chairman of the ASHRAE Technical Committee 9.2 (1972-1975), I became involved in the development of ASHRAE Standard 90-75: *Energy Conservation in New Building Design*. In 1978, I was appointed Chairman of the Committee that revised ASHRAE Standard 62-73 as ASHRAE Standard 62-1981: *Ventilation for Acceptable Indoor Air Quality*. In 1980-1981, I was appointed as Chairman of an *ASHRAE Presidential Ad Hoc Committee on Legionnaire's Disease* that prepared two seminal

white papers on the sources, amplification sites, and energy and economic impacts of preventing future outbreaks of the disease in buildings. In October 2001, I was appointed as Chairman of an *ASHRAE Presidential Study Group and Ad Hoc Committee on Building Health and Safety Under Extraordinary Incidents* that prepared a white paper, which was accepted as a policy paper by the Board of Directors, and formed the basis of ASHRAE G29-2009: "*Guideline for Risk Management of Public Health and Safety in Buildings,*" of which I served as a member.

National Institute of Building Sciences (NIBS)

I have participated on NIBS projects for more than ten years. From July 2002 – June 2003, I was principal investigator of a project co-sponsored by GSA and ASHRAE to "*Develop and Implement a "Continuous Accountability" Protocol for Implementation of GSA/ PBS P-100.*" From July 2005 – June 2006, I was a team member that *provided physical security assessments for Department of Veteran Affairs Medical Centers.* From August 2004 – February 2007, I was a team member for the development of a "*Design Standard for Raised Floor Systems With and Without Underfloor Air Distribution," as a Supplement to the "PBS P100 Facility Standards for the Public Building Service.*" From July 2007 – December 2008, I was a team member that provided *post-occupancy building performance evaluations* of four U.S. Courthouses for the GSA/PBS. Since September 2008, I have been serving as a member of the Ad Hoc Subcommittee of the NIBS High Performance Building Council on the "*Development of requirements for providing higher performance of building operations in preparation and response to a disaster or catastrophic event than is presently provided by code.*" Since May 2010, I have participated on and chaired a committee to develop plans for the *improved design for persons with low vision*; these improvements have strong implications for effective use of energy within buildings.

## Summary of Opinions

| Item | Opinion |
|---|---|
| 1 | There is no assurance that patients will be less immune compromised, or less likely to be carriers of airborne infectious diseases than those who visit OSHPD 3 clinics. |
| 2 | No studies or reports have been submitted to suggest that 1) OSHPD 3SE clinics within existing facilities pose smaller risks to patients than in freestanding clinics, or 2) the risks to the general population in the existing facility would not be increased due to the integration with an OSHPD 3SE clinic and its HVAC system. |
| 3 | Based on the available information, it is likely that OSHPD's amendment to the 2013 California Mechanical Code to reduce the distance between air intakes and plumbing vents from 25 feet to 10 feet will increase health and safety risks to building occupants. |
| 4 | Based on the available information, it is likely that OSHPD 3SE clinics with just one MERV 8 filter bank will increase health and safety risks to patients, and to other occupants throughout the building. |

| Item | Opinion |
|---|---|
| 5 | Based on the available information, it is likely that the use of chases and plenums in OSHPD 3SE clinics will increase health and safety risks to building occupants, increase fire safety risks, and increase energy costs. |
| 6 | The proposed increase in length of flexible duct will likely increase the risk of airborne infection, decrease the fire protection and the performance of the HVAC system, and increase the building energy waste. |
| 7 | The cumulative effect of these changes is likely to have an amplified impact on health and safety of the patients and on energy waste. |

## Specific Comments and Opinions

1. The proposed limitations on activities at OSHPD 3SE clinics[2] provide no assurance that patients will be less alleric or immune compromised, or less likely to be carriers of airborne infectious diseases than those who visit OSHPD 3 clinics.
    a. A primary goal of the OSHPD 3SE proposals is to make it "more likely that clinics will be constructed in impoverished and rural communities."[3]
    b. The Center for Disease Control has stated that immunocompromised patients have the greatest risk of infection by airborne microorganisms, including persons with "diabetes" and persons with respiratory illnesses such as "emphysema."[4]
    c. Because of their intended locations, OSHPD 3SE clinics are at least as likely to receive patients who are:
        i. carriers of airborne infectious diseases who aerosolize particles, or
        ii. allergy- or immune-compromised who are susceptible to airborne infectious diseases through exposure to aeroallergens, aerosolized fungi and bacteria, and viruses within the clinic.[5]
    d. Diabetes rates in California have risen 38% in California in the past decade, with especially high rates among the underinsured and in the rural areas of the California Central Valley.[6]

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[2] See 45-day Express Terms for Proposed Building Standards of the OSHPD, regarding proposed changes to CMC and CPC, Title 24, Parts 4 and 5, Section 217.0: Definitions, 8 February 2013, pages 1-2.

Also see Final Express Terms for Proposed Building Standards of the OSHPD, regarding proposed changes to the CBC California Code of Regulations, Title 24, Part 2, 15 November 2012, 49 pages.

[3] OSHPD, Response to California State Pipe Trades Comment (Oct. 8, 2012).

[4] Guidelines for Environmental Infection Control in Health-Care Facilities Recommendations of CDC and the Healthcare Infection Control Practices Advisory Committee (HICPAC) (2003), page 6, http://www.cdc.gov/hicpac/pdf/guidelines/eic_in_HCF_03.pdf; accessed 21 March 2013.

[5] Kowalski WJ and Bahnfleth W. 1998. Airborne Respiratory Diseases and Mechanical Systems for Control of Microbes. *HPAC Journal*, July 1998, pp 34-48 (cited by OSHPD in responses).

e. The percentages of children in California diagnosed with asthma range from a high of over 30% in rural Kings County to a low of approximately 8% in Orange County, with the statewide mean of nearly 15%.[7]

f. Since 2001, the percent of Californians diagnosed with asthma has increased from 11.3% to 13%.[8] This study reported that "asthma is most common in Central Valley and in Northern California counties, and least common in wealthy and coastal San Francisco." The report also revealed that:
   i. "Asthma tends to be harder on people whose family income fell under about $41,300 for a family of four."
   ii. "Low-income people went to the emergency room or urgent care twice as often as wealthier people."
   iii. "Hospitalization rates for low-income kids and adults [were] five times higher than for the more affluent."
   iv. "Second-hand smoke exposure – which can worsen asthma symptoms – is more than three times more common in low-income homes."

g. "Infectious diseases account for 20-30% of physician office visits, with acute infection of the respiratory tract as the most common reason for consulting a physician. There have been multiple outbreaks of measles, tuberculosis, and other infectious diseases traced to physician office or clinics."[9]

h. An important host factor in the risk of acquiring infections in clinics is age[10]:
   i. Children in waiting areas may spread viruses, such as chicken pox and measles, through the air of the clinic.
   ii. The function of the immune system wanes with age. Elderly patients frequently have more chronic illnesses, such as diabetes, chronic lung disease, malignancy, dementia, and malnutrition, all of which complicate their course of disease and increase the risk of infection.

i. Carriers of airborne infectious diseases may be infectious before any identifying symptoms become evident.

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[6] Schillinger D. 2012. California Diabetes Program, Diabetes in California Counties (7/9/2012), http://www.caldiabetes.org/content_display.cfm?contentID=1160; accessed 27 March 2013.

[7] http://www.centralcalasthma.org/index.php?id=58, accessed 15 March 2013.

[8] http://californiawatch.org/dailyreport/asthma-hits-states-poor-hardest-7539, accessed 15 March 2013.

[9] Friedman C and Petersen KH. 2004. *Infection Control in Ambulatory Care.* An official publication of the Association for Professionals in Infection Control and Epidemiology (APIC), page 1.

[10] Ibid, page 7.

j. Patients with unrecognized infectious diseases are seen in clinics, so there needs to be an increased focus on infection prevention and control programs in these settings.[11]
k. "[T]he basic principles of disease transmission and prevention are the same in ambulatory care service areas as in traditional hospital settings."[12] Accordingly, a patient with an airborne infectious disease will be just as infectious in an OSHPD 3SE clinic as in a hospital; but the risk of spread of this infection through ventilation systems will be greater in the OSHPD 3SE setting because of the reduction in filtration and other protective HVAC system requirements.
l. Examination and diagnostic clinics in underserved or low-income communities are more likely to see persons with undiagnosed airborne infectious diseases, such as TB.[13] *These are exactly the populations that OSHPD is claiming that the OSHPD 3SE clinics would serve.*
    i. "The risk of seeing a patient with TB; for example, is higher at clinics caring for the medically underserved, low-income populations, alcoholics, foreign-born, and intravenous drug abusers."
    ii. The risk of seeing patients is also higher "where there is a likelihood of children accompanying the patient who might be contagious."
m. Primary care insurance companies commonly require persons to consult with their primary care physician before seeing a specialist, so persons with airborne infectious diseases are likely to go to clinics for initial diagnosis/care.
n. The proposed regulations allow, but do not require, OSHPD 3SE clinics to have airborne infection isolation (AII) rooms. Without AII rooms, occupants in these clinics will not be protected from those patients with airborne infectious diseases.
o. The proposed OSHPD 3SE clinics have less infection control than OSHPD 3 clinics. Therefore, the adequacy of primary care has been diminished, especially for underserved populations such as low-income areas.
    i. Medically underserved and low-income populations are more likely to carry airborne infectious diseases such as TB.
    ii. Accordingly, OSHPD 3SE clinics may be more likely to receive patients with undiagnosed airborne infectious diseases than OSHPD 3 clinics.

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[11] Ibid, page 1.

[12] Ibid, page 2.

[13] Ibid, pages 55-56.

p. The proposed regulations provide no studies or reports to suggest that OSHPD 3SE clinics are unlikely to see patients with undiagnosed airborne infectious diseases.
q. A comprehensive evaluation of the potential risk for OSHPD 3SE patients to be carriers of airborne infectious diseases or to be immune compromised should be prepared by OSHPD prior to approving these regulations.

2. OSHPD 3SE clinics may be freestanding new or converted structures, or they may be "contained within existing commercial or residential buildings as 'storefront' units." [14]
   a. For freestanding clinics in new or converted and renovated structures, the exposure risks to patients will be as described in Item 1, above.
   b. For clinics that are installed as "storefront units" in existing facilities (e.g., shopping malls, office buildings, public housing buildings), the exposure risks to not only patients but also to other occupants in the facilities are likely to be higher than for OSHPD 3SE clinics in freestanding new or converted (i.e., renovated) structures:
      i. The proposed changes to the CMC and CPC in Title 24 do not require the OSHPD 3SE clinic to be physically isolated from the existing building. To the contrary, the changes apparently encourage the integration of the clinic with the existing building.
      ii. As interior entrances and exits between the clinic and the existing building are not excluded, infiltration and exfiltration of contaminated air is not controlled by pressurization, which potentially exposes both patients within the clinic and occupants within the existing facility to infectious agents and other contaminants.
      iii. The HVAC systems that provide indoor air quality control within the existing facilities are likely to have become degraded since their installations, and are likely to be inadequate for infection control within OSHPD 3SE clinics.[15] Mean frequencies of occurrence in HVAC performance degradation were reported in two studies of over 50 facilities in which occupant complaints were reported:

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[14] See 45-day Express Terms for Proposed Building Standards of the OSHPD, regarding proposed changes to CMC and CPC, Title 24, Parts 4 and 5, Section 217.0: Definitions, 18 Feb 13, pages 1-2, and 5-6.

[15] http://www.aerias.org/DesktopModules/ArticleDetail.aspx?articleId=46, accessed 16 March 2013. The values referenced in this website are from:

Woods, J.E. "Cost Avoidance and Productivity in Owning and Operating Buildings". In *Occupational Medicine: State of the Art Reviews*, Vol.4, No. 4, October - December, 1989, pp. 753-770.

- 90% inappropriate control strategies.
- 80% thermal and contaminant load imbalances with system capacities.
- 75% inadequate maintenance;
- 64-75% inadequate outdoor air;
- 46-75% inadequate air distribution to occupied spaces;
- 57-65% inadequate filtration of supply air;
- 60-63% inadequate drain lines and drain pan function;
- 38-45% contaminated ductwork and linings;
- 16-20% malfunctioning humidifiers;

c. Accordingly, even if these clinics were generally smaller than freestanding clinics, the population of building occupants that may be exposed to airborne infectious diseases transmitted through HVAC systems may actually be greater than in freestanding clinics. Furthermore, the proposed OSHPD 3SE regulations impose no limitations on the size of OSHPD 3SE clinics or the number of examination rooms.

d. The proposed regulations provide no studies or reports to suggest that OSHPD 3SE clinics to be located within existing facilities are:
   i. Unlikely to see patients with undiagnosed airborne infectious diseases.
   ii. Likely to pose a smaller risk of exposing patients to airborne hazards than freestanding clinics, or that
   iii. The risks to the general population in the existing facility would not be increased due to the integration with an OSHPD 3SE clinic and its HVAC system.

e. A comprehensive evaluation should be prepared by OSHPD of the potential risks that clinics installed as "storefront units" in existing facilities (e.g., shopping malls, office buildings, public housing buildings) may pose to patients or other occupants in the facilities.

3. For OSHPD 3SE clinics, the proposed supply air filtration is reduced from two filter banks with filters of a minimum efficiency of MERV 8 and MERV 14 to just one filter bank with filters of a minimum efficiency of MERV 8. [16] This reduction in filtration requirements is likely to increase health and safety risks to patients and other building occupants. Moreover, this increased health and safety risk will be further exacerbated if the OSHPD 3SE clinic is located in an existing building.
   a. As shown in Table 4-B, this proposal would cause all areas within an OSHPD 3SE clinic to have no better filtration than the minimum

[16] Table 4-B: *Filter Efficiencies for Central Ventilation and Air Conditioning Systems in General Acute Care Hospitals, Outpatient Facilities, and Licensed Clinics*. Express Terms for Proposed Building Standards of the OSHPD, regarding proposed changes to CPC, Title 24, Parts 4 and 5, 8 February 2013, page 3.

provided for "administrative, med staff support areas, bulk storage, soiled holding areas, food preparation areas, public cafeterias, and laundries."

i. The areas at increased risk within an OSHPD 3SE clinic would include all patient examination areas and their support rooms, medication stations, clean utility rooms, consultation rooms, and speech pathology and treatment rooms.

ii. The number of filter beds and filter efficiencies required by FGI[17] and ASHRAE Standard 170-2008, Table 6-1,[18] are:

1. Two filter banks with MERV 7 and 14 filters, respectively, for "inpatient care, treatment, and diagnosis, and those spaces providing direct service or clean supplies and clean processing (except as noted below)"; and "AII (rooms)."
2. One filter bank with MERV 7 filters for "Administrative; bulk storage; soiled holding spaces; food preparation spaces; and laundries." Also, "all other outpatient spaces."

iii. The locations and types of filter banks, which are required by FGI and ASHRAE Standard 170-2008, are intended to reduce the risk of infections in areas where patients are examined, diagnosed or treated:

1. "Filter bank No. 1 shall be placed upstream of the heating and cooling coils such that all mixed [i.e., outdoor and recirculated] air is filtered."
2. Filter bank No. 2 shall be installed downstream of all wet air cooling coils and the supply fan. All second filter banks shall have sealing interface surfaces." This sealing is provided to prevent contaminated air from bypassing the filter media.

b. The proposed reduction in filter efficiencies for all OSHPD 3ES spaces will increase the risk of airborne infectious diseases.

i. Airborne infectious diseases can spread through HVAC ventilation systems, especially if the return air is recirculated through low efficiency filters (TB, measles, etc.);[19]

ii. The combination of MERV 8 and MERV 14 filters will capture, during each air cycle through the system, approximately 90% of the upstream airborne particles in the size range of 1.0-3.0 μm,

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[17] Facility Guideline Institute. 2010. *Guidelines for the Design and Construction of Health Care Facilities* (reference to ASHRAE Standard 170-2008).

[18] ANSI/ASHRAE/ASHE Standard 170-2008. *Ventilation of Health Care Facilities*: Section 6.3 – Outdoor Air Intakes and Exhaust Discharges, pages 4-5.

[19] ASHRAE Handbook. 2011. *HVAC Applications*: Chapter 8 - Health-Care Facilities, page 8.2.

which includes bacteria the size of TB, whereas a MERV 8 filter, by itself, will only capture in each cycle approximately 50-70% of airborne particles in the larger size range of 3.0-10.0 μm, which includes pollen and mold spores, but the capture efficiency of smaller particulates, the size of TB, is much less than 50%.[20] [21] As few as one to ten TB bacilli can be infectious for humans.[22] A TB infective can produce 1-249 bacilli per hour.[23] Moreover, TB can remain airborne indefinitely in water droplets of 5 μm size or less.[24]

iii. Without the second bank of MERV 14 filters, TB or other airborne infectious agents can spread from exam room to other rooms in the clinic and throughout the building.

c. If a patient with TB or other airborne infectious disease is examined at a clinic, the risk of having the airborne infectious agents spread through the HVAC system will be higher in OSHPD 3SE facilities with only one MERV 8 filter bank, when compared to OSHPD 3 clinics with two filter banks of MERV 8 and MERV 14.

d. Because OSHPD 3SE buildings are not limited in size and are likely to be located in larger commercial or office buildings, the population at risk from the spread of airborne infectious agents may be greater than in a freestanding OSHPD 3SE or an OSHPD 3 clinic, which is not exempt in the proposed changes.

e. The OSHPD proposals are not supported by any technical or medical studies or reports demonstrating that this proposed regulatory change will not result in increased health and safety risks or other environmental risks.

f. Based on the available information, a fair argument exists that the proposal to allow patient examination areas and their support rooms, medication stations, clean utility rooms, consultation rooms, and speech pathology and treatment rooms in OSHPD 3SE clinics to have just one MERV 8 filter bank instead of two filter banks of MERV 8 and MERV 14 will increase health and safety risks to patients, and to other occupants throughout an existing building.

g. A comprehensive evaluation of this risk should be prepared by OSHPD prior to approving these regulations. This evaluation should

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[20] ASHRAE Handbook. 2012. *HVAC Systems and Equipment*: Chapter 29 – Air Cleaners for Particulate Contaminants, page 29.9.

[21] ASHRAE. Guideline 29-2009. Guideline for the Risk Management of Public Health and Safety in Buildings., Table 3, page 14.

[22] Kowalski WJ and Bahnfleth W. 1998. HPAC Engineering, Airborne Respiratory Diseases and Mechanical Systems for Control of Microbes (July 1998), page 37.

[23] Ibid.

[24] ASHRAE Handbook. 2011. *HVAC Applications*: Chapter 8 - Health-Care Facilities, page 8.2.

demonstrate from a statistically significant sample of site-specific data the minimal filter efficiencies in which concentrations of particulate contaminants downstream from the filters in the supply air of the HVAC system do not exceed acceptable health risks to patients in OSHPD 3SE clinics.

4. For OSHPD 3SE clinics, Section 407.4.1.4 (2)[25] proposes exemption from the requirement that "no space above the ceiling be utilized as an outside-air, relief-air, supply-air, exhaust-air, or return-air plenum." Moreover, Section 602.1 proposes that OSHPD 3SE but not 1, 2, 3 or 4 clinics be permitted to use "concealed building spaces or independent construction within buildings [as] ducts and plenums." These exemptions are likely to increase health and safety risks to patients and other building occupants, especially if the 3SE clinic is located in an existing building.
    a. While ductwork has a singular function of transporting supply, return, or exhaust air with minimum differences in thermal or contaminant conditions between their points of connection (e.g., between the HVAC equipment and the occupied spaces), plenums and chases (e.g., concealed building spaces) have multiple functions: distribution of electrical services; electronic signals; domestic, hydronic and process water; condensate and wastewater; specialty gases; and supply and return air. As a result, unducted supply or return air in plenums and chases is usually mixed with air from other pathways that contain thermal or contaminant sources.
    b. Evidence in the literature and my own investigations and testimony reveal that supply and return air plenums located above ceilings and in concealed spaces or chases, especially in existing buildings, are contaminated with dusts, mold spores, rodent droppings and microorganisms from dead pests and other sources, which are readily aerosolized into the return air of the HVAC system or directly into the occupied spaces.[26]
        i. "The return air plenum in the ceiling, and concealed spaces or chases that connect with the plenum, can become sources (or amplification sites) of microorganisms when fire and acoustical insulation and ceiling tiles become wet." [27]

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[25] Section 407.4.1.4 (2), Express Terms for Proposed Building Standards of the OSHPD, regarding proposed changes to CMC, Title 24, Parts 4 and 5, 8 February 2013, page 3.

[26] ASHRAE. 2003. *HVAC Design Manual for Hospitals and Clinics*, Section 9.5.2: Fully Ducted versus Plenum Returns, page 97.

[27] Patterson R, et al. 1993. Indoor Allergens: Assessing and Controlling Adverse Health Effects. Institute of Medicine, National Academy Press, Washington, DC, 220-221.

ii. Contaminated return air plenums and chases have been identified as sources of illness and infections to patients and building occupants.[28] [29]

c. Reliance on plenums rather than ducts can result in indoor air quality problems, increased risk of spread of airborne infectious diseases and increased energy use. I have personally observed problems with return air plenums in numerous of the over 250 buildings I have investigated, including serious plenum issues in medical out-patient clinics. I have also published academic articles on these issues and testified on these issues in court trials.[30]

   i. Known problems with return air plenums above the ceiling include:

      1. "Air from common plenums or ducted returns enters chases or risers and then is transported, usually by a return air fan, back to an AHU for exhaust or for reconditioning. Because of the difficulty with regard to access, contamination that may occur in common return plenums (e.g., microbial growth, friable asbestos and man-made insulation) can be removed only with great difficulty."[31]
      2. Room-side elements of exterior walls (e.g., drywall) and demising walls typically are not sealed to the deck above a return air plenum, and become "concealed spaces" and pathways through which moisture and microorganisms (e.g., Aspergillus sp.) can be transported to the return air plenums, increasing the risk of exposure to patients and other occupants, especially in existing buildings.
      3. If the return air plenum and chases or risers are common to other areas within an existing building, the risk of infection throughout the facility is likely to increase,

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[28] Woods testimony at trial. 1998. Weisfogel vs. Collard, et al. In Supreme Court of the State of New York, County of Nassau, Index #17605/94, (Case involved an outpatient clinic.)

[29] Woods testimony at trial. 1990. Call et al vs. Prudential Insurance et al. Torrence County Superior Court, California. (Case involved fitting out a space in an existing building.)

[30] See e.g., Morey PR and Woods JE. 1987. Indoor Air Quality in Health Care Facilities. In Occupational Medicine: State of the Art Reviews, Vol. 2, Jul-Sep, pages 547-563;

Woods testimony at trial. 1998. Weisfogel vs. Collard, et al. In Supreme Court of the State of New York, County of Nassau, Index #17605/94, (Case involved an outpatient clinic).

Woods testimony at trial. 1990. Call et al vs. Prudential Insurance et al. Torrence County Superior Court, California, (Case involved fitting out a space in an existing building).

[31] Morey PR and Woods JE. 1987. Indoor Air Quality in Health Care Facilities. In Occupational Medicine: State of the Art Reviews, Vol. 2, Jul-Sep, pages 547-563.

especially if the plenums throughout the building have not been cleaned.

4. Return air plenums adjacent to exterior walls or roofs are likely to incur moisture transfer and air leakage, which increases the risks of amplification of microorganisms and infection.
5. The heat transfer from exterior plenum walls and roofs typically imposes additional thermal loads, which require additional heating and cooling capacities of the HVAC system and demand larger rates of energy consumption.
6. If fan-powered variable air volume (FPVAV) terminal units are installed in the return air plenum, unfiltered plenum air will be mixed with the ducted supply air and increase the risk of transporting contaminants from the plenum directly into patient examination and support areas.
7. Compared to ducted return air, plenums reduce noise attenuation and increase acoustic bridging between patient exam/consultation rooms and adjacent spaces, increasing the loss of patient privacy.
8. If this exemption is allowed, fire safety risks will increase due to allowance of outside air into plenum environment. Moreover, plenums in existing buildings are more likely to contain cables that do not meet the UL 910/NFPA 262 flame spread and smoke tests. Studies have shown that for the 9 years starting in 1988 and ending in 1996, the percentage of cables failing the UL 910/NFPA 262 test increased from 10% to over 50%.[32]
9. If these exemptions are allowed, the introduction of chase, relief or exhaust air into the return air plenum will increase risks of contaminating the return air to the HVAC system. Moreover, these exemptions are likely to cause pressure imbalances in the system and increase risks of infection.
10. If these exemptions are allowed, the use of the ceiling plenum for distribution of supply air to patient exam and support rooms is likely to increase the risk of infection, and to increase the energy consumption of the facility.
11. The likelihood of poorly performing HVAC systems or potentially dangerous air quality conditions (mold, etc) can be high in existing buildings that have not been well

[32] Stanitis G, and Dohmann F. 2013. The Evolution of Plenum Cable Fire Standards and the Impact of those Standards on Material Specification, A History of Plenum Cable Fire Safety Issues, http://www.wireville.com/news/news01.html; accessed 27 March 2013..

maintained.[33] Allowing existing plenum systems to be used without any upgrades increases the risks that performance, maintenance or contamination issues in existing systems will not be discovered or remediated.

ii. Section 3.1-8.2.4.1 of the FGI Guideline[34] does not allow return air plenums: "for patient care areas, return air shall be via ducted systems."

d. The risks and concerns regarding the use of chases and plenums are no different in an OSHPD 3SE clinic than they are in an OSHPD 3 clinic.

e. The OSHPD 3SE proposals are not supported by any technical or medical studies or reports demonstrating that these proposed regulatory changes will not result in increased health and safety risks, fire risks, increased energy costs or other environmental risks.

f. Based on the available information, a fair argument exists that the proposal to allow the use of chases and plenums instead of ducts in OSHPD 3SE clinics may increase health and safety risks to building occupants, increase fire safety risks, and increase energy costs. A comprehensive evaluation of this risk should be prepared by OSHPD prior to approving these regulations.

5. For OSHPD 3SE clinics, Section 602.3.1[35] proposes an exemption from the maximum 10 foot limit on the length of flexible ducts that can be used "to connect supply, return or exhaust-air terminal devices to rigid duct systems." An OSHPD response assumed in its calculations a length of flex duct of 100 feet, thus indicating that the allowable length is essentially unlimited. [36] This allowable increase in length will likely increase the risk of airborne infection, decrease the fire protection and the performance of the HVAC system, and increase the building energy waste.

   a. Section 602.3.1 does not distinguish between "flexible air ducts" and "flexible air connectors." Without the exception, both products are limited to 10 feet. However, with the proposed exception, the lengths of both products in OSHPD 3SE clinics would be unlimited.

      i. Flexible air ducts must pass fifteen UL tests; flexible air connectors are not required to pass the flame penetration,

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[33] Woods, J.E. "Cost Avoidance and Productivity in Owning and Operating Buildings". In *Occupational Medicine: State of the Art Reviews*, Vol.4, No. 4, October - December, 1989, pp. 753-770.

[34] Facility Guideline Institute. 2010. *Guidelines for the Design and Construction of Health Care Facilities:* Section 3.1-2.2.4.1 – Return Air Systems, page 234.

[35] Section 602.3.1, Express Terms for Proposed Building Standards of the OSHPD, regarding proposed changes to CMC, Title 24, Parts 4 and 5, 8 February 2013, page 4.

[36] Response from OSHPD to Thomas Enslow, 8 October 2012, Title 24, Parts 4, Section 602.3.1.

puncture, or impact tests.[37] Because of the absence of the additional UL tests, a flexible connector should not be used in an application where the 14-foot length limit is exceeded.

ii. Prepackaged lengths of flexible air ducts for commercial applications range from 6 – 50 feet. Prepackaged lengths of flexible air connectors for commercial applications range from 6 – 25 feet.

b. Both flexible air ducts and air connectors are available with corrugated aluminum or multi-ply metalized/polyester cores. Section 602.3.1 requires that "an impervious liner shall be provided to isolate insulation material from conditioned air." The exception for OSHPD 3SE clinics would remove this requirement, which is available for microbial resistance. Therefore, this exception increases the risk of transporting microorganisms by the supply air directly into to patient areas.

c. Poorly installed flexible duct (i.e., not sufficiently stretched out and secured) is normal for its use in buildings, not the exception.

i. At ideal (i.e., "horizontally stretched") test conditions, the pressure drop is approximately the same as rigid galvanized sheet metal duct. [38]

1. At moderate compression of 15%, the pressure drop increases approximately 4x compared to the stretched conditions.
2. At 30% compression, the pressure drop increases approximately 10x.

ii. The increased roughness (i.e., friction factor) that occurs during this compression is due to the protrusion of the corrugated aluminum or multi-ply metalized/polyester cores into the airflow volume, which presents niches for microbial growth, especially when the humidity of the supply air exceeds 70%RH.[39] [40]

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[37] Fetters D. 2004. The Difference Between Flexible Air Ducts and Flexible Air Connectors. *Technical Bulletin TT-03*, Hart and Cooley, Inc., Holland Michigan, 2 pages.

[38] Bass A, Walker IS, Sherman MH. 2002. Compression Effects on Pressure Loss in Flexible HVAC Ducts. Lawrence Berkeley National Laboratory. http://www.escholarship.org/uc/item/0d76400v (accessed 20 March 2013).

[39] ASHRAE. 2010. Standard 62.1-2010: *Ventilation for Acceptable Indoor Air Quality*, Section 5.4.1 – Resistance to Mold Growth, page 6.

[40] CDC. 2003. *Guidelines for Environmental Infection Control in Health-Care Facilities*, Recommendations of CDC and the Healthcare Infection Control Practices Advisory Committee (HICPAC), page 33.

iii. "Flexible duct use should be limited due to its more extensive pressure losses, particularly when crimped or coiled, and its greater susceptibility to abuse or damage."[41]

d. The use of flexible duct in OSHPD 3SE clinics is highly likely to result in increased energy waste and costs.
   i. Splices in flexible air ducts, required for long-length runs, are likely to cause air leaks.
   ii. Additional fan power, as well as energy consumption for additional heating and cooling of the replacement air will be required to compensate for the leaks and the pressure drops due to crimps and coils in the installed flexible duct.
   iii. The conclusion of no significant energy impact, provided in the OSHPD response,[42] was based on simplistic calculations that are known to underestimate the pressure losses incurred by compressed, crimped, or coiled flexible duct.[43]

e. Poor air flow and leaky supply duct runs are ventilation hazards associated with increased potential of airborne disease transmission.[44]
   i. "Decreased performance of healthcare facility HVAC systems, filter inefficiencies, improper installation, and poor maintenance can contribute to the spread of health-care–associated airborne infections."

f. Energy efficiency and poor performance issues from use of flexible air ducts are not different in OSHPD 3SE clinics than in other OSHPD clinics.

i. The OSHPD proposals are not supported by any technical or medical studies or reports demonstrating that this proposed regulatory change will not result in increased energy use and costs, increased health and safety risks or other environmental risks.

j. Based on the available information, a fair argument exists that the proposal to allow OSHPD 3SE clinics to use HVAC systems with more than 10 feet of flexible duct may increase energy use and increase the risk of poorly performing HVAC systems, which can increase the risk of spread of airborne infectious diseases.

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[41] ASHRAE. 2003. *HVAC Design Manual for Hospitals and Clinics*, Section 9.5.1: General [Ductwork] Design Considerations, pages 96-97.

[42] Response from OSHPD to Thomas Enslow, 8 October 2012, Title 24, Parts 4, Section 602.3.1.

[43] Bass A, Walker IS, Sherman MH. 2002. Compression Effects on Pressure Loss in Flexible HVAC Ducts. Lawrence Berkeley National Laboratory. http://www.escholarship.org/uc/item/0d76400v (accessed 20 March 2013).

[44] CDC. 2003. *Guidelines for Environmental Infection Control in Health-Care Facilities*, Recommendations of CDC and the Healthcare Infection Control Practices Advisory Committee (HICPAC), pages 13-21.

k. A comprehensive evaluation of this risk should be prepared by OSHPD prior to approving these regulations.

6. I also note that OSHPD's 2013 California Mechanical Code amendments reduce the minimum distance between outdoor intakes for HVAC systems and plumbing vents from 25 feet to 10 feet **for** OSHPD 3SE clinics.[45] This reduction is likely to increase health and safety risks to patients and other building occupants.
   a. Plumbing vents discharge gaseous, vaporous, and inert and viable particulate effluents from toilets, showers and bathtubs, sinks in patient rooms and support areas, including laboratories, and other fixtures (e.g., clothes washers, dish washers) that are connected to the sanitary sewer system.
   b. Sewer gas in building plumbing systems may pose serious risks to public health from toxic gases, including hydrogen sulfide gas, methane, carbon dioxide and ammonia, and also from airborne pathogens, including tuberculosis, coxsackie A&B, dysentery, rotavirus, echovirus, cholera, common cold, hepatitis A, typhoid, polio and SARS.[46]
   c. Effluents from plumbing vents that enter the HVAC outdoor air intake will degrade indoor air quality and are likely to pose health and safety risks.[47]
   d. FGI[48] and other national standards[49] and references[50] [51] require at least 25 foot distance between HVAC air intakes and plumbing vents,

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[45] Section 407.2.1: *Outdoor Intakes*, Express Terms for Proposed Building Standards of the OSHPD, regarding proposed changes to CMC, Title 24, Parts 4 and 5, 8 February 2013, page 2;

Section 906.2.1: *Vent Termination*, Express Terms for Proposed Building Standards of the OSHPD, regarding proposed changes to CPC, Title 24, Parts 4 and 5, 8 February 2013, page 7.

[46] Hutter, GM. 2013. Meridian Engineering and Technology, Reference Data Sheet on Sewer Gas (Hydrogen Sulfide, Carbon Dioxide, Methane, Ammonia, Biological Agents); http://www.meridianeng.com/sewergas.html, accessed 27 March 2013.

Declaration of Dr. Phyllis Fox, Ph.D., P.E., In the Matter of Air Admittance Valves, IAPMO Docket # 1138-06 (November 1, 2005).

[47] ASHRAE. 2012. *Position Document on Legionellosis*, pages 6-8.;

Hutter GM. 2013. Meridian Engineering and Technology, Reference Data Sheet on Sewer Gas (Hydrogen Sulfide, Carbon Dioxide, Methane, Ammonia, Biological Agents), http://www.meridianeng.com/sewergas.html ;

Declaration of Dr. Phyllis Fox, Ph.D., P.E., In the Matter of Air Admittance Valves, IAPMO Docket # 1138-06 (November 1, 2005).

[48] Facility Guideline Institute. 2010. *Guidelines for the Design and Construction of Health Care Facilities*: Section 3.1-5.4.2.2(5).

[49] ANSI/ASHRAE/ASHE Standard 170-2008. *Ventilation of Health Care Facilities*: Section 6.3 – Outdoor Air Intakes and Exhaust Discharges, page 4.

due to the greater likelihood that patients in health care facilities carry infectious diseases, or may be highly susceptible to exposures of aeroallergens or other toxic or noxious contaminants.

i. *Section 6.3.1 of ASHRAE 170-2008 does not make an exception for plumbing vents, as is made in the new OSHPD regulations.*

e. The reduction in distance between intakes and plumbing vents is not supported by any technical or medical studies or reports that demonstrate the proposed regulatory change will not result in increased health and safety risks.

f. Based on the available information, a fair argument exists that the reducing the distance between air intakes and plumbing vents from 25 feet to 10 feet will increase health and safety risks to building occupants.

7. In addition to the potential impacts of the individual provisions of the OSHPD 3SE proposal, the cumulative effect of these provisions may have an additive impact on health and safety of the patients and on energy waste.

   a. A cumulative effect from the four proposed changes is likely:

      i. The minimum distance has been reduced from 25 to 10 feet between outdoor intakes for HVAC systems and plumbing vents[52],

      ii. The supply air filtration has been reduced to one filter bank with filters of a minimum efficiency of MERV 8. [53]

      iii. The requirement has been exempt that "no space above the ceiling be utilized as an outside-air, relief-air, supply-air, exhaust-air, or return-air plenum" (Section 407.4.1.4 (2), and the use has been permitted of "concealed building spaces or independent construction within buildings [as] ducts and plenums" (Section 602.1). [54]

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[50] ASHRAE Handbook. 2011. *HVAC Applications*: Chapter 8 - Health-Care Facilities, page 8.2.

[51] ASHRAE. 2003. *HVAC Design Manual for Hospitals and Clinics*, Section 4.7.2: Location of Outside Air Intakes, pages 40-41.

[52] Section 407.2.1: *Outdoor Intakes*, Express Terms for Proposed Building Standards of the OSHPD, regarding proposed changes to CMC, Title 24, Parts 4 and 5, 8 February 2013, page 2;

Section 906.2.1: *Vent Termination*, Express Terms for Proposed Building Standards of the OSHPD, regarding proposed changes to CPC, Title 24, Parts 4 and 5, 8 February 2013, page 7.

[53] Table 4-B: *Filter Efficiencies for Central Ventilation and Air Conditioning Systems in General Acute Care Hospitals, Outpatient Facilities, and Licensed Clinics*. Express Terms for Proposed Building Standards of the OSHPD, regarding proposed changes to CPC, Title 24, Parts 4 and 5, 8 February 2013, page 3.

[54] Sections 407.4.1.4 (2) and 602.1, Express Terms for Proposed Building Standards of the OSHPD, regarding proposed changes to CMC, Title 24, Parts 4 and 5, 8 February 2013, pages 3-4.

iv. The requirement has been exempt that "flexible ducts of no more than 10 feet (3048 mm) in length may be used to connect supply, return or exhaust-air terminal devices to rigid duct systems."[55]

b. When considered together as a system, these four changes are likely to incrementally amplify the risk of infectious agents being exposed to patients in OSHPD 3SE clinics compared to the risk of exposure in OSHPD 3 or 3SE clinics without the proposed changes:
   i. The reduced distances between the outdoor intake and plumbing vents will result in increased concentrations of gaseous, vaporous, and particulate (viable and non-viable) contaminants to enter into the mixed air stream in the HVAC system (e.g., roof-top unit).
   ii. The air from the ceiling plenum and concealed chases, which is recirculated to the mix air stream of the HVAC system, is likely to be more contaminated that air recirculated from ducted returns.
   iii. The penetration of the elevated concentration of contaminants in the mixed air stream, as impacted by i and ii, above, will be increased through the single bank of MERV 8 filters compared to the penetration through the two filter banks of MERV 8 and MERV 14 filters in series. Thus, the concentration of particulate matter in the supply air of the HVAC system with MERV 8 will be increased, with a differential increase of smaller particles (i.e., 1.0 – 3.0 μm), compared to the system with both MERV 8 and 14 filters.
   iv. The supply air distributed through long lengths of compressed flexible air duct to the terminal devices in the patient areas is likely to amplify infectious agents due to the niches provided by the ridges compared to rigid galvanized sheet metal ducts.

c. A comprehensive evaluation of this cumulative risk should be prepared by OSHPD prior to approving these regulations. This evaluation should be determined from a statistically significant sample of site-specific data that demonstrate:
   i. No increase in health or safety risks to patients in OSHPD 3SE clinics when the combination of proposed changes is implemented.
   ii. No increase in thermal loads, HVAC capacities, power requirements, or energy consumption for OSHPD 3SE when the combination of proposed changes is implemented.

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[55] Section 602.3.1, Express Terms for Proposed Building Standards of the OSHPD, regarding proposed changes to CMC, Title 24, Parts 4 and 5, 8 February 2013, page 4.

Respectfully Submitted,

James E. Woods, Ph.D., P.E.

James E. Woods, Ph.D., P.E.

250 Pantops Mountain Road, Suite 5221, Charlottesville, Virginia 22911

Phone: 434.972.2575; Fax: 434.972.2576; Mobile: 703.953.5009

Email: jewoods3@aol.com

25 February 2013

**James E. Woods, Ph.D., P.E.,** is an Indoor Environments Consultant residing in Charlottesville, Virginia, and the former Executive Director of the Building Diagnostics Research Institute. In 1997 he retired as the William E. Jamerson Professor of Building Construction at Virginia Polytechnic Institute and State University. Previously, he served as Senior Engineering Manager and Senior Staff Scientist at Honeywell (1983-1989), and was Professor of Mechanical Engineering and Architecture at Iowa State University (1974-1983). He has over 49 years experience in energy and environmental analyses, and has been responsible for more than 30 research projects and 250 investigations related to indoor environmental quality, energy utilization, and human responses in residences, office buildings, public assembly and monumental buildings, hospitals, schools, laboratories, and commercial aircraft. He has authored or co-authored seven books, more than 200 technical papers and is the co-holder of two patents. He has served as a consultant or advisor to many private and public agencies, including design engineering and architectural firms, building owners, insurance companies, law firms, utility companies, and state and federal agencies.

Dr. Woods is Fellow and Life Member of the American Society of Heating Refrigerating, and Air Conditioning Engineers (ASHRAE). He has chaired and served on numerous ASHRAE committees related to indoor air quality, environmental health, building energy utilization, industrial air conditioning, physiology and human environment, thermal conditions for human occupancy, and ventilation and infiltration requirements.

The professional experience of Dr. Woods includes:

- From 1979 to 1983, established and directed the Building Energy Utilization Laboratory at Iowa State University, where he led studies that evaluated the performance of buildings, energy requirements, and uses of conservation methods and alternative energy resources to provide for acceptable indoor environments; consulted with Iowa Electric Light and Power Co. on alternative energy sources in Iowa; and twice testified before the Iowa State Commerce Commission on Certification Hearings on the need for New Coal-Fired Power Plants.
- From 1983 to 1989, as Senior Staff Scientist and Senior Engineering Manager at Honeywell, he was responsible for scientific developments of a multi-divisional and international program in indoor air quality and technical direction of new business unit: Indoor Air Quality Diagnostics. Under his direction, protocols were developed to diagnose the relationships between building energy management and indoor environmental control for occupant health and safety.
- From 1989 to 1997, as William E. Jamerson Professor of Building Construction at Virginia Polytechnic Institute and State University, he was responsible for instruction and research pertaining to human responses, energy utilization, and control of indoor environments; developed protocols on "Quantification of Accuracy in Building Diagnostics"; consulted with Johnson Controls, Inc. on new control and service strategies for indoor air quality and energy management, consulted with the Architect of the Capitol, Washington, D.C., on Evaluation of Indoor Air Quality and energy management in the Capitol Complex; testified in court cases on building performance problems; and chaired and co-edited the proceedings for the International Healthy Building Conference in 1997.
- Since retiring from Virginia Tech in 1997, he has served as an HVAC Excellence Review Team member for the U.S. General Services Administration (GSA) - in 2006 was appointed to the GSA National Register of Peer Professionals - where he has reviewed more than 50 designs for new and renovation projects; has served as a member of teams assembled by the National Institute of Building Sciences (NIBS) to conduct physical security assessments of medical centers for the Department of Veterans' Affairs (DVA), to conduct post-occupancy evaluations for GSA and DVA facilities, and to study for the Department of Homeland Security (DHS) means to assure increased blast resistance and chemical/biological and other security measures in "High Performance Buildings"; and has served as a merit reviewer for the DOE FOA 115: "Recovery Act: Advanced Energy Efficient Building Technologies," and for the "DOE Energy Efficient Building Systems Design Hub."
- Since 2010, he has served on a committee of NIBS to explore means for improving environmental design for people with low vision and is currently serving as Chair of the NIBS Committee on Low Vision Design. A major issue to be resolved is the potential conflict between mandates for reduced building energy consumption and the health, safety and security of occupants in the visual environment, including those with visual impairments.

Dr. Woods received his M.S. in Physiological Sciences (1971) and his Ph.D. in Mechanical Engineering (1974) from Kansas State University, and his B.S. in Mechanical Engineering (1962) from the University of New Mexico. He has maintained his professional registration as a Mechanical Engineer in Iowa since 1979.

16 March 2013

# CURRICULUM VITAE

Name: James E. Woods, Jr.

Home Address: 250 Pantops Mountain Road
Suite 5221
Charlottesville, VA 22911-8702
Phone: (434) 972-2575
Fax: (434) 972-2576
Mobile Phone: (703) 593-5009
e-mail: jewoods3@aol.com

Born: 25 August 1939, Albuquerque, New Mexico

Education: B.S., University of New Mexico, 1962 (Mechanical Engineering)

M.S., Kansas State University, 1971 (Physiological Sciences)

Ph.D., Kansas State University, 1974 (Mechanical Engineering)

Registration: Professional Engineer, Mechanical, Iowa 9066, 1979

Authorized Class A Energy Auditor, Iowa 101, 1979

Professional and Academic Experience: Private Consultant (January 2010 to present). Responsible for providing consultation on indoor environmental quality and building performance issues.

Executive Director, The Building Diagnostics Research Institute, Inc. (July 2002 to 2009). Responsible to an independent Board of Directors for the research, training and public outreach activities offered by this not-for-profit corporation. The mission of this Institute is to leverage more than 25 years of building diagnostics experience in order to enhance health, safety, security and productivity.

Founding Director, HP-Woods Research Institute (May 1997 to July 2002). Responsible for development and overall direction of all research and professional training programs offered by this not-for-profit corporation.

William E. Jamerson Professor of Building Construction, College of Architecture and Urban Studies, Virginia Polytechnic Institute and State University (August 1989 to May 1997). Responsible for undergraduate and graduate instruction in mechanical and electrical systems and for research pertaining to human responses and control of indoor environments. Director of Indoor Environment Program (November 1991 to March 1995). Director of Center for Health, Safety, and Productivity (March 1995 to May 1997).

Senior Engineering Manager, Honeywell Building Controls Division (January 1986 to August 1989). Responsible for technical direction of new business unit: Indoor Air Quality Diagnostics.

Senior Staff Scientist, Honeywell Physical Sciences Center (November 1983 to January 1986). Responsible for scientific development of a multi-divisional and international program in indoor air quality.

Director of Center for Advancement of Building Technologies, Iowa State University, Ames, Iowa (June 1982 to November 1983).

Professor, Departments of Mechanical Engineering and Architecture, Iowa State University, Ames, Iowa (July 1980 to November 1983). Responsible for instruction in environmental control systems for architectural students, for participation in teaching related mechanical engineering courses, and for development and instruction of graduate level courses in environmental control systems and building energy utilization. Director, Building Energy Utilization Laboratory (1980 to November 1983). Full Member, Graduate Faculty, June 1977 to November 1983.

Associate Professor, Departments of Mechanical Engineering and Architecture, Iowa State University, Ames, Iowa (July 1977 to July 1980). Responsible for instruction in environmental control systems for architectural students, for participation in teaching related mechanical engineering courses, and for development and instruction of graduate level courses in environmental control systems and building energy utilization. Associate Member, Graduate Faculty, June 1975 to June 1977.

Assistant Professor, Departments of Mechanical Engineering and Architecture, Iowa State University, Ames, Iowa (May 1974 to June 1977). Responsible for development and instruction of environmental courses in architecture and mechanical engineering.

Instructor, Department of Mechanical Engineering, Kansas State University, Manhattan, Kansas (August 1973 to May 1974). Responsible for instruction in laboratory techniques and career development.

Research Associate, Engineering Experiment Station, Kansas State University, Manhattan, Kansas (July 1973 to May 1974). Responsible for Engineering and Facilities at the Institute for Environmental Research.

Instructor, Department of Physiological Sciences, Kansas State University, Manhattan, Kansas (January 1973 to May 1974). Collaborated on interdepartmental research and assisted in environmental physiology instruction.

Faculty Research Assistant (Temporary), Engineering Experiment Station, Kansas State University, Manhattan Kansas (July 1972 to January 1973). Worked toward Ph.D. requirements and collaborated on research concerning environmental requirements for laboratory animals, under contract to NIH, Animal Resources Branch, Division of Research Resources.

NIH Bioenvironmental Engineering Fellow, Kansas State University, Manhattan Kansas (August 1968 to July 1972). Pursued graduate study in physiological sciences and mechanical engineering, and collaborated on research concerning environmental requirements for laboratory animals, under contract to NIH, Animal Resources Branch, Division of Research Resources.

Chief Engineer, Envirco, Inc., Division of Becton Dickinson and Co., Albuquerque, New Mexico (January 1967 to August 1968). Responsible for design of laminar flow cleanrooms.

Mechanical Engineer, Envirco, Inc., Albuquerque, New Mexico (November 1965 to January 1967). Responsible for repair and modifications of environmental chambers service under contract to Sandia Corporation, Albuquerque, New Mexico.

Service Sales Engineer, Johnson Service Co., Albuquerque, New Mexico (June 1962 to November 1965). Responsible for repair and modification of air conditioning control systems throughout the State Of New Mexico.

Apprentice Pipefitter, Johnson Service Co., Albuquerque, New Mexico (September 1960 to June 1962). Assisted in installing and servicing automatic control systems in buildings.

Research Experience (Principal Investigator):

National Center for Energy Management and Building Technologies (NCEMBT): Development of a Scientific Outreach Program Pilot, which put into perspective the research being conducted at NCEMBT as it related to technical and social issues. The pilot focused on the issue: are buildings performing as intended?" (March 2007 – September 2009).

U.S. General Services Administration: Development of a "Design Standard for Raised Floor Systems With and Without Underfloor Air Distribution," as a Supplement to the "PBS P100 Facility Standards for the Public Building Service." (August 2004 – February 2007). Under Contract by the National Institute of Building Sciences.

US Army Engineer Research and Development Center-Construction Engineering Research Laboratory: "Study of Current Industry Standards for Chemical, Biological, and Radiological (CBR) Control in Existing DOD Buildings." (September 2003 – June 2004).

U.S. General Services Administration: "Develop and Implement a "Continuous Accountability" Protocol for Implementation of GSA PSB P-100." (July 2002 – June 2003). Co-sponsored by the National Institute of Building Sciences and the American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc.

National Energy Management Institute: "Develop a Protocol for Evaluating the Performance of Underfloor Air Distribution (UFAD) Systems." (July 2002 – December 2004).

A-K Steel Corporation: "Evaluation of AgION™ Bioretardant Effectiveness on Steel." (November 2000 - March 2001).

Montgomery County (MD) Public Schools, U.S. Department of Education, U.S. Environmental Protection Agency (USEPA), U.S. Department of Energy, Lennox Industries, Inc.,, Air Conditioning and Refrigeration Technical Institute, National Institute of Building Sciences, National Energy Management Institute, North American Insulation Manufacturers Association, National Institute of Science and Technologies, and others: "Health, Energy and Productivity in Elementary Schools: A Pilot Study." (January 2000 - July 2002).

Helsinki University of Technology: "Indoor Air Quality, Climate and Technology in the U.S: an Overview of Business and Legal Issues." (October 1998 - March 1999).

American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE):

"RP-700. Development of Research Protocols for Evaluating the Relationship Between the Indoor Environment and Productivity" (September 1994 - June 1996).

"RP-207. Relationships Between Measures of Thermal Environment and Measures of Worker Productivity" (1978 to 1981).

"RP-202. Ventilation Requirements in Hospital Operating Rooms, Phase I" (1977 to 1983).

Indoor Environment Program (IEP) and Center for Building Health, Safety, and Productivity (CBHSP) Industry-University Affiliates Program. "Quantification of Accuracy in Building Diagnostics" (August 1993 - May 1997).

North American Insulation Manufacturer's Association (NAIMA). "The Question of Fiber Glass Emissions from Fiber Glass Duct Board and Duct Liner: A Review of the Literature." (August 1993 - September 1996).

Virginia Beach City Public School. "Achieving, Maintaining and Assuring Healthy Schools." (December 1992 - May 1994).

United Technologies Research Center. "The Effectiveness of Human Sensory Response and Perception Components of IAQ Questionnaires in Evaluating the Indoor Environment." (June - December 1992).

Intercept Chemical Co., Interface Research Co., and Porter Paint. "Evaluation of the Efficacy of Intercept as an Antimicrobial Agent in Porter Paint Applied in HVAC-systems." (May 1991 - January 1992).

Union Carbide Chemical & Plastics Corp. "Development of Gas and Vapor Removal Technology." (May 1990 - May 1994).

Philip Morris USA. "Development of Ventilation Control Strategies." (April 1991 - December 1994).

American Hospital Association. "Hospital Ventilation Requirements":

Phase 1: "Purposes of Ventilation and Impact of Ventilation Controls in Health Care Facilities" (January 1983 - April 1985).

Phase 2: "Protocol Validation" (August 1986 - July 1989).

Douglas Aircraft Company. "Development of Advanced Control Strategies for Passenger Cabin Environments." (September 1984 - January 1986).

State of Minnesota, Department of Energy and Economic Development. "Development of Optimal Environmental Control in a Residence Retrofit for Energy Efficiency" (May 1984 - January 1986).

Southern California Gas Company. "Characterization of Nitrogen Dioxide in Residences." (January 1984 - November 1984).

Iowa State University Energy Research House. Research Director (January 1982 to November 1983):

"Interactive Effects of Window Management Systems on residential Energy Requirements". Collaborated with John Knowland.

"Development of a Multi-point Sampling Technique for Air Exchange Rate Measurement in Buildings". Collaborated with Eduardo A. B. Maldonado.

"Experimental Comparison of Two Alternative Ventilation Systems for Energy Efficient Indoor Air Quality Control". Collaborated with Jean-Claude Golinval.

"Optimal Control of Residential Heating Systems". Collaborated with Roy R. Crawford.

Iowa Energy Policy:

"Indoor Air Quality Assessment of Weatherized Buildings" (1981 - 1982).

"Computer Modeling for Building Load Characterization" (1981 - 1982).

"Petroleum Conservation Measures Assessment" (1979).

"Implement a Class A Energy Audit Program" (1978 - 1981).

"Development of an Energy Management Program for Buildings Owned or Operated by the State of Iowa" (1977 - 1982).

"Ventilation Requirements and Energy Conservation in Buildings Owned or Operated by the State of Iowa" (1977 - 1980).

Iowa State Research Foundation. Co-principal Investigator: "Construction and Evaluation of an Energy Research House" (1976 - 1981).

Mary Greeley Memorial Hospital Grant. "Bioenvironmental Internship Program" (1976 - November 1983).

Iowa State University Engineering Research Institute. "Solar Energy Utilization in Buildings" (1975 - November 1983).

Consulting
and Advisory

Experience: The National Institute of Building Sciences, Washington, DC. Member of Ad Hoc Committee of the NIBS dealing with the improvements in building design to accommodate persons with Low Vision. (December 2010 – present).

U.S. Department of Energy, Washington, DC. Participant in review teams to evaluate proposals submitted by universities, government laboratories, and corporations regarding research related to energy efficiency in buildings (November 2009 – November 2010).

U.S. General Services Administration, Washington, DC. Participant of GSA's HVAC Quality Assurance Review Panels for projects being designed (November 2003 - present). Member of the GSA National Register of Peer Professionals (November 2006 – present).

The National Institute of Building Sciences, Washington, DC. Member of Ad Hoc Subcommittee of the NIBS High Performance Building Council dealing with the development of requirements for providing for higher performance of building operations after a disaster or catastrophic event than is presently provided by code. (September 2008 – present).

The National Institute of Building Sciences, Washington, DC. Participated on team that provided post-occupancy building performance evaluations of U.S. Federal Courthouses, U.S. Land Ports of Entry, and U.S. Federal Buildings for the U.S. GSA. (July 2007 – December 2008).

Setty and Associates, Ltd., Fairfax, VA. Consulted on HVAC and building performance design issues. (June 2007 – present).

The National Center for Energy Management and Building Technologies, Alexandria, VA. Technical Advisor and Consultant. (June 2007 – December 2009).

Green Building Initiative, Portland, Oregon. Chair of Green Globes Assessor Personnel Committee (February 2007 – June 2008).

The National Institute of Building Sciences, Washington, DC. Participated on team that provided physical security assessments for Department of Veteran Affairs Medical Centers. (July 2005 – June 2006).

McCormick & Priore, P.C., Philadelphia, PA. Marlene Goodman v. Archstone-Smith. Consulted with regard to impact of HVAC system on moisture migration through windows in a building at the University of Pennsylvania. (May 2005 – June 2006).

Joseph R. Loring & Associates, Washington, DC. Consulted on condensation potential in Entrance Pavilion of Old DC Courthouse. (January – April 2005).

Louisiana State University Health Care Facility, Shreveport, Louisiana. Consulted with regard to impact of ductwork construction and HVAC system performance on sepsis control in health care facilities (November 2003 – March 2004).

Shook, Hardy and Bacon, LLP. Archstone-Smith Properties, Florida. Consulted with regard to impact of HVAC systems on moisture migration and mold growth in several high-rise condominiums (October 2003 – June 2004).

Smith and Cushion, PLC. Charles W. Hand Investment Properties, LLC, and AEI Architects and Engineers in Arbitration re: Baymont Inn and Suites, Cookeville, Tennessee. Consulted with regard to impact of HVAC system on moisture migration and mold growth in the building (May- October 2003)

Peterson, Bernard, Vandenberg, Zei, Geisler & Martin. Shirlee Daily v. G.L. Homes et al (Bailey Engineering Corp.) In the Circuit Court of the 15th Judicial Circuit in and for Palm Beach County, Florida. Case No. CA-02-004050 AF. Consulted with regard to mold growth in Shrilee Daily's home and health consequences (May 2002 to October 2005).

Gallagher and Kennedy, P.A. Cause No. 2000-CI-07843; Samoth USA, Inc., et al. vs. Promus Hotel Corporation, et al. Consulted on potential causes of HVAC malfunctions associated with floods at Four-Points Sheraton Hotel, San Antonio, Texas (April 1999 to May 2002).

Donohue Brown Mathewson & Smyth. Attorneys at Law. Consulted on potential causes of occupant complaints at East High School, St. Charles, Illinois (March – October 2001).

Sachnoff and Weaver, Ltd. Glenna Shubert, et al. vs J. C. Penney, et al., In the District Court, 71st Judicial District Harrison County, Texas. Case Number 95-0986. Consulted on potential caused of occupant complaints at J. C. Penney's corporate headquarters located at 6501 Legacy Drive, Plano, Texas (February 2001 to December 2001).

U.S. Department of State, Office of Foreign Buildings Operations. Prepared and conducted training for HVAC design engineers on "Whole Building Issues Affecting HVAC." (May 2000 – December 2002).

Unger, Swartwood, Indest & Acree, P.A. Consulted on potential causes of occupant complaints in Veteran Administration Outpatient Clinic, Daytona Beach, Florida (July 1999 to 2001).

Schneider, Kleinick, Weitz, Damashek & Shoot. Lacewell vs. Turner Construction, et al. Case Index #6436/89, Supreme Court of the State of New York, County of Nassau. Consulted on potential causes of employee illnesses in operating suites (May 1999 - October 2000).

Koonz, McKenney, Johnson, DePaolis and Lightfoot. Marla Brin v. S.E.W. Investors, et al. In District of Columbia Superior Court, C.A. No. 98-1615. Consulted on potential causes of occupant complaints in U.S. Environmental Protection Agency Headquarters Building (i.e., Waterside Mall (May 1999 to May 2008).

Berkebile, Nelson, Immenschuh, McDowell, Architects, Kansas City, MO. Consulted on causes of moisture incursion and mold impaction in hotel Guest Rooms and methods of remediation (December 1998 – June 2002).

Aerosol Monitoring & Analysis, Inc., and National Oceanic & Atmospheric Administration. Silver Spring, MD. Consulted on potential water incursion pathways in a high rise building, and its impact on mold growth and occupant complaints (July 1998 - August 1999).

Peterson, Bernard, Vandenberg, Zei, Geisler & Martin. Madelyn Warcholik, et al, vs M.A. Mortenson, et al. In the Circuit Court of the Thirteenth Judicial Circuit in and for Hillsborough County, Florida. Case No.: 01-93-6015H; consolidated with Case No.: 94-8277-F, 94-8276-I, and 94-5137-B. Consulted on potential causes of occupant complaints in the Bloomingdale High School, Tampa, Hillsborough County, Florida (February 1998 - October 1999).

Mitchell, McNutt, Threadgill, Smith and Sams. Arbitration between Engineering Resource Group, Inc. (and its insurance compant. DPIC Claim No. 15-E59537?ERG/Itawambe) and Itawamba Community College, Fullerton, MS. Consulted on the extent to which the design, construction, and operations of the HVAC systems may have contributed to water incursion in a dormitory (October 1997 - March 1998).

Bio-tec, Inc., and Capital One Services, Inc. Richmond VA. Consulted on potential water incursion pathways in a high rise building, and its impact on mold growth and occupant complaints (September - December 1997).

Gallagher and Kennedy. James J. Lange et al vs. Southwest Water Conditioning, Inc., dba Culligan-Phoenix, et al; in the Superior Court of the State of Arizona in and for the County of Maricopa; Cause No. CV95-02786. Consulted on potential afects the design, construction, and operations of the residence and its systems may have had on the complaints of the residents (October 1997 -December 1998).

Meagher and Geer. American National Red Cross vs TAC Engineering Co., Inc., and Palanisami & Associates, Inc., dba Palanisami & Associates. In Fourth Judicial Court, County of Hennepin, State of Minnesota, Civil File No. 96-18092. Consulted on potential causes of microbiological growth on surfaces in the building and whether design, construction and operations of the building was likely to have affected the occupants (February 1997 - August 2001).

Schneider, Kleinick, Weitz, Damashek & Shoot. Weisfogel et al v. Collard et al. Index No. 17605/94, Supreme Court of the State of New York, County of Nassau. Consulted on potential causes of nosocomial infections of employees (December 1996 - November 1998).

Franklin and Hance, P.S.C., Louisville, KY. Re: Lin Quinkert v. Jewish Hospital. Case No. 96-CI-01037, Jefferson Circuit Court, Division Eleven (11). Consulted on potential causes of aspergillosis infections of patients (October 1996 - 2001).

The Travelers Indemnity Co., the Aetna Casualty and Surety Co., Walnut Creek, CA. Re: Coco Palms Resort, Kauai, HI. Consulted on hurricane damage to HVAC system and building components (February 1996 - January 1997).

Heinrich, Gordon, Hargrove, Weihe & James, Fort Lauderdale, Florida. Re: R. Paul Bauer, et al vs Barton-Malow Co. et al. Case No. 93-8734/Div. A: Class Representation, and Case No. 93-8734/Div. A: Consolidated, In the Circuit Court in and for Hillsborough County, Florida. Consulted on potential causes of occupant complaints in the Polk County Courthouse (May 1995 - December 1996).

Danaher, Tedford, Lagnese & Neal, P.C., New York, NY. Re: General consulting on indoor environmental control for client (Isolatek, International) (July 1995 - 1997).

James E. Glass Associates, Miami, Florida. Re: Martin County, Florida vs. PDR Architects, Inc., etc., et al. Case No. 95-274 CA (03), Indian River County Circuit Court. Consulted on potential causes of occupant complaints in the Courthouse and the Constitutional Office Building, Martin County, Florida (July 1995 - April 1996).

Hinshaw and Culbertson, Chicago, Illinois. Re: General consulting on indoor environmental control for client (ServiceMaster, Inc.) (October 1995 - June 1996).

Tazewell County Virginia Administration. Resolving Indoor Air Quality Problems in Tazewell County Administration Building (November 1993 - May 1994).

Calawalder, Wickersham, and Taft, Washington, D.C. Consulted on protocol for tracer gas test for migration of chemicals or odors from a swimming pool into a condominium. (August - December 1993).

Sullivan, Ward, Bone, Tyler, Fiott & Asher, Attorneys-at-law. (Southbend, MI). Re: Respondek v Air Quality, et al. Case No. 91-118188 NO, State of Michigan in the Circuit Court for the County of Wayne. Consulted on Worker exposure in isolated enclosure (June 1993 - January 1994).

Energetics Engineering, Fort Myers, Florida. Consulted on ventilation design for Northern Trust Building, Naples, FL. (December 1992 - December 1993).

Edelman and Edelman, P.C. Attorney-at-Law, Brooklyn, NY. Re: Robert D. Brown vs G.M.V. Construction Corp. et al In the Supreme Court of the State of New York, County of Westchester. Consulted on occupant and exposure due to design, construction, and operation of a high school science room. (November 1992 - July 1996).

Hinshaw and Culbertson, Chicago, Illinois. Re: Court No. 92 L 1685 (DuPage County Courthouse). Bostick vs. Jones et al. Consulted on potential causes of occupant complaints in Courthouse, DuPage County, Illinois (September 1992 - April 1996).

The United States Pharmacopeial Convention, Inc., Rockville, MD. Consulted on owner-occupied building regarding concerns about IAQ in new facility (August 1992 - December 1993).

Pauly, Curry, Sturgeon and Vanderford. Lawyers , Charleston, WV. Re: Civil Action No. 91-C-3990. Tucker et al. vs. The Kanawha County Board of Education et al. Consulted on compliance of HVAC systems installed in 1983 in Andrew Jackson Jr. H.S., Charleston, WV, with ASHRAE Standards (including ASHRAE Standard 62-1981) (May 1992 - September 1995).

London and Fant. Houston, TX. Re: Case No. 90-009348; Connie Rodgers, er vir, et al., vs. Benjamin Moore & Co. et al. Consulted on occupant exposures and system performance in Scudder Elementary School, Wimberly Texas (April 1992 - 1996).

Gordon, Feinblatt, Rothman, Hoffberger, and Hollander, Attorneys-at-Law, Baltimore, MD. Re: Case No. 90-CA 10594; Joanne Bahura, et al. vs. S.E.W. Investors, et al. Consulted on occupant exposure in Waterside Mall Complex, Washington, DC (May 91 - 1997).

Roth, Uribe, and Fincer, Attorneys-at-Law, Brownsville, TX. Re: Cheryl Sue Wallingford vs. Centennial Towers, et al. Consulted on occupant exposure due to renovations in office building in Austin, Texas (February 1992 - July 1992).

Architect of the Capitol, Washington, D.C. Consulted on Evaluation of Indoor Air Quality in the Capitol Complex (Aug 1991 - 1998).

Kapsa and Meyer, Attorneys and Counselors-at-Law, Las Vegas, NV. Re: Holoyda et al. vs. the Fieldstone Co. et al. Consulted on occupant exposures due to design, construction and operation of residence in San Diego, CA (September 1991 - December 1991).

Center for Indoor Air Research, Lithicum, MD. Member of Science Advisory Board. (May 1991 - March 1999).

Henrico County Public School Board, Henrico County, VA. Re: Case No. CL 91-1509; The School Board of the County of Henrico, Virginia vs. Highfill-Smith Associates, Inc. Consulted on occupant exposure resulting from original design of the HVAC system for Montross School (Feb 91 - 1993).

National Institute of Occupational Safety and Health, Cincinnati, OH. Peer review of project entitled "Control Technology Guidelines for HIV Treatment Facilities" (June 1991 to 1994).

Johnson Controls, Inc., Milwaukee, WI. Consulted on new control and service strategies for indoor air quality (January 1990 - 1998).

Madison Area Technical College, Madison, WI. Consulted on operations and maintenance for control of indoor air quality (December 1989 - 1992).

Sullivan, Ward, Bone, Tyler, Fiott & Asher, Attorneys-at-law, Southbend, MI. Re: Moore vs. Madison Center. Consulted on ventilation system design (October 1989- July 1990).

Simke, Chodes, Silberfeld & Anteau, Inc., Law Office, Los Angeles, CA. Re: Call et al vs. Prudential Insurance et al. Consulted on effects of design construction and operation in Airport Towers, office building. Torrence, CA (March 1990 - October 1990).

Simon, Peragine, Smith and Redfearn, Counselors at law, New Orleans, LA. Re: State of Louisiana vs. Robert E. McKee et al. Consulted on design of HVAC system for K wing of LSU Hospital, Shreveport, LA (December 1989 - September 1991).

City of Columbus Ohio. Member of Indoor Air Quality Task Committee (August 1989 - 1993).

American Lung Association, New York, New York. Member of Indoor and Outdoor Air Pollution Technical Advisory Group (October 1987 to 1993). Member of Science Advisory Board (January 1991 - 1997).

Environmental Protection Agency, Washington D.C.and Research Triangle Park, NC. Member of Science Advisory Board Committee on Indoor Air Quality (September 1986 -

1987) and Committee on Indoor Air Quality and Total Human Exposure (October 1987 - 1991). Member of Science Advisory Board (January 1991 - December 1992).

Building Research Board of the National Research Council, Washington, D.C. Member of Board (September 1986 - July 1992).

Shand, Morahan and Co., Inc., Evanston, Illinois (Professional Liability Insurance Carriers). Consulted on moisture migration problems in the Indian Country Apartments, Indianola, Iowa (February 1983 - October 1983).

National Bureau of Standards, Gaithersburg, Maryland. Consulted on Environmental Control for Archival Record Storage (January 1983 - May 1983).

Heaphy and Herbert, Attorneys at Law, Holland Michigan. RE: Lynne Hall, et al. vs. Ottawa County, et al. Consulted on Control Strategies, System Design Capacities, and Building Requirements for Ottawa Country Human Services Building, Holland Michigan (February 1982 - March 1985).

California Energy Commission. Sacramento California. Consulted on ventilation requirements in the new (1983) Energy Conservation Standards for New Nonresidential Buildings (1982 - August 1983).

Willow Creek Estates, Ames Iowa. Designed a passive and active solar energy system to retrofit heat pump and domestic hot water systems in Two Buildings of the Apartment Complex (May 1982 - October 1982).

State of Minnesota, Department of Health, St. Paul, Minnesota. Consulted on indoor formaldehyde concentrations for possible inclusion in State Building Code (1982).

Charles J. R. McClure and Associates, Inc., Consulting Engineers, St. Louis, Missouri. Consulted on ventilation requirements and HVAC design for the Science Building, Southeast Missouri State University (1981 - 1982).

American Hospital Association, Chicago, Illinois. Consulted on Ventilation, Energy Conservation and Indoor Air Quality (1981 - 1984).

State of Wisconsin. Consulted on indoor air quality, formaldehyde, and vent less kerosene heater issues (1979 - 1983).

Iowa Electric Light and Power Co., Cedar Rapids, Iowa. Consulted on alternative energy sources in Iowa (1979 - 1983).

Ekono, Oy, Consulting Engineers, Helsinki, Finland. Consulted on ventilation requirements for Baghdad Palace Conference Center, Baghdad, Iraq (1979 - 1983).

ASHRAE/DOE representative to Iowa for Emergency Building Temperature Restriction (EBTR) program (1979 - 1980).

Member of Ventilation Advisory Committee, Lawrence Berkeley Laboratory, University of California (1978 - 1983).

Chairman of ASHRAE Advisory Committee to DOE/HUD residential ventilation project (1977 - 1979).

University of Florida, College of Veterinary Medicine. Gainesville, FL. Consulted on NIH Research Project: Environmental Requirements for Laboratory Animals (1974 - 1977).

Mayo Foundation and Clinic, Rochester, Minnesota. Consulted on thermo-regulation research projects (1973 - 1977).

Expert Witness Experience (Sworn Testimony): Congressional Hearings:

U.S. Senate Subcommittee on Environmental Protection of the Committee on Environment and Public Works:

"Comments on Senate Bill 1629 - Indoor Air Quality Act of 1987". Washington, D.C., 20 November 1987.

U.S. House of Representatives Committee on Science. Space, and Technology:

On H.R. 1066, The Indoor Air Quality Act of 1991. Subcommittee on Environment. Washington, D.C. May 9, 1991. Testimony on behalf of the American Lung Association and the American Thoracic Society.

"Indoor Air Quality Research. Current Status and Future Needs". Energy Development and Application Subcommittee, and Natural Resources Agriculture Research and Environment Subcommittee. Washington, D.C., 2 August 1983.

"Energy Research in the Midwest". Energy Development and Application Subcommittee. Des Moines, Iowa, 20 January 1981.

U.S. House of Representatives Committee on Energy and Commerce:

"On Impacts of Indoor Air Pollution." subcommittee on Health and the Environment. Washington, D.C. 10 April 1991

Testimony at Trial:

Weisfogel vs. Collard, et al. In Supreme Court of the State of New York, County of Nassau, Index # 17605/94. Testified in Nassau County, New York, 13 November 1998. Testified on how the design, construction, and operations of the Flower Hill Professional Building affected the in indoor environment and the subsequent onset of discomfort complaints, symptoms, and illness reported by tenants who worked on a suite of medical offices in the building.

Martin County, Florida vs. Pate Construction Co. Inc., et al. Case No. 95-274 CA (03), Indian River County Circuit Court. Testified in Indian River County, Florida, 15 April 1996. Testified on effects of design, construction, and operation of the new Courthouse and Constitutional Office Building on the well-being of the occupants.

County of DuPage vs. Hellmuth, Obata, and Kasabaum, Inc. et al. in the Circuit Court of the 19th Judicial Circuit, Lake County, Illinois, Case No. 92L 1779. Testified in Lake County, Illinois 7-8 December 1994. Testified on effects of design and operation of the new Courthouse on the well-being of the occupants.

Joanne Bahura, et al., vs. S.E.W. Investors, et al. In the Superior Court of the District of Columbia, Civil Division Case No. 90-CA10594. Testified on owners effects on well-being of occupants during renovation in Washington, D.C. on 8, and 15-16 November 1993.

Cheryl Sue Wallingford vs. Centennial Towers, et al. In the District Court, Travis County, Texas, 345th Judicial District. Testified in Austin Texas, 16 September 1992. Testified on architects', mechanical engineers', general contractors', building owners' effects on well-being of occupant during renovation.

Call et al vs. Prudential Insurance et al. Torrence County Superior Court. Testified in El Segundo, California, 15 October 1990. Ruled to be qualified as expert to testify Re: architects', mechanical engineers', general contractors', mechanical contractors', building owners' effects on well-being of occupants during building fit-out.

Administrative Hearings:

Deposition: Samoth USA, Inc., et al. vs. Promus Hotel Corporation, et al. Cause No. 2000-CI-07843. Deposed in Dallas, Texas on 8 February 2002.

Deposition: Glenna Shubert, et al. vs J. C. Penney, et al., In the District Court, 71st Judicial District Harrison County, Texas. Case Number 95-0986. Deposed in Dallas, Texas on 14 August 2001.

Deposition: Marla Brin v. S.E.W. Investors, et al. D.C. Superior Court C.A. No. 98-7615. Deposed in Washington, D.C. on 24 January 2000.

Deposition: Madelyn Warcholik, et al, vs M.A. Mortenson, et al. In the Circuit Court of the Thirteenth Judicial Circuit in and for Hillsborough County, Florida. Case No.: 01-93-6015H; consolidated with Case No.: 94-8277-F, 94-8276-I, and 94-5137-B. Deposed in Reston, Virginia on 9 March 1999.

Testimony before Binding Arbitration Board: Wailua Associates vs. The Aetna Casualty and Surity Co., et al. in the United States District Court for the District of Hawaii, Civil No. 94-00446-ACK. Hearing held in Kauai, Hawaii on 29-30 May 1996.

Deposition: Martin County, Florida vs. Pate Construction Co. Inc., et al. in the Nineteenth Judicial Circuit Court in and for Indian River County, Florida, Case No. 95-274-CA. Deposed in Miami, Florida on 13 February 1996.

Testimony before the Department of Labor, Occupational Safety and Health Administration: Indoor Air Quality Proposed Rule 29CFR, Parts 1910, 1915, 1926 and 1928 Washington, D.C. on 23 September 1994.

Depositions: Moira C. Bostic et al. vs. Hellmuth, Obata, and Kasabaum, Inc. et al., and County of DuPage vs. Hellmuth, Obata, and Kasabaum, Inc. et al. in the Circuit Court of the 19th Judicial Circuit, Lake County, Illinois, Case Nos. 92L 1695 and 92L 1779. Deposed in Chicago, Illinois 16-17 May 1994.

Depositions: Connie Rodgers, er vir, et al., vs. Benjamin Moore & Co. et al. In the 157th Judicial District Court of Harm County, Texas, Case No. 90-009348. Deposed in Blacksburg, VA October 5-6 1992; deposed in Roanoke, VA 16 March 1993; and deposed in Blacksburg, VA 10 September 1993.

Deposition: Joanne Bahura, et al., vs. S.E.W. Investors, et al. In the Superior Court of the District of Columbia, Civil Division Case No. 90-CA10594. Deposed in Washington, D.C. on 9 June 1992 and in Baltimore, MD on 23 June 1992.

Deposition: Cheryl Sue Wallingford vs. Centennial Towers, et al. In the District Court, 345th Judicial District, Texas, Case No. 465,318. Deposed in Blacksburg, VA, 25 May 1992.

Deposition: Holoyda et al. vs. The Fieldstone Co. et al. Superior Court of the State of California, in and for the County of San Diego. Case No. 629571. Deposed in San Diego, CA, 16-18 Dec 1991.

Deposition: State of Louisiana vs. Robert E. McKee et al. First Judicial District Court, Caddo Parrish, Louisiana. Case No. 307,146. Deposed in Blacksburg, Virginia. July 19, 1991.

Deposition: Call et al vs. Prudential Insurance et al. Torrence County Superior Court. Deposed in El Segundo, California on September 5, 1990.

Deposition: Lynne Hall, et al vs. Ottawa County, et al. Michigan District Court for Ottawa County. Deposed in Grand Rapids, MI, March 1985.

Deposition: Hedstrom-Powell, Inc. vs. Bill Leach and Iowa Power and Light Co., a Corporation. Case No. 45-26122. Iowa District Court for Polk County. Deposed in Bloomington MN, 15 August 1984.

Deposition: Kero-Sun, Inc. vs Consumer Union of the United States, Inc., d/b/a Consumer Reports. Case No.B82Civ620. U.S. District Court, District of Connecticut. Deposed in New York, NY, 28 January 1983.

Court Appearance: Manufactured Housing Institute, Inc., et al vs. Department of Industry, Labor and Human Relations, State of Wisconsin. Case No. 81-CV-4933.

Circuit Court, for Dane County, Wisconsin. Testified in Madison, WI, 13-14 April 1982.

Deposition: Manufactured Housing Institute, Inc., et al vs. Department of Industry, Labor and Human Relations, State of Wisconsin. Case No. 81-CV-4933. Circuit Court, for Dane Country, Wisconsin. Deposed in Madison WI, 1 March 1982.

ASHRAE Board of Directors Hearings on Appeal by Formaldehyde Institute on ASHRAE Standard 62-1981: "Ventilation for Acceptable Indoor Air Quality". Washington, D.C., November 1981.

DOE Public Hearings on Proposed Energy Conservation Standards for New Buildings. U.S. Department of Energy, Kansas City, 16 April 1980.

On an Act to Create 101.025 of Wisconsin Statutes Relating to Suspension of Certain Requirements for Ventilation of Public Buildings and Places of Employment. Wisconsin Joint Committee for Review of Administrative Rules, Madison, Wisconsin, September 1979.

Guthrie County Certification Hearings on New Coal-Fired Power Plant. Iowa State Commerce Commission (GCU-79-1). Guthrie County, Iowa, August 1979.

Louisa County Certification Hearings on new Coal-Fired Power Plant. Iowa State Commerce Commission. Louisa County, Iowa, 1978.

Honors and Awards:

Appointed by Commissioner of Public Building Service of the U.S. General Services Administration to the National Register of Peer Professionals as – November 2006

"Industry Person of the Year Award" presented by IAQ Publications at the Indoor Environment '96 Conference, Baltimore MD, 16 April 1996.

International Academy of Indoor Air Sciences, elected as Charter Member 1992.

ASHRAE Fellow, Elected and awarded January 1992.

Administrator's Special Citation. Health Resources and Services Administration, Washington, D.C. 1983. For: "Outstanding and specific contribution which has had a substantial impact toward advancing the mission of the Agency".

ASHRAE Presidential Citation of Honor. 1982. For: "Outstanding contribution to technical achievement and Society leadership regarding in-door air quality during 1981-1982".

ASHRAE Distinguished Service Award. 1981.

ASHRAE Best Paper Award. 1981. For: "An Experimental Validation of a Rational Model for Dynamic Responses of Buildings". ASHRAE Trans., 86 (Part 2): 497-520, 1980. Paper recognized in 1997 as one of the 10 best papers in ASHRAE's Centenary Celebration.

Titulaire de la Chaire Francqui Internationale. 1981. Sponsored by the Foundation Francqui, Liege, Belgium, 1981.

Ralph G. Nevins Memorial Award. 1978. For accomplishments in thermal environmental engineering. Sponsored by ASHRAE.

Annual Research Paper Award from American Association for Laboratory Animal Science. 1975. For: "Influence of Group Size on Heat Dissipation from Dogs in a Controlled Environment". Lab Anim. Sci. 24 (1, Part I): 72-79, 1974.

Kansas State Sigma Xi Student Travel Award. 1970. For presentation of paper: "A Direct Calorimetric Analysis of Heat and Moisture Dissipated from Dogs. "ASHRAE Trans. 78 (Part II): 170-183, 1972.

Organizations and Societies:

Air-Conditioning and Refrigeration Institute:

Member, Building Environment Subcommittee of the ARI Research and Technology Committee (1992 - 1998).

Member, ARTI 21-CR IEQ Subcommittee (June 1998 - July 2003).

American Association for the Advancement of Sciences, 1980 - 1999.

American Association of Laboratory Animal Science, 1975 - 1977.

American Society of Heating, Refrigerating and Air Conditioning Engineers:

Member of Standards Guideline Committee GPC29: "*Guideline for Risk Management of Public Health and Safety in Buildings.*" Published as G29-2009. (December 2005 – January 2009).

Chairman, Technical Resource Group 7-Underfloor Air Distribution. (May 2007 – January 2009).

Presidential Representative to the Steering Committee of The Infrastructure Security Partnership, January 2002 – July 2006.

Chairman, Presidential Study Group and Ad Hoc Committee on Building Health and Safety Under Extraordinary Incidents, October 2001 - June 2003, Member June 2003 – July 2006.

Member, Nominating Committee, July 2001 - June 2003.

Member, Board of Directors, July 1997 - June 2000.

Member, Continuing Education Committee, June 1994 - 1997.

Chairman, Environmental Health Committee, July 2000 - 2002; Member, June 1988 - 1991, and June 2004 - present; Chairman of Research Subcommittee, June 1988 - 1991.

Chairman, Presidential Ad Hoc Committee on Proposed Scope of Indoor Air Quality Activities, 1986.

Member (Voting or Non-voting), Standards Project Committee 129P: Ventilation Effectiveness, 1985 - 1997.

Member, Standards Committee, 1981 - 1985, 1991 - 1994, July 2003 – June 2007.

Chairman, Presidential Ad Hoc Committee on Legionnaire's Disease, 1980 - 1981.

Chairman, Standards Project Committee 62: Ventilation Requirements for Acceptable Indoor Air Quality, 1978 - 1982.

Member, Research and Technical Committee, 1978 - 1981.

Chairman, Program Committee, 1977 - 1978. (Member 1973 - 1978, Vice-Chairman 1976 - 1977).

Member of Technical Committees:

TG1.GLE (TC 1.7) General Legal Education, 2001 - present.

TG9 (TC 9.5) Residential and Small Building Applications, 2002 - present.

TC 2.1 Physiology and Human Environment, 1972 - present (Member or Corresponding Member); Chairman, 1988 - 1991.

TC 2.3 Gaseous Air Contaminants and Gas Contaminant Removal, 1980 - present (Member or Corresponding Member).

TC 4.3 Ventilation Requirements and Infiltration, 1975 - present (Member or Corresponding Member).

TC 5.4 Industrial Air Cleaning, 1971 - 1976, (Member).

TC 9.2 Industrial Air Conditioning, 1968 - 1976 (Chairman 1972 - 1975).

American Society of Testing and Materials:

Member of Committee D-22: Sampling and Analysis of Atmospheric Conditions (October 1985 - 2002).

Member of Subcommittee D-22.05: Indoor Air Quality. Chairman of Task Group D-22.05.01: Related Factors ( 1985 - 1989).

Construction Specifications Institute (Associate Member 1993 - 1995).

George Mason University, Construction Engineering Institute, Fairfax, VA. Member of Board of Directors of CEI. (July 2007 – September 2010).

International School for Indoor Air Sciences. Member 1993 -2000; President 1995 - 1997).

International Society of Indoor Air Quality and Climate. Elected as a Founder January 1992:

Member of Nomination Committee, 1993-1994; and 1996 to 1999.

Chairman of Healthy Buildings/IAQ '97 International Conference held in September 1997 in Washington DC at the National Institute of Health Campus.

National Research Council of the National Academy of Sciences, National Academy of Engineering, and National Institute of Medicine:

Member, Committee on Benefits of DOE R&D on Energy Efficiency and Fossil Energy, Board of Energy and Environmental Systems, May 2000 - October 2001.

Member, Institute of Medicine Committee on Indoor Allergens, 1992-1993.

Member, Building Research Board, September 1986 to July 1992.

Member, Building Research Board Committee on Setting Standards for Life Cycle Costs in Federal Buildings, June 1989 to December 1990.

Chairman, Building Research Board Committee on Indoor Air Quality, 1986 to 1987. Report Published as: Policies and Procedures for control of Indoor Air Quality, National Research Council, Washington, D.C., 1987.

Member, Institute of Laboratory Animal Sciences Committee on Environmental Requirements for Laboratory Animals, 1983 - 1985.

Member, Assembly of Life Sciences Committee on Indoor Air Pollutants, 1979 - 1981.

United Nations Council on Tall Buildings, Vice Chairman of Committee on Indoor Environmental Design, 1984 - 1990.

Pi Tau Sigma, Member 1969 - present.

International Institute of Refrigeration, American Secretary of Commission E-1: Air Conditioning, 1985 - 1987.

International Solar Energy Society, Member 1979 - 1983.

Iowa Solar Energy Association, Member of Board of Directors, 1981 - 1983.

Society of the Sigma Xi, Member 1971 - 1983.

References: Professor Arthur E. Bergles, Professor Emeritus, Department of Mechanical Engineering, and former Dean, College of Engineer, Rensselaer Polytechnic Institute, Troy, New York.

Professor Emerson L. Besch, Professor Emeritus, Department of Physiological Sciences, and former Associate Dean, College of Veterinary Medicine, University of Florida, Gainesville, Florida 32610.

Dr. Robert A. Goldstein, Vice President for Research, American Juvenile Diabitis Association; formally Division Director, Allergy, Immunology and Organ Transplant, National Institute of Allergy and Infectious Diseases, Bethesda, Maryland.

Professor Brian Leaderer, Chairman, Department of Epidemiology, Yale School of Medicine, 60 College Street, P.O. Box 3333, New Haven Connecticut 06510.

Professor Frederick H. Rohles, Jr., Director Emeritus, Institute for Environmental Research, Kansas State University, Manhattan, Kansas 66502.

Vijay K. Gupta, P.E., Chief Mechanical Engineer, Office of Design and Construction Programs, U.S. General Services Administration, Washington, DC.

Earle Kennett, Vice President, National Institute of Building Sciences, Washington, DC.

Patents: U.S. Patent 4,382,437. Issued 10 May 1983. Self-contained Passive Solar Heating System. Iowa State University.

U.S. Patent 3,629,999. Issued 28 December 1971. Vortex flow contamination control device, through Becton Dickinson and Co. Also patent applications for this device in Japan, France, Great Britain, Italy, Switzerland, Norway, and Denmark. Patent assigned to ISU Research Foundation in 1978.

Invited Papers: Gupta, V.K. and Woods, J.E. 2011. Lessons Learned about the Performance of Underfloor Air Distribution Systems with Pressurized Plenums. *Cooling India*, Vol 7, No. 2, pp 48-54.

Woods, J.E. 2008. Expanding the Principles of Performance to Sustainable Buildings. *Real Estate Issues*, Vol. 33, No. 3, pp 37-46.

Gupta, V.K and Woods, J.E. 2007. The Performance of Underfloor Air Distribution Systems. AIA Website, AIA Soloso, December 2007.

Woods, J.E. 2007. Who's Accountable? Accountability Will Assure Buildings Perform. *EcoStructure Magazine,* Vol. 7, No. 3 (April), pp 28-30.

Hitchcock, P.J., Mair, M., Inglesby, T.V., Gross, J., Henderson, D.A., O'Toole, T., Ahern-Seronde, J., Bahnfleth, W.P., Brennan, T., Burroughs, H.E., Davidson, C., Delp, W., Ensor, D.S., Gomory, R., Olsiewski, P., Samet, J.M., Smith, W.M., Streifel, A.J., White, R.H., Woods, J.E. 2006. Improving Performance of HVAC Systems to Reduce Exposure to

Aerosolized Infectious Agents in Buildings; Recommendations to Reduce Risks Posed by Biological Attacks. *Biosecurity and Bioterrorism: Biodefense Strategy, Practice and Science*, Vol. 4, No. 1, pp 41-54.

Woods, J.E. 2004. "What Changes are occurring in Building Performance and Preparedness?" HPAC Engineering Journal, February 2004. (On line: www.HomelandSecurityForBuildings.com).

Woods, J.E. 2003. "Health Protective Features and Practices in Buildings: A White Paper." Prepared for Discussion at a Federal Facilities Council Workshop on Implementation of Health Protective Features and Practices to Improve Indoor Environmental Quality in Buildings, National Research Council, Washington, DC, November 2003.

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"Indoor Pollution Law Report". Monthly newsletter edited by L.G. Kirsch and the Environmental Law Group of Calawalder, Wickersham, and Taft, Washington, D.C. and published by Leader Publications, New York (April 1987 - 1994).

"Contracting Business". Monthly Magazine published by Penton Publications, Cleveland OH (1985 - 1987).

"Indoor Air". International Journal of Indoor Air Quality and Climate. Munksgaard, a/s. Copenhagen, Denmark. (August 1999 - 2003).

Non-Refereed Publications and Other Presentations:

Woods, J.E. 2012. Improving the Performance of Buildings for People with Low Vision." Invited presentation at Fairfax Host Lions Club, 20 November 2012, Fairfax, Virginia.

Woods, J.E. and Novosel, D. 2012. White Paper: *New Paradigms for an Educated and Skilled Workforce (ESW) in Buildings*. 13 pages. Presented at NEMI Focus Group on High Performance Buildings, 8-9 August 2012, Las Vegas, NV.

Woods, J.E. 2012. "The Importance of the Thermal Envelope." Presented at Seminar on the *AIA+ 2030 Challenge*, Sponsored by the American Institute of Architects, 9 May 2012, Washington, D.C.

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Woods, J.E. 2011. Oral and Written Testimony at National Institute of Building Sciences Hearing on "Commercial Building Data Needs," 18 July 2011, Washington, D.C. Final Report 7 Dec 2012 available at NIBS, Washington, DC.

Woods, J.E. 2011. "The Importance of the Thermal Envelope." Presented at Seminar on the *AIA+ 2030 Challenge*, Sponsored by the American Institute of Architects, 29 June 2011, Washington, D.C.

Woods, J.E. (Editor) 2011. *"Proceedings of the Workshop on Improving Building Design for Persons with Low Vision."* Sponsored by the U.S. General Services Administration and the National Institute of Building Sciences, 29-30 September 2010.

Woods, J.E. 2009. "Measuring Building Performance during Design and Operations." Presented at *Professional Seminar for Wiss, Janney, Elstner Associates, Inc.*, Fairfax, VA, 23 September 2009.

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Woods, J.E. 2008. "Lessons Learned from Building Performance Evaluations of two U.S. Courthouses: Wayne L. Morse (New) and Byron G. Rogers (Renovation)." Presented at the *GSA HVAC Excellence Workshop: Sustainability. Functionality, Operability and Maintainability*, Belleview, WA, 3-5 June 2008.

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Woods, J.E. 2007. "Energy Conservation, Federal Energy Policy Act and the new

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Roller, H. and Woods, J.E. "Class A Energy Auditors: Honest Effort or Token Compliance." *Proceedings of State Energy Audit Impact '79*. American Institute of Industrial Engineers, Dallas, Texas, 5-7 March 1979.

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Mehta, D.P., Woods, J.E., and Brueck, D.M. "A Rational Model for Thermodynamic Analysis of Occupied Spaces." *Proceedings of the Building Energy Management Conference*. Woods, J.E. et al (eds). Iowa State University, Ames, Iowa ISU-ERI-Ames 79058, 1978.

Gathy, B.S., Woods, J.E., and Peterson, P.W. "Enhancement of Energy Management Through Micro-processor Control." *Presented at the 23-24 October 1978 Conference at*

*Purdue University on Documentation and analysis of Improvements in Efficiency and Performance of HVAC Equipment and Systems.*

Woods, J.E. and Peterson, P.W. "Development of a Building Energy Management Program for State Buildings in Iowa." *Presented at the Winter Annual Meeting of the American Society of Mechanical Engineers*, December 1978.

Van't Land, J.A., Woods, J.E., and Peterson, P.W. "Comparative Performance of Solar Assisted heat Pump Systems in Northern Climates." *Proceedings of the Third Annual heat Pump Technology Conference.* Oklahoma State University, Stillwater, Oklahoma, April 1978.

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Woods, J.E. and Peterson, P.W. "Impact of Environmental Control on Residential Energy Use Management." *Proceedings of First International Conference on Energy Use Management.* Pergamon Press, Vol. 3, 1977, pp. 305.

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Woods, J.E. and Peterson, P.W. "Evaluation of an Energy Conserving Research House Involving Multi-modal Operation of Solar and Heat Pump Systems." *Proceedings of the 1977 Annual Meeting of American Section of International Solar Energy Society.* Vol. 1: 6.8, 1977.

Woods, J.E. "Solar Energy - Today and Tomorrow." *Presented at the Iowa Farm Electrification Council, Annual Meeting*, Des Moines, Iowa, January 1977.

Woods, J.E. "Managing Heating and Cooling in the Home." *Energy Sources: Toward Iowa 2000 Work-shop, Cedar Rapids, Iowa*, September 1976.

Woods, J.E. "Solar Energy Application for the Home." *Energy Sources '75 Workshop, Iowa State University*, Ames, Iowa, October 1975.

Woods, J.E. and Nevins, R.G. "Ventilation Requirements and energy Conservation." *Proceedings of Sixth International Congress on Climatistics.* Milan, Italy, Vol. 4: 4.11.1., 1975.

Woods, J.E., Besch, E.L., and Nevins, R.G. "Heat and Moisture Transfer in Filter-top Rodent Cages." Abstract. *Presented at the American Association for Laboratory Animal Sciences,* 25th Annual Session, October, 1974.

Woods, J.E. (Symposium Chairman). "Air Conditioning for Particulate Control in Industrial Processes". *ASHRAE Trans.* 80 (Part 1): 435, 1974.

Woods, J.E. "Design of New Buildings for Efficient Energy Use." *Presented at the Annual Meeting of Kansas Hospital Engineers and Administrators,* Kansas State University, March 1974.

Woods, J.E. "Check List for Efficient Energy Use." *Presented at the League of Kansas Municipalities Conference on Energy and the Cities, Topeka*, Kansas, February, 1974.

Kruckenberg, S.M., Besch, E.L., and Woods, J.E. "Air Exchange Rates and Ammonia in Animal Rooms." *Presented at 25th Annual Session, American Association for Laboratory Animal Science,* 1974.

Woods, J.E. "Micro-environments for Laboratory Animals." *Presented at a Symposium on the Environmental Requirements for Laboratory Animals*, University of California at San Diego, February, 1974.

Woods, J.E. and Nevins, R.G. "Experimental Evaluation of Heat and Moisture Transfer in Animal Cage Environments." Abstract. *Presented at the American Association for Laboratory Animal Science*, 24th Annual Session, October, 1973.

Besch, E.L. and Woods, J.E. "Effects of Air Exchange on Gaseous and Viable Particulate Contaminants." Abstract. *Presented at the American Association for Laboratory Animal Science,* 24th Annual Session, October, 1973.

Woods, J.E. and Rohles, F.H. "Psychrometric Data for Human Factors Research." *ASHRAE Symposium Bulletin CO-73-8*: Air Conditioning for Man's Living Environment, 1973.

Besch, E.L. and Woods, J.E. "Heat Dissipation Rhythms of Dogs in a Controlled Environment." Abstract. *Physiologist* 15 (3):85, 1972.

Woods, J.E. and Nevins, R.G. "Analysis of Animal Cage Environments." Abstract. *Presented at the American Association for Laboratory Animal Science*, 23th Annual Session, October, 1972.

Nevins, R.G. and Woods, J.E. "Air Distribution Design Principles for Laboratory Animal Spaces." Abstract. *Presented at the American Association for Laboratory Animal Science, 23th Annual Session*, October, 1972.

Woods, J.E. (Forum Moderator). "Air Conditioning for Particulate Control in Industrial Processes." Abstract. *ASHRAE Journal* 14 (9): 64, 1972.

Woods, J.E. (Symposium Chairman). "Environmental Control of Printing Plants." *ASHRAE Symposium Bulletin*, 1971.

Woods, J.E. and Besch, E.L. "Dissipation of Body Heat in Dogs in a Controlled Environment." Abstract. *Physiologist* 14 (3): 252, 1971.

Major Advisor: Doctoral Student at Virginia Polytechnic Institute and State University:

Sensharma, Nisha. Ph.D. in Environmental Design and Planning, fall 1995. Dissertation: "Developing Human Response and Exposure Criteria for Evaluating Indoor Environments" (Co-Major Advisor with Dean Patricia K. Edwards).

Doctoral Students at Iowa State University:

Crawford, Roy, R. Ph.D. in Mechanical Engineering, fall 1983. Dissertation: "Time-Optimal Control Strategies for Residential Heating Systems Using State-Space Techniques."

Maldonado, Eduardo A.B. Ph.D. in Mechanical Engineering, summer 1982. Dissertation: "A Method to Characterize Air Exchange in Residences for Evaluation of Indoor Air Quality."

Mehta, Desh Paul. Ph.D. in Mechanical Engineering, winter 1980. Dissertation: "Dynamic Thermal Responses of Buildings and Systems."

Master's Students at Virginia Polytechnic Institute and State University:

Bain (Goodwin), Anna K. M. Science in Architectural Studies with specialty in Construction Management, fall 1995 (non-thesis).

Master's Students in Mechanical Engineering at Iowa State University:

Fobelets, Alan. M.S., summer 1983. Thesis: "A Characterization of Energy Requirements and Environmental Performance in Buildings."

Ludwig, Jerry F. M.S., spring 1981. Thesis: "Evaluation of Control Strategies for Lightweight Radiant Panel Heating and Cooling Systems."

Maldonado, Eduardo A.B. M.S., winter 1979. Thesis: Application of Heat Pipes in Solar Energy Systems."

Reynolds, Gary L.M.S., fall 1979. Thesis: "A Site-Specific Simulation of Energy Utilization in Operating Rooms."

Van't Land, James A.M.S., winter 1979. Thesis: "Economic Feasibility of Solar Assisted Heat Pumps in Iowa."

Tasker, Henry A. M.S., fall 1978. Thesis: "Application of the Pitot Rake Concept to Multiple Ducts."

Opila, Raymond E.M.S., spring 1978. Thesis: "Minimum Load Requirements for Residential total Energy Systems in Northern Climates."

Stroeh, Hans H. M.S. non-thesis program in Mechanical Engineering, winter 1978. Creative component resulted in manuscript: "Development of a Hospital Energy Management Index."

Goodyear, Richard L.M.S. non-thesis program in Mechanical Engineering, summer 1975. Creative component resulted in manuscript: "Efficient Home Heating with Vapor Absorption Heat Pump."

Master's Students in Architecture at Iowa State University:

Papamichael, Konstantinos. M. Arch, spring 1983. Thesis: "Application of Configuration Factors for Evaluating the Luminous Performance of Window Systems."

Wan, Yu-Pu. M. Arch, spring 1983. Thesis: "Architectural Implications of Energy, Environment and Economic Policies in Taiwan."

Foster, James J. M. Arch, fall 1982. Thesis: "Development of Criteria for Solving Window Design Problems."

Contothanassis, Yannis P. M. Arch, winter 1981. Thesis:"Rehabilitation as an Alternative to New Construction in Iowa."

Teng, Mee H.M. Arch, spring 1981. Thesis: "Control of Indoor Air Quality by Use of Operable Windows."

Hurd, Thomas R.M. Arch, fall 1979. Thesis: "Evaluation of the Relative Importance of Building Envelopes and Internal Loads on Annual Energy Consumption."

Fullarton, Stuart R.M. Arch, fall 1978. Thesis: "Energy Characteristics of Buildings in Iowa."

Courses Taught at VPI&SU (Referenced to 1994-96 Catalog):

BC 3014. Building Systems Technology I. Five credit hours, four lectures per week. Methods are presented which enable the student to analyze the various aspects of the constructed facility. Mechanical and electrical systems are treated in detail. Technical aspects of various constructor activities are discussed.

BC 4005. Construction Practice. Five or six credit hours, two laboratories per week. The course explores business and construction practices related to the operation of the construction firm. The course examines law as it relates to construction, financial and personnel management, and cost control. Project management topics are studied through application on a building project, formal presentations and critiques are required.

BC 4014. Building Systems Technology II. Five credit hours, three lectures per week. The course exposes the many considerations inherent in the process of design analysis and construction planning of building projects. Using relevant codes, standard practices, and state of the art analytical tools, the students conduct the analysis requisite to an assigned project. Lectures by the faculty and seminars by practitioners are intended to address issues that are provoked by and during the analysis.

Arch 5035. Advanced Environmental Controls. Three credit hours, one lecture per week. Advanced studies of environmental controls, the system, and its physical environmental factors, including development in building systems, urban systems, service systems,

construction systems, materials and component systems, psycho-physical considerations, systems analysis, and computer technology.

Arch 5974. Independent Study. Variable credit course.

Arch 5994. Research and Thesis. Variable credit course.

EDP 7994. Research and Dissertation. Variable credit course.

Courses Taught at ISU (Referenced to 1983-85 Catalog):

Arch 312. Introduction to Architectural Technologies II. (Third Year Course). 3 Semester Credits. 3 Lectures per week. Concepts of control of thermal, luminous, and acoustic environments. Overview of plumbing, mechanical, and electrical systems. Concepts of energy and environmental impact.

Arch 511. (Previously listed as Arch 312A or Arch 444). Architectural Luminous Environment. (Fourth or Fifth Year Course). 3 Semester Credits. 3 Lectures per week. Prerequisite: Arch 312. Natural and artificial lighting. Visual stimuli, comfort, discomfort, perception, and active and passive systems of control. (I also included a field problem.)

Arch 512. (Previously listed as Arch 313A or Arch 446). Architectural Thermal Environment. (Fourth or Fifth Year Course). 3 Semester Credits. 3 Lectures per week. Pre-requisite: Arch 312. An integration of the concepts of thermal stimuli, comfort, discomfort, active and passive systems of control. (I also included a field problem.)

Arch 513. (Previously listed as Arch 411A or Arch 447). Architectural Acoustic Environment. Architectural Acoustic Environment. (Fifth Year Course). 3 Semester Credits. 3 Lectures per week. Pre-requisite: Arch 312. An integration of the concepts of acoustic stimuli, comfort, discomfort, active and passive systems of control. (I also included a field problem.)

Arch 517. Advanced Studies in Building Systems. (Fifth Year Course). 3 Semester Credits. 3 Lectures per week. Pre-requisites: Arch 512 or ME 440. Integration and development of technical building systems. (Each professor taught this course differently. I emphasized mechanical systems, environmental control, code compliance, fire safety, emergency egress, handicapped access, and life-cycle cost effectiveness).

Arch 541. Human Thermal Environments. Cross-listed Course with Mechanical Engineering 541.

Arch 699. Research. Thesis research.

ME 330. Thermodynamics. (Previously listed as ME 344, also ME 321) 3 Semester Credits. 3 Lectures per week. Pre-requisite: Physics and Junior Standing. (For students electing one course in engineering thermodynamics). First and second laws of thermodynamics. Properties and processes for pure substances. Selected applications including cycles for power and refrigeration. Psychrometrics.

ME 440. (Previously listed as ME 406). Principles of Heating and Air Conditioning. 4 Semester Credits. 4 Lectures per week. Pre-requisites: Physics or Arch 312. Basic principles of thermodynamics, heat transfer and refrigeration. Computation of building heat loss and heat gain. Principles of air distribution and duct design. Applications of commercial equipment.

ME 441. (Previously listed as ME 426). Refrigeration and Air Conditioning. 3 Semester Credits. 3 Lectures per week. Pre-requisites: ME Course in Heat Transfer. Fundamentals of vapor compression and absorption refrigeration systems. Cryogenic cycles used to liquify and separate gases. Applications to air conditioning, food processing, low temperature storage, and super-conducting systems.

ME 442. (Previously listed as ME 427). Heating and Air Conditioning Design. 3 Semester Credits. 2 Lectures and 3 Hours of Lab per week. Pre-requisite: ME 441. Analysis of building energy requirements. Development of active and passive methods for heating and cooling structures. Design and layout of heating, ventilation and air conditioning systems.

ME 540. (Previously listed as ME 528). Solar Energy Thermal Systems. 3 Semester Credits. 3 Lectures per week. Pre-requisite: ME Course in Heat Transfer. (Offered primarily for graduate students.) Application of heat transfer and thermodynamics to the design and analysis of solar energy collectors and systems. (I introduced this course in 1976.)

ME 541. (Previously listed as ME 529). Human Thermal Environments (Arch 541). 3 Semester Credits. 3 Lectures per week. Pre-requisites: ME 440 or 441 or Arch 512. (Offered primarily for graduate students). Investigation of physical, climatological, and physiological factors that influence human response to thermal environments. Analytical methods for evaluating thermal performance of buildings and for quantitatively expressing human response to indoor thermal environments. (I introduced this course in 1977.)

ME 640. (Previously listed as ME 647). Advanced Thermal Environmental Engineering. 3 Semester Credits. 2 Lectures and 2 Hours Lab per week. Pre-requisites: ME 441 and ME Course in Engineering Measurements. Application of non-steady thermodynamics analysis to the thermal performance of buildings. Investigation of part-load performance of systems. (I introduced this course in 1979.)

ME 699. Research. Thesis or Dissertation Research.

# HVAC DESIGN MANUAL
## FOR
# HOSPITALS AND CLINICS

American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

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# CHAPTER 3
# FACILITY DESCRIPTIONS

## 3.1 INTRODUCTION—HEALTH CARE FACILITIES

A hospital is an institution for treating and caring for four or more persons who need medical attention 24 hours a day, every day. Hospitals can be classified in three ways: (1) by length of stay, (2) by the diseases of its patients, and (3) by the type of ownership.

- Short-term hospitals are those where patients stay less than 30 days.
- Specialty hospitals, such as cancer centers, centers for women and children, or mental health centers, define themselves by the type of services provided.
- Ownership can be of three types:
  - Community owned
  - Proprietary (either nonprofit or for-profit)
  - Government owned, as by the Department of Defense or the Veterans Administration.

### 3.1.1 Acute Care Hospital

An acute care hospital provides all types of medical care and is where the length of a patient's stay is more than one day and less than thirty days. Many hospitals also have associated outpatient care on the same campus.

### 3.1.2 Mental Health Hospital

A mental health hospital is a specialty hospital that provides psychiatric care to patients for more than one day.

### 3.1.3 Primary Care Outpatient Center

A primary care center serves as the patient's first point of entry into the health care system and as the continuing focal point for all needed health care services. Primary care practices provide patients with ready access to their own personal physician or to an established backup physician when the primary physician is not available.

Primary care practices provide health promotion, disease prevention, health maintenance, counseling, patient education, and diagnosis and treatment of acute and chronic illnesses in a variety of health care settings (e.g., office, inpatient, critical care, long-term care, home care, and day care).

Primary care practices are organized to meet the needs of patients who have undifferentiated problems and where the vast majority of patient concerns and needs are met in the primary care practice itself. Primary care practices are generally located in the patient's community, thereby facilitating access to health care while maintaining a wide variety of specialty and institutional consultative and referral relationships for specific care needs. The structure of the primary care practice may include a team of physicians and non-physician health professionals.

### 3.1.4 Small Primary (Neighborhood) Outpatient Facilities

A small primary outpatient facility is typically a neighborhood clinic or doctors' office building. These facilities will have anywhere from one to as many as ten different doctors' offices. They are usually under 5,000 square feet (465 square meters) in area.

### 3.1.5 Outpatient Surgical Facilities

There are a number of surgical procedures that can be performed as outpatient surgery. Discharge

Persons w/ infectious airborne diseases seen 1st at Primary Care Center for Diagnosis.

# CHAPTER 4
# OVERVIEW OF HEALTH CARE HVAC

## 4.1 INTRODUCTION

Health care facility HVAC systems are required to meet a variety of demands and applications, at a high standard of performance, in many ways unique to the buildings they serve. In perhaps no other application is the HVAC system a more important, and integral, component of the building's *process*—or that process more vital to human safety and health. The variety and level of demands placed on the HVAC systems, the nature of loads and design conditions, requirements for dependability and system hygiene, and—not least—the necessity to interface with a variety of other complex building systems, all make the HVAC system design uniquely challenging. It is the intent of this chapter to provide an introduction to the demands and services required of health care HVAC systems, as well as a brief discussion of the more salient design considerations.

### 4.1.1 Required HVAC Services

As in other types of buildings, health care facility HVAC systems are required to establish comfortable environmental conditions through the control of temperature, air movement, relative humidity, noise, and objectionable odors. Environmental control is important, not merely in providing personal comfort, but in facilitating the healing process: simply stated, a comfortable patient heals faster. In addition, health care facility HVAC systems are called upon to support a variety of medical functions, practices, and systems critical to health and safety, including the following:

- *Infection Control.* Medical facilities are places where relatively high levels of pathogenic (disease-causing) microorganisms are generated and therefore require stringent practices and controls to safeguard the staff and patient population. The HVAC system is one of several tools and processes used in the control of infection.
- *Environmental Control for Specific Medical Functions.* Certain medical functions, treatments, or healing processes demand controlled environmental temperature and/or relative humidity conditions that exceed the requirements of mere personal comfort.
- *Hazard Control.* Many medical facilities include functions where chemicals, fumes, or aerosols are generated that pose health or safety hazards. HVAC equipment is used in such applications to remove, contain, or dilute the environmental concentration of such contaminants to safe levels.
- *Life Safety.* HVAC systems contribute to the detection and containment of fire and smoke and may be called upon to evacuate or exclude smoke from atria or exit enclosures. Engineered smoke control systems may be called for to provide complex zoned pressurization control.

Depending upon the type of medical facility, the characteristics of its patient population, and the nature of medical procedures performed, the range and criticality of services required in the above-listed categories will vary. Similarly, the complexity of the HVAC system design and the need for close coordination with the design of other major building systems will vary by facility.

### 4.1.2 Basic Classification of Health Care Facilities

Health care facilities range widely in the nature and complexity of services they provide and (generally speaking) in the relative degree of illness or

injury of the patients treated—from a neighborhood general practitioner's office to large regional or university medical centers and specialty hospitals. As a rule, environmental control requirements and the relative role of the HVAC system in life safety and infection control become more important with increasing complexity of the medical services provided and the degree of illness of the patient population. A description of the several classifications of health care facility and departmental functions is provided in Chapter 3 of this manual.

## 4.2 INFECTION AND SAFETY HAZARDS

Health care facilities include by their nature populations and processes that produce biological, chemical, and radiation hazards to human safety and health. Additional chemical or biological hazards can enter from the natural environment or be generated within building materials and equipment as a result of poor design or maintenance. Examples of potential chemical hazards include highly volatile substances and solutions used in laboratory and disinfection processes, leaking anesthesia gas, and carbon monoxide or other combustion gases entering outside air intakes. Radiation hazards can result from improperly handled nuclear medicines or poorly shielded X-ray processes. This chapter will deal largely with the control of the biological hazards represented by the microorganisms that cause nosocomial (acquired in the hospital) infections. The term "contaminant," however, will often be used to refer to the airborne hazards from any sources.

### 4.2.1 Sources of Infectious Organisms

A primary source of pathogenic microorganisms in the health care environment is the patient suffering from contagious disease. In addition, several other significant and potentially deadly sources of infection include the microbes carried on the person of every human being, contaminated outside air or water supplies, and microbe "amplification" or growth sites within the building itself. Due to these factors, the health care environment will often have relatively larger concentrations of microorganisms than are found in conventional buildings. Exposed to these are those persons—the patient population—most susceptible to acquiring life-threatening infection via several potential pathways.

- Patients with open wounds from trauma, burns, or surgery present an opportunity for microbes to bypass the body's protective outer covering, the skin.
- In some patients, the body's natural immune system is weakened by disease, injury, or medical treatment, resulting in decreased ability to fight off infection. In the most severe such "immune-compromised" patient cases (such as bone marrow transplant patients), the body's immune system may be completely dysfunctional.
- Contagious diseases not considered dangerous to the general public, such as measles and chicken pox, pose grave health risk to the fetuses of pregnant mothers who may acquire the infection through, for example, exposure to other patients in a waiting room.

The risk of infection is not limited to patients. Visitors, and more particularly health care workers, are easily exposed to contagious disease through a variety of circumstances and means.

### 4.2.2 Modes of Transmission: Direct Contact and Airborne

Disease may be transmitted through two primary means: direct contact (including ingestion) and airborne. The means of transmission is determined by the nature of the infectious organism and/or how it enters or exists within the building environment.

**Direct contact transmission** results when the pathogen enters the body through a wound, open sore, or vulnerable body location (mouth, eyes, etc.) via contact with unwashed hands, infectious body fluids, droplets from sneezes or coughs, or other infected objects or material. Examples of direct contact infection opportunities include:

- *Hand contact*, as when unwashed hands have had contact with an infection source (an ill patient, a contaminated equipment surface, etc.) and in turn transfer the organism by touching a vulnerable part of one's own or another's body.
- *Contact of a vulnerable body part with an infected body fluid*, such as might occur in an accidental splash of contaminated blood droplets from a laboratory specimen.
- *Needle stick*, whereby a health care provider accidentally sticks a contaminated syringe needle into his or herself.
- *Insect transmission*, by bite or by direct transfer of pathogens from a contaminated substance (trash, animal droppings, etc.) to human food or food preparation surfaces.
- *Contact with infected liquid droplets produced by a sneeze, cough, or talking by a person with*

*contagious disease.* Many of these droplets are of a mass and size (>5 microns) that cause them to settle out of the air quickly, limiting "infectivity" to a radius of several feet. A single sneeze can produce 100,000 aerosolized particles; coughing can produce on the order of 10,000 particles per minute.

Studies indicate that the great majority of nosocomial infections result from direct contact, the greatest single cause being the unwashed hands of health care providers.

**Airborne transmission** is usually distinguished as resulting from respiration of particles or aerosols of low mass and size (1.0-5.0 microns) that can remain indefinitely suspended in air. Infectious bacteria, fungi, and viruses normally are transmitted into the air in forms larger than the individual microbe, such as via attachment to organic or inorganic dusts and particles such as soot, skin cells, or the "droplet nuclei" that are the residual of aerosolized liquid droplets. Particles of this size are easily respirated deeply into the lungs, where in a suitably vulnerable host or in high enough concentration, they can overcome the body's immune system and cause disease. Typical means of airborne transmission include the following:

- *Sneezing, coughing, and talking by an infected person* produce many particles light enough to remain suspended in air. These activities can therefore spread infection by both the direct and airborne infection routes.
- *Resuspension into air of in-situ microbes*, settled or trapped in building dust or debris, furnishing materials (including bed coverings), equipment, and room finishes and released by disturbing activities such as bed-making, maintenance, and construction work.
- *Aerosolization of contaminated water droplets* via shower heads, spray humidifiers, or evaporative cooling equipment (including cooling towers). Aerosolization of infectious particles or droplets also can occur via surgical and autopsy procedures, particularly those involving powered cutting or abrasion tools.
- *Carriage on human skin flakes* (squames), which the average person sheds into the environment at a rate of about 1,000 squames per hour (Hambraeus 1988).
- *Amplification (reproduction) within HVAC airflow equipment*, especially areas where moisture and dirt can accumulate, such as cooling coil drain pans, wet filters, and porous duct linings exposed to direct moisture.

It is the airborne route of infection over which the HVAC system is most effective as part of the health care facility's overall infection control effort.

### 4.2.3 Exposure Classifications

Health care authorities have established exposure levels for a number of pathogens, representing the number of infectious organisms, or the number per unit volume of air, which pose significant threats of disease in healthy individuals. The CDC Action Level is one such indicator of relative infection potential or "infectivity." For example, the CDC Action Level for the Tuberculosis bacillus or the Ebola virus is 1.0 infectious unit (a single microorganism), detectable in any sampled volume of air; these particular microorganisms are considered among the most deadly. The Infectious Dose is another such indicator and varies from a single microbe to thousands, depending upon the species of microorganism.

## 4.3 INFECTION CONTROL

### 4.3.1 An Overall Approach

Health care professionals utilize a wide range of specialty equipment and engineering controls and observe rigid operational disciplines, practices, and techniques, to control infection. Infection control equipment and practices are regulated by federal and state government authorities, which also set standards for engineering controls. In addition, civilian agencies such as the Joint Commission for the Accreditation of Healthcare Organizations (JCAHO), as well as in-house infection control committees, act as safety and infection control "watch dogs."

Some common infection control approaches include the following.

- Surgical, medical treatment, and invasive diagnostic instruments, appliances, and materials undergo sterilization or high-level disinfecting processes and are protected from contamination until used by enclosure in sterile packaging.
- Hand washing and surgical scrub stations are provided to sanitize the hands of health care providers before they touch a patient.
- "Gowning" and other sterile garments, including masks, hair and foot coverings, and gloves, cover the person of surgical personnel.
- "Sterile Technique" and "Aseptic Technique" are practiced during surgical and other invasive procedures.

- Government- and industry-regulated practices control the handling, storage, and disposal of potentially infectious materials, such as used dressings and syringe needles, pathology specimens, and blood products. Regulations also define personal protective equipment requirements for health care workers.
- Room and fixed equipment surfaces in surgical and other invasive treatment or diagnostic rooms are sanitized prior to use. Other cleaning, sanitizing, laundering, disinfection, and general good housekeeping practices are observed throughout the health care facility.
- Facility floor and circulation plans are normally designed to minimize "clean" and "dirty" cross traffic and provide for separate storage of contaminated and clean materials.
- Diagnosed or suspected cases of contagious disease are isolated in disease isolation spaces specially designed to prevent the spread of infection.
- Patients with severely suppressed immune systems are housed or treated in protective isolation spaces designed to exclude airborne pathogens.
- Directional airflow control, filtration, exhaust, and dilution ventilation are applied as engineering controls to minimize exposure to airborne contaminants.
- Environmental temperature and relative humidity in surgical and other critical spaces are kept within ranges that help support bodily immune functions and/or inhibit pathogen viability.

This list is not complete but is intended to convey the fact that the HVAC system is but one element, albeit an important one, of an overall infection control program. In addition to providing "active" infection controls, such as apply in the final four infection control approaches listed above, a properly designed HVAC system can be an important contributor to overall building sanitation by helping to prevent envelope condensation and other building conditions conducive to microbe growth. Conversely, a poorly designed HVAC system can provide numerous opportunities not only within the building, but within the system itself, for the generation of pathogenic organisms.

### 4.3.2 The HVAC System's Role in Infection and Hazard Control

The HVAC system contributes to infection and hazard control through "engineering control" functions including dilution ventilation, contaminant exhaust, directional airflow control, and filtration, as well as by controlling environmental temperature and relative humidity. In many applications, all or most of these functions are performed simultaneously.

**Dilution ventilation**, combined with contaminant exhaust, is the process of lowering the concentration of airborne contaminants in a space by **exhausting contaminated air** and supplying the space with contaminant-free makeup air. Effectiveness is generally proportional to the space air change rate and the relative efficiency of the air delivery system in mixing the clean air throughout the space. According to the specific medical application and nature of the contaminants, the makeup air may consist totally of fresh (outside) air or be a combination of fresh and recirculated (properly filtered) air.

**Directional airflow** is the control of airflow into or out of a room, or unidirectionally through a defined "clean" area of a room, according to the specific functional requirement. Directional airflow has three major applications:

- Establishment of directional airflow into or out of one space from the space or spaces adjoining. The directional control of the airflow is achieved by the establishment of a relative differential pressure between the spaces. Directional airflow out of a space (positive relative pressurization) is utilized when there is a need to protect room occupants or materials from airborne contaminants outside the space. Airflow into a space (negative pressurization) is utilized when it is desired to prevent contaminants released in the space from spreading to adjoining areas. The actual achievement of a specific room pressure differential, relative to surrounding spaces, is dependent not only upon the room's relative supply-return/exhaust airflow configuration but also upon the airtightness of the room's construction. A generally accepted practice to ensure the achievement of directional airflow between spaces is the establishment of a minimum 75 cfm (35 L/s) flow differential and/or a 0.01 in. w.g. (2.5 Pa) pressure differential.
- Within rooms, directional flow, sometimes referred to as "plug" or laminar flow, may be achieved to a limited extent with special low-velocity, nonaspirating supply diffusers that project unidirectional airflow for a distance into the space. In concept, this arrangement provides a "wash" of clean air to remove or exclude contaminants from the "clean" zone of influence, to be exhausted at strategically located exhaust or return registers; in actuality, the location of the

exhaust or return opening has a minimal effect on room airflow pattern.

- Directional airflow control is also the principle utilized in laboratory fume hoods, biosafety cabinets, and other specially manufactured protective ventilation equipment. The equipment is normally designed to establish a relatively high (usually about 100 fpm [0.5 m/s]) flow velocity over the working surface, sufficient to transport and remove volatized or aerosolized contaminants from the worker's breathing zone. More detailed information for such medical specialty exhaust equipment may be obtained from publications of the National Council of Government Industrial Hygienists.

**High efficiency filtration** is used to remove the majority of microorganisms from the air supply.

- Filters rated 90%-95% efficiency (using the ASHRAE Dust Spot Test Method) may be expected to remove 99.9% of all bacteria and similarly sized particles. Such filters are required by some codes and standards to be installed in all patient treatment, examination, and bedroom spaces.
- The HEPA filter shall exhibit a minimum efficiency of 99.97% when tested at an aerosol of 0.3 micrometer diameter and is mandated by some codes for protective environments and specialty operating rooms. In addition to being very effective at bacteria and mold filtration, HEPA filters are also effective in filtering viable viruses, which, although occurring in sizes as small as 0.01 micron, are normally attached to a particle (such as a droplet) much larger in size.

Combination HEPA filter/fan recirculation air units, including portable models, are employed in some protective environment and disease isolation applications, particularly for existing buildings with limited ventilation upgrade capability. These units supplement central ventilation systems to (in effect) achieve a greater number of air changes in the space. The effectiveness of all filters can be compromised by leakage at filter gaskets and frames.

Filter rating using Minimum Efficiency Reporting Value (MERV) is discussed in Chapter 9.

**Ultraviolet germicidal irradiation** (UVGI) is being seen increasingly in microbiocidal HVAC applications. Airborne microorganisms are destroyed by exposure to direct UVGI in the wavelength range of 200-270 nanometers, given suitable exposure conditions, duration, and intensity. Air-handling unit and duct-mounted and packaged UV-fan recirculation units are available that help eliminate viable microorganisms from the air supply or prevent their growth on irradiated equipment. Upper-level room UVGI arrangements are available that continuously irradiate the upper areas of a room but avoid direct radiation of the lower, occupied levels, where the radiation could be harmful. As only part of the space is radiated, many authorities question the effectiveness of upper-level UVGI. In general, all UVGI equipment must be adequately maintained to be effective; dust can reduce lamp output, and burned-out lamps are normally not readily evident. In addition, UVGI is less effective when air relative humidity exceeds about 70%. For these and possibly other reasons, most codes and authorities will accept UVGI only as "supplemental" protection (to HEPA filtration systems) for disease and protective isolation applications. Refer to Chapter 12 for additional information.

**Space temperature and relative humidity** influence the potential for infection in several different ways.

- Several studies indicate that the survival rates of airborne microorganisms in the indoor environment are greatest in very low, or very high, ranges of relative humidity (RH), depending upon the nature (bacteria, virus, fungi) and species of the organism. Evidence seems to indicate that most microorganisms are less viable, and therefore less infectious, in a middle-range RH of 40-70%.
- Moderately humidified environments are believed to increase the settling rate of infectious aerosols; a possible reason for this is that in more humid surroundings relatively heavy aerosol droplets are less likely to dry, lose mass, and remain suspended in the air.
- Excessively dry conditions can lead to drying of the mucous coatings on special tissues in the upper and lower respiratory tracts, which have the function of capturing respirated particles before they can be breathed deeply into the lungs.
- High temperatures in an operating room, or RH levels greater than 60%, can lead to patient sweating, which in turn can increase the risk of infection from microorganisms carried on the patient's own skin.

## 4.4 CRITERIA

Among the HVAC designer's first tasks is to establish the design criteria for a project. Most state

and federal government agencies, and many local governments, establish criteria for the design of health care facilities within their jurisdictions. The jurisdiction may utilize its own criteria and codes or cite model, national, or international building codes or design standards. Some private health care institutions and corporations also establish design requirements. Frequently adopted or cited codes, standards, and design guidelines relating to health care facility HVAC systems include:

- The American Institute of Architect's *Guidelines for Design and Construction of Hospital and Health Care Facilities* (AIA Guidelines).
- Standards and handbooks of the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE).
- National Fire Protection Association (NFPA) standards.
- The Joint Commission on Accreditation of Healthcare Organizations' "Environment of Care" standards.
- The American Conference of Governmental Industrial Hygienists' publication *Industrial Ventilation*.
- Centers for Disease Control and Prevention (CDC) guidelines and recommended practices.
- Model mechanical codes, including the Standard, BOCA, ICBO, and Uniform Mechanical Codes.

Typical criteria for HVAC design include indoor and outdoor environmental design conditions, outside and total air change requirements, economic considerations for equipment selection, requirements for redundancy or backup equipment capacity, solar characteristics, room pressure relationships, filtration, and other criteria needed for systems and equipment selection and sizing. Other factors and data that influence the HVAC design, such as envelope and equipment insulation, glazing characteristics, occupancy schedules, and ventilation or conditioning requirements for special equipment or processes, may be provided by specific project documentation or may require investigation by the designer.

In addition to basic design criteria, the designer is responsible for acquainting him/herself with applicable government regulations and should establish in the project's Scope of Work who has responsibility for any permits required by the jurisdiction.

Table 4-1 provides a summary of "best practice" recommendations. These specifically address room conditions, including space pressurization, minimum outdoor and total air, exhaust, recirculation, relative humidity, temperature, and supplemental guidance for many typical hospital and clinic rooms. Table 4-1 illustrates the selected "best practice" requirements from both the *1999 ASHRAE Handbook—HVAC Applications* and the 2001 AIA Guidelines. Notes from both references regarding individual rooms are summarized with Table 4-1. These criteria should be used when not superseded by criteria from the owner or local jurisdiction.

These "best practice" criteria are based upon committee experience in design application of existing criteria (Appendix F, Table F-1). Rationale for design is discussed in more detail in relevant chapters and appendices in this manual.

## 4.5 ENERGY EFFICIENCY AND OPERATING COST

Health care facilities continuously face the challenge, and pressure, of being cost-effective. The annual operating costs of HVAC systems, including both energy consumption and maintenance materials and manpower, constitute a significant portion of overall building costs. Subject to compatibility with the health care functions of the facility, including considerations of redundancy and dependability of service, operational cost should be a primary consideration in the selection of major HVAC systems and equipment.

Systems and equipment should be designed with overall energy efficiency in mind, and consideration given to the application of such potential energy-cost -saving features as heat recovery, airside economizers, electric demand shifting, hybrid cooling, solar energy, and heat pumps. To determine the relative cost-effectiveness of two or more project alternatives, the most comprehensive and straightforward economic method is a life-cycle cost analysis (LCCA). This analysis takes into consideration all cost elements associated with a capital investment during the life cycle of use of the system or equipment purchase. Additional information on economic analyses is provided in Appendix E of this manual.

## 4.6 EQUIPMENT SIZING FOR HEATING AND COOLING LOADS

### 4.6.1 Design Capacity

Design criteria for health care facilities include temperature, relative humidity, and ventilation requirements affecting equipment capacity and cooling/heating load. In some cases it may be necessary to establish and maintain a range of room conditions, with different setpoints for summer or winter operation. The HVAC design must ensure that the required

uration and sizing of HVAC plant and air-handling equipment.

Depending upon facility type, location, system characteristics, applicable criteria, and owner desires, the following services and equipment may be required to be connected to the emergency power system. Refer to Appendix G for more details.

- Ventilation: supply, return, and exhaust fans to maintain critical pressure relationships or to control hazards or contaminant levels.
- Heating and steam generation equipment: boilers, pumps, fuel supply, air-handling units, and other equipment needed to support heating of inpatient areas, freeze protection, and supply of steam to sterilization or other critical processes.
- Domestic water pumps.
- Domestic hot water generation and recirculation for patient care and dietary areas.
- Cooling generators, pumps, and air-handling and other equipment necessary to continue cooling for critical inpatient or sensitive equipment areas.
- Controls needed to support the above equipment.

In developing commissioning requirements, designers should ensure that equipment to be connected to the EP system is tested in both normal and emergency power modes of operation.

## 4.7 VENTILATION AND OUTSIDE AIR QUALITY

Health care facilities require large amounts of fresh, clean, outside air for breathing and for control of hazards and odors through dilution ventilation and exhaust makeup. Under normal circumstances, outside air contains much lower concentrations of microorganisms, dust, soot, and gaseous contaminants than indoor air. When filtered by high efficiency filtration, such as is mandated by many codes, outside air can be virtually free of microorganisms and particulates. When outside air is not at an acceptable quality level, as may occur in heavily industrialized areas, special gas adsorption filtration may be required on air intakes. In addition to a good source of outside air, adequate ventilation requires the careful location of intakes to avoid contamination, exhaust of contaminants, an adequate and controlled quantity of makeup air, and good distribution and mixing of the clean air throughout the spaces served. *ASHRAE Standard 62-2001, Ventilation for Acceptable Indoor Air Quality* should be utilized as a minimum standard for ventilation design.

### 4.7.1 Ventilation Air Quantity

Many codes and standards provide minimum outside airflow rates for individual health care facility spaces, based either on a flow rate per person or room air change rate basis. Standard 62-2001 is often cited as a minimum standard for determining outside air quantity for individual spaces and in addition provides guidance for calculating minimum outside air rates for central systems. Minimum total room airflow rates (combined outside air and recirculation) are also often mandated by codes or criteria, based upon the cumulative dilution effect of central systems serving large numbers of spaces, the air-cleaning effectiveness of high efficiency filtration, or the minimum flow required to ensure good air mixing and comfort.

### 4.7.2 Location of Outside Air Intakes

Outside air intakes must be located an adequate distance away from potential contamination sources to avoid intake of contaminants. Typical minimum separation requirements are 25 feet (7.6 meters), established by the *AIA Guidelines*, and 30 feet (9.1 meters), according to the *ASHRAE Handbook—HVAC Applications*. These distances should only be considered as preliminary guides: greater separation may be required depending upon the nature of the contaminant, the direction of prevailing winds, and the relative locations of the intake and contaminant sources. The *ASHRAE Handbook—Fundamentals* provides further design guidance and calculation methods to help predict airflow characteristics around buildings, stack/exhaust outlet performance, and suitable locations for intakes. General guidance that should be observed for all projects includes the following.

- Do not locate intakes in proximity to combustion equipment stacks, motor vehicle exhausts, building exhausts and stack vents, and cooling towers.
- Keep intakes well above ground level, to avoid contamination from such sources as wet soil or piled leaves and to avoid standing water or snowdrifts. For similar reasons, roof-mounted intakes should terminate well above the roof level (3-4 feet [0.9-1.2 meters] in many codes).
- Provide for adequate access to outside air intake plenums to enable periodic inspection and cleaning. Security considerations may dictate that access be available only via building interiors or via locked equipment room doors.

els of temperature and relative humidity are sometimes employed in patient therapy, for example:

- Conditions of 90°F (32°C) and 35% RH have been found beneficial in treating certain kinds of arthritis.
- An environment of 90°F (32°C) and 95% RH is sometimes used for burn patients.
- A temperature in the middle 80s (°F) (around 30°C) is sometimes called for in pediatric surgery.

Such high temperatures and/or relative humidities are normally not practically maintainable on a large space (or area) basis and, when called for, would be established in limited environmental enclosures or when using special equipment.

### 4.8.2 Noise Control

Noise control is of high importance in the health care environment because of the negative impact of high noise levels on patients and staff and because of the need to safeguard patient privacy. The typical health care facility is already full of loud noises from a variety of communications equipment, alarms, noisy operating hardware, and other causes without the noise contribution from poorly designed or installed HVAC equipment. High noise levels hinder patient healing largely through interference with rest and sleep. In addition, like uncomfortable thermal conditions, loud noises degrade the health care provider's working environment, increase stress, and can cause dangerous irritation and distraction during the performance of critical activities. Sources of excessive HVAC noise include:

- Direct transmission of mechanical and/or medical equipment room noise to adjacent spaces.
- Duct-borne noise generated by fans and/or high air velocities in ducts, fittings, terminal equipment, or diffusers and transmitted through ductwork to adjoining occupied spaces.
- Duct breakout noise, when loud noises in ductwork penetrate the walls of the duct and enter occupied spaces.
- Duct rumble, a form of low-frequency breakout noise caused by the acoustical response of ductwork (particularly high-aspect-ratio, poorly braced rectangular duct) to fan noise.

One standard means of quantifying room noise levels is the noise criteria (NC) method, which assigns a single-number noise level to a curve of sound pressure level values (in decibels, dB) established for each of the eight audible octave bands. The higher the NC level, the more noisy the space. One characteristic of the NC approach is that it takes into account the subjective perception of noise level by the human ear relative to the frequency of the sound, recognizing that low-frequency noises are better tolerated than high-frequency. Several codes and standards provide maximum NC levels for typical health care facility spaces.

Patient privacy can be compromised when private conversations are intelligibly transmitted between adjoining spaces. Frequent causes of this problem are inadequate acoustical insulation (isolation) properties of the construction elements separating rooms, inadequate sound-dampening provisions in ductwork, and/or inadequate background room sound pressure level. The HVAC ductwork design and diffuser/register selections can greatly influence the latter two causes, by providing a minimum level of background sound contribution from the air distribution system and by ensuring effective attenuation in ductwork. Chapter 9 of this manual provides more detailed information of the causes of, and solutions for, HVAC noise.

## 4.9 HVAC "SYSTEM HYGIENE"

Although the general topic of nosocomial infection cause and control was discussed above, the designer must be aware of the potential for infection risks that can arise through poor design or maintenance of the HVAC equipment itself. Any location where moisture and nutrient matter collect together can become a reservoir for growth of deadly microorganisms. Generally, hard surfaces (such as sheet metal) require the presence of liquid moisture to support microbe growth, whereas growth in porous materials may require only high (> 50%) relative humidity. Nutrient materials are readily available from such sources as soil, environmental dust, animal droppings, and other organic and inorganic matter. The task of the HVAC designer is to minimize the opportunity for moisture and nutrients to collect in the system, through proper design of equipment, including adequate provisions for inspection and maintenance. Potential high-risk conditions in an HVAC system include:

- Outside air intakes located too close to collected organic debris, such as wet leaves, animal nests, trash, wet soil, grass clippings, or low areas where dust and moisture collect. This is a particular concern with low-level intakes and a primary reason for code-mandated separation

# CHAPTER 6
# DESIGN CONSIDERATIONS FOR EXISTING FACILITIES

## 6.1 GENERAL CONSIDERATIONS FOR EXISTING FACILITIES

### 6.1.1 Typical Existing Conditions

After their initial construction, most hospitals go through extensive remodeling, upgrading, and additions. In many cases, the HVAC systems currently installed represented the best technology available at the time. Thus, most hospitals have a wide variety of HVAC system types, ages, and conditions of equipment—and usually physical space limitations. The following are typical conditions and issues encountered in existing health care facilities.

- Air filtration may not be up to current standards.
- Older equipment may not have the capacity to meet new cooling loads or may be at end of its life cycle.
- Controls may be older—in need of upgrade or lacking in performance.
- Ductwork may be dirty, especially return and exhaust ducts.
- Hydronic systems may exhibit deterioration of piping.
- Systems may not be appropriate for changing functions/technology, such as required to change a patient room into a laboratory space.
- There may be a lack of balancing capability, with resulting improper air or water flow.
- Systems are in dire need of retro-commissioning and may not have performed from day one.
- Central chiller plants may contain CFCs and/or need to be upgraded due to age of equipment, lack of flexibility, or capacity.
- Horizontal or vertical space for distribution may not be available to permit addition of new systems or elements.
- Systems may be energy-intensive.
- There may be a lack of sufficient clearance for adequate maintenance.
- There may be significant "deferred" maintenance.

### 6.1.2 Facilities Condition Assessment (FCA)

To understand the capabilities and limitations of an existing HVAC infrastructure, a comprehensive evaluation and master plan are needed. Such a plan is referred to as a "facilities condition assessment" (FCA). The facilities condition assessment is a process in which a facility's site utilities, architecture, and engineering infrastructure are surveyed and evaluated to identify deficiencies and the capital resources required to correct the deficiencies (Habbas and Martyak 2000). Deficiencies may cover a variety of issues such as:

- Indoor air quality
- Deferred maintenance
- End of life cycle
- Regulatory agency requirements
- Technology-driven obsolescence
- Equipment inefficiency
- Lack of capacity

The following are key elements of a facilities condition assessment:

- Identify each system and the areas and subsystems served. Assess the age, condition, and longevity of major systems and equipment.
- Identify capacities of equipment and major distribution systems. Identify spare capacity and capacity deficiencies.

sion, and permit adequate access for inspection and maintenance is of fundamental importance. It is important that no open-faced insulation be used where water accumulation is likely, such as downstream from cooling coils or humidifiers. Specifically, no lining is allowed after final filters in accordance with the AIA *Guidelines for Design and Construction of Hospital and Health Care Facilities* (AIA 2001).

Fibrous air-handling unit insulation should be isolated from the airstream using an impermeable liner, e.g., Mylar, or "sandwiched" double-wall sheet metal construction. The primary concern is that exposed fibrous insulation can collect dust and moisture to form a perfect growth environment for dangerous microorganisms, although the insulation media may be of inert material that will not of itself support microbial growth. Once contaminated, there is virtually no way of effectively cleaning or disinfecting insulation. Some manufacturers offer liner coatings, which effectively prevent fiber erosion, while still other products are available with plastic or foil coverings to exclude dirt and moisture and improve cleanability. These materials may not, however, have the long-term durability or cleanability of sheet metal. All interior air-handling unit surfaces must be accessible for inspection and cleaning; liners or interior panels should be of a light color and interior lighting should be available to enhance the effectiveness of maintenance tasks. The panels in double-wall casings should have a "thermal break" construction to prevent condensation on the outside surface in humid summer weather.

### 9.3.2 Outside Air Intakes

Designers must carefully consider the location of the outside air intake for an air-handling unit. Intakes must not be located near potential contaminant sources, such as boiler and generator stacks, laboratory exhaust vents, plumbing vents, cooling towers, ambulance waiting and vehicle parking areas, loading docks, and helipads. Many sources provide generally accepted criteria for minimum separation distances from the outside air intake to potential contaminant sources to ensure adequate separation and dilution. These spacings vary from 10 to 75 feet (3 to 23 m)—with 25 feet (7.6 m) recommended by the AIA *Guidelines* and 30 feet (9.1 m) suggested by the *ASHRAE Handbook—HVAC Applications* (ASHRAE 1999a). Designers must use judgement in the application of such rules, however; 30 feet (9.1 m) may be insufficient separation from a given contaminant source given the source's concentration and nature, the direction of prevailing winds, and building geometry. Certain airborne pathogens, such as Legionnaire's disease bacteria, are known to have been transmitted much longer distances from aerosolized sources such as cooling towers. Designers must apply professional judgement and, when in doubt, utilize analysis techniques such as those described in the *ASHRAE Handbook—Fundamentals*, Chapter 14 (ASHRAE 2001a). Individual circumstances may justify the use of modeling techniques or field simulation to select the best outside air source locations.

Outside air intakes should be located a minimum of 8 feet (2.4 m) above grade (10 feet [3 m] according to some codes and criteria) to avoid taking in grass clippings, leaves, bird feathers, or other debris (often wet) that can clog intake louvers, screens, and filters and provide a reservoir for microbial growth. When located atop buildings, intakes should be located well above roof level (a minimum of 3 feet [0.9 m] according to most codes) to avoid intake of debris from the roof. In cold regions, designers must consider locations for air intakes that will avoid the possibility of snow drifts. All intakes should be equipped with a factory-fabricated louver designed to exclude wind-driven precipitation and with a bird screen to exclude birds or small mammals. Avoid placing an intake near horizontal surfaces (such as a shelf or ledge) that can cause rain splash to penetrate horizontally through the louver or can become a dangerous microbe growth source from collected bird droppings or other organic debris.

### 9.3.3 Freeze Protection

Burst coils or automatic unit shutdown due to exposure to subfreezing temperatures are frequent occurrences in buildings and result from a number of factors: inadequate air mixing, unintended exposure of coils to 100% outside air, condensate backup in steam coils, and improperly located or installed freezestats. The time required to replace a damaged coil and clean up the flooded (and possibly treatment-chemical-contaminated) air-handler casing can put an air-handling unit out of service for a long period during the most critical environmental conditions. Water leakage in a casing from a damaged cooling coil can provide an environment suitable for microbial growth and may go undetected for an extended time. The potential impact to a health care facility under such conditions can be very serious and costly. This chapter will discuss some general freeze-prevention considerations and practices. It is

erate more noise than it attenuates. The designer needs to include suitable transition space and provide appropriate details and instructions for the contractor.

### 9.3.14 Second Filter Bank

Many of the spaces in a health care facility require a higher level of filtration than is provided by a prefilter (typically 30% dust spot efficiency) alone. The AIA *Guidelines,* for example, recommend a filtration level of 95% (MERV 14-15) for all patient care areas, whether in clinics or in full-service hospitals. Some codes require HEPA filtration for inpatient applications, especially where patients are particularly vulnerable to infection, such as protective isolation rooms for immunocompromised patients and orthopedic operating rooms. Designers must ensure (and require in contract documents) that space is allocated for replacing filters. All filters should be provided with a differential pressure indicating manometer mounted on the air-handling unit to indicate when replacement is required.

The second filter (normally the final filter installed in the air-handling unit) is (along with the cooling coil) a determining factor in establishing the overall dimensions of the air-handler. Design air velocity for health care facility air-handling unit filters should not exceed 500 fpm (2.5 m/s) for filters of 95% efficiency (MERV 15) and below. HEPA and higher efficiency filters (MERV 17 and above) should be designed with a 300 fpm (1.5 m/s) velocity limit. To ensure adequate airflow throughout the range of filter resistance from clean to dirty, designers should use the filter manufacturer's recommended final resistance when calculating fan pressure requirements. If no final resistance recommendation is available, a value of 1.4 in. w.g. (350 Pa) is recommended for 80%-95% efficiency filters (MERV 13-15). Be aware that when filters are "clean," resulting in system resistance lower than the fan selection point, the fan motor must be adequately sized to accommodate the higher brake horsepower requirements at that operating condition.

### 9.3.15 Airflow Monitors

Airflow monitoring arrays are often provided in the return and supply airstreams for VAV systems to enable differential supply-return fan flow control. In addition, they are frequently employed, in both VAV and constant volume systems, to monitor outside air flow. In order to accurately measure velocity (and therefore flow volume), monitoring arrays require a reasonably uniform entering velocity profile. Establishing that profile normally requires a certain extent of straight upstream duct, usually specified by the device manufacturer in terms of unit diameters, and a smoothly transitioning discharge arrangement. Designers should consult manufacturer's recommendations, ensure that the space requirements are taken into account in laying out the fan room, and reflect the requirements in the construction documents. Designers also need to consider the range of flow that they intend the device to measure to ascertain that it is not only sufficiently accurate over that range but can physically sense flow at lower velocities (a particular concern with pitot-type velocity sensing).

### 9.3.16 Dehumidification Equipment

Dehumidification by the primary cooling coil is often sufficient to limit relative humidity to the maximum values permitted by codes. Very stringent upper limit relative humidity requirements may dictate supplemental dehumidification using mechanical refrigeration or desiccant equipment. Some designers address this issue by providing automatic controls to reset the cooling coil discharge temperature below that required for cooling to provide dehumidification; such a strategy requires reheat of the air supply for comfort conditioning.

## 9.4 AIR-HANDLING SYSTEM ALTERNATIVES

Chapter 5 of this manual deals with the various HVAC systems and where they are (or are not) typically recommended for use. This chapter addresses only some of the major considerations involved in selecting among the most common system alternatives. Depending upon the facility department or area under consideration, single- and dual-duct systems, both constant and variable air volume (VAV), are frequently encountered in health care facilities. Multizone systems are less frequently encountered due to the larger number of ducts associated with these systems. Many, but not all, code authorities will permit VAV systems to serve spaces that do not have specific relative pressure requirements, including examination rooms and "normal" patient bedrooms, in addition to administrative and office spaces. Constant volume systems are commonly used for spaces such as disease isolation and ICU bedrooms, operating rooms, and laboratories, where discrete pressurization relative to contiguous spaces must be maintained. VAV systems should be able to perform in these applications given appropriate attention to pressure control and minimum ventilation require-

wheel diameter for single-inlet centrifugal fans and 1 wheel diameter for double-inlet fans has been recommended (Trane 1982). With a blow-through arrangement, the downstream coil can cause an adverse system effect if located too close to the fan discharge. In addition to lowering performance, a coil located too close to the discharge can result in uneven velocity distribution across the coil face, diminishing coil capacity and possibly creating droplet carryover. When the coil cannot be located a suitable distance downstream from the fan discharge, a baffle plate (typically recommended to be 50% perforated) located downstream from the fan, approximately two-thirds of the distance to the coil, will provide a more even air distribution across the coil face

- *Draw-Through Fan Reheat.* The air leaving the cooling coil in an air-handling unit is often very close to the saturation point. This may also be the case if a humidifier is provided, although controls are normally set to limit the airstream relative humidity to not more than 85%. Various system factors can cause a saturated airstream to condense on downstream equipment, fittings, filters, or ductwork, contributing to microbe growth Many designers choose a draw-through design to take advantage of the "reheat" imparted by the enthalpy input at the supply fan, thus heating the airstream a few degrees above the saturation point. Blow-through fan arrangements cannot take advantage of fan heat for this purpose, and wetting of downstream components can be a significant concern.
- *Final Filter Location.* Locating the final filter too close to the fan discharge, under either arrangement, can lead to uneven air distribution across the filter and possible damage from excessively high velocities. A greater concern, however, is potential wetting of the filter if located in the saturated airstream downstream from the cooling coil or humidifier. Wet filters easily become microbe growth sites, due to the availability of moisture and nutrients (dirt) at the same location. In addition, the capture of moisture droplets by filters can vastly increase filter pressure drop, leading to reduced system ventilation performance. One major air-handling unit manufacturer recommends against locating the final filter downstream from the cooling coil in a blow-through configuration (Trane 1996). This may create a dilemma when code or criteria provisions (such as the AIA *Guidelines*) require that final filters be located downstream of the coils. To help reduce the chance of wetting the filter, the cooling coil face velocity should be limited to 450 fpm (2.3 m/s).
- *Cooling Coil Trap Design.* The cooling coil condensate drain will be under either negative or positive pressure—depending upon which arrangement is selected—when the fan is operating. Refer to Figures 9-1 and 9-2 for design recommendations.
- *Issues Summary.* Key issues affecting the selection of a draw-through or blow-through air-handling configuration include:

  — *Draw-through advantages*: A compact unit length; more efficient fan operation when discharge is properly designed; a reduced incidence of moisture carryover from the cooling coil as a result of more uniform coil face velocities.

  — *Draw-through disadvantages*: Poor mixing of return and outside air that may cause temperature stratification and tripping of the freezestat; supply air temperature downstream of the cooling coil increases due to fan heat (a concern if not properly addressed during design).

  — *Blow-through advantages*: Heat load from high-pressure fans is absorbed by the cooling coil, permitting a higher discharge air temperature for any given space load; the fan more thoroughly mixes airstreams, reducing stratification and nuisance freezestat trips; less of the unit casing is subjected to the high-humidity environment downstream of the cooling coil.

  — *Blow-through disadvantages*: To prevent moisture carryover from the cooling coil, face velocities must be on the order of 400-450 fpm (2.0-2.3 m/s); the unit is larger; more careful design is required.

## 9.5 DUCTWORK

### 9.5.1 General Design Considerations

Duct systems for health care facilities may be designed using any of the major duct sizing approaches described in the *ASHRAE Handbook—Fundamentals* and SMACNA and other industry publications, including the equal friction, static regain, T-method, and other approaches. *Fundamentals* provides guidance as to velocity and pressure loss limitations, as well as economic considerations of the several methods. Designers should be aware that careful attention to duct system velocity limita-

tions is especially warranted in health care facility design, due to the common imposition of background noise level criteria. Due to the variety of systems required for health care service, the ductwork design must be carefully coordinated with the electrical, fire protection, plumbing and HVAC piping, and other building services, as well as with architectural and structural elements, to ensure sufficiency of space. Most designers recommend fully ducted installations, using all-metal duct construction, particularly for inpatient facilities, and the avoidance of duct liner except when absolutely necessary to attenuate ductborne noise. Other health care facility ductwork considerations are as follows.

- Various organizations, including ASHRAE and SMACNA, publish guidelines for selecting fittings and determining pressure losses. The manufacturers of distribution equipment such as diffusers, sound attenuators, fire dampers, and inlet louvers normally publish pressure loss characteristics. Designers must be cautious, however, because the published pressure losses (as well as noise output levels) often correspond to specific "idealized" inlet or connection arrangements that may not be possible in actual building situations.
- Designers should be careful to show or specify the duct pressure classes for supply, return, and exhaust ductwork to ensure adequate construction and sealing according to SMACNA standards.
- Designers must ensure that specifications or drawings include provisions for the necessary fittings to enable testing and balancing. Splitters (when allowed and permitted) and balancing dampers must be shown or detailed wherever required. Designers should provide suitable ductwork configurations to enable accurate pitot traverses in main and branch ductwork.
- Access openings should be provided where required for system maintenance and inspection. These include not only suitably framed and gasketed (as required) openings in the duct but also coordination with the architectural design to ensure that corresponding ceiling access is provided. Duct access doors should be provided at fire and smoke dampers, on both sides of duct-mounted coils, at humidifiers, and as required by the client or codes to facilitate duct cleaning.
- Whenever permitted by space conditions, utilize long radius elbows to minimize pressure losses and improve performance and cleanliness. "Square" elbows with turning vanes should be avoided, especially in exhaust and return systems, because they collect dust and debris, leading to reduced airflow performance.
- Flexible duct use should be limited due to its higher pressure losses, particularly when crimped or coiled, and its greater susceptibility to abuse or damage. Many designers limit flexible duct connections to a maximum length of 5-6 feet (1.5–1.8 m).

Flex Ducts

### 9.5.2 Fully Ducted versus Plenum Returns

Most designers prefer fully ducted return systems in health care facilities, including outpatient clinics, largely due to their inherently superior sanitary characteristics. Some codes mandate fully ducted systems for all inpatient facilities. Ducted returns protect the airstream from direct exposure to such potential plenum conditions as accumulated dust, microbes or odors generated by wet materials (from piping leaks, roof leaks, or floor leaks in multi-story facilities), rodent droppings, fibers from deteriorated flame proofing or equipment, and smoke from smoldering wiring insulation or other sources during a fire. To minimize the latter possibility, NFPA codes require that electrical cables installed in plenums utilized for air movement must be of the plenum-rated type. Above-ceiling plenums, in particular, are prone to disturbance by maintenance activities that could release opportunistic fungi or allergens into a return airstream. Ducted returns in addition minimize "cross-talk" wherein audible conversations are transmitted between rooms via open return connections, particularly when room partitions do not extend above the ceilings.

plenums

### 9.5.3 Duct Cleaning

Ductwork collects deposits of dust and can become contaminated with microbial colonization. The extent of this problem varies with the level of filtration, HVAC system maintenance, geographic location, climate, and other factors. Accumulated dust in ductwork has been implicated by some scientific studies with increased occupant health complaints, such as itchy eyes, cough, and allergic reactions (Brosseau 2000a). Numerous studies also attribute hospital nosocomial infection outbreaks to microbes growing in ductwork or air-handling equipment. In addition, excessive dust buildup in ducts can result in significantly reduced air system performance, including underventilation. In recent years large numbers of companies have emerged that specialize in ductwork cleaning, and the National Air Duct Cleaners Association has published guidelines

and specifications for this work (NADCA 2002). Cleaning processes require access into the interior of the ductwork and involve placing the duct under vacuum in combination with mechanical or power brushing, air washing, contact vacuuming, and sometimes steam cleaning. In addition, microbial biocides and encapsulants may be utilized. The effectiveness of duct cleaning in reducing the incidence of hospital nosocomial infection is in question. The process of cleaning may, particularly without careful coordination with the hospital staff and the exercise of stringent containment measures, actually increase the level of contaminants within a health care facility.

Studies have shown that dust accumulated in ductwork contains large amounts of organic materials such as human and animal hair, skin flakes, fungal spores, insect parts, and plant materials (Brosseau 2000a). These materials can provide nutrition for microbe growth and can themselves cause allergic reactions in sensitive persons. Dust buildup occurs to a much greater degree in unfiltered duct systems, such as return or exhaust ducts, and in particular upon fittings against which the airstream impacts or that cause high turbulence eddies (such as fan plenums, elbows, turning vanes, and dampers).

It is known that duct-cleaning operations can release large quantities of airborne particles, and high levels of chemical compounds, into the general hospital environment (Brosseau 2000b). Although standard procedures place the duct being cleaned under negative pressure (vacuum) during the procedure, the surrounding area can become contaminated, if the negative pressure is carelessly maintained, by not providing adequate time for disinfecting or encapsulant chemicals to dry or by work done outside of the duct to gain access for the procedure. An increase in the level of airborne particles, including opportunistic microbes such as *Aspergillus* that are a frequent component of building dust, is known to increase the risk of nosocomial infection in hospitals, particularly among the immune-compromised. Chemical applications, particularly when improperly applied or mixed, can result in occupant complaints of irritation or adverse health effects. At least one hospital investigation correlated a higher incidence of occupant health complaints during a duct-cleaning/disinfection procedure with symptoms corresponding to MSDS data for the chemicals being used (Carlson and Streifel 1996). For these reasons a number of authorities and industry associations strongly advocate that duct-cleaning projects be carefully coordinated beforehand with the facility staff, that the procedure be carried out only by properly trained and qualified personnel, and that all necessary containment and protective measures be carefully adhered to.

In order to facilitate duct cleaning, designers should provide duct access door openings in accessible locations at periodic intervals in major ductwork and at the fittings where dust is likely to most heavily accumulate (as indicated above). A survey of duct-cleaning companies also recommended that to minimize dust accumulation, designers avoid the use of interior duct linings or glass fiber ductwork.

The Centers for Disease Control (CDC) and U.S. Environmental Protection Agency (EPA) advise that there is no indication that duct cleaning results in a lower incidence of infection or other health problems (CDC 2001). It is recognized, however, that cleaning can result in improved air system performance. The general industry position for hospitals appears to be that routine duct cleaning may be justified on exhaust systems, and perhaps return systems, due to their greater potential for dust accumulation and the lesser risk of redeposition of dust into the facility, but that careful consideration be given before cleaning supply ductwork. For facilities with inpatient spaces, and particularly for those housing immune-compromised patients, duct cleaning should only be considered in cases of severe contamination, using the most carefully planned procedures, with all necessary isolation and protective measures understood and enforced by both contractor and hospital staff.

## 9.6 TERMINAL UNITS

Terminal units are control devices installed between the ductwork system and the room air distribution system. Depending upon the application, they could be constant volume, variable volume, or fan powered, with or without reheat. Terminal units are divided into two broad categories: constant volume and variable volume. A terminal unit is considered to be variable volume if the airflow to the space varies. If variable volume is selected, the designer must ensure that minimum air flow output is adequate to meet outside air and total air ventilation requirement. Airflow is constant for constant volume terminal units.

### 9.6.1 Constant Volume Terminal Unit

Constant volume terminals are connected to a constant volume fan system that serves multiple zones. Supply air is cooled to satisfy the zone with the largest cooling load. Air delivered to other zones is then reheated with heating coils (hot water, steam,

# CHAPTER 12
# ROOM DESIGN

## 12.1 GENERAL INFORMATION

This chapter describes ventilation designs for various spaces in a health care facility. These designs have been used in practice to restrict air movement between spaces, dilute and remove airborne microorganisms and odors, and maintain required temperature and humidity levels. The designs are intended to perform their functions dependably with no more than normal maintenance. See Chapter 14 for additional details.

The information in Chapter 4 provides a background for the design of ventilation for the various spaces discussed in this chapter. Information provided herein includes diffuser types, layout suggestions, typical loads, and system applications for environmental control, infection control, and process cooling. Information regarding the physical size and shape of the rooms, the processes they may hold, potential equipment, people, and lighting loads, and specific infection control needs can be found in Chapter 3, "Facility Descriptions."

## 12.2 ROLE OF VENTILATION IN INFECTION CONTROL AND COMFORT

### 12.2.1 How Does Airborne Infection Occur?

In order to determine the role of ventilation in health care infection control, the process of acquiring an infection in either an open wound or via respiration must be understood. Particles that are found in every environment are not necessarily viable particles and are not necessarily infectious particles. Infectious particles may not necessarily cause infections. Infectious particles may, if in high enough concentrations, become an infectious dose that in turn may overwhelm a host's immune defenses. This process is described by the biological force of infection relationship (Heirholzer 1993):

$$\text{Infection} \cong \text{Dose} \times \text{Site} \times \text{Virulence} \times \text{Time} / \text{Level of Host Defense}$$

This equation states that airborne infectious particles must be present in a concentration equal to or greater than the infectious dose for a long enough time in a susceptible host for a colonization to occur to the point where an infection begins. Infection then may or may not lead to disease.

### 12.2.2 What Role Can Ventilation Design Play?

Among the biological forces of infection parameters in the above relationship, ventilation can affect the infectious dose by control of the airborne infectious particle concentration and the time of exposure by lowering the mean age of air in a space. By concentrating on the control of contaminant concentration and time of exposure, real engineering can be accomplished with measurable results. In this way, rational ventilation rates, filter efficiencies, and pressure relationships can be determined (Hermans 2000).

No single generalized ventilation design solution can solve all airborne infectious particle concentration problems and be continuously cost-effective. Ventilation designers, who must always consider the cost of installation and operation of their systems, need effective control strategies for air systems to make a design work in practice. Unfortunately, ventilation control systems do not measure the concentration of infectious particles in a space. A ventilation system cannot, therefore, increase airflow rates, vary the air cleanliness, or improve air distribution in response to a burst of airborne infectious particles. Until a real-time and cost-effective monitor for

infectious particles (or a valid surrogate) is created, ventilation systems will be designed for fixed conditions of source generation of contaminants. Ventilation system design will be controlled by the traditional parameters of temperature, humidity, flow rate, and pressure. These are the tools the designer has available to address infection and comfort control.

### 12.2.3 Which Infectious Particles Should Be Controlled?

The choice of which particles to focus upon for ventilation design (or for a ventilation standard), depends entirely upon the expected clinical use of the space. Airborne candidates for control in most common patient-occupied spaces are *M. tuberculosis*, measles virus, Varicella zoster, and some fungal spores. These particles all have been shown to be transported between spaces by ventilation systems (Riley 1980; Murray et al. 1988; Streifel et al. 1989; Riley et al. 1978).

infectious diseases transported by ventilation systems!

Patients with *M. tuberculosis*, measles, or chicken pox should be in Airborne Infectious Isolation rooms. Patients who are susceptible to infection will be in a Protective Environment. These spaces will require ventilation designs that are concerned with concentration control or with protection. Of these infectious agents, M. tuberculosis is a good organism for control focus simply because there has been enough research to suggest a ventilation effectiveness. A minimum ventilation rate is suggested in the next section.

Finding a design organism for the general patient room is difficult. Although any patient room could contain an undiagnosed infectious patient, providing ventilation to every room for such a possibility would be prohibitively expensive. General patient rooms need to be cooled and heated to maintain conditions described in Table 4-1 for the comfort of the patient. Patient rooms need ventilation to make up the exhaust from the toilet room if one is attached.

### 12.2.4 Can Ventilation Design Contribute to Airborne Infection?

Ventilation systems can be a source of infectious particles and must be designed in such a way as to avoid becoming amplifying sites for organisms to grow and become aerosolized. Air systems are rarely the original source of pathogens but can quickly become a reservoir for amplification. All places where moisture and a food source can accumulate in the ducts or air-handler must be eliminated. Air systems can distribute pathogens from an internal source to a susceptible person nearly anywhere in the distribution system if there is inadequate filtration. Any place where dust and dirt can accumulate in a patient room and subsequently become wet is a result of bad design practice. Air cooling coils located within the patient room to cool air below its dew point are particularly bad, due to the moisture they create mixing with the dust they collect. Any finned element, whether cooling or heating, may become a amplifier for pathogens.

### 12.2.5 Ultraviolet Germicidal Irradiation in a Room

Properly maintained upper-room ultraviolet germicidal irradiation (UVGI) lamps can kill a significant percentage of the viable particles floating in the air of a room. The best ventilation rates for effective UVGI are in the range of 10-12 ACH for winter (with an all-air heating system) and 6 ACH for summer (or in winter with a convective heat source below the window) (Memarzadeh 2000). Well-mixed air is a critical requirement for effective killing.

### 12.2.6 Why Is Filtered Air Important in Health Care Settings?

Basically, without air filtration, particle concentrations in indoor environments tend to build up. Even inert or dead particles can cause toxic effects in some people, even normally healthy people. For patients with respiratory problems, high particle counts are detrimental.

The most compelling argument for filtration is to reduce the transmission of pathogenic substances that will travel from person to person (or from the environment to a susceptible person) and be deposited either in an open wound, as in the case of an invasive procedure, or into the respiratory system. Particles have a tendency to become deposited either in the upper respiratory tract or the lower respiratory tract, depending upon their size (Morrow 1980).

The physics of particle deposition probability in the lung has been theorized to be based upon the size of the particle, as shown in Figure 12-1. Upper respiratory tract (URT) deposition for the larger particles helps protect the more sensitive lower membranes of the lung. Notice the range of 0.2 micron to 5.0 micron where the deposition fraction in the upper tract drops off and the fraction in the lower tract (LRT) increases. This range of particles will tend to enter the lung and become deposited in the deepest areas, there to colonize and potentially infect and cause disease. Some particles that fall in this range

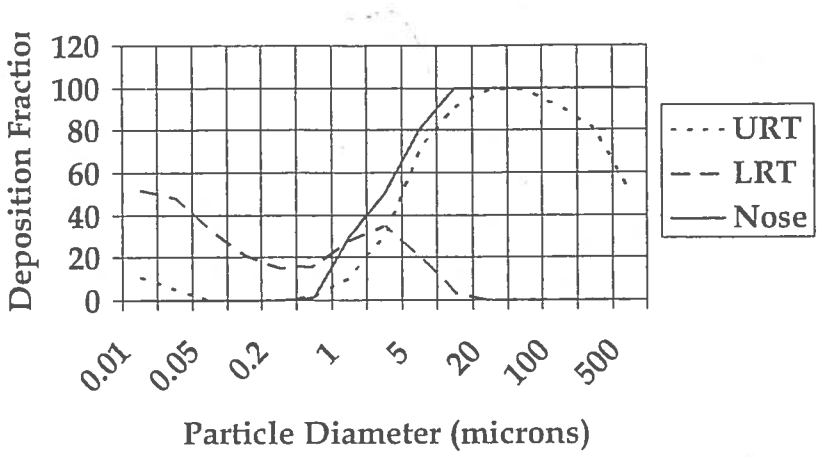


**Figure 12-1** Particle deposition in the lung.

are *Streptococcus*, anthrax, *aspergillus*, diphtheria, and tuberculosis.

These types of organisms are dangerous to healthy humans and much more so to those with suppressed immune systems. The likelihood of coming across these kinds of pathogens is greater in hospitals than in a private home or on the city street. It is, therefore, necessary for the health care ventilation designer to be aware of the risk of transmission of these organisms through ventilation systems and of the opportunity to capture them on appropriate filter media.

### 12.2.7 Application of Standard 52.2 to Health Care Ventilation Systems

The requirement for air filtration in hospitals has a long history. In the October 22, 1947, *Federal Register*, the Public Health Service published rules for construction of hospitals funded with federal funds. Commonly referred to as the "Hill Burton" rules, the requirements set minimum conditions for the environments of certain critical areas inside hospitals. The rules said in part: "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." The humidifier requirement was necessary due to the use of explosive anesthetics. The filter requirement is not as obvious. Since these systems were required to be 100% outside air, the intent wasn't to prevent recirculating internally generated airborne pathogens. The heating coils during this time may have needed filters for protection if they used closely spaced fins on tubes, but this type of coil was not common in 1947. It is more likely that the heating coil was a cast iron type not unlike the room radiators of the period (and not likely to require filters). What remains, as a logical reason for the filter requirement, is to protect the patient from airborne contaminants present in the supply air. This is the primary reason high-efficiency filters are used today in health care ventilation systems.

Health care ventilation filtration systems are required to be tested using ASHRAE Standard 52 (ASHRAE 1992, 1999b). The minimum efficiencies of required filters are listed in several guidelines and design handbooks (ASHRAE 1999a; AIA 2001).

The *Guidelines for Design and Construction of Hospitals and Health Care Facilities* provide the filtration requirements adopted in most states for health care design (AIA 2001). These requirements, converted to equivalent MERV ratings, are shown in Table 12-1.

All health care facilities, whether or not they are governed by the guidelines, should follow the above minimum requirements for filter efficiencies. Following are further thoughts on filtration.

- The deposition versus particle size graph (Figure 12-1) suggests filters should stop particles that will pass by the upper respiratory tract (URT) and deposit on the lower respiratory tract (LRT). Viruses are generally below 0.3 μm in diameter and, if they are free floating, they will very likely deposit deep into the lung. Not much can be done about this by using filtration. Kowalski et al. (1999) suggest that filter efficiencies for virus-sized particles are difficult to deter-

**Table 12-1. Filter Efficiencies for Central Ventilation and Air-Conditioning Systems in General Hospitals**

| Area Designation | No. Filter Beds | Filter Bed No. 1 (MERV) | Filter Bed No. 2 (MERV) |
|---|---|---|---|
| All areas for inpatient care, treatment, and diagnosis, and those areas providing direct service or clean supplies such as sterile and clean processing, etc. | 2 | 8 | 15 |
| Protective environment room | 2 | 8 | 17[a] |
| Laboratories | 1 | 12 | – |
| Administrative, bulk storage, soiled holding areas, food preparation areas, and laundries | 1 | 8 | – |

Notes: Additional roughing or pre-filters should be considered to reduce maintenance for filters with efficiencies higher than 75 percent. The minimum efficiency Reporting Value (MERV) is based on ASHRAE 52.2-1999.

a. HEPA

mine because of problems in modeling filter performance using the diffusion model (Kowalski et al. 1999).

- Since the effect of filtration on free viruses is not understood sufficiently to make a recommendation for filter efficiencies, it has been suggested that the best method to control virus concentrations in room air is dilution with outside air (Hermans and Streifel 1993).
- If viruses are not the particles to establish filter efficiency, then some other particle is needed.
- Bacteria fall into the size range of 0.2 μm to 2.0 μm. This particle size range is within the ability of present day filter media. This range is also the size particle most likely to be deposited deep in the lung. Notable pathogens that fit this range and are communicable are *Chlamydia Pneumonia* at 0.28 μm and *Mycobacterium tuberculosis* at 0.64 μm logmean diameter.
- The choice of filters for patient care areas is 90% by the dust spot method. However, under Standard 52.2 this filter may only have an efficiency of 84% at the 0.3 to 1.0 μm particle size range. Since the infectious dose for TB is as low as 1 bacillus (Ryan 1994), this filter would not be the best choice.
- There is a choice of filters above 90% dust spot efficiency. The MERV chart shows several filters in this range. MERV 15 is probably necessary for use in any area involving a patient where respiratory infections exist. Fungal spores are another threat to patients. Stopping such spores is relatively easy with filters of MERV 13 and higher. These could be used with any patients having normal immune systems and no open wounds.
- Laboratories can be served by filters of MERV 12 and higher.
- Pre-filters should be at least MERV 8.

### 12.2.8 Surgical Site Infections

A distinction between infection and contamination must be made. An *infection* is defined as a pathologic condition of tissue characterized by signs of inflammation (redness, swelling, pain, heat, purulent secretion) with or without general bodily reaction (fever, prostration, etc.). *Contamination* is defined as the seeding of microorganisms that may or may not develop into an actual infection, depending on such factors as susceptibility of the host, the quantitative load and virulence of the invading microorganisms, and other factors. A surgical wound infection is initiated by contamination of the wound, may develop within a few days after surgery, or may be delayed and not become evident until months, or even years, after contamination. Surgical wound infections may be superficial, involving skin and subcuticular tissue, or deep, involving deeper subcutaneous tissues, fascia, muscle, bone, joints, internal organs, or body cavities (peritonitis, pleuritis).

Sources of contamination and infection may be endogenous (originating from the patient) or exogenous (from anywhere outside the patient). Contact contamination is contamination carried into the surgical wound by touching or penetrating the raw tissue of the surgical wound with contaminated surgical instruments or foreign body implants or by contact with contaminated gloves or apparel of the surgical team. Airborne contamination is carried into the surgical wound by means of microorganisms present in the air. Contamination may reach an open surgical wound by direct or indirect pathways. Indirect contamination occurs when instruments are seeded by airborne microorganisms and then placed into the surgical wound, thereby combining airborne with contact contamination. Bioparticles are microscopic particles that carry microorganisms (bacteria, viruses, fungi, etc.). Airborne bacteria or viruses

may be carried on bioparticles—such as dust particles, lint particles, shed skin scales (scurf)—or in moisture globules or may be airborne as actual bacteria or spores, singly or in clusters.

Assumption that surgical rooms more likely to transmit airborne infections not supported.

No more than an estimated 2% of all surgical wound infections are attributable to airborne contamination (2% of the 1-3% wound infection rate in clean-clean operations, or 0.02% to 0.06% of all surgical wound infections). Clean-clean operations are defined as surgical operations in which no preexisting infection is encountered, no break in technique has occurred, or in which the gastrointestinal, billiary, gentiolurinary, or respiratory tracts have not been entered. Airborne organisms assume a more important role as a cause of wound infection when (1) an air-handling system becomes grossly contaminated due to faulty design, faulty installation, poor maintenance, misuse, or abuse; (2) a large foreign body is surgically implanted, as in complete joint replacement; (3) the patient's immune mechanism is suppressed; and (4) the quantity and/or virulence of the invading microorganisms is overwhelming.

## 12.3 HEALTH CARE ROOM DESIGN CRITERIA

### 12.3.1 Inpatient Care Units

The general medical/surgical patient room ventilation design is intended for patients with near normal immune systems that protect the patient from the normal airborne organisms found in the ambient environment. General patient rooms should have the following design parameters.

Ordinary or general patient rooms should have neutral or slightly positive pressure differential with respect to the corridor. Pressure differentials should be maintained between patient rooms and any adjacent sterile area, soiled utility, toilet, locker room, or isolation room. This requirement is intended to limit the migration of smoke, but in the health care setting it has the added benefit of limiting the transfer of airborne organisms into the room. Positive pressures to the corridor should be maintained where allowed. Exhaust all air from patient toilets at 2.0 cfm per square foot (10.2 L/s per square meter) or at code-required flow rates, whichever is larger. Introduce replacement air to the toilet room, if necessary, equal to or slightly less than exhausted air as part of a central ventilation system. Provide all necessary cooling with air from a central air-handling system. Use no wet coils in the room, such as with fan-coil arrangements. If radiant cooling panels are used, ensure that the chilled water temperature always remains above the room dew-point temperature. Provide heating by air or from flat and smooth radiant panels. Use no fin tubes or convectors. Diffusers can be of Group A and Group E, but not Groups B, C, and D (refer to Chapter 9, Section 9.8.3). Pay close attention to the air diffuser performance. Minimum required ventilation flow rates are increased by poor air diffusion. The entire room volume should be well mixed with supply air. Choose diffuser throw lengths that allow no stagnant areas. Provide air volumes to offset the heat gains in the room or as required by the local authority having jurisdiction (AHJ), whichever is greater. Assume internal heat gain from a television set.

### 12.3.2 Nursing Station

Equipment loads should assume four ordinary personal computers, two cardiac patient monitors, and possibly a pneumatic tube station. Exhaust a nourishment room as if it were a kitchen; makeup air should come from the nursing station. Provide an accurate thermometer on an adjustable thermostat for staff use.

### 12.3.3 Isolation Rooms

Isolation bedrooms may generally be classified into two types: Airborne Infectious Isolation Rooms (AII) for patients having an airborne-communicable disease and Protective Environment (PE) rooms for patients suffering from weakened immune systems and who require protection against infectious airborne agents. For the AII room, the HVAC system functions as one of the multiple levels of infection control designed to contain patient-generated infectious microbials within the room in order to prevent the spread of infection to other patients and staff. In the case of the PE room, it is the patient who must be protected against infectious microbials, including opportunistic pathogens that would normally not pose an infection risk to healthy individuals. Design requirements for each type of isolation room follow.

### 12.3.4 Airborne Infectious Isolation Rooms (AII)

AII rooms are used to house patients with suspected or known respiratory diseases such as *Mycobacterium tuberculosis*. These rooms provide a volume within which airborne particles are contained, diluted, and directed outside. AII rooms have two major ventilation design criteria: (1) negative air pressure relative to all adjoining spaces and (2) an air distribution pattern within the room that is favorable to airborne infection control.

These observations provide a roadmap for determining the types of energy efficiency improvements that should be incorporated into any health care facility. Such improvements can be easily made in a manner that will make a significant impact on energy consumption without affecting space comfort, health, or life safety requirements.

## 16.4 DESIGN OF ENERGY EFFICIENT HVAC SYSTEMS

As illustrated by the energy usage tables in the previous section, between 36% and 46% of the annual energy costs of the typical health care facility are related to the operation of the HVAC systems. This includes ventilation fan energy, outdoor air cooling and dehumidification, outdoor air heating and humidification, as well as thermal mixing and reheating required to maintain space comfort. For this reason, it is especially important to implement energy efficient strategies in the design of new (or retrofit) HVAC systems. (See Appendix H for sample control strategies.)

### 16.4.1 Variable Air Volume (VAV) System Application Opportunity

In most locations, state health codes may allow a reduction in minimum total air flow rates and minimum outdoor air flow rates during unoccupied periods (see Table 4-1). This reduction can apply to any of the spaces in a health care facility that are in unoccupied status as long as the required directional pressurization control is maintained for the space. Significant energy savings can be achieved by designing the air-handling systems serving these spaces as variable air volume systems. The AIA (American Institute of Architects) and ASHRAE allow ventilation rates to be reduced to 25% of the occupied period rates as long as continuous directional control and space pressurization are maintained at all times and the full (occupied) ventilation air change rates can be reestablished any time the space is being utilized (see further discussion below under unoccupied period control strategies).

A designer should consider the following factors when evaluating how effective a variable volume HVAC system will be in a health care facility:

A. Hours of operation of the spaces being served by the HVAC system.

B. Magnitude of the difference between the minimum ventilation air changes per hour (see Table 4-1 in Chapter 4) and the air flow required to meet space sensible cooling load requirements.

C. Requirements for continuous directional control—positive, negative, neutral, or no requirement (see Table 4-1 in Chapter 4).

For example, in spaces that are occupied 24 hours daily (i.e., emergency rooms, 24-hour laboratory or pharmacy areas, intensive care units, nurseries, etc.) and/or where the space sensible cooling air flow requirements are not significantly greater than the minimum ventilation air change rate requirements, reducing air flow will probably not reduce energy consumption greatly.

However, in spaces where

1. no continuous directional control or minimum ventilation air change rates are required, or
2. there are significant unoccupied hours, or
3. where space sensible cooling air flow requirements are significantly greater than the minimum ventilation air requirements,

then significant reductions in energy consumption can be achieved through use of variable volume control of the HVAC systems. Most spaces in health care facilities fall into these categories, including:

- Most surgery and recovery suites
- C-section suites
- Radiology, X-ray, mammogram, nuclear medicine, CAT scan, ultrasound, MRI, and PET areas
- Physical/occupational therapy areas
- Office areas
- Dietary areas
- Laundries
- Outpatient areas and surgeries
- Cardiac catherization areas
- Waiting areas
- Maintenance departments and other support areas
- Examination rooms and treatment rooms

In a typical health care facility, only about 20% of the facility is occupied more than 60-70 hours per week. Operating suites and surgical prep areas are rarely used more than 60-80 hours per week, except for a few operating suites, recovery areas, and radiology areas dedicated to emergency services. Such spaces usually only constitute about 20% of the total surgery areas in a facility. Typical schedules are illustrated in Table 16-6, using data derived from multiple field surveys.

A variable volume air-handling system should be provided with variable frequency controllers for the supply air and return/relief air fans. The design should also include a separate minimum outdoor air

# APPENDIX D
# INFECTION CONTROL ISSUES

## D.1 INTRODUCTION

Airborne transmission of disease has been a problem since mankind has lived indoors. Sunlight (UV radiation) kills most microbes that cause disease in humans. Many respiratory pathogens have adapted to our comfortable indoor environments, thereby escaping the deadly sunlight. Airborne pathogens have always been a problem. Current concerns, such as microbial resistance to antibiotics, the incidence of other nosocomial infections, and the high cost and morbidity of nosocomial infections, magnify the problem.

Robert Bazell of NBC News reported on December 27, 2000: "It's a danger of staggering proportions. Every year, one in twenty Americans—8 million people—develop an infection, with 88,000 of them dying. The biggest threat: "supergerms" resistant to antibiotics...."

Although HVAC engineers are primarily concerned with problems that are "airborne" (respiratory infections), other nosocomial infections can be ameliorated by engineering and/or architectural considerations. Kowalski and Bahnfleth produced a superb review of airborne respiratory disease, control of microbes, and mechanical systems published by *HPAC* in July 1998. The paper is reproduced at the end of this appendix.

Health care facilities are the only places where nosocomial infections can be acquired. Patients who have the worst infections wind up at a hospital. Patients who have the most drug-resistant organisms wind up at a hospital. Infected patients without regular medical care (without medical insurance) wind up in hospital emergency rooms (and waiting rooms) after they have put off seeking help as long as possible. A community's worst and most drug-resistant infections are, therefore, concentrated in a single community location—the hospital where we take our most vulnerable and susceptible loved ones. It is incumbent upon us as citizens, hospital workers, architects, and engineers to do our utmost to prevent the spread and proliferation of infection.

## D.2 CONTEXT FOR INFECTION CONTROL

Our current health care system has a few quirks that might discourage all-out infection control. Hospitals are not compensated directly for the costs of instituting infection control programs. Also, hospital *revenues* are *higher* as infections and complications increase. The incentive for hospitals to control infections is lacking in the milieu of "running hospitals like businesses." The situation is similar to the "change-order" mechanism in design-construction. Hospital stays are becoming shorter, so infections (and other complications) may not become evident until after a patient is discharged. Thus, an infection might be treated outside of the hospital and therefore not be reported in hospital infection statistics. Hospital infection statistics are difficult to obtain because many hospitals consider that data proprietary information.

## D.3 NOSOCOMIAL INFECTION COSTS AND MORBIDITY

"The total number of nosocomial and other institutional infections exceeds 4 million per year, a number substantially larger than the total number of admissions for all cancer, accidents and acute myocardial infarctions combined" (Martone et al. 1998). Table D-1, reflecting the costs of nosocomial infections, is taken from Chapter 30 in *Hospital Infections* (Martone et al. 1998).

The numbers in the table do not reflect the extra pain and suffering that patients and their families

**Table D-1. Estimated Extra Days, Extra Charges, and Deaths Attributable to Nosocomial Infections Annually in U.S. Hospitals**

| | Extra Days | | Extra Charges | | | Deaths Directly Caused by Infections | | Deaths Contributed by Infection | |
|---|---|---|---|---|---|---|---|---|---|
| | Avg. per infection[a] | Est. U.S. total[b] | Avg. per infection [1975][a] | Avg. per infection [1992][c] | Est. U.S. total [1992][b] | [%][d] | Est. U.S. total[b] | [%][d] | Est. U.S. Total[b] |
| Surgical wound infection | 7.3 | 3,726,000 | $ 838.00 | $ 3,152.00 | $1,609,000,000.00 | 0.64 | 3,251 | 1.91 | 9,726 |
| Pneumonia | 5.9 | 1,339,000 | $1,511.00 | $ 5,683.00 | $1,290,000,000.00 | 3.12 | 7,087 | 10.13 | 22,983 |
| Bacteremia | 7.4 | 762,000 | $ 935.00 | $ 3,517.00 | $ 362,000,000.00 | 4.37 | 4,496 | 8.59 | 8,844 |
| Urinary tract infection | 1.0 | 903,000 | $ 181.00 | $ 680.00 | $ 615,000,000.00 | 0.10 | 947 | 0.72 | 6,503 |
| Other site | 4.8 | 1,946,000 | $ 430.00 | $11,617.00 | $ 656,000,000.00 | 0.80 | 3,246 | 2.48 | 10,036 |
| All sites | 4.0 | 8,676,000 | $ 560.00 | $ 2,100.00 | $4,532,000,000.00 | 0.90 | 19,027 | 2.70 | 58,092 |

a. Adapted from R.W. Haley et al., *American Journal of Medicine*, 1981, 70:51.
b. Estimated by multiplying the total number of nosocomial infections estimated in the SENIC Project [*American Journal of Epidemiology* 1985, 121:159] by the average extra days, average extra charges, or percentage of infections causing or contributing to death, respectively.
c. Estimated from Haley et al., *American Journal of Medicine* 1981; 70:51, by pooling data and adjusting for inflation.
d. Unpublished analysis of data reported to the National Nosocomial Infections Surveillance System in 1980-1982, J.M. Hughes et al.

must undergo when these infections occur, nor do they reflect such things as 6-12 months of waiting, while debilitated, before an orthopedic prosthesis can be replaced.

## D.4 ISOLATION

Patients who have infectious diseases are placed in isolation *after* they have been diagnosed. Undiagnosed patients are transported through hospital corridors and to imaging labs before being diagnosed as infectious. More and more invasive procedures are being performed in imaging labs, even though those labs have not been designed for sterile procedures and have not been designed for adequate cleaning and disinfecting after serving infected patients. Hospital personnel make multiple contacts with undiagnosed patients before they are recognized as infectious. Less trained hospital workers make inappropriate contact with infected patients even while in isolation.

Hospitals are hiring more and more untrained people for patient care because of cost concerns. Hospital turnover often outpaces universal infection control training. Hand washing is by far the most important procedure in infection control. Handwashing sinks or supplies, however, are often not placed conveniently near the exits of patients' rooms. Obviously, all of these problems do not exist in all hospitals.

The growing cost and morbidity of nosocomial infections to society suggests that a concerted multidisciplinary approach to solutions is necessary. Solutions that may have significantly high first costs should not be rejected out of hand.

## D.5 ANTEROOMS

The incidence of nosocomial tuberculosis infections rose steadily until 1993. Improved ventilation techniques are responsible for significantly reversing that trend in the past several years. Ventilation strategies make a difference. Infectious patients are placed in rooms that are negatively pressurized to prevent infecting microbes from spreading. Immunosuppressed patients are placed in positively pressurized rooms to prevent them from coming into contact with infectious organisms. Immunosuppressed patients who are also infected are placed in rooms that have anterooms.

Why not place all infectious patients and immunosuppressed patients in rooms with anterooms? After all, many infected patients, particularly, tuberculosis patients, are somewhat immunosuppressed from debilitation and are highly susceptible to secondary infections. Likewise many immunosuppressed patients, particularly AIDS patients, already harbor communicable secondary infections. It makes no difference whether their room is negatively pressurized or positively pressurized. The important point is that their air is separated from everybody else's air—which anterooms can do. Undiagnosed patients should be placed, upon admission, in rooms with anterooms, so that there is less chance of spreading organisms before diagnosis. This would require more anterooms and higher first costs, but it would cut down the confusion of pressurization, cut down the number of room transfers, afford flexibility in the number of available isolation rooms, decrease the spread of organisms before diagnosis, and, probably prevent a few cases of nosocomial infection.

More infections are spread by the droplet route and by contact than by the airborne route. Anterooms

prevent infection from spreading by the airborne route—and also by the droplet and contact routes. Anterooms control access to patient rooms. Food service personnel leave patients' trays in the anterooms rather than taking them to the patients' bedsides and then going directly to another bedside. Only trained personnel are allowed into the room proper. Although more breaks in isolation technique result from personnel error than from HVAC or architectural inadequacy, anterooms and designs cognizant of infection dangers can augment and enforce compliance with isolation techniques. Anterooms allow easy access to isolation materials: sinks, masks, gowns, gloves, and soap. Anterooms that are positively pressurized to both the patient room and to the corridor—combined with patient room air supply over the patient's bed and exhaust low between the bed and the door—achieve effective isolation in all circumstances.

## D.6 INFECTION

Infections are caused by microorganisms, not by just any microorganism, but microorganisms that have evolved to use us (humans) as a place to live or as something to eat without regard to our ultimate well-being or survival. Microorganisms (viruses, rickettsia, bacteria, protozoa, fungi) predate us by hundreds of millions of years and will no doubt postdate us as well. Our ability to eradicate microorganisms is far overshadowed by their ability to eradicate us. Microorganisms evolve rapidly into new forms or into old forms with new processes to adapt to whatever environment they enter or to whatever environmental danger (antibiotics) they encounter. They accomplish this by replicating themselves (and mutating) at warp speeds compared to our ability to replicate ourselves. Microorganisms can evolve into resistant forms faster than we can develop and test antibiotics and faster than we can develop measures of protection and treatment.

Most microorganisms are not harmful to humanity. Many microorganisms are necessary for our well-being, not just those that produce our wine, our bread, our cheese, and our medicines, but those that make our soil fertile and those that enter at the bottom of the food chain. Some microorganisms are even necessary within our own bodies (coliforms such as *E. coli*) to break down unneeded materials.

We humans (and all other organisms that inhabit our planet) have developed elaborate protections against the invasion of disease-producing (pathological) microorganisms. Some of our protective measures are skin; an immune system; white blood cells that act like protozoans themselves and devour bacteria; mucus in our digestive and respiratory systems; ear wax; strong acids in our stomachs; colonization of friendly bacteria (*Lactobacillus*); tears; microscopic hairs that line our respiratory systems and carry away debris and microbes; and, brains that have learned how to make antibiotics, develop isolation protocols, and design protective ventilation systems. Breakdown of any one of these protections can result in successful invasion by destructive microorganisms. Many microorganisms (virulent microorganisms) can invade us, even if all of our protective mechanisms are intact.

In this manual, we are primarily concerned with the last mentioned item, that is, the provision of safe ventilation in health care facilities—air movement that is not laden with noxious microorganisms, chemicals, odors, or particles; air movement that does not transfer disease from one person to another. This goal can better be accomplished with knowledge and understanding of how disease spreads (epidemiology); with understanding of how hospitals house, board, transport, and manage diseased patients; and with realization that health care provision scenarios are changing, population and crowding are increasing, intercontinental travel and commerce are increasing, hospital stays are shortening, inpatients are more debilitated, the costs and morbidity resulting from hospital-acquired infections are staggering, and microorganism resistance to antibiotics is increasing. It is the hospital that we all turn to in cases of disease and disaster. It behooves us to make this last bastion of our health as safe as possible. Perhaps we should not reject measures of infection protection because they have not yet proven to be effective but, rather, reject them only when they have proven to be ineffective.