CRITERIA AND METHODS OF CONTROLLING HOSPITAL INDOOR AIR QUALITY

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Introduction

For more than 100 years, the relative importance of contact and airborne vectors for contamination or infection of patients and staff has been debated. Moreover, the debate has been concerned with the relative importance of endogenous and exogenous sources of contamination. Historically, concern has been concentrated on the hospital operating room, the quantity of air supplied to the room, and whether the air should be recirculated. More recently, energy conservation and cost containment programs in hospitals have extended the concern for effective methods of air quality control to include all areas of the hospital.

In this paper, indoor and outdoor sources of gases and vapors, inert and viable (i.e., biological) particulates, and radionuclides are characterized for nine functional categories within hospitals; susceptibilities and expected responses (i.e, strains) of occupants within these functional categories are described; preliminary criteria for acceptable air quality are proposed; and methods of control that are now available to achieve these conditions are reviewed.

Contaminant Characterization

Outdoor Sources

The quality of the outdoor air must be known before it can be successfully used for ventilation. In ASHRAE Standard 62-1981, if the quality of the outdoor air does not comply with values provided in two tables, the air must be cleaned by appropriate techniques before compliance with that standard may be claimed (1).

Above-grade. Concentrations of contaminants within the zone bounded by the building site (i.e., meso-environment) require special consideration. If the quality of this outdoor air is unknown, it cannot be controlled and the use of ventilation systems under these conditions may be counter-productive. For example, in the ASHRAE Position Paper on Legionellosis (2), increased ventilation rates were considered and the outdoor air (i.e, macro-environment) or in the make-up air (i.e, meso-environment) can be potentially higher than in the indoor air; and 2) ventilation with outdoor air was not cost-effective for Legionella bacteria due to the cost of the required filtration.

Below-grade. The meso-environment is also the source of contaminants that enter the hospital through the building sub-structure. The soil surrounding the building contains air, soil gases (e.g., radon), and water. In addition to non-viable components, soil also contains living organisms whose metabolic and decay processes cause changes in the composition of the soil. The soil characteristics may be due to natural phenonomen, but they may also be due to anthropogenic factors. For example, landfill may exhibit substantially different characteristics than the original soil. Such cases have been reported in which high concentrations of radon from mine tailings, industrial wastes (e.g., dioxin), pesticides, and fertilizers were detected in the soil gas.

Indoor Sources

Functional categories. In addition to the primary health care functions that a hospital provides, it contains nearly every type of function found in other buildings. Because of this complexity, lists of more than 120 functional areas have been published by various organizations. A composite of these lists characterizes these functions in nine functional categories: 1) Administrative Facilities including support offices, main lobby, admitting and business areas, and médical records; 2) Diagnostic and Treatment Facilities including laboratory, pathology and radiology suites, rehabilition and inhalation therapy areas, pharmacy, dental and other services such as counselling and educational services; 3) Nursery and Pediatric Facilities including full-term, special care, observation and premature nurseries, and pediatric and adolescent nursing; 4) Nursing Facilities including medical, surgical, post-partum and psychiatric nursing units, and intensive care units; 5) Surgical Facilities including operating, recovery and waiting rooms, and service areas such as scrubbing and sterilizing facilities; 6) Central Sterilizing and Supply Facilities including sterilization room and general stores; 7) Obstetrical Facilities including delivery, labor, birthing, recovery rooms, and service areas such as scrubbing and sterilizing facilities; 8) Emergency Facilities including trauma and waiting rooms, and service areas such as scrub stations and toilet facilities; and 9) Service Facilities including dietary, dining, laundry, mechanical, and employee facilities, maintenance shops, and waste processing facilities.

Human occupancy. In many functional areas of the hospital, the hospital staff, patients, and visitors may be the primary indoor sources of acoustic, thermal, and mass stressors:

- o Sound power from conversational speech ranges from 8 - 91 uW (3);
- o Heat dissipation ranges from 0.7 - 3 Mets (4);
- o Respiration results in typical emission rates of -38 g/hr O_2, 32 g/hr CO_2, and 12 g/hr water vapor for healthy, sedentary adults, but may vary by a factor of 10 due to activity levels and respiratory quotients (4, 5);

- o Sweating results in typical emission rates of 17 g/hr water vapor for sedentary, healthy adults, and values may vary by a factor of 10 due to activity level and state of health (4, 5);
- o Other gaseous bioeffluents are also generated by occupants (6);
- o Particulates may be generated by talking, coughing, skin sluffing, and other functions at rates of 7 million/min, each containing an average of 4 viable bacteria (7, 8, 9).

Processes. Alternatively, processes conducted within the various functional areas may be the primary sources of acoustic, visual, thermal, and mass stressors:

- o Combustion processes of tobacco smoking, vented and unvented heaters and appliances, vehicle garages, and welding procedures generate significant thermal loads in addition to the gaseous and particulate emissions (5, 10);
- o Housekeeping activities (e.g., bed-making, floor cleaning, dusting) may result in significant aerosol and gaseous generation rates (e.g., more than 10^5 bacteria/m^2 of bedding during bed-making (11), effluents from 88 different formulations of sanitizing agents, air fresheners, deodorizers, detergents, and solvents (12), disinfecting patients' rooms with HCHO (13, 14));
- o Laboratory procedures involve the use of chemical and physical agents normally covered by occupational safety and health regulations, commonly including HCHO, xylene, and cyanide (12);
- o Sterilization procedures with ethylene oxide (ETO) for prosthetics and other items that cannot tolerate the heat from steam autoclaves may result in significant emissions of ETO into the laboratory, if purge cycles are not properly operated, and both ETO and steam procedures add significant heat loads (15);
- o Laundry procedures can result in aerosol generation of viable and non-viable particles from the bedding, linen, and clothing, emission of gaseous contaminants from the dirty zone, and emissions of detergents particles, water vapor, and thermal loads;
- o Dietary procedures can result in emissions of volatile organics, water vapor, and heat during the cooking process; generation of viable and non-viable particles, gases, and vapors during food disposal; and emissions of detergent particles, droplet nuclei, water vapor and heat during dishwashing procedures;
- o Surgical procedures expose both the surgical team and patients to contact and airborne sources of infection including the primary pathway of particles (i.e., skinflakes) shed by the team into the field of surgery (8, 9); the surgical team and especially the anesthesiologists are also exposed to fugitive concentrations of anesthetic gases including nitrous oxide and halothane (16);
- o Environmental control systems may be intermediate sources of gaseous, vaporous, and particulate contaminants including bacteria, molds, fungi, amoeba, and protozoa on warm/wetted surfaces and have been implicated in diseases such as legionellosis, humidifier fever, and allergic brochopulmonary aspergillosis (17).

Building materials. Materials and furnishings may also be significant sources of acoustic, visual, thermal, and mass stressors. Noise, light, and heat transmission, absorption, and reflection characteristics are well documented. However, similar characteristics for the gases, vapors, particulates, and radionuclides are not as readily available. These materials may emit significant amounts of contaminants. Sources include; masonry and wood products; thermal and acoustic insulation; fabrics such as carpeting, drapery, upholstry, and wallpaper; and paints and adhesives (5, 10).

Human Responses

A summary of contaminant sources, susceptible populations, and expected strains to unacceptable concentrations of contaminants within each functional category, shown in Table 1, indicates that a set of common sources and common strains may be expected in all functional categories. However, several of the categories also have important unique characteristics.

Proposed Criteria

A proposed set of air quality criteria for acceptable control within the functional categories is shown in Table 2. These criteria presuppose that the thermal, lighting, and acoustic criteria for each category are also met. Compliance with these criteria would be met when both the objective and the subjective measures were achieved.

Methods of Control

This review of the types and sources of contaminants found in the functional categories indicates that gases and vapors are ubiqitous. However, a review of the literature indicates that the primary method of controlling the concentrations of these gases and vapors is by dilution with outdoor air, with little or no treatment provided for that outdoor air, even when its concentrations exceed established guidelines and standards (2). A simple mass balance of a one-compartment model indicates that in the case of a uniformly mixed space, three methods of control may be applied: source control, removal, and dilution (5). For purposes of improved environmental control and reduced costs of energy and operations, it is recommended that:

1. Source control be evaluated as the primary method of reducing emissions of gases such as CO, NO_2, N_2O, halothane, ETO, HCHO, HCN, and xylene;
2. Exposure to residual gases, vapors, and particulates be minimized by controlling the air distribution patterns within and between the rooms in which the sources exist or which the most susceptible populations occupy;
3. Optimize the use of removal and dilution control strategies to achieve the acceptable environmental quality and minimum life-cycle costs.

References

(1) ASHRAE Standard 62-1981. Ventilation for Acceptable Indoor Air Quality. American Society of Heating, Refrigerating, and Air Conditioning Engineers, Atlanta, 1981.

(2) ASHRAE position paper on Legionellosis. Part I: Basic information. Part II: Environmental, energy and economic implications. American Society of Heating, Refrigerating, and Air Conditioning Engineers, Atlanta, 1981.

(3) Knudsen, V.O., and Harris, C.M. Acoustical Designing in Architecture. American Institute of Physics, 1978, 35.

(4) Fanger, P.O. Thermal Comfort. Robert E. Krieger Publishing Company, Malabar, Florida, 1982.

(5) Woods, J.E. Sources of indoor contaminants. ASHRAE Trans. 1983, 89, 1.

(6) Wang, T.C. A study of bioeffluents in a college classroom. ASHRAE Trans. 1975, 81, 1, 32-44.

(7) Riley, R.L., Wells, W.F., Mills, C.C., Nyka, W., and McLean, R.L. Air hygiene in tuberculosis: quantitative studies of infectivity and control in a pilot ward. Am. Rev. Tuber, Pulm. Dis., 1957, 75, 420-431.

(8) Solberg, C.O. Role of airborne bacteria transmission. In Proceedings of the 1978 International Working Conference: Hospital Ventilation Standards in Energy Conservation. Lawrence Berkeley Laboratory Report LBL-10475, 1980, 7-25.

(9) Clark, R.P. and Cox, R.N. The generation of aerosols from the human body. In: J.F.P. Hers and K.C. Winkler (Eds.), Airborne Transmission and Airborne Infection. John Wiley and Sons, Inc., New York, 1973, 413-426.

(10) Wadden, R.A., and Scheff, P.A. Indoor Air Pollution. John Wiley and Sons, Inc., New York, 1983.

(11) Walter, C.W. Prevention and control of airborne infection in hospitals. Annals New York Academy of Sciences, 1980, 312-330.

(12) Rainer, D., and Michaelsen, G.S. Hospital Ventilation Standards and Energy Conservation: Chemical Contamination of Hospital Air, Final Report. Lawrence Berkeley Laboratory Report LBL 10475, March 1980.

(13) Peters, J., and Spicher, G. Room disinfection by formaldehyde vaporization. Hyg. Med., 1981, 6 (8), 337-344, (in German).

(14) Maisonnett, M., and Czernichow, P. Purification and disinfection of air in hospital facilities. Rev. Prat., 1980, 30 (51), 3501-3517, (in French).

(15) Samuels, T.M. Local exhaust and cycle purges reduce ETO release. Hospitals, Feb. 1981, 67-69.

(16) Whitcher, C., Piziali, R., Sher, R., and Moffat, R.J. Development and Evaluation of Methods for the Elimination of Waste Anesthetic Gases and Vapors in Hospitals. National Institute of Occupational Safety and Health Publication No. (NIOSH) 75-137, 1975.

(17) Committee on Indoor Pollutants. Indoor Pollutants. Report by the National Research Council. National Academy Press, Washington, DC, 1981.

Table 1. Sources, susceptible populations, and strains within functional categories

Functional Category	Sources of Contamination[a]	Susceptible Populations	Strain[b] (Response)
1. Administrative Facilities Copy machines, Decorative Plants	Tobacco smoke, Consumer products,	Administrative staff, Visitors	
2. Diagnostic and Treatment Facilities	Volatile chemicals, Sterilants and disinfectants (HCHO, ETO), Bedding and clothing	Medical and nursing staffs, Technical staff, Patients	Infections, Tissue deterioration
3. Nursery, Pediatrics, and Adolescent Nursing Facilities	Volatile chemicals, Sterilants and disinfectants, Consumer products, Bedding and clothing, Decorative plants	Infants, Mothers, Adolescent patients, Medical and nursing staffs, Visitors	Infections
4. Nursing Facilities	Volatile chemicals, Sterilants and disinfectants, Consumer products, Bedding and clothing, Decorative plants	Patients, Visitors, Medical and nursing staffs	Infections
5. Surgical Facilities, 7. Obstetrical Facilities, 8. Emergency Facilities	Nature of surgery, Surgical sheets and gowns, Anesthetics, Volatile chemicals, Aerosols, Sterilants and disinfectants	Patients, Medical and nursing staffs	Infections
6. Central Sterilization and Supply	Volatile chemicals, Anesthetics, Sterilants and disinfectants	Technical staff	
9. Service Facilities	Other bioeffluents, Volatile chemicals, Aerosolized soaps, food particles and detergents, Sterilants and disinfectants, Bedding and clothing, Utility supplies, Combustion equipment, Electricla equipment	Patients, Medical and Medical and nursing staffs, Technical staff, Administrative staff	Infections

[a] Sources common to all categories: Human bioeffluents, Building materials, Insecticides and pesticides, Housekeeping, HVAC systems, Outdoor air.

[b] Strains common to all categories: Odor, Eye and skin irritation, Respiratory difficulty, Headaches, Dizziness, Sleepiness.

Table 2. Proposed criteria for acceptable air quality in hospitals

Airborne Contaminant	Criteria: Objective (Stressor)	Criteria: Subjective (Strain)
Gases and Vapors:		
Anesethetic gases (N_2O, halothane)	≤ 5 ppm (8 hr TWA)	Absence of headaches or fatigue.
Carbon dioxide (CO_2)	≤ 2500 ppm for continuous exposure if gas removal equipment is used; otherwise ≤ 1000 ppm for continuous exposure	Odors from human bioeffluents may be detectable when CO_2 ≥ 1000 ppm.
Carbon monoxide (CO)	≤ 3 ppm for exposures ≥ 24 hrs	Odorless.
Ethylene oxide (ETO)	≤ 1 ppm in labs, 8 hr TWA; otherwise ≤ 0.3 ppm	Concentrations are ≤ 0.001 odor threshold.
Formaldehyde (HCHO)	≤ 0.1 ppm for continuous exposure	< 50% occupants expected to detect odor.
Hydrogen cyanide (HCN)	≤ 5 ppm for 10 min	Odor threshold for trained persons.
Nitrogen dioxide (NO_2)	≤ 0.05 ppm for continuous exposure	< 0.5 odor recognition threshold.
Water vapor (H_2O)	30 - 60% RH	Thermal and odor acceptability.
Xylene	< 0.75 ppm	Odor threshold 0.5 - 1.0 ppm.
Particulates:		
Inert	≤ 75 ug/m^3 (TSP)	Concentrations should be less in areas with susceptible populations (allergic, hypersentive occupants).
Biological	≤ 1000 CFU/m^3 except for special clean areas	Absence of odor, infection, contagion.
Radionuclides:		
Radon	≤ 0.01 WL	Absence of tissue deterioration

SUMMARY

J.E. Woods, M.A. Ficht, and R.J. Albrecht: Criteria and Methods of Controlling Hospital Indoor Air Quality. As energy conservation and cost containment have become more important to health care services, new control strategies are being evaluated which may provide improved air quality while reducing operating costs. In this paper, some sources of gaseous, vaporous, particulate (i.e, inert and viable), and radioactive contaminants are identified within nine functional categories of the hospital. Susceptibilities and expected strains of hospital occupants in response to exposure to these contaminants are described. From these factors, preliminary criteria for control purposes are recommended, and available methods of control are reviewed. It is concluded that control of gases, vapors, and radionuclides may be as important to occupant well-being as control of viable particulates, and that air distribution patterns within and between rooms are as important to dilution and removal control as the quantity of air supplied to the rooms.

RESUME

J.E. Woods, M.A. Ficht, and R.J. Albrecht: Critère et Méthodes de Réglage de la Qualité of l'Air à l'Intérieure d'une Clinique. Pendant que la conservation de l'énergie et la maîtrise des dépenses sont devenues de plus en plus importantes pour les services de santé, des stratégies nouvelles de réglage sont en train d'être évaluées qui pourraient fournir une qualité d'air améliorée et à la fois réduire les frais d'opération. Dans ce rapport, quelques origines des contaminants gazeuses, vaporeux, en paillettes (c.a.d. inerts et viables) et radio-actives sont identifiés, trouvés en neuf catégories fonctionnels de la clinique. Les susceptibilités et tensions chez les occupants en réponse à ces matières contaminantes sont décrits. A partir de ces facteurs, des critères préliminaires dans le dessin de réglage sont recommandées, et les méthodes de réglage disponibles sont examinées. Il est conclu que le réglage des gaz, vapeurs, et radio-nuclides peut être ausse importants pour le bien-être des occupants de la clinique que le réglage des paillettes viables, et que la distribution de l'air dedans et entre les chambres sont, pour le réglage de la dilution et enlevement, d'une importance égal à la quantité d'air fourni à la chambre.

KURZFASSUNG

J.E. Woods, M.A. Ficht, and R.J. Albrecht: Richtlinien und Methoden zur Regelung der Luftqualität in Krankenhäusern. Energie- und Kosteneinsparung sind heute von zunehmender Wichtigkeit fur Krankenpflegeanstalten. Wir berichten hier über neue Regelungsstrategien, die erwogen wurden, verbesserte Luftqualität versprechen und gekoppelt sind mit reduzierten Betriebskosten. Luftverunreinigung durch Gase, Dampfe, Teilchen (Staub, Bakterien) und radioaktive Elemente wurden identifiziert in 9 Krankenhausabteilungen. Die Empfindlichkiet un Beanspruchung der Menschen im Krankenhaus, die diegen Verunreinigungen ausgesetzt werden beschrieben. Vorlaufige Richtlinien zur Regelung dieser Faktoren wurden ausgearbeitet und vorhandene Methoden begutachtet. Wir sind überzeugt, dass die Regelung luftverseuchender Gase, Dämpfe und radioakt. Elemente eben so wichtig für das Wohlsein der Kranken sein kann wie die Beseitigung von Krankheitsträgern, und dass die Luftverteilung zwischen Zimmern und innerhalb eines Zimmers die Luftqualitüt eben so fördert wie die zugeführte Luft selbst.