Indoor Air Quality for Hospitals

by Elia Sterling,
Theodor D. Sterling & Associates Ltd.

Introduction

For the past 20 years Theodor D. Sterling & Associates has provided consulting services specializing in indoor and outdoor environmental quality issues.

We are frequently called upon to deal with indoor air and other environmental quality problems. Often these problems have resulted in complaints of sick buildings where occupants are reporting a high frequency of discomfort and health problems.

Common complaints are eye, nose and throat irritation, headache, fatigue, nausea, dizziness and skin irritation accompanied by symptoms of lack of fresh air, stuffiness, poor temperature control and unpleasant odours.

Sick building problems first came to light in the 1970's with the introduction of technology for energy efficiency in buildings. The quality of the air inside office buildings, health care facilities and other non-industrial workplaces has been of growing concern over the last twenty years. The World Health Organization has estimated that 30% of newly-built or renovated buildings have the potential for problems associated with poor indoor air quality (IAQ) and the "sick building syndrome". Often, sick building problems have been blamed on energy efficiency but today there is no reason why a building cannot be both energy efficient and have a healthy environment.

Table One: Causes of IAQ Problems in 1,891 White Collar Workplaces Investigated by North American Government Agencies

	NIOSH 529 Buildings (1971-88) NIOSH, 1989		HWC 1362 Buildings (1984-89) Kirkbride, 1990	
Problem Type	Number	Percent	Number	Percent
Inadequate Ventilation	280	53	710	52
Indoor Contaminants	80	15	165	12
Outdoor Contaminants	53	10	125	9
Building Fabric	21	4	27	2
Biological Contamination	27	5	6	0.4
Unknown	68	13	329	24

The IAQ Problem

Lets take a closer look at the specific causes of IAQ problems that have been identified in investigations throughout North America. Since the early 1980's there have been thousands of IAQ investigations conducted by government and private organizations.

Results have been reported by various Government agencies and private consultants. Table 1 summarizes the results from 1891 investigations conducted by the National Institute of Occupational Safety and Health (NIOSH) in the United States and Health and Welfare Canada (NIOSH, 1989, Kirkbride, 1990).

The findings of the U.S. and Canadian agencies are remarkably similar. In over 50% of investigated buildings, inadequate ventilation was identified as the primary cause of IAQ problems. The term "inadequate ventilation" refers to a range of HVAC system inadequacies, such as lack of outside air, poor air distribution, poor thermal control and inadequate maintenance procedures.

Other identified causes include contamination from specific indoor sources, infiltration of outdoor contaminants, contaminants from building materials and interior furnishings and microbial contamination.

An illustration of the complexity of investigating IAQ problems is the finding that the cause could not be determined by the investigators in between 13% and 24% of the buildings being investigated.

While the reported findings from NIOSH and Health and Welfare Canada provide an important insight into the causes of IAQ problems, this summary table may over simplify the actual field situation. Table One summarizes *one* primary problem in each investigated building. However, our own field experience rarely identifies a single problem in a building. Typically, several inadequacies are identified within a building, which in combination contribute to occupant discomfort and ill-health.

Table Two summarizes our research groups' findings (Collett, 1993). Our findings are generally similar to the

Elia Sterling is President of Theodor D. Sterling and Associates Ltd. in Vancouver, B.C. He holds a degree in Architecture and is affiliated with such societies as: Air and Waste Management Association (AWMA), American Society of Heating Refrigerating and Air Conditioning Engineers (ASHRAE), American Society for Testing Materials (ASTM), Architectural Institute of British Columbia (AIBC), Environmental Assessment Association (EAA), Human Factors Association of Canada (HFAC), etc. He can be contacted at #250 - 1122 Mainland Street, Vancouver, B.C. V6B 5L1

government agencies, with the exception that we rarely identify only one problem per building.

Table Two shows specific causes that have been identified as contributing to IAQ-related problems. Lets look at each cause in turn.

The causes of IAQ-related problems that we have identified can be broadly categorized into two types:

1. Design and operational inadequacies of HVAC systems; and
2. The presence of specific contaminants from a variety of sources.

These two categories are not mutually exclusive. For example, the presence of elevated formaldehyde concentrations resulting from off-gassing from interior furnishings may be diluted by adequate ventilation or intensified by a lack of outside air or poor air distribution.

In our experience, the single most frequent cause of complaint is inadequate control of the indoor environment by the mechanical ventilation system. Problems such as inadequate outside air supply and poor air distribution within a space can be related to both the design and operational characteristics of the HVAC system.

Design problems may be a function of the original design decisions for a building. One common example is low outside air ventilation rates designed for optimum energy efficiency.

Some examples of operational deficiencies include building operators closing outside air dampers (again for energy efficiency), and inappropriate minimum damper settings (particularly in variable-air-volume systems).

Other problems include unbalanced air distribution systems and the presence of barriers to effective air movement, such as partitioning of a space or occupant blocking of diffusers themselves.

Mitigation of design-related inadequacies is general capital intensive, such as the replacement of air handling units. However, operational deficiencies can often be rectified by inexpensive "fine tuning" of the HVAC system.

Table Two: Investigator's Conclusions from Reports Contained in the Building Performance Database (Collett, 1993)

Suspected Cause	Number of Reports	Percent
Ventilation Control Problem	159	39.0
Ventilation Infiltration Problem	40	10.0
Indoor Sources	115	28.1
Stress	12	2.9
Ergonomic/Workstation Design	5	1.2
Undetermined Cause	42	10.2
No Problem	35	8.6
Total	408	100.0

Poor thermal control is also common. Similar to the ventilation-related problems, this can be the result of both design and operational deficiencies. Design problems occur in buildings in which heating and cooling capacities were determined and designed at a time before the proliferation of electronic equipment in the work environment, which have added substantial heat loads to buildings.

However we have found that, operational parameters are more often the cause of thermal control problems. Indoor environmental conditions can often be improved by providing appropriate thermostat set points, moving a thermostat to a location more representative of the area that it is controlling and educating occupants as to the proper operation of the thermostat.

Infiltration of contaminants through the outside air intakes is also a frequent problem. Such infiltration is generally a function of the outside intake immediately adjacent to pollutant sources such as loading zones, bus stops and exhaust outlets. These are clearly design related problems and mitigation is often costly, including relocation of the intake or addition of specialized filtration, such as activated carbon.

We have identified migration of contaminants from one area of a building to another as a problem in more than 10% of investigated buildings. Sources of cross contamination include underground parking garages, printing facilities, restaurants and inadequately ventilated smoking lounges. Because of the many special use areas, I expect this problem is more pervasive in hospitals and health care facilities. One specific area where cross contamination can be particularly troublesome is laboratory fume hoods.

In general, cross contamination problems can often be mitigated through initial determination of the pressure relationships (air flows from positively pressurized to negatively pressurized spaces). Adjustment of these relationships, for example, by the provision of local exhaust systems, can minimize the potential for contaminant migration.

Contamination from specific indoor sources has also lead to IAQ problems. Sources include off-gassing of formaldehyde and volatile organic compounds from furnishing materials, fibrous insulation in ceiling plenums, excessive dust loading due to poor or no filtration, or housekeeping and janitorial procedures and specific occupant activities. In buildings where off-gassing problems have been identified, ventilation control problems have also frequently been recognized, particularly with a lack of outside air not effectively diluting and removing the indoor-generated contaminants.

The presence of strong point sources in certain hospital locations may dictate the need for control by local exhaust systems. In hospitals, common point source contaminants include: ethylene oxide, anesthetic gasses, formaldehyde, glutaraldehyde, antneoplastics, pentamidine, asbestos, freon, mercury, solvents, cytotoxics, sterilants and germicides.

Another problem common to hospitals is microbial contamination. We have found that microbial contamination occurs from two principle sources: the presence of standing water within one

or more components of the HVAC system, e.g. a blocked condensate drainage tray; and an episode of water leakage or flooding. Of course, another source of microbial contamination is patients with infectious diseases. For example, the threat of tuberculosis is again appearing. Research is underway to determine the potential spread of this bacterium through the HVAC system

The presence of standing water in an HVAC system suggests that regular inspections are not occurring and can be mitigated by an improved preventative maintenance problem. One example of extreme concern is the humidification system. We often find microbial slime growing on these systems. If not rectified, microbial problems can be distributed widely throughout a building, creating the potential for serious health impairment and requiring extensive and costly decontamination.

A common source of standing water in hospitals are portable room humidifiers which can be a significant source of airborne microbes. These humidifiers are a perfect medium for the growth of bacterium. If this bacterium is aerosolized it can be inhaled and pose an infectious hazard. Another potential contamination source are high efficiency filters used in special care units. Recent studies have shown that fungus colonization can occur and serve as a source of potential infection. For example, in 1987, four bone marrow transplant recipients in a U.S. medical center became colonized with chaetomium species caused by contamination of the filters in the special care unit.

Occasionally, we have identified contamination from adjacent industrial plants or infiltration of pollutants from the underlying soil as causes of the indoor problems. In hospitals such contamination is often caused by other buildings within the same complex.

How serious is the indoor air quality problem? While many IAQ complaints reported in workplaces are discomfort rather than serious health effects, there can be a dramatic impact on both absenteeism and productivity. The problem in hospitals is more serious. The U.S. CDC estimates that 5% of patients in acute care facilities acquire infections often as a result of indoor air contamination. They have estimated the cost of additional hospitalization due to these infections exceeds 4 billion dollars a year. Clearly poor IAQ can have serious economic consequences for hospitals.

Standards for Control of IAQ

Ventilation problems have been demonstrated to be the major cause of poor IAQ. The ventilation industry has historically been governed by self imposed regulations. American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) is the organization primarily responsible for setting industry standards. Lets take a look at how these standards have evolved over the last century, particularly with respect to IAQ.

Up until 1936, ventilation requirements were based on ventilation by natural means, primarily opening windows.

After 1936, mechanical ventilation became more and more popular and by the 1970's was almost the sole means of ventilation for commercial and office buildings. In fact, hospitals played an important role in development of the science of air conditioning and mechanical ventilation. The Royal Victoria Hospital in Belfast was one of the first mechanically ventilated buildings (Banham, 1969).

The ventilation air was driven by a pair of steam engines powered by waste steam from the hospital's laundry boilers. Another innovation of this early hospital HVAC system was humidity control. This was accomplished by moistening the filters in a process similar to that currently used for evaporative cooling.

In response to the growing importance of mechanical ventilation, the first ASHRAE standard was published in 1973 just prior to the oil embargo. The design standard was 15-25 cfm of outside air per person (ASHRAE/ANSI, 1973).

The ventilation standard was revised in 1981 to correspond to the U.S. energy standard. This standard was the first to introduce the concept of acceptable indoor air quality. Unfortunately, at the time industry opinion was that smoking was the only cause of poor IAQ and a dual level was imposed. 5 cfm for non-smoking buildings and 20 cfm for buildings permitting smoking (ASHRAE/ANSI, 1981).

Needless to say, most buildings were designed at 5 cfm whether or not non-smoking policies were implemented. Unfortunately this design flaw occurred in many of our nations hospitals.

We now know that smoking is only one of the multitude of sources that contribute to the complex problems of poor IAQ.

Finally in 1989, a new ventilation standard was introduced in response to growing concerns of poor indoor air quality (ASHRAE/ANSI, 1989). ASHRAE Standard 62-1989 forms the basis of HVAC system requirements in the CSA Standard "Special Requirements for HVAC Systems in Health Care Facilities" (CSA, 1991). ASHRAE 1989 increases the minimum ventilation rate back to 15 CFM per person.

Indoor air quality problems are not only related to ventilation. Air conditioning which includes control of temperature and humidity also has an impact. Temperature and humidity standards have evolved in parallel to ventilation standards. ASHRAE Standard 55-1992 describes acceptable temperature and humidity parameters for typical buildings (ASHRAE, 1992). However, for a number of reasons hospitals should not be designed to this standard. Patients can be much more susceptible to discomfort and illness caused by variations in temperature and humidity. The findings of research we conducted for Health and Welfare Canada show an optimal zone between 40-60% relative humidity for hospitals. One major reason for this narrow range is that humidity at a minimum of 50% reduces bacterial growth but higher than 60% can cause condensation resulting in microbial contamination (Sterling, 1987).

Solutions to the IAQ Problem

Ninety percent of buildings that are going to exist in the year 2000 have already been built. Many of these buildings were constructed or renovated

between 1975 and 1989, and are likely to experience IAQ problems. How do we cure these buildings?

Phased Approach

Our approach which is based on cost effective problem solving is probably the most applicable to hospitals.

This is a phased program of gathering information from building occupants and maintenance personnel, combined with the measurement of specific indoor pollutants and the inspection of easily observable ventilation parameters.

The strategy consists of seven phases illustrated in Figure 1 which together act to:

1. Determine whether an environmental problem exists in a building.
2. Identify the probable causes of the problem.
3. Design and implement modifications to alleviate the problem.

This approach is not cast in stone, but is necessarily flexible to deal with a wide variety of field situations and levels of building complexity.

Phase 1-3

The first phase of investigation is an initial assessment in which information about occupant concerns and the physical building are gathered from the following sources:

1. Meetings with the building owner, operator and occupants.
2. Review of architectural and engineering plans, if they are available.
3. Walkthrough inspection to identify pollutant sources, inspection of the design configuration of the building, the operational conditions of the building's mechanical systems and observation of the actual use of the occupied space.

Phase Two is the assessment of occupant concerns.

Our experience suggests that the approach must be flexible, responding to the specific requirements of a particular project. A standardized questionnaire may be greatest value in building complexes with large occupant populations. Questionnaire surveys are also particularly useful when evaluating the impact of demographic differences and psycho social factors.

In phases three and four we evaluate the chemical composition and thermal condition of the indoor air.

In phase three, five parameters are monitored to indicate the general performance of the building's mechanical systems:

- Carbon dioxide as an indicator of the adequacy of the outside air supply.
- Carbon monoxide as an indicator of the infiltration of combustion by-products.
- Respirable suspended particles as an indicator of filtration effectiveness and the general dust loading of the indoor environment.
- Temperature and Relative Humidity as indicators of thermal comfort.
- In hospitals microbial measurements may also be included in this phase.

Portable, direct reading instruments are used to gather instantaneous data at sampling locations throughout the building and also an outdoor site, adjacent to the air intakes for the building. Of course this is with the exception of microbial measurement.

Indoor sampling locations are selected to reflect different uses of a space, to incorporate all HVAC zones, and to investigate "problem" locations identified in the previous phases. Multiple sampling passes through each site are undertaken throughout a working day to evaluate diurnal variations.

In addition, one or more continuous monitoring stations are set up to record trends in carbon dioxide, temperature and relative humidity. The continuous monitors are typically placed into "worst case" locations as identified in the walkthrough inspection.

Other environmental parameters that are monitored if a problem is suspected include anesthetic gases and sterilizing agents.

Phases 4 - 7

For Phase Four, additional IAQ sampling may also be undertaken, as dictated by the findings from the previous phases. In particular, if specific point sources of indoor pollution are identified in the walkthrough inspection, or if the occupants symptomology suggests the presence of a particular contaminant. Follow-up measurements may include sampling and analysis for formaldehyde, airborne fungi and bacteria, total and specific volatile organic compounds, ozone and nicotine.

If inadequate mechanical system performance has been implicated as a cause of IAQ-related problems, but has not been fully confirmed, quantification of ventilation performance parameters may be necessary in Phase Five.

Actions include air flow measurement to determine flows through the duct work, and supply and exhaust vents, and tracer gas evaluation to determine air exchange rates on specific floors or the overall building.

Tracer gas, such as SF_6, may also be used to investigate the patterns of air flow within a building, for example to determine whether air from a parking garage is infiltrating other areas within a building. Tracer gas or possibly smoke pencil tests may also be used to determine if special clean areas such as operating and recovery rooms are being contaminated by other areas.

Phase Six begins when conclusions have been drawn from the implementation of one or more of the preceding phases and the cause(s) of the IAQ problems have been determined. In this phase, retrofit actions to rectify the problems and improve indoor environmental conditions must be developed and implemented.

A final, but important, phase is follow-up assessment to determine the effectiveness of the retrofit actions. Ideally, the assessment should include objective measurement of IAQ and thermal parameters. However, we have found detailed follow-up assessment is rarely feasible in our consulting work.

Commissioning to Improve Hospital IAQ

Of course the best solution to indoor air quality problems is to design the building to avoid them in the first place. The environmental consultant should play an important role in the commissioning

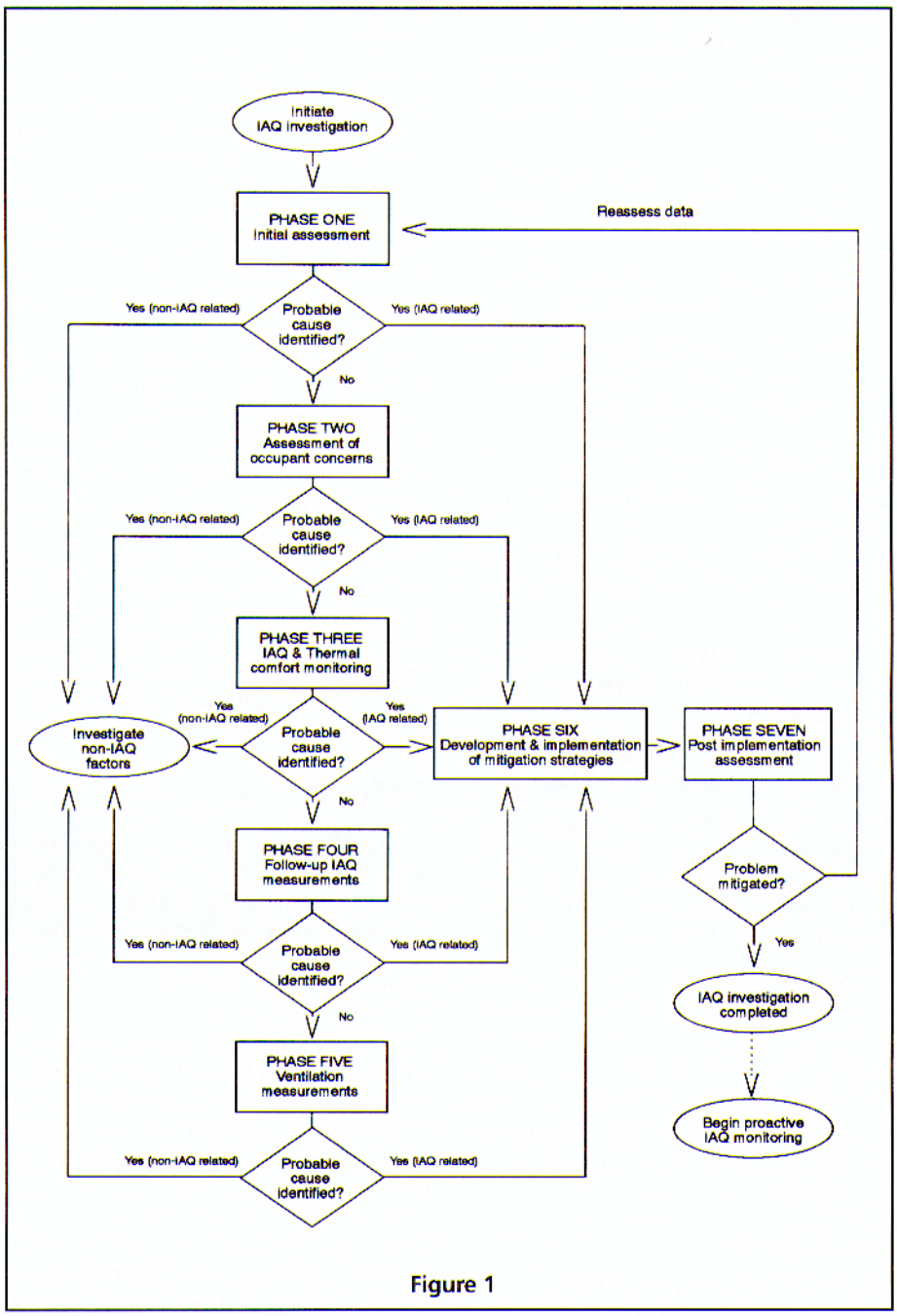


Figure 1

process. The ideal strategy for achieving a high quality indoor hospital environment is for environmental consultants to begin working with the design team at the program and conceptual stages of a project to commission the building to avoid IAQ problems. The hospital is unique in that its design requirements affect the maintenance of an aseptic environment. Those involved in the design must have a detailed understanding of the hospital and its function

The overall role of the environmental consultant is:

1. To formulate a program of environmental goals and objectives for the design.
2. To review the design schematics to evaluate whether the environmental objectives have been reached.
3. To inspect the building after construction and test building performance relative to the environmental objectives.
4. To provide an on-going program of IAQ and building performance assessment.

The consultant's input should encompass all phases of the design and development process from program through acceptance.

Program Phase

In the program phase, which is really the pre-design conceptual stage, the following actions should be taken:

- Review the projected occupant activities and densities, with particular attention on special use areas such as laboratories, operating and recovery rooms, nurseries and kitchens.
- Identify all special use areas where critical conditions must be maintained and also where toxic gasses and other products will be used and stored.
- The types of special use areas will also determine the need for local exhaust to supplement the base building HVAC system.
- Identify sources of outdoor pollution in the vicinity of the building site, such as exhaust systems and cooling towers of neighboring buildings, or parking structures. This may also include assessment of underlying soil and ground water conditions which will interact with the building structure.
- In the program phase, targets for outside air ventilation rates and thermal performance should be set. Use ASHRAE and CSA Standards to determine minimum requirements.

Design Phase

Much of the IAQ-related efforts in the commissioning process will occur in the design phase, such as:

- An examination of the manufacturer's safety information about products specified in the contract document that may be suspected contributors to indoor pollution.
  For example, products such as carpets, flooring, adhesives, wall coverings, sealants, insulating and fireproofing materials, paints and varnishes.
- Also, request manufacturers to provide information on curing, drying and airing procedures for their products to minimize subsequent emission rates. Manufacturers can be asked questions such as:

(a) What information do they have about emission of volatile organic compounds;

(b) What steps do they take, both in production and post-production treatment, to reduce emissions prior to installation in the building; or

(c) Is it possible for the manufacturer to air out the product before installation. If so, for how long and under what conditions?

At the design phase, you should also:

- Review the design documentation for compliance with applicable air quality thermal comfort codes and standards
- Review the design intent under all projected modes of operation and anticipated outdoor conditions, such as minimum and maximum outdoor temperatures, when reduced outside air ventilation rates may occur.
- Review orientation of air intakes and exhausts, with respect to cross-contamination and adjacencies to local pollution sources such as garages, loading and parking zones and cooling towers.
- Review the design documents to determine that clean areas will not be contaminated by other sources.

In addition, you should also review:

- Plans for temporary ventilation and filtration during construction and initial occupancy. This might include bake out or flush out procedures, or the use of unitary filtration equipment.
- Provision of local exhaust systems for special use areas.
- Types and efficiencies of filtration systems.
- The design of HVAC system components such as condensate drains, water baffles and cooling towers for the effective control of standing water, to minimize the potential for microbial contamination.
- Provision of access doors and inspection points to all chambers and plenums, which are large enough to allow proper cleaning and servicing.
- Specifications and placement of HVAC insulation materials.

Construction Phase

During construction, there is a need to:

- Inspect to verify that HVAC system components have been constructed as designed.
- Verify that all critical components are accessible for future cleaning and services.
- Verify the proper and careful installation of insulation materials.
- Review implementation procedures for temporary ventilation and filtration during construction.

Acceptance Phase

As part of the acceptance phase, there is a need to:

- Examine all HVAC internals for cleanliness and readiness for operation.
- Test and verify operation of all air handling system components that use free water.
- Examine all insulating materials for integrity and proper installation.
- Review test and balance reports and compare to design intent. This might include spot checks of ventilation rates and temperature and humidity control.
- Conduct pre-occupancy testing for parameters such as CO2, formaldehyde, temperature and relative humidity to verify that IAQ procedures have been effective.
- Verify that all system operations and maintenance manuals are available.

Post Acceptance

During the post acceptance phase:

- Verify adoption of any temporary ventilation rates and schedules planned for the initial occupancy periods.
- Review plans for post commissioning IAQ testing, allowing comparison of IAQ conditions in the building with applicable codes and standards.
- We recommend that periodic IAQ audits are undertaken to verify acceptable IAQ performance over time.

Conclusion

This paper has provided an overview of a wide range of issues including discussion of problems associated with and causes of poor IAQ and has suggested ways in which IAQ problems can be avoided in both existing and new hospitals. Much of the material covered is not specific to hospitals. There are two reasons for this. The first is that hospitals, in addition to special issues are plagued by the same indoor air quality problems as other buildings. The second reason is more complex and I feel we should reflect upon it. Published IAQ research is rarely focused on problems in hospitals.

Does this mean that there are no air quality problems in hospitals? I think not. However, until adequate research is conducted and documentation is presented it will be very difficult for engineers to find appropriate solutions to this perplexing and costly problem.

References

ASHRAE. 1973. *ASHRAE Standard ANSI/ASHRAE 62-1973: Standards for Natural and Mechanical Ventilation.* Atlanta. American Society of Heating, Refrigerating and Air Conditioning Engineers.

ASHRAE. 1981. *ASHRAE Standard ANSI/ASHRAE 55-1981: Thermal Environmental Conditions for Human Occupancy.* Atlanta. American Society of Heating, Refrigerating and Air Conditioning Engineers.

ASHRAE. 1989. *Standard 62-1989: Ventilation for Acceptable Indoor Air Quality.* Atlanta: American Society of Heating, Refrigerating and Air Conditioning Engineers.

ASHRAE. 1992. *Standard 55-1992: Thermal Environmental Conditions for Human Occupancy.* Atlanta: American Society of Heating, Refrigerating and Air Conditioning Engineers.

BANHAM, R. 1969. *The Architecture of the Well-Tempered Environment.* The Architectural Press, London.

COLLETT, C.; ROSS, J.; STERLING, E. 1993. Review of Strategies Used to Investigate Indoor Air Quality

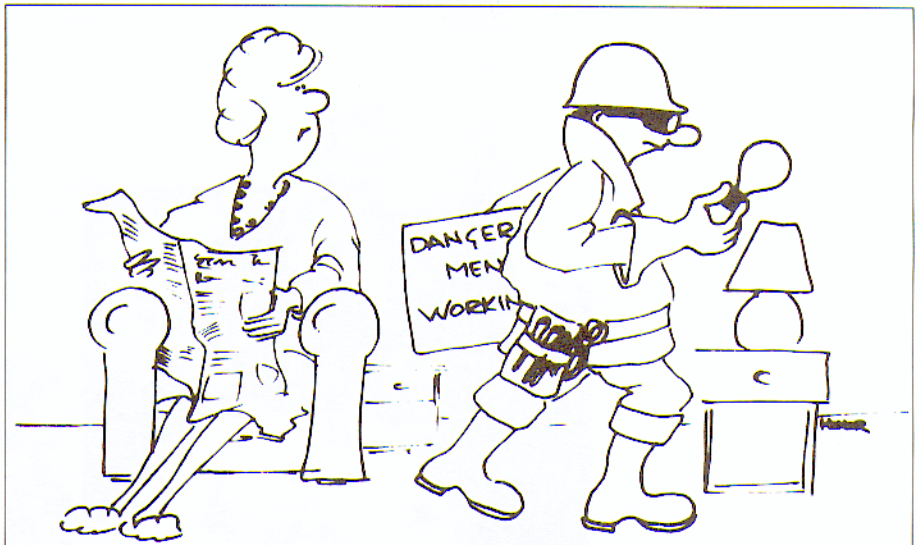
Problems. *Presented* at "Building Design, Technology and Occupant Well-Being in Temperate Climates", Brussels.

CSA. 1991. *CSA Standard CAN/CSA - Z317.2-M91 "Special Requirements for Heating, Ventilation, and Air Conditioning (HVAC) Systems in Health Care Facilities.* Toronto: Canadian Standards Association.

KIRKBRIDE, J.; LEE, H.; MOORE, C. 1990. Health and Welfare Canada's Experience in Indoor Air Quality Investigation. *Indoor Air '90* (Vol 5) Walkinshaw, D.S. (ed). pp 99-106. Ottawa: International Conference on Indoor Air and Climate.

NIOSH. 1989. *Indoor Air Quality: Selected References.* Division of Standards Development and Technology Transfer, Cincinnati: National Institute for Occupational Safety and Health.

STERLING, E.; MCINTYRE, E.; COLLETT, C. 1987. Field Measurements for Air Quality in Office Buildings: A Three Phased Approach to Diagnosing Building Performance Problems. *Sampling and Calibration for Atmospheric Measurements (ASTM STP 957),* Taylor, J.K. (ed). pp. 46-65. Philadelphia: American Society of Testing and Materials.



"All that to change a lamp?"