PRESCRIPTION FOR A HEALTHY BUILDING HEATING, VENTILATING AND AIR-CONDITIONING SYSTEM

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Abstract

This paper covers many aspects of indoor air quality problems in buildings and how the heating, ventilating and air-conditioning engineer should provide systems so as to minimize those problems. First, a careful survey of the building, its use and occupancy should be made, noting unusual pollutant sources. Next the applicable Standards and Codes should be referenced for suitability. Then the most appropriate outdoor air quantities should be chosen for the spaces. This may require Code variances. Outdoor air suitability should be assured. The system design should include meticulous detail to easy accessibility for testing, balancing and maintenance. Operational strategies should be clearly set out to be compatable with the known and expected use patterns. To accomplish this, many new research results need to be assimilated, and new Standards and Code information will need to be applied, often before Code adoption.

Disclaimer

The opinions expressed here are the author's own and are not necessarily those of the American Society of Heating, Refrigerating and Air-Conditioning Engineers, (ASHRAE), the National Bureau of Standards, (NBS), or others.

Introduction

It is with great pleasure that I note that Dr. Lindvall has decided to focus this conference on "Healthy Buildings". It has been my feeling that, although research on indoor air quality has been extensive, and has increased over the last decade, it has raised more questions for the person who has to put this information into practice in buildings than it has answered. ASHRAE has recognized this in its special IAQ conferences, begun in 1986, and continued in 1987, and 1988. These conferences, which stress applications, rather than research, will probably become a regular feature of ASHRAE programs. However, I was disappointed that more application work was not apparently available. I hope conferences like these will help to put more practical information in the hands of the practitioners. Certainly the research is far from complete, but there is much useful information available, and new buildings, and major retrofits are going on-line every day. The best current information should be available to the practitioner at all times.

Therefore I will be so presumptuous as to take a page from Dr. Lindvall's medical experience, and set out my opinions as to how I would write a "prescription" for healthy HVAC systems. Of course, no doctor can guarrantee good health, due to the many unknowns, and the same is true here.

There are several good reasons for increased IAQ concern.

Higher energy costs and conservation.

- 0 Buildings are being built and retrofited with tighter envelopes. Buildings do leak more than expected. Recent work by NBS has measured infiltration to often be about one air change per hour. In many cases the ventilation requirements could be met by infiltration alone.
- 0 Reduced outdoor air supplied to commercial buildings. Energy costs have caused many operators and designers to strive for the minimum code requirements, sometimes achieving even less.
- 0 There has been an over-reaction to energy expressed in many codes, sometimes specifying as the minimum rate the minimum from ASHRAE Standard 62-1981 (Ventilation) of 5 fpm/person, (2.5 L/S/person), without regard for the fact that the mimimum is only for extra-clean environments not often found in practice.

New materials introduced into buildings.

- 0 Construction materials, paints, plastics, etc. outgas some pollutants, not heretofore found in buildings.
- 0 Carpets, wall coverings, furniture, etc. also outgas new pollutants and sometimes more old ones.
- 0 New machines, business processes, maintenance proceedures, personal care products. etc. are also sources of pollutants.

Increased reasearch and publicity.

- 0 "Sick" building syndrome has occured often enough to sensitize the public to this rare but spectacular problem.
- 0 Radon investigations and publicity have pointed up additional health concerns.
- 0 Research has identified new and previously known pollutants, some heretofore thought to be innocuous, as possible or real health threats.

Control Methods.

The control methods for IAQ problems are simple in concept, but difficult and often expensive to achieve, depending upon the application.

- 0 Source removal or substitution. This is usually the most effective means, but the sources often cannot be specifically identified, or if identified, cannot be removed easily or substituted.
- 0 Source emanation reduction, by the use of enclosures, coatings, etc. is usually expensive and often not too effective.

- 0 Behavior changes, which involve personal choices by the occupants in their uses of the spaces, and the machines and processes therein to minimize exposure to pollutants can sometimes be effective, but are often real or perceived reductions in performance or lifestyle.
- 0 Ventilation. There are many aspects of ventilation (dilution, local exhaust, etc.) which the HVAC practitioner has as his tools, and must be further developed by him. This paper will cover many of them.
- 0 Contaminant removal from the air. Air treatment devices are available to the HVAC practitioner, and they will be further covered. In addition, pollutant settling and "plate-out" on surfaces occurs.

Tools for the HVAC Practitioner

There are several basic tools, or information sources available to the practitioner, and others are being developed and becoming more available. Some important ones will be covered.

Codes and Underlying Standards.

Codes have been the regulatory documents, designed to protect the public from IAQ problems, among other hazards. There about 5000 codes in the U.S, covering states, municipalities, etc. for almost all inhabited areas of the country. Codes usually specify minimum outdoor air (OA) ventilation requirements and permit more. Exceptions may be the many relatively new energy codes, which call for no more than the minimum requirements where ventilation is concerned. These many codes for ventilation are almost always based on the ASHRAE Ventilation Standard 62, or its predicessor. Standard 62 is the only consensus standard available in the U.S, and is therefore considered the source of state-of-the-art information. However, code bodies are often deliberate in their actions, and the provisions of the reference documents may by modified or changed in the codes for many reasons.

The ASHRAE Standards 62, and all other ASHRAE standards, are advisory and have no force in law. They are intended to be references for adoption by others as appropriate. ASHRAE has been involved in ventilation since its inception, and for approximately 50 years ASHRAE has been identified with consensus ventilation standards.

In 1946, the American Standards Association, (ASA), the American National Standards Institute (ANSI)'s predicessor, issued its "Light and Ventilation" Standard ASA A53.1, authored by a committee including ASHRAE members. As far as I can recall, this was the only consesus standard for ventilation available in the U.S. until 1973. This Standard covered only windows, skylights, etc. which could be opened for natural ventilation. In its appendix it listed some mechanical ventilation rates in cubic feet per square foot of floor area, (cfm/ft2), (L/s/m2). This document is still referenced in some U.S. codes.

In 1965 ASHRAE assumed responsibility for ASA A53.1 and began a revision under the approved consensus proceedures. It was completed and re-issued in 1973 as ASHRAE Standard 62-73 "Standard for Natural and Mechanical Ventilation". The Standard included a quantitative definition of acceptable outdoor air, (OA), and provided for OA rate reductions from the listed tabular values if high-quality air treatment devices were used on the recirculated air. In addition it recognized that ventilation is usually for occupants, so most of the tabular values were listed as cfm/person, (L/s/person), rather than cfm/ft2. Extensive tables were given for various types of occupancy and a minimum and a recommended column were given. Energy conservation was considered, hence the minimum column, but higher quality environments were also thought desirable. For many years this became the principle basis for codes in the U.S, adopted or modified after 1973.

During the energy crisis, ASHRAE issued its well-known Standard 90-75 "Energy Conservation in New Buildings". This Standard specified that only the minimum column of Std 62-73 be used, and that no more than that be used. For energy conservation, the minimum requirement also became the maximum.

ASHRAE revises all of its standards on a five-year cycle, and so Std. 62-73 was updated and reissued as Std 62-1981, "Ventilation for Acceptable Indoor Air Quality". This is the current ASHRAE Standard for ventilation, but it was rejected by ANSI on appeal from the Formaldehyde Institute, who objected to the limit for formaldehyde listed in a table. ASHRAE refuted the charge, but it was upheld. Probably for this reason, Std. 62-1981 has not been widely referenced in building codes, even though it represents ASHRAE's most current approved information.

This current Standard 62-1981 has several important changes and provisions from Std 62-73. Among them are:

- The minimum OA rate was kept at 5 cfm/person, (2.5 L/s/person).
- A two-path approach was introduced. In addition to the prescriptive method, whereby tables provided quantities of OA to be introduced into spaces to comply with the standard, a performance approach was included, which allowed for any solution, so long as certain contaminant concentrations were not exceeded. Although it was realized that this latter approach would seldom if ever be used, it was felt worthwhile to allow for innovative solutions.
- The prescriptive tables were updated, and "non-smoking" and "smoking permitted" columns were included.
- Only minimum amounts of OA were included, with no larger "recommended" amounts listed.
- Options for recirculation through air treatment devices were updated.

Because of the rapid advances in research, this standard was immediately put into early revision by ASHRAE. A newly-constituted committee has been working hard on the problem, and a new revision is expected to have ASHRAE approval by the time of this conference.

This revised draft is Std 62-1981R. There are several changes now being considered, and some important ones are listed below :

- The minimum OA rate has been tripled, to 15 cfm/person, (7.5 L/s person)! This has been in response to new odor research in the U.S. and abroad.
- The tabular values of OA to be used have been updated.
- The tabular values include "smoking permitted" expectations, but lower expected smoking rates have been assumed, reflecting new information on reduced smoking among adults in the U.S. No non-smoking values are listed.
- Ventilation effectiveness is recognized, and several other control options are listed.
- Some additional energy-saving options are included.

In summary, building codes covering ventilation in the U.S. may be based upon, or reference, ASA A53.1, ASHRAE 62-73, and in rare cases, ASHRAE 62-1981. However, the most up-to-date information is in the unapproved revision of ASHRAE 62-1981R! While noone can predict what the revision will contain, when and if approved, it has undergone extensive review, and its information should be judiciously used by practitioners now. It may well be approved before this meeting.

Because of the many variables which are not under the control of the HVAC practitioner, there is no system which can be guaranteed to be IAQ problem-free. While the building codes are legal documents, their use, for reasons outlined above, likewise cannot prevent IAQ problems, and in some cases, adherence to them may exacerbate them.

The ASHRAE "Thermal Comfort" Standard, 55-1981 is another important informational document for the practitioner. Without adequate thermal comfort, satisfaction with the total environment is impossible. In addition, research work has shown that people often confuse "too warm" with "stuffy" and therefore often report air quality sensations erroneously.

The Important Pollutants and their Comfort and Health Effects.

While it cannot be expected that the HVAC practitioner be an expert, he should have some knowledge of these, to aid him in his understanding of problems.

- The Effects of Important Pollutants on:
  - Comfort -- Odors are by far the most significant and common IAQ complaint. Odors can affect occupant's performance, attendance at work, etc. Comfort effects are soon remedied by leaving the offending environment.
  - Acute Health -- These effects are relatively short-term diseases, such as colds, influenza, asthma etc. They are often lost-time performance problems, but clear up in days or weeks after the offending material (virus, bacteria, allergen, etc.) is removed or much reduced, or the body's immune system has handled the problem. There are usually no sensory perceptions involved.
  - Chronic Health -- These effects are long-term, and are irreversable, often taking decades to develop to a diagnosable stage. Lung cancer is an example. These are also usually without sensory effects, so the occupants are not immediately aware of the hazard.

This is only the briefest of treatments on the effects of pollutants, and the particular important pollutants and their sources will not be further covered here, since other papers have included far more than I can. (See Bibliography).

It is important for the practitioner to have some general knowledge of these pollutants and their effects, since there are some specific ventilation parameters which can be used now for control purposes in specific cases, and other strategies will surely be developed.

Important Pollutant Sources.

The practitioner should know in a general way the sources of pollutants which can outgas into the inside air. There are four sources of importance.

- 0 The outside air.
- 0 The people and their activities, which do not pollute unless the people are occupying the building, such as the operation of office machines.
- 0 The building materials, furnishings, maintenance products, etc.
- 0 The HVAC system, and associated equipment.

There is not space to cover these in more detail, and others have done it better. Work in the U.S. sponsored by the Environmental Protection Agency, (EPA) and the Department of Energy, (DOE) is progressing such that soon there will be a catalog of materials and their outgassing potentials. The use of this type of reference will be invaluable to architects in selecting the most appropriate materials, and to engineers in devising ventilating systems to cope with problem situations.

Up-to-date HVAC System Information.

In addition to his usual professional information, well summarized in the ASHRAE Handbook series, and other documents, there are several issues which he should know more about, in my opinion. Much of this information can be found in the ASHRAE Handbook, but it is not aggregated in an "air quality" format, for easy reference by the practitioner. Also recent research has indicated important new considerations, which need more attention.

The practitioner should review the following:

0 Information (from ASHRAE and Others) on:
- 0 System Design Concepts
- 0 System Operation
- 0 System Maintenance

System operation and maintenance have been implicated in many cases as being the cause of "sick" buildings. Accumulated dust, moisture, etc. can become "environmental niches" for the rapid growth of micro-organisms, molds, etc. which can be dislodged and enter the air stream. some of these materials are pathogenic or allergenic, and can also be odorous, and just plain annoying. The HVAC system's purpose is to move air, and therefore any contaminant located within it has a larger probability of becoming airborne than contaminants located within the space.

Recent work by Fanger, (Berlin, 1987, see Bibliography,) has documented, for 20 more or less random non-residential buildings in Copenhagen that the HVAC system contributed, on the average, about twice as much to the subjective annoyance of the inside environment as the people who ordinarily occupied the space! In fact, he concludes that for some buildings, the inside environment would be more acceptable if the HVAC system were shut off, and only the resulting infiltration was used to dilute the contamination! Other work has also often implicated the HVAC system as being a significant contributor to "sick" building problems.

These new results indicate to me that much more attention should be paid to HVAC system design, operation and maintenance, both for new buildings and for existing buildings.

- Particulate Air Cleaners
  These can also become "environmental niches" if not kept clean. ASHRAE Standard 52-1981 describes test methods to assist the practitioner to evaluate their performance.

- Gaseous Removal Equipment
  No standards exist for performance in general ventilating systems. Manufacturers data should be critically evaluated.

- Heat Reclaim Methods and Equipment
  Important for energy conservation, there are many types to be evaluated, and their impact on IAQ should be considered.

- Ventilation Concepts
  Local exhaust concepts, and some newer ones, such as ventilation effectiveness, (ASHRAE has a standard for evaluating ventilating effectiveness under development, SPC 129P), and differential pressure control for pollutant migration control in spaces may also be used.

- Variable Air Volume (VAV) Systems
  These popular energy-conserving systems are in wide use. However they require special IAQ attention. It is difficult, if not impossible to insure that the correct rate of OA is delivered to each zone under all operating conditions. Different occupancy loads and other system sensible and latent loads are problems, and most systems have several VAV boxes on each air handling system. ASHRAE Standard 62-1981R recognizes this and includes guidance information.

I have chosen to mention only a few considerations which I believe to be very important, but of course, the practitioner must know much more.

The Prescription for a Healthy HVAC System

The following items should be taken into account on all new projects, as well as renovations, where possible.

- In the Planning Phase --
  - Work with the Architect/Owner --

- 0 Establish best estimates of planned and future uses of spaces, and their occupancy and process loads.
- 0 Investigate the materials to be used for their possible pollutant contributions. Ask the material suppliers.
- 0 Similarly investigate furnishings and other materials.
- 0 Ask questions -- You or the architect cannot possibly know all the answers, but the suppliers should also be asked to provide information on what and how much pollutants may outgas from their products.

0 System Design Considerations --

- 0 Select Design OA Rates for Zones --
  - 0 Use best estimates from ASHRAE Standard 62-1981 and 62-1981R.
  - 0 Check building codes and reconcile differences.
  - 0 Use a minimum OA rate of 15cfm/person, (7.5 L/s/person).
  - 0 If ventilation effectiveness is expected to be much less than 1.0, increase the OA rates inversely. This is a judgment call. Small office cubicles 1.5 m high, for example, impede mixing in spaces and in some measured cases have created situations where the ventilation effectiveness has been as low as 0.5! Recent Scandinavian work has shown promise for design of ceiling-mounted diffusers which have greater aspiration, and mixing ability. Such new designs should be investigated.

- 0 Other Considerations--
  - 0 Minimize building exhaust recycling into intakes, and intake locations which can induce pollutant intake from loading docks, local exhausts from restrooms, kitchens, etc. Discussions with the architect/owner should resolve these problems insofar as possible.
  - 0 Consider local exhausts for special situations, and provisions for adding some in the future. Local exhaust systems used near concentrations of machines, for example, has been a solution to some specific problems.
  - 0 Consider differential pressure control to prevent contamination from, say, a smoking area, from permeating other areas.
  - 0 Provide means to increase or decrease OA rates in the future as the space uses may change.

- 0 Energy Considerations --
  - 0 Consider heat reclaim equipment -- ASHRAE Standard 84 gives test methods for such equipment.
  - 0 Consider treating the return air, where appropriate, with particulate filters, (ASHRAE Standard 52) and gaseous removal equipment, to minimize the use of OA, but the minimum of 15 cfm/person, (7.5 L/s/person) should be used. (ASHRAE Standard 62-1981R gives guidelines.)
  - 0 Consider OA control for variable occupancy and lead- lag- shutdown and startup. Controlling OA rates according to the number of people in the space is becoming more practically possible. (ASHRAE Standard 62-1981R gives guidance here as well.)

- 0 Air Handling System Design --
  - 0 Select materials which do not produce or promote contaminants. Non-metallic duct linings can produce air-borne particles and also collect dirt and bio-organisms which can multiply there under some conditions, and become airborne again.
  - 0 Avoid standing water in condensate drains, equipment rooms, ducts, etc. Be sure condensate drains drain dry! Standing water has been implicated in many IAQ problems, since some airborne particles lodge there. Under the proper temperature and other conditions, rapid growth can occur, and large quantities of bio-matter can be entrained in the duct system. Even condensate pans in terminal, under-window units have caused problems.
  - 0 Where sumps are necessary, proceedures for treating the water for bio-matter control should be provided.
  - 0 Provide easy access for equipment maintenance and cleaning, including the ducts. The buildup of dirt in the system over time has also fostered bio-matter growth which has been a cause of problems. Even new ductwork probably will contain dead pidgeons, fragments of workers lunches, etc., which could be problems, as well as barriers to proper airflow.
  - 0 Easy access should also be provided for testing and checking instruments for system commisioning,(ASHRAE is developing a Guideline, GPC 1P), and testing and balancing, (ASHRAE is developing a Standard, SPC 111P).

- 0 Documentation --
  - 0 Include records of your design choices and the rationale behind them. This is particularly important if constraints on the project have dictated changes in your best estimates.
  - 0 Include complete operational proceedures to ensure operation as designed, even if these are not your responsibility.
  - 0 Include recommended maintenance proceedures, filter maintenance and replacement, coil cleaning, sump cleaning, etc. are particularly important to trouble-free operation over time.

In at least one case, a system operation was modified by a subsequent addition of an energy conservation operational system. IAQ problems developed, and consultants were called in. After an extensive and expensive study, the problem was apparently solved by simply restoring the system to its originally designed OA rates and distibution, and providing thorough maintenance!

Conclusions

Indoor air quality problems will persist and increase in the near future for the HVAC practitioner. Being knowledgable of the field and of the problems IAQ can produce, and applying that knowledge will go a long way toward discharging his responsibility. When conditions are outside his control, due to economics or other constraints, he should be very careful to document his conclusions, and be sure to transmit important information to the responsible parties.

There are many actions the practitioner can take now, and he should prepare himself to apply new proceedures as soon as possible.

The field is changing rapidly as new research results are released, and a concerted effort should be made to keep informed about new developments.

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