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IAQ-BASED HVAC DESIGN CRITERIA

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ABSTRACT

HVAC design criteria that have evolved during the past 20 years have focused increasingly on energy conservation. The increased use of variable air volume systems (VAV) was recommended during the late 1960s due to the energy conservation and resulting economy of operation they provide. Thermal control design criteria were emphasized rather than ventilation. The energy conservation objectives of post-1973 HVAC designs increased this trend. Currently, increased attention to indoor air quality (IAQ) has resulted in changes in criteria and shifts in HVAC design practices.

This paper examines the criteria now used and the ways in which they affect design and HVAC performance and presents a discussion of IAQ-based design criteria. Project specific criteria should be developed and evaluated in terms of available HVAC components and systems. Generally applicable criteria will be developed in the future.

INTRODUCTION

Since the mid-19th century advent of mechanical building ventilation and, later, combined ventilating, heating, and air-conditioning (HVAC) equipment in buildings, ventilation systems have been designed according to evolving criteria. Among these criteria are the provision of adequate oxygen, the control of carbon dioxide air levels, and the control of odor from human biofluents (Banham 1986; Bevirt 1984; ASHRAE 1986). But the dominant design criterion in modern systems has been regulation of the thermal environment.

During the past 20 or 30 years, HVAC design criteria increasingly have focused on achieving building energy conservation goals and objectives (Kinsey and Sharp 1964; McGuiness et al 1980: Stein et al 1986: Rodahl 1987) and on reduction of construction costs. Different equipment options and design strategies also have evolved to achieve objectives designers and clients (Banham 1984, Rodahl 1987). But most design criteria and strategies now in common use focus on control of the thermal environment and on lowering first costs for HVAC equipment. The result is insufficient concern for other aspects of HVAC system design including indoor air quality.

The use of variable air volume systems (VAV) was promoted during the late 1960s due to their energy-conserving performance and resulting operational economy (Kinsey and Sharp 1964). By reducing outside air supply volumes and distributed air volumes when not required for thermal regulation of interior spaces, smaller volumes of outside air requiring conditioning are used, thus reducing the cost of heating, cooling, or controlling humidity of outside supply air. By recirculating interior space exhaust air, air movement or circulation is achieved without increasing the outside air volume that must be conditioned. However, in conditions of extremely warm or cold outside air temperatures or minimal interior space thermal conditioning requirements, volumes of outside supply and space distribution air can become too low to maintain acceptable indoor air quality.

As early as 1969, reports of indoor/outdoor air quality relationships indicated that indoor air was often worse than outdoor air, even in polluted exterior environments (Yocum et al 1969). However, the significance of that finding (which has been validated many times in recent years and for many pollutants) was not widely recognized until indoor air quality problems abounded in the late 1970s.

Energy supply shortages and cost increases following the 1973 Arab oil embargo resulted in intensified efforts to conserve energy. In buildings this often meant reducing outside air supply, either through mechanical systems or through leakage in the building envelope. Radical reductions in air exchange rates that conserved energy also increased concentrations of many indoor air contaminants. Occupant complaints of illness and discomfort accelerated efforts to characterize and improve indoor air quality. The results were clear. Since the late 1970s, growing interest in indoor air quality and improved methods for measurement of indoor air pollutants have produced powerful evidence that indoor air quality must be more thoroughly considered in buildings with low ventilation.

The four principal control methods for indoor air quality are (1) pollutant source elimination or modification, (2) outside air supply, (3) air cleaning, and (4) space air distribution (ASHRAE 1987). Source control is outside the scope of this discussion. The other three methods are elements of ventilation and are the principal concerns of this paper.

INDOOR AIR QUALITY CONTROL

Background and Terminology

The performance standards for the completed building are referred to in architectural terms as parts of the building "program" which represents the owner's or client's requirements to the design and construction team. The overall building design as well as the individual building components and systems are developed to meet the program requirements. All too often, important aspects of the building program are left vague or unspecified. Others are addressed by codes, regulations, industry standards, and design guidelines that are implicit program elements. Elements of the program that take the form of measurable or testable requirements against which the design and the completed building can be evaluated are the "design criteria."

The objective of building ventilation is maintenance of acceptable air quality in the zone of occupancy. The achievement of this objective is measured against set standards. These standards include thermal and contaminant parameters that are the design criteria related to meeting the overall objective of acceptable indoor air quality. The design, construction, and operation of building ventilation are evaluated against the design criteria.

The contents of ASHRAE Standard 62-1981 are an implicit part of the design criteria. Designers utilize the standard along with cost and other considerations to evaluate proposed designs and to select and detail the final design. However, practical means for evaluating the performance of actual buildings using these criteria are not specified. They serve primarily as design criteria.

The State of California Occupational Safety and Health Division of the Department of Industrial Relations deliberated adoption of ASHRAE Standard 62-1981 for existing buildings. Among the most difficult issues it faced were the measurement of compliance and the mechanism for enforcement. Yet many investigators of problem buildings or buildings with air quality complaints utilize the elements of Standard 62-1981 as a guideline.

The Design Process

Apart from source control, indoor air quality is controlled principally by the volume of outside air introduced, the quality (or contaminant levels) of distributed air (both outside air and recirculated air), and the distribution of the air within the building spaces. Selecting and combining system elements during HVAC design require the consideration of these mechanisms in combination with each other and for the proposed building plan, section, and materials. The process must also address the contaminants that will be generated by the building and brought in from outdoors, and the anticipated occupant uses and activity patterns. This can be facilitated by identifying the source distribution by contaminant type or class or removal mechanism.

Source distribution involves the spatial and temporal characteristics of contaminant entry or emission into building air. Broad source categories include the base building, occupants and their activities, outside air, maintenance and repair activities, and episodic sources. Table 1 lists the major sources by spatial and temporal categories.

IAQ-RELATED HVAC DESIGN CRITERIA NOW USED AND POSSIBLE CHANGES

Outside Air Supply

Since the inception of ASHRAE's predecessor organization, ASHVE, outside air supply rates have been the subject of guidelines and standards. Recently, in order to avoid excessive energy costs and consumption associated with unnecessary or ineffective ventilation, efforts have been made to develop minimum acceptable ventilation rates for indoor air quality. These rates were adopted and published by ASHRAE as Standard 62-73 and 62-1981. The 62-73 rates were also incorporated in ASHRAE's energy conservation standard, 90-75. In 1981, specified levels of specific contaminants were also part of the standard, and the quality of outside air was not assumed acceptable without validation by the designer (ASHRAE 1973, 1975, 1981).

Results of research and investigations of problem buildings have been used (directly or indirectly) to evaluate the recommended ventilation rates. The result is an increase from 5 cfm to 15 cfm per occupant in the currently proposed revision. Generally, it was found that 5 cfm per occupant did not provide adequate outside air supply to achieve comfort and avoid complaints related to indoor air quality. Additionally, under certain conditions, contaminant levels were found to rise above accepted or recommended levels when outside air supply levels were less than 15 cfm per occupant (ASHRAE 1986).

Several issues exist concerning outside air supply volumes which require attention. Many recently constructed existing buildings or buildings now under construction are designed to provide 5 cfm per person. Building HVAC systems designed and constructed using 5 cfm per occupant for design are not likely to have the capacity to provide the 15 cfm per occupant recommended in the currently proposed standard. This will present problems if it is determined that indoor air quality is unacceptable due to insufficient ventilation.

While existing buildings are not required to meet the new standards, over time, occupant expectations of indoor air quality may result in local or state governmental actions related to indoor air quality. With increased public awareness and understanding of indoor air quality considerations, issues will emerge that have not yet been articulated. For example, maximum specific contaminant levels may be adopted as the human physiological and health effects of contaminants become better understood. This will result in the need to modify HVAC systems to achieve compliance.

This may not be a problem in all such buildings, but further evaluative work needs to be done to determine whether modifications are warranted and can be effective. These modifications may involve the use of one or more of the following: supplemental air cleaning; modified space air distribution; additional heating, cooling, and humidity control capacity; modified control system installations; and modified system operation programming.

An issue that has not been addressed in the ventilation standards is the possible discrepancy between outside air supply volumes at building supply fans, at difusers, and in the occupants' breathing zone. Design procedures implicitly assume that air passing through the diffuser is what is delivered to the occupants. However, research on ventilation effectiveness and ventilation efficiency suggest that this is usually not the case. Different interior layouts, ceiling heights, HVAC layouts, and operational conditions will result in the delivery of different quantities of outside air in the breathing zone of building occupants. This problem has only relatively recently been addressed by researchers and some designers. This work will be discussed below under "ventilation efficiency."

Air Cleaning

Sufficient technology (knowledge and hardware) exists to clean air to meet virtually any standards. However, cost-effective removal of some gaseous contaminants and very small particles is not available for buildings of normal occupancy--residences, offices, schools, stores, public assembly buildings, etc. Therefore, designers must develop designs using criteria based on the best available information regarding the negative impacts of indoor air contaminants and the technology available to reduce or eliminate their concentrations. Currently, where insufficient information exists about the negative impacts of particular substances, designs tend to not provide for their removal. Thus, by default, the operative design criterion driving air-cleaning design decisions is control of those substances about which sufficient information exists to warrant it. Unfortunately, insufficient information exists about the negative impacts of most identified indoor air contaminants at their characteristic levels, and the costs of unnecessary removal can be large.

Air cleaning is not as selective as we might like it to be, and we often remove more than the target contaminant by the use of air-cleaning technology. This results in additional costs of equipment and operation, which may be significant.

The technology available for clean rooms used in "high tech" industries is not considered affordable for wider application. In effect, this means that our understanding of the negative impacts of small-particle air contamination does not warrant the very large expense for equipment and operating costs to remove them in most buildings.

Some sophisticated work on this subject has been done by Weschler and co-workers for telephone equipment buildings (1986). Designers of spacecraft for long-term human occupancy have addressed the problem, but cost considerations are quite different from those in most building designs. Technological innovations and information on the negative health and other impacts of contaminants will allow more cost-effective use of air cleaning.

The trade-offs between cleaning and recirculating return air and conditioning and circulating outside air vary greatly from case to case. The critical factors are the thermal properties and contaminant contents of both the outside air and the return air relative to the design conditions. More information should be developed to assist designers in establishing criteria to be used in making these design decisions.

<u>Space Air Distribution</u>

This method of indoor contaminant control has a large potential for significant improvement in ventilation efficiency and, thereby, in indoor air quality. However, current designs dominated by thermal regulation criteria (as well as cost constraints) have not adequately considered space air distribution in terms of non-thermal contaminant control.

Problems in modeling space air distribution include typical design situations where the layout of interior partitions and furnishings is not known at the time of the overall HVAC design. Typically, the design of many office buildings occurs in two distinct and disjointed phases. The overall base building design is completed by one entity and the interior layouts, including the local HVAC distribution system, are designed by another at a later time. The first engineer does not have necessary information on detailed space utilization, layout, furnishings, etc., and the second engineer does not have the latitude to modify components in the base building.

The problem described above can be overcome by a number of methods. The base building HVAC designer can require a more detailed program statement that clarifies the range of possible occupant densities, activities, and layouts. This program statement becomes a part of the building design documentation, and the design assumptions and decisions can be documented according to the program statement. If, at the point of design of the local distribution system, changes are made in the original program, the corresponding changes can be required, where necessary, in the base building HVAC system.

Modeling the performance of the distribution system with detailed plans for interior partitions and furnishings can be performed either mathematically or empirically. Additional work will be needed to translate the findings of researchers into practical procedures for designers wishing to mathematically model distribution system design to determine ventilation efficiency. Such work should receive high priority from those who are funding research activities. Test facilties available to perform field studies of proposed systems will develop as the needs for their services grows. Commercial test facitlities already exist to test the thermal performance of HVAC systems and exterior wall systems. They can easily be adapted to test ventilation efficiency.

TOWARDS IAQ-BASED DESIGN CRITERIA

Economic Considerations

The cost of financing for the past 20 years has placed a premium on capital. Therefore, construction costs are often minimized and operational costs are burdened. As energy costs rose in the mid- to late 1970s, increased emphasis on minimizing operational costs became important in design criteria. Currently, stable energy costs have reversed this trend, although the reversal may be temporary. As demands for better air quality result in increased attention to and emphasis on HVAC system performance, additional funding may become available for the design and construction as well as the operation of HVAC systems.

Health Considerations

As time passes, new information is developed on the health effects of exposure to indoor air contaminants. In general, the trend appears to be that additional information results in increased concern about most contaminants. To the extent that this is true, additional support can be expected for effective indoor air quality control. Smaller tolerance for failure in system performance will support effective on-line monitoring connected to system controls. Backup systems or multiple strategies for operation may become more common, particularly in sealed buildings with only mechanical ventilation.

IAQ-Based Design Criteria

General Criterion. The design of the HVAC system and the timing of its operation (or the phases and components of its operation) must be responsive to the temporal and spatial distribution of sources of indoor air contaminants.

The development of systems to meet this criterion and all of the detailed criteria that derive from it requires improvements in the design process in making trade-offs among the major indoor air quality control measures. The concept that can help unify the process is ventilation efficiency.

Ventilation Efficiency. Researchers have developed the concepts of "ventilation efficiency" and "ventilation effectiveness" as two different measures of the ability of the HVAC system to provide adequate ventilation to building occupants. The types of measurements determine the nature of the results. Persily (1986) identified the two major ventilation efficiency categories as those that quantify the distribution of supply air and those that quantify pollutant-removal effectiveness. The results of this work indicate that most building ventilation systems actually perform at far less than 100% efficiency in delivering adequate outside air to maintain acceptable indoor air quality.

Many researchers reporting on ventilation efficiency and theoretical work on ventilation effectiveness, as well as laboratory and field studies, have found large variations in the removal rates of pollutants or the distribution of outside supply air. However, the results of their findings have not been observed to impact the design of most HVAC systems. That is, design criteria have not reflected concern about the efficiency or effectiveness of ventilation. This paper does not propose specific factors for target or guideline ventilation efficiency or ventilation effectiveness. It does suggest that designs be evaluated according to their predicted ventilation efficiency (modeled mathematically or in a mock-up).

CONCLUSION

Building projects vary significantly and at this time, a generally applicable set of IAQ-based design criteria cannot be specified. However, as specific criteria are developed for various projects and their utility is tested in actual designs, researchers and professionals will be able to develop general criteria in the future.

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