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Environmental Energy Technologies Division

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ABSTRACT

Minimum outdoor air ventilation rates (VRs) for buildings are specified in standards, including California's Title 24 standards. The ASHRAE ventilation standard includes two options for mechanically-ventilated buildings – a prescriptive ventilation rate procedure (VRP) that specifies minimum VRs that vary among occupancy classes, and a performance-based indoor air quality procedure (IAQP) that may result in lower VRs than the VRP, with associated energy savings, if IAQ meeting specified criteria can be demonstrated. The California Energy Commission has been considering the addition of an IAQP to the Title 24 standards. This paper, based on a review of prior data and new analyses of the IAQP, evaluates four future options for Title 24: no IAQP; adding an alternate VRP, adding an equivalent indoor air quality procedure (EIAQP), and adding an improved ASHRAE-like IAQP. Criteria were established for selecting among options, and feedback was obtained in a workshop of stakeholders. Based on this review, the addition of an alternate VRP is recommended. This procedure would allow lower minimum VRs if a specified set of actions were taken to maintain acceptable IAQ. An alternate VRP could also be a valuable supplement to ASHRAE's ventilation standard.

BACKGROUND AND REVIEW OF EXISTING INFORMATION

Current Standards

ASHRAE Standard 62.1-2010 (ASHRAE 2010) provides two alternative procedures for selecting minimum ventilation rates (VRs) for zones of mechanically-ventilated commercial buildings. In the "ventilation rate procedure" (VRP), users adopt a prescriptive minimum VR selected from a table, with indoor air quality (IAQ) assumed to be acceptable at that VR, regardless of the building's features. The prescribed minimum VRs differ by occupancy category and are the sum of two quantities: a minimum outdoor air flow per unit floor area, and a minimum outdoor air flow per occupant. Prescribed VRs, historically, were the rates needed to maintain visitor satisfaction with odors from occupants, but more recently represent rates needed to satisfy occupants and have, in limited ways, considered indoor emissions from both occupants and the building itself. The VRP yields minimum VRs for the various building zones and a procedure for using the zone-level VRs to determine the outdoor air flows, which can be used to specify HVAC system sizing during the design phase of a new building.

Standard 62.1 also includes an alternative (and rarely used) "indoor air quality procedure" (IAQP), with both objective and subjective components, intended to provide greater flexibility and potentially enable energy savings. In contrast to the VRP, the IAQP is a performance-based design approach that does not prescribe specific VRs by building use. The IAQP allows flexibility in the approaches used to achieve adequate levels of indoor air quality (IAQ), possibly including combinations of outdoor air ventilation, indoor contaminant source control, air cleaning, or other strategies. Application of a comprehensive

IAQP protocol (including both objective and subjective assessments of IAQ) is performed in stages, with the final stage occurring after the building is constructed and occupied. The first step in the IAQP is to specify a set[1] of contaminants of concern (CoCs) and for each a concentration limit (CL) from a cognizant authority. CoCs may have indoor or outdoor sources. The CLs are indoor concentrations not to be exceeded. Users of the IAQP are free to select which contaminants are considered and which CLs are used to determine their maximum concentrations. To satisfy the objective component of the IAQP, indoor source strengths of each CoC must be calculated based on predicted contaminant emissions from building materials and contents. Outdoor air pollutant concentrations are determined from available air quality data. Using mass balance models to predict indoor CoC concentrations, an overall IAQ control strategy must then be identified that will maintain indoor concentrations of all CoCs below CLs. The IAQP allows VRs lower than those specified in the VRP, if the designer can demonstrate that, at that lower VR, all CoC concentrations would be below selected CLs. Once this design strategy is applied, and the building is constructed and occupied, a subjective test of the perceived air quality is performed to demonstrate that visitors and/or occupants are "satisfied" with the air quality. The IAQP provides guidance but does not specify the procedure for assessing satisfaction with air quality and it is up to the user to select the level of satisfaction that must be provided. Subjective assessments of IAQ are normally based on survey responses, collected either from occupants after a period of time in the building (adapted responses) or from panels of simulated visitors immediately after they enter the building (unadapted responses).

The IAQP is designed to allow minimum VRs that will maintain indoor contaminant concentrations below targets and that also maintain subjectively assessed acceptable IAQ, without over-ventilating and wasting energy. While the IAQP may allow VRs to be reduced relative to those required by the VRP, application of the IAQP in some circumstances may require higher VRs. Although the IAQP has been used to a limited extent, at least one large retail chain uses the IAQP to specify the minimum ventilation requirements for approximately 800 of its stores (Grimsrud, Carlson et al. 2011) throughout the U.S. In this case, the applied IAQP-based VRs were significantly lower than the VRs prescribed in the VRP.

California's Title 24 building efficiency standards (California Energy Commission 2008) mandate minimum prescribed VRs for commercial buildings. Title 24 standards currently include a prescriptive procedure similar to ASHRAE's prescriptive VRP, but do not include an alternative procedure, akin to ASHRAE's IAQP. In California, there is ongoing consideration of the merit of incorporating an IAQP-like procedure into the state's Title 24 building efficiency standards.

Published IAQP Case Studies

Relatively few published evaluations of the IAQP were identified. Grimsrud, Bridges et al. (1999) applied the IAQP to a large retail store in Minnesota. Indoor contaminant concentrations and ventilation rates were measured over nine 48-h periods spaced throughout a year. The CLs and CoCs, selected from the then-current public review draft of ASHRAE Standard 62, included 1000 ppm for carbon dioxide, 9 ppm for carbon monoxide, 50 $\mu g/m^3$ for particles, 120 $\mu g/m^3$ for formaldehyde, and 1000 $\mu g/m^3$ for total volatile organic compounds (TVOCs). Based on analyses, not explained in detail, the IAQP VR was 0.5 L/s-m^2 which was one third of the 1.5 L/s-m^2 required when applying ASHRAE's VRP. The IAQP VR was driven by the need to limit indoor concentrations of TVOCs, and cleaning activities were identified as a

[1] The IAQP is actually more complicated than described above, because it requires a consideration of mixtures of contaminants; however, in practice the effects of mixtures is generally ignored. The case studies of the IAQP described subsequently did not consider mixtures of contaminants, or addressed mixtures in only a cursory manner. To simplify the discussion in this paper, mixtures are not considered. Conclusions would most likely be unchanged if mixtures had been considered.

major source of TVOC. The calculation of the IAQP VR neglected brief night-time spikes in indoor concentrations of carbon monoxide and particles linked to a propane-powered floor burnisher. Very similar methods were subsequently employed to determine IAQP ventilation rates in three additional large retail stores owned by the same corporation (Grimsrud, Carlson et al. 2011), although the selected CL for formaldehyde was slightly lower (100 µg/m^3). Maintaining formaldehyde levels below the selected CL of 100 µg/m^3 resulted in an IAQP VR of 0.35 L/s-m^2, with less ventilation required to maintain other CoCs below their selected CLs.

Stanley and Lamping (2008) describe a case study of applying the IAQP in the wing of a high school located in a hot and humid U.S. climate zone. In this application, VRs were reduced to 2.5 L/s per person and filters containing activated carbon and potassium permanganate were used to remove selected air pollutants. Eleven CoCs were selected and calculations indicated that indoor concentrations of these CoCs would be maintained below the selected CLs. The selected CL for formaldehyde, from Health Canada, was 120 µg/m^3. With a reduced VR plus air cleaning, modeled ammonia and phenol concentrations were about 50% of their respective CLs, 500 and 100 µg/m^3, respectively. Modeled concentrations of other CoCs were smaller percentages of their respective CLs. After implementation, indoor concentrations of some of the CoCs were measured in five classrooms on a single day. The measured concentrations were below the selected CLs. Indoor concentrations of formaldehyde, often considered a key CoC, were not measured. An analysis of data from a complaint log indicated complaints before, but not after, implementation of the IAQP.

Lamping and Muller (2009) briefly describe modeling to evaluate use of the IAQP in four schools located in San Antonio, TX. The modeled IAQP incorporated particle and gas-phase filtration and reduced VRs by approximately 70% to 2.5 to 3.5 L/s per person. Predicted indoor concentrations of formaldehyde and nitrogen dioxide were lower with application of the IAQP than in the base case VRP, and were also reported as below the target CLs; however, the CLs were not specified. Predicted HVAC energy savings were 51% to 65%. The same paper describes the use of models to evaluate application of the IAQP to a lecture hall, a retail store, a movie theatre, and an office building. The locations of these buildings were not specified. In each case a reduction in VR was coupled with application of particle and gas-phase air cleaning. The selected CoCs varied among the buildings. For the lecture hall and office building, the CL selected for formaldehyde was 120 µg/m^3. The CLs employed for the retail buildings were not specified and formaldehyde was not considered a CoC for the movie theatre, presumably because contaminant emissions from occupants were assumed to drive the need for ventilation. The analysis evaluated reductions in VR from 54% to 75% to 2.5 L/s per person in the lecture hall, movie theatre, and office building. The text provided unclear information on the final VR in the retail building. The modeling indicated that indoor concentrations of CoCs would be maintained below selected CLs in all cases. The projected annual energy cost savings in the movie theatre was $23,000 (percentage not given) with an $8000 annual cost for air cleaning. The projected annual energy cost savings in the office was $11,000 (percentage not given), with an annual air cleaning cost of $21,000, resulting in a $10,000 annual increase in operating costs. However, the reductions in HVAC capital costs enabled by use of the IAQP offset 28 years of increased operational costs. The authors concluded that use of the IAQP with reduced VRs and air cleaning can significantly reduce HVAC capital costs and energy costs.

Stanke (2012) described the process for implementing the IAQP in detail but included no evaluation other than stating that it “requires designers to make many judgments” and that consequently “the required minimum outdoor air rates found using the IAQP are likely to vary considerably from one designer to the next.”

To evaluate the potential energy and IAQ implications of the IAQP, Apte, Mendell et al. (2011) modeled indoor contaminant levels and energy use in a large “Big-Box” retail store at three different VRs. The three VRs were: a low rate of 0.2 L/s-m^2 reported as considered for use in some Big-Box stores; 1.2 L/s-m^2 from ASHRAE Standard 62.1-2007 (ASHRAE 2007) assuming the default occupant density; and 0.7 L/s-m^2, which equals the midpoint between these two values. A set of CoCs was selected based on a comparison of published indoor contaminant concentrations to available CLs from the California EPA and other authorities. Estimated concentrations of these CoCs were compared with the lowest available health, olfactory, and irritant CLs. The highest VR maintained all modeled indoor contaminant concentrations below the selected CLs, but the lowest VR did not, and the midpoint VR did so only marginally. Higher VRs increased indoor concentrations of some outdoor-sourced air pollutants. Lowering VRs in Big Box stores in California from 1.2 L/s-m^2 to 0.2 L/s-m^2 was estimated to reduce total energy use by 6.6% and to reduce energy costs by 2.5%. The authors concluded that indoor pollutant source reduction, air cleaning, and local ventilation may be needed at reduced VRs, and even at the current recommended VRs.

Dutton, Chan et al. (2013) describe research to evaluate indoor air quality in a large Big-Box retail store using both the objective and subjective IAQP assessments. In addition, the report describes application of the objective IAQP assessment to 12 additional retail stores. The lowest available CLs for selected COCs were used in this work. All of the stores were located in California. Key findings of Dutton, Chan et al. (2013) follow:

> Calculations of IAQP-based VRs showed that for the BIg-Box store and 11 of the 12 other stores, neither the building's current measured VR, nor the Title 24-prescribed VR, would be sufficient to maintain indoor concentrations of all CoCs below the selected stringent CLs.
>
> Calculated IAQP VRs – i.e., the VRs needed to maintain all CoCs below the selected CLs – were often well above the minimum VR specified in Title 24. For many stores, the IAQP VR, assuming no indoor pollutant source reduction and no application of gas-phase air cleaning, was several times higher than the Title 24 VR. Thus, based on these analyses the IAQP did not provide a broad opportunity for VR reductions and associated energy savings in stores unless pollutant source reduction or gas-phase air cleaning were utilized.
>
> In most stores, IAQP VRs were determined by the need to meet California's stringent 9 µg/m^3 CL for formaldehyde. Even when applying the higher 16 µg/m^3 CL for formaldehyde from the National Institute for Occupational Safety and Health, formaldehyde remained the driver for IAQP VRs in the majority of stores.
>
> Ventilation was found to be generally ineffective for maintaining indoor particle levels below applicable CLs, because outdoor air was often the largest source of particles and because outdoor air particle concentrations often exceeded the particle CL. Filtration was indicated as a more effective method than ventilation in controlling indoor particle levels.
>
> Within the Big-Box store, with the calculated IAQP-based VR applied, measurements indicated that all CoCs were controlled below CLs (within margins of error); however, the IAQP-based VR exceeded the VR specified in Title 24. At all three studied VRs, including a rate below that prescribed in Title 24, the percentage of subjects reporting acceptable air quality exceeded an 80% criterion of acceptability.

The case studies described above have selected different CoCs and CLs. The CoCs and CLs selected are important determinants of IAQP VRs, with the CL for formaldehyde particularly influential. The first four case studies described above (Grimsrud, Bridges et al. 1999, Stanley and Lamping 2008, Lamping and Muller 2009, Grimsrud, Carlson et al. 2011) used 100 or 120 µg/m^3 as CLs for formaldehyde and found that IAQP VRs were substantially less than the minimum VRs specified in ASHRAE's VRP. The 100 µg/m^3

limit is from a committee of the World Health Organization and the 120 μg/m^3 limit is from Health Canada. The subsequent two studies (Apte, Mendell et al. 2011, Dutton, Chan et al. 2013) applied generally stricter CLs, including, for formaldehyde, the California Environmental Protection Agency's 9 μg/m^3 limit (California EPA) and the 16 μg/m^3 limit of National Institute for Occupational Safety and Health. These studies found that IAQP VRs were generally higher than the minimum VRs specified in ASHRAE's VRP and California's Title 24 standards.

Dutton, Chan et al. (2013) and Mendell and Apte (2011) have pointed out limitations of ASHRAE's IAQP. At present, the users of the ASHRAE IAQP have complete flexibility to select "critical contaminants" and CLs. Many users will not have the necessary expertise to select the contaminants most relevant to occupants' health and sensory satisfaction. Also, use of the IAQP is hampered by limitations in current data on indoor pollutant emission rates and air cleaner performance. Designers did not use the IAQP because they felt its flexibility, and the novel expertise and data required, would expose them to liability for designs that failed in practice to provide the specified level of IAQ. In contrast, the exposure to liability was less when applying the highly prescriptive VRP. Also, there are no constraints that prevent a designer using the IAQP from making selections that provide whatever answer they desire. ASHRAE's IAQP requires that the user select a minimum level of acceptability for IAQ, interpreted as the minimum percentage of occupants satisfied with IAQ. The protocol requires a "subjective occupant evaluation conducted in the completed building to determine the minimum outdoor airflow rates required to achieve the level of acceptability specified". This subjective test of acceptability is often considered impractical because of the costs, and skills required for implementation. Also, few IAQP users will have the expertise needed to implement the subjective test. These two papers also describe some limitations of VRPs, which are assumed to provide adequate IAQ. Because VRPs do not consider the strength of indoor pollutant sources, they provide no guarantee of adequate IAQ. Also, because VRPs consider neither the specific indoor pollutants nor building features such as the use of air cleaning equipment, VRPs do not allow for reductions in prescribed VRs to save energy even in buildings with reduced indoor contaminant emission rates.

A limitation of VRPs is that they require no post occupancy evaluation (POE) of IAQ. The IAQP requires a POE only of satisfaction with IAQ. In theory, POEs of IAQ would enable adjustment of VRs, or implementation of other measures, as needed to meet IAQ targets, with a potential for energy savings. In practice, however, POEs for IAQ are likely to be considered impractical. Measurements of indoor contaminants are complex and expensive, requiring special tools and skills. Also, at present, the reasons why higher VRs are associated with reduced acute health symptoms, increased work performance, and decreased absence are not fully understood; thus, it is difficult to know what to measure in a POE. In the longer term, IAQ measurement methods may improve and become less costly, making POEs a viable element of strategies for balancing building energy and IAQ requirements.

METHODS FOR DEVELOPING RECOMMENDATION

Four IAQP-related options for Title 24 were formulated, based on the strengths and limitations of the current ASHRAE IAQP and VRP standards. These options were then presented and discussed in a workshop with the project advisory committee and other experts, including members of the committee responsible for ASHRAE Standard 62.1-2010. After obtaining feedback from workshop participants, criteria were selected for comparative evaluations of IAQP options, options were assessed relative to these criteria, and recommendations were developed regarding the incorporation of an IAQP in Title 24. These recommendations reflect the analyses and experimental evaluations of the IAQP that are summarized above, the comments of workshop attendees, and the judgment of the authors.

The criteria selected for evaluation of the IAQP options were as follows:

1. An IAQP, if adopted and properly and successfully implemented, should be at least as protective to occupant health as the current prescribed minimum VRs in Title 24.
2. To justify the effort that would be required of the California Energy Commission to develop an IAQP:
    a. Utilization of the IAQP must be expected to significantly improve IAQ or save energy.
    b. Significant adoption of the IAQP must be anticipated, which requires an IAQP that is practical to implement.
3. The risks and consequences of degraded IAQ, in instances of misuse or poor implementation of the IAQP, should not be substantially larger than the risks of poor IAQ with current procedures.
4. The potential for an IAQP to stimulate innovations in technology and practice that would lead to better IAQ and/or energy savings should be considered in the development of recommendations.

RESULTS

IAQP options

Four IAQP options for Title 24 were developed and presented in the workshop. This section describes the options and the feedback from workshop attendees.

Option 1, No IAQP: Title 24 does not adopt any form of an IAQP.

Option 2, Alternate VRP: Title 24 develops an alternate VRP with moderately (e.g. 30% to 40%) lower required minimum VRs plus mandatory implementation of multiple other IAQ control measures. Users would be allowed to choose between the existing specified minimum VRs in Title 24 and the alternate VRP. For this document, the mandatory additional measures have not been defined in detail; however, these measures would include: a) use of a high efficiency particle filtration system, e.g., filters with a MERV rating $\geq$ 11 (ASHRAE 2012); b) implementation of source control measures for volatile organic compounds, such as the measures specified in the LEED system, or implementation of gas-phase air cleaning that meets specified criteria for volatile organic compounds; and c) direct venting of combustion-generated pollutants to outdoors or capturing and venting combustion pollutants with a capture hood that meets specified criteria. These mandatory measures would be selected with the goal of providing better IAQ and a lower overall health risk than the current Title 24 requirements, while enabling energy savings. In many buildings, where outdoor sources of particles dominate, the high efficiency filter would not be needed to counteract the effects of reduced VRs on overall indoor particle concentrations; however, the high efficiency filter would assure that indoor air concentrations of particles from indoor sources do not increase. In addition, the high efficiency filter, together with reduced VRs, would diminish indoor exposures to particles from outdoor air, which are one of the larger known sources of adverse health risk. Note that the alternative VRP is not a performance-based procedure and thus, strictly speaking, is not an IAQP.

Option 3, Equivalent IAQ Procedure (EIAQP): Title 24 develops and adopts a procedure that allows reductions in VRs, up to a specified maximum amount (e.g., 50%), if the user demonstrates via mass balance calculations and/or experiments that indoor concentrations of all COCs (or mixtures of COCs) are maintained equivalent to or lower than concentrations expected from application of Title 24's specified minimum VRs. The EIAQP would specify a list of COC's. This procedure would enable use of air cleaning systems to compensate for reduced VRs, but like the current VRP it would not assure a specific level of IAQ. Users would need to demonstrate removal of all COCs by air cleaning at a rate sufficient to compensate for the decreased CoC removal resulting from the reduced VR.

Option 4, Improved ASHRAE-Like IAQP: Title 24 develops and adopts an IAQP similar to that specified in ASHRAE, but with COCs (or mixtures of COCs) and CLs specified. In addition, the procedure for measuring satisfaction with air quality and the minimum level of satisfaction would also be specified.

Feedback from Workshop Attendees

Attendees at the workshop provided variable feedback on the four options listed above. Most practitioners considered IAQPs impractical and indicated that they would be little used in California because of the moderate climate. Some health professionals expressed concerns that IAQPs were not sufficiently health protective or were subject to misuse or failures to achieve goals. Option 4 (improved IAQP) establishes a higher standard for IAQ than the current VRP and Option 3 (EIQP) requires equivalent IAQ; however, misuse and failures are possible. Some attendees indicated that they valued the potential of IAQPs to stimulate innovations in technologies and practices, and also to motivate building owners to pay more attention to IAQ. Two attendees clearly favored adoption of an IAQP. The overall level of support appeared to be highest for Options 1 (No IAQP) and 2 (Alternative VRP), as these were viewed as the most practical and to pose the lowest risks of degraded IAQ.

Evaluation of IAQP Options Relative to Criteria

Table 1 provides a subjective assessment, after considering the feedback obtained in the workshop, of each of the four options relative to the decision criteria. In this table, the symbols ++, +, –, – – indicate exceeds, meets, may fail, or likely fails the respective criterion. Option 1, not adding an IAQP and, thus, using only the Title 24 VRP, was the reference condition for the assessment. Based on this subjective evaluation, option 2, the alternate VRP, was projected to meet all criteria. By design it improves IAQ. The risks of poor IAQ were considered similar to the risks of poor IAQ when the reference-case VRP was applied. The option's limited flexibility and reliance on existing specified technologies reduce risks. Innovation can be stimulated through periodic revisions of the alternate VRP that open the door for new technologies and practices. Option 3, the equivalent IAQ procedure, was projected to meet criteria 1, 2, and 4, but to fail to meet both criterion 2b (significant adoption expected) and criterion 3 (acceptable risks). Option 3 was presumed to be infrequently adopted because of the complexity of implementation and to pose significant risks because of the uncertainty in long term performance of air cleaning systems for gaseous pollutants. In addition, the costs of maintaining the effectiveness of current gas phase air cleaning systems may lead to insufficient maintenance and degraded IAQ. Option 4, the improved ASHRAE-like IAQP, was projected to meet criteria 1, 2a, and 4. Because of its high degree of flexibility, this option has the largest theoretical IAQ and energy benefits. However, based on the limited extent of use of ASHRAE's IAQP, option 4 was considered unlikely to be significantly adopted. Additionally, the risks of degraded IAQ under option 4 were judged to be fairly high because of: a) current uncertainties in indoor pollutant emission rates; b) uncertainties about the long term performance of air cleaning for gaseous pollutants; and c) potential failures to maintain gas phase air cleaning systems.

Table 1. Assessment of IAQP options relative to decision criteria.

IAQP Option	Criterion				
	1. As Health Protective as Title 24*	2a. Energy Saved or IAQ Improved*	2b. Significant Adoption Expected	3. Acceptable Risks from Improper Implementation	4. Stimulus for Advances in Technology and Practice
1. No IAQP	Reference Condition	Reference Condition	Reference Condition	Reference Condition	Reference Condition
2. Alternative VRP	+ +	+	+	+	+
3. EIAQP	+	+	–	–	+**
4. Improved ASHRAE –like IAQP	++	++	– –	–	+**

*when the option is properly and successfully implemented

**would stimulate advances only if adoption rate is higher than anticipated

Symbols: ++ exceeds . . . ; + meets . . . ; – may fail . . . ; – – likely fails the criterion. .

RECOMMENDATIONS

Based on the evaluation of the IAQP options, the recommendation to the California Energy Commission is to pursue option 2 and develop an alternative VRP with the potential to save a modest amount of energy, improve IAQ, and stimulate advances in technology and practice. Future versions of ASHRAE's ventilation standard (ASHRAE 2010) might also benefit from addition of an alternative VRP. Application of the alternative VRP might be excluded for some occupancy categories with strong, complex, or poorly understood sources of contaminants. The risks associated with this option are low. We note, however, that the prediction of significant adoption is based solely on judgment. A survey could be implemented to obtain further information on the likely rate of adoption. Pursuing options 3 or 4 is not recommended, because of the expected low rates of adoption of these more complex options. As more data become available on indoor contaminant emission rates from building materials, products used in buildings, and people, and as more data on performance of gas phase air cleaners become available, options 3 and 4 may become increasingly feasible.

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