



A longitudinal study of ventilation rates in California office buildings and self-reported occupant outcomes including respiratory illness absence



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ABSTRACT

Background: Limited evidence has associated lower ventilation rates (VRs) in offices with higher illness-related absence rates.

Methods: We studied spaces in office buildings, selected without knowledge of their VRs, in three California climate zones. In each study space, real-time logging sensors measured carbon dioxide and thermal parameters for one year. Web-based surveys every three months collected data on occupants' health outcomes. Using multivariate models, relationships were assessed between CO₂ concentrations, or VRs estimated from CO₂, and adverse occupant outcomes including respiratory infections and illness absences. For all outcomes, positive associations were hypothesized with higher CO₂ levels (and negative associations with higher VRs).

Results: Low survey response limited sample size and study power. In the 16 study spaces, CO₂ concentrations were uniformly low over the year, and most estimated VRs ranged from twice to nine times the California office minimum VR standard (7 L/s or 15 cfm per person). Primary CO₂ and VR metrics had no statistically significant relationships with occupant outcomes.

Conclusions: Within the observed range of uniformly low CO₂ and high VRs (mostly 16–42 L/s per person), little variation in contaminant concentrations would be expected, which would explain lack of relationships with occupant outcomes. These high VRs resulted partly from frequently used energy-saving “economizer” cycles in moderate California climates, but VRs at other times also substantially exceeded required VRs. These findings suggest, consistent with theory, that within a higher VR range, increased VRs do not reduce respiratory illness. Further studies are needed to better characterize such relationships.

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1. Background

Indoor air pollutants in office buildings, which may cause adverse effects in occupants, can be emitted by the buildings and their contents, including furniture, equipment, and the occupants themselves [1]. Outdoor air brought into offices by mechanical

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ventilation systems is the primary means used to control levels of indoor-generated pollutants. (Source control or air cleaning can also be used to control indoor air pollutants, some of which are best removed by means other than outdoor air ventilation.) Heating or cooling the introduced outdoor air to comfortable indoor levels requires increased energy as VRs increase. Adverse human outcomes of current potential concern in setting minimum standards for commercial VRs include building-related symptoms, infectious respiratory disease, asthma exacerbations, illness-related work absence, reduced work performance, and poor perceived air quality [1], although most of these are not considered in current standards.

Standards for minimum VRs in commercial buildings historically have been based on subjective acceptability of air quality,

Abbreviations

ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
BA	Bay Area
CO ₂	carbon dioxide
CV	Central Valley
cfm	cubic feet per minute
GEE	generalized estimating equation
HZEB	Healthy Zero Energy Building
HVAC	heating, ventilating, and air-conditioning
IRR	incident rate ratio
IAQ	indoor air quality
MERV	<i>Minimum Efficiency Reporting Value</i>
OR	odds ratio
parts per million	ppm
T	temperature
RH	relative humidity
SBS	sick building syndrome
SC	South Coast
VR	ventilation rate

assessed in laboratory studies that considered occupants to be the only pollutant sources. More recently, standards have considered, to a limited extent, research on how VRs affect prevalence of “sick building syndrome” (SBS) symptoms. SBS symptoms, including symptoms that may be irritant or allergic in origin, have been used extensively as a measure of health-related outcomes in offices. Chemical and non-infectious biological pollutants indoors may cause irritation, allergies, or dissatisfaction with indoor air quality. Lower VRs have been associated with elevated prevalence and intensity of SBS symptoms [2,3]. Research now suggests that VRs elevated above the current commercial ventilation standards would further reduce SBS symptoms [1,3,4], and that satisfaction with perceived air quality in most office buildings is lower than desired, even with VRs at the current standard [5,6]. It is not known if SBS symptoms can be severe enough to contribute to illness-related absence.

Additional evidence suggests that VRs are associated with other effects in occupants, including communicable respiratory disease and illness-related absence [1]. Illness absence from work may be related to respiratory infections, asthma, allergies, gastrointestinal infections, or other disease, and can serve as an indicator of health effects sufficiently severe to miss work. Building occupants can emit infectious respiratory agents that cause illness in other occupants [7]. The primary hypothesis underlying this study is that lower VRs in office buildings, as indicated by higher measured carbon dioxide (CO₂) concentrations, would lead to greater indoor air concentrations of agents causing infectious respiratory disease, which would lead to higher rates of illness absence in the occupants. This hypothesis is supported by prior findings in a variety of indoor settings, as summarized by Li et al. [7], and Sundell et al. [1]. Various findings are consistent with this hypothesis, in offices [8,9] and other indoor settings [10–12], [13–15].

Some studies, however, have found no changes in health effects with changes in VR within a high range of VRs; e.g., for respiratory infections [16], and for symptoms [17]. This fits with theoretical predictions that at higher VRs, concentrations of indoor-generated pollutants are not much reduced by further increased VR [3]. A range of high ventilation rates within which further increases would not be expected to provide further health benefits for

occupants has not been defined, and such a range would vary by indoor contaminant sources and specific occupant endpoints.

This project was part of the Healthy Zero Energy Building (HZEB) Study, intended to provide data on costs and benefits of decreasing or increasing minimum VR standards, to help support evidence-based and energy efficient but health-protective ventilation standards for commercial buildings in California. In setting energy-conscious VR standards, adverse effects on occupants from inadequate ventilation can be considered as costs to be weighed against the benefits of reduced energy use and energy costs.

The primary goal of this study was to quantify the associations between measured CO₂ concentrations or estimated ventilation rates (VRs) in offices and adverse effects among building occupants – primarily respiratory illnesses and illness-related absences from work, but also acute health symptoms at work and dissatisfaction with air quality at work. Since CO₂ is a product of human respiration, indoor CO₂ concentrations can be used as a proxy to evaluate the effectiveness of ventilation in controlling airborne concentrations of human-produced infectious respiratory agents, which could contribute to illness and absence. Exposure variables analyzed in this study thus included daily *mean indoor CO₂* as an indicator of bioeffluent exposures. However, since ventilation standards specify minimum VRs, this study also included daily *maximum indoor CO₂*, which with some assumptions can be used to estimate VRs, and also the estimated VRs based on maximum CO₂ concentrations.

2. Methods

2.1. Building recruitment

Buildings in California were solicited for participation by emails, flyers, and phone calls to the employers. Eligible office buildings were from the public or private sector in three distinct climatic regions of California – Bay Area, Central Valley, and South Coast. In each participating building, at least one study space was selected, each with if possible at least 30 occupants. The study space was either a subset of the building and its workers, or the full building, within which relatively uniform VRs were anticipated (e.g., contiguous spaces or spaces with shared air recirculation from air handling systems). A single building could contain multiple separate study spaces. If multiple study spaces in a building were available, spaces with the most occupants were selected for inclusion, with the number of spaces included depending on willingness of the building owner or employer to allow employee participation. Buildings or study spaces containing unusual contaminant sources were excluded. The target size of the study was a total of 30–40 study spaces.

Given the high expected refusal rate during building recruitment (based on our prior experience), the sample was not intended to be representative of California commercial buildings, but was a sample of convenience. Recruitment, enrollment, and data collection were conducted in a rolling manner, with data collection beginning in the earliest recruited buildings while other buildings were being recruited. Data were collected for at least a full year within each building, but study periods were not simultaneous across all study buildings.

2.2. Environmental data

Several types of environmental data were collected: measurements of indoor CO₂ concentration, temperature (T), and relative humidity (RH), along with information on selected characteristics of the buildings and ventilation systems. Other indoor air pollutants were not measured. CO₂ was monitored by the Vaisala

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