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Health and economic implications of natural ventilation in California offices

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ABSTRACT

This study examines the human health implications of natural ventilation in California office buildings. We modeled work-time exposures using field data on indoor and outdoor ozone and particulate matter from four case studies in naturally ventilated offices and published data from mechanically ventilated offices. We also modeled the amount of time that windows would be open in the naturally ventilated office and used the results to estimate the difference in pollutant exposures for occupants of naturally ventilated versus mechanically ventilated, air-conditioned offices. Based on published concentration–response equations, we estimated the incremental changes in health outcomes that resulted from the difference in exposures for occupants in the two types of offices. We also estimated the differences in sick building symptom rates based on symptom prevalence rates in naturally ventilated and air-conditioned offices. Finally, we developed first-order estimates of the health-related costs and benefits of retrofitting 10 percent of California's current office space to use natural ventilation. Findings included an increase in annual health-related costs from increased exposure to ozone and particulate matter of between $130 million and $207 million, and a reduction in sick building syndrome symptom costs, valued between $4.3 million and $11.5 million. Our estimates have a high degree of uncertainty and exclude potentially significant health-related costs and benefits of both naturally ventilated and air-conditioned buildings. Nonetheless, these estimates indicate that health-related costs of natural ventilation are significant and warrant further study. We also explore several mitigation options that could limit the health and economic impacts of natural ventilation.

1. Introduction

Natural ventilation, if used appropriately, has the potential to provide significant HVAC energy savings [1]. A substantial body of research indicates that occupants of naturally ventilated offices have fewer sick building syndrome symptoms than occupants of air-conditioned offices [2]. Sick building syndrome symptoms are 30–200 percent more frequent in air-conditioned buildings. Prior efforts to quantify the costs of sick building syndrome symptoms have focused narrowly on medical costs to treat symptoms [3]. Responses from the Building Assessment Survey and Evaluation (BASE) study indicate an increase in self-reported illness absences and reduced productivity as a result of sick building syndrome symptoms [4]. However, weaknesses in survey questions limit the validity of these results. At least one additional study has found an increase in the number of sickness absences and hospital visits for female occupants of air-conditioned buildings compared to occupants of naturally ventilated offices [5]. Neither of these studies is sufficient to fully quantify potential secondary costs associated with sick building syndrome symptoms.

Applying natural ventilation strategies in buildings is expected to change occupant exposure to outdoor air contaminants compared to the exposure to these pollutants for occupants of air-conditioned buildings. Of particular importance are effects of natural ventilation on exposures to two outdoor pollutants: particulate matter (PM) and ozone. Both are known to have significant health impacts [6–8]. A recent analysis estimated that, by 2020, the Clean Air Act [9] will have prevented more than 230,000 early deaths with an associated direct economic benefit of $2 trillion, primarily from reducing exposures to PM and ozone. A separate study [10] found that the cost of exposure to particles less than 2.5 microns in diameter (PM2.5) and ozone in California alone was more than $28 billion annually.

Buildings provide partial shelter from outdoor air pollutants such as PM and ozone. In mechanically ventilated buildings, outdoor air passes through a particle filter before being delivered to

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the occupied space, but in naturally ventilated buildings, outdoor air enters the occupied space directly through operable windows. In both types of buildings, PM and ozone are removed from the air to some extent by deposition on indoor surfaces. Several prior studies have quantified the relationship between the indoor concentrations divided by the outdoor concentrations (I/O ratio) of particulate matter, including particles smaller than 2.5 microns, in air-conditioned commercial buildings [11,12]. Weschler [13] summarizes the results of several studies of I/O ratios of ozone in buildings, in which the majority of the commercial buildings used air conditioning. However, few prior studies have assessed indoor concentrations of PM or ozone in naturally ventilated offices.

We did not find any prior studies that assessed how exposures to ozone and PM resulting from natural ventilation affect occupants' health and health-related costs in comparison to those for occupants of air-conditioned buildings. In addition, there are no reports of the costs and benefits associated with reduction in sick building syndrome symptoms in naturally ventilated buildings.

This study focuses on analyzing the health-related risks and benefits of retrofitting California offices to use natural ventilation. These costs and benefits are quantified both in terms of the number of cases of specific health outcomes and the monetary value to society. Quantifying the monetary value of these costs and benefits aids in weighing tradeoffs and analyzing the significance of a building's ventilation choices.

2. Methods

We made first-order estimates of the difference in annual exposure to ozone and PM2.5 for office workers in naturally ventilated offices compared to workers in conventional air-conditioned offices with sealed windows and particle filtration. Based on the differences in contaminant exposures, we predicted the difference in the number of cases of several health outcomes. We then calculated the costs associated with each health outcome to quantify the economic consequences of broader adoption of natural ventilation. Fig. 1 shows a broad overview of our methods. The exposure model estimates indoor hourly ozone and PM2.5 concentrations and occupants' exposure to those concentrations based on typical time spent at work. The model is based on a set of constants derived from both new and previously published empirical data. We collected new data through four case studies of naturally ventilated offices. Using the exposure model, we calculated the difference in exposures for occupants of naturally ventilated versus air-conditioned offices using measured outdoor particle, ozone, and temperature data from 15 cities throughout California. The cities were selected to represent the largest population centers in each of the 15 California Title-24 climate zones. We used a health impact assessment model to translate occupant exposures into health outcomes and their associated costs. Our risk model uses published literature relating exposures to specific health outcomes in the form of concentration–response (C–R) functions that predict annual cases of those outcomes.

In addition to performing the analysis illustrated in Fig. 1, we estimated the effects of natural ventilation versus air conditioning on prevalence of sick building syndrome symptoms based on a review of data from 11 studies [2]. We then calculated the associated health costs based on an estimate of the annual health care costs for symptoms and the size of the affected population.

2.1. Field study methods

Because limited data have been published on indoor ozone and particle concentrations in naturally ventilated offices, measured field data were needed to inform our exposure models. Accordingly, we collected data on indoor and outdoor concentrations of ozone and PM2.5, ventilation rates, and window usage in four naturally ventilated offices. Measured ozone and PM2.5 were assumed to be generated outdoors and brought into the building via ventilation. For periods where spikes in indoor concentrations of particles were seen and attributable to indoor sources such as soldering, these data were excluded from the analysis. Indoor concentrations of ozone and particles were considered to be independent of occupant density, hence occupancy data were not collected.

For the data collection effort, we selected buildings that were either solely naturally ventilated or could be operated in natural ventilation mode and gave priority to offices in the research team's local area because of the need for daily site visits to monitor window use. The four buildings selected represent typical naturally ventilated offices in a range of sizes.

Office 1 occupies the second floor of a two-story building located in Alameda CA. The office space has a total floor area of 250 m^2, split into two large open-plan areas. The building does not have a mechanical ventilation system. When necessary, space heating is provided by small electrical resistance heaters. Twelve overhead ceiling fans with fully variable control are available for occupants to use to increase indoor air movement. Fifteen sash windows located on all four sides of the office provide natural

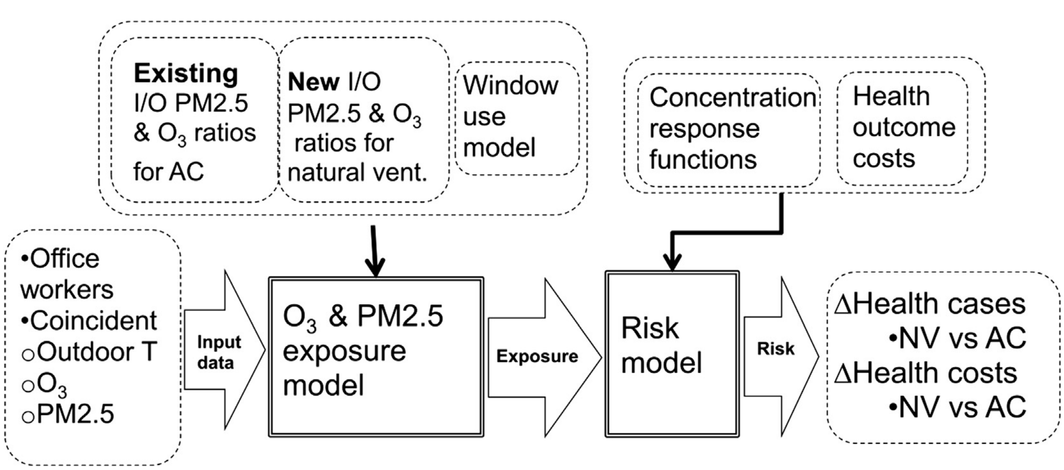

Fig. 1. Method overview flow diagram.