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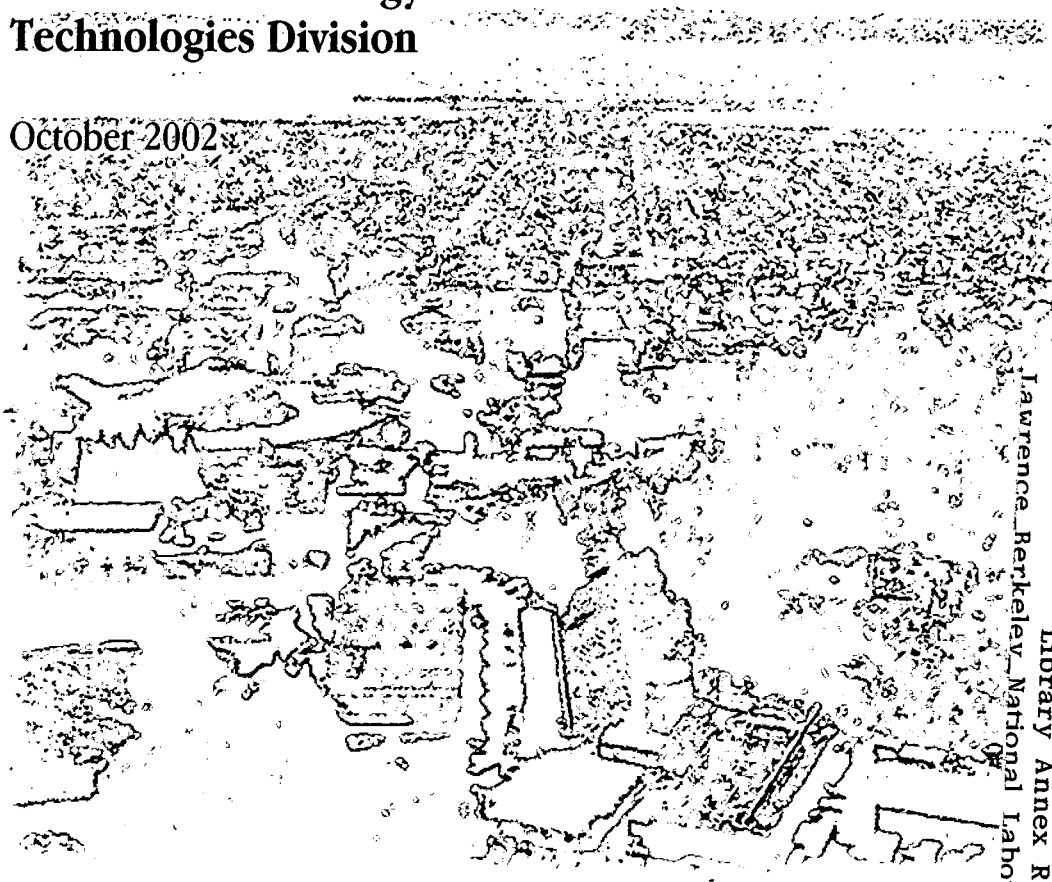

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ABSTRACT

Using the 100 office-building Building Assessment Survey and Evaluation (BASE) Study dataset, we performed multivariate logistic regression analyses to quantify the associations between indoor minus outdoor CO_2 concentrations (dCO_2) and mucous membrane (MM) and lower respiratory system (LResp) Sick Building Syndrome (SBS) symptoms, adjusting for age, gender, smoking status, presence of carpet in workspace, thermal exposure, relative humidity, and a marker for entrained automobile exhaust. Using principal components analysis, we identified a number of possible sources of 73 measured volatile organic compounds in the BASE office buildings and investigated the potential impact of these VOCs on SBS symptom prevalences. Additionally, we included an analysis to evaluate the hypothesis that certain environmentally-mediated health conditions (e.g., allergies and asthma) confer increased susceptibility to SBS within the office buildings. Adjusted odds ratios (ORs) for statistically significant, dose-dependant associations ($p<0.05$) for dry eyes, sore throat, nose/sinus congestion, and wheeze symptoms with 100-ppm increases in dCO_2 ranged from 1.1 to 1.2. These results suggest that increases in the ventilation rates per person among typical office buildings will, on average, reduce the prevalence of several SBS symptoms up to 70%, even when these buildings meet the existing ASHRAE ventilation standards for office buildings. VOC sources were associated with mucous membrane and lower respiratory irritation. Furthermore, VOC sources may be indirectly involved in indoor chemical reactions with ozone that produce irritating compounds associated with SBS symptoms. O-xylene, possibly emitted from furniture coatings was associated with short breath (At the maximum concentration: OR = 8; 95% CI=2.5 to 25). Building occupants with certain environmentally-mediated health conditions are more likely to experience SBS symptoms than those without these conditions (ORs ranged from 2 to 11).

KEYWORDS

Sick building syndrome, Ventilation, Carbon dioxide, Logistic regression, BASE study, Volatile organic compounds, Principal Component Analysis, Indoor pollutant sources

INTRODUCTION

SBS is used to describe a set of symptoms with unidentified etiology frequently reported by workers in office buildings. The individuals who suffer from SBS report that the symptoms occur when they spend time indoors, and that the symptoms lessen while away from the building (Levin, 1989). Understanding the multifactorial etiology of sick building syndrome (SBS) in office buildings has been a major challenge. Evidence for the hypothesis that building characteristics and related indoor environmental quality affects health outcomes continues to accumulate (Mendell, 1993; Fisk, 2000). These health outcomes include SBS symptoms, allergy and asthma symptoms, and respiratory illnesses. Indoor air quality also appears to influence rates of absence, work performance, and health care costs (Fisk, 2000).

VOCs and SBS symptoms in the literature

Although volatile organic compounds (VOCs) are suspected to be important contributors to SBS, analyses of data from field studies have generally failed to identify a relationship between VOC concentrations and symptom prevalences. Ten Brinke, et al. (1998) reported a new approach for developing VOC metrics; a few of these VOC metrics were statistically significant predictors of SBS symptoms reported in the California Healthy Buildings Study. In particular, Principal Component Analysis (PCA) was used to group correlated VOCs into a reduced set of Principal Component vectors (PCs) that are hypothesized to be associated with

VOC sources. The PCs were then used in a logistic regression analysis to estimate the association between SBS symptoms and the VOC exposure metrics while adjusting for other building-specific, environmental, and occupant-related covariates. This approach, in addition to regression using individual VOC concentrations, was recently applied in models to study the association of VOCs with self-reported SBS symptom data in a 28-building (1994-1995) subset of the Building Assessment Survey and Evaluation (BASE) study (Apte and Daisey, 1999). The BASE study is described below.

Carbon dioxide and SBS symptoms in the literature

The primary source of CO_2 in office buildings is the respiration of building occupants. At concentrations occurring in most indoor environments, the increase in indoor carbon dioxide (CO_2) concentration above that outdoors can be considered as a surrogate for concentrations of other occupant-generated pollutants, particularly bioeffluents, and for ventilation rate per occupant, but not as a causal factor in human health responses (ASHRAE, 1999; ACGIH, 1991). CO_2 concentrations in office buildings typically range from 350 to 2,500 ppm (Seppänen et al., 1999). The Threshold Limit Value for 8-hour time-weighted-average exposures to CO_2 is 5,000 ppm (ACGIH, 1991), thus CO_2 concentrations encountered in the normal operation of buildings are not expected to directly cause health symptoms. Currently, the American Society of Heating, Refrigeration, and Air-conditioning Engineers (ASHRAE) recommends a minimum office building ventilation rate in offices of 10 Ls^{-1} per person, corresponding to an approximate steady state indoor concentration of 870 ppm (ASHRAE, 1999), based on the assumptions that outdoor CO_2 is 350 ppm and indoor CO_2 generation rate is 0.31 $Lmin^{-1}$ per person.

In a recent review (Seppänen et al., 1999), about one-half of 22 studies of SBS symptoms in office buildings found that increased indoor CO_2 levels were positively associated with a statistically significant increase in the prevalence of one or more SBS symptoms. SBS symptoms associated with CO_2 included headache, fatigue, eye symptoms, nasal symptoms, respiratory tract symptoms, and total symptom scores. Seventy percent of studies of mechanically ventilated and air-conditioned buildings found a statistically significant association between an increase in CO_2 and SBS symptoms. Building ventilation rates were also associated with SBS symptoms. An analysis of the 41-building 94-96 BASE dataset found statistically significant dose-response relationships between dCO_2 and the following symptoms: sore throat, nose/sinus, combined mucous membrane symptoms, tight chest, and wheeze; the adjusted odds ratios for these symptoms ranged from 1.2 to 1.5 per 100 ppm increase in dCO_2 (Apte et al., 2000).

In this paper, we concentrate on building-related upper respiratory and mucous membrane (MM) irritation symptoms (i.e., dry eyes, sore throat, and nose/sinus)[1], and lower respiratory (LResp) irritation symptoms (i.e., tight chest, short breath, cough, or wheeze)[2]. In a dataset collected in 100 US office buildings, we explore the relationship of these symptoms to indoor concentrations of VOCs and building ventilation as inferred from occupant-generated indoor

[1] Abbreviated symptom phrasing is used throughout the paper. "Dry eyes" abbreviates "dry, itching, irritated eyes." "Sore throat" abbreviates "sore or dry throat." "Nose/sinus" abbreviates "stuffy or runny nose, or sinus congestion." "Tight chest" abbreviates "chest tightness." "Short breath" abbreviates "shortness of breath."

[2] Abbreviated symptom phrasing is used throughout the paper. "Tight chest" abbreviates "chest tightness." "Short breath" abbreviates "shortness of breath."

CO_2 concentrations, while controlling for a variety of potentially confounding individual-level and environmental variables.

METHODS

The BASE Study

The data analyzed in this paper were collected in 100 randomly selected large U.S office buildings from 1994 to 1998 by the U.S. Environmental Protection Agency for BASE study (Girman et al., 1995; Womble et al., 1996). These buildings were all at least partially mechanically ventilated and all but one was air-conditioned. BASE buildings were studied during one-week periods either in winter or summer. Environmental data were measured during the week of questionnaire administration. The BASE protocol is discussed fully elsewhere (Womble et al., 1993; BASE Website).

The BASE questionnaire confidentially collected occupant information, including gender, age, smoking status, job characteristics, perceptions about the indoor environment, and health and well-being. The SBS symptoms elicited from the questionnaire included: dry eyes, nose/sinus, sore throat, sneeze, tight chest, short breath, cough, or wheeze; fatigue; headache; eyestrain; and dry or itchy skin. In this study, we restrict our analyses to the mucous membrane (dry eyes, nose/sinus, and sore throat) and lower respiratory (tight chest, short breath, cough, or wheeze) SBS symptoms. To qualify as a SBS symptom in the analyses presented here, the occupant must have reported a symptom occurrence at least 1-3 days per week during the previous month, and the particular symptom must have shown improvement when the occupant was away from work. Additionally, these symptoms are analyzed both individually and in the following combined categories: Mucous Membrane (MM) = at least one of dry eyes, nose/sinus, and sore throat; Lower Respiratory (LResp) = at least one of tight chest, short breath, cough, or wheeze.

BASE questionnaire responses were used to test the hypothesis that sub-populations with certain environmentally-mediated health conditions are more likely to experience and/or report SBS symptoms. The variables used for this purpose include previously diagnosed dust allergy, mold allergy, hayfever, eczema, asthma, and migraine. Self-reported sensitivity to (environmental) tobacco smoke and chemical sensitivity were also considered. These health condition variables were used individually in some models and were combined in other models (one or more of any of the above variables into a general susceptibility variable). It is thought that individuals with these conditions may have a lower threshold in terms of responding to factors that are associated with SBS symptoms.

At each office building, CO_2, carbon monoxide (CO), temperature, relative humidity, and VOCs were measured at three indoor locations and outdoors. CO_2 and indoor temperature were collected as 5-minute averages. VOC samples using both canister and multisorbent tube collection methods were collected and analyzed by gas chromatograph-mass spectrometry for up to 73 VOC species, of which 37 VOC compounds were analyzed and detectable for at least 41 buildings (Table 1). Formaldehyde (measured in 100 buildings) and acetaldehyde (measured in 86 buildings) samples were collected and analyzed as well. Due to several changes in the selected VOC analytes for laboratory quantitation over the data collection period, and due to non-detectable levels of the majority or all samples of certain VOC species, only 19 measured VOC species are available for analysis in all 100 buildings of the 94-98 BASE dataset. Outdoor VOC concentrations were available in the BASE dataset, but they

were not subtracted from the indoor concentrations for any of the analyses presented in this paper – only measured indoor concentrations were used.

Spatial-average pollutant concentrations and average temperatures were calculated based on data from the three measurement sites. Time-averaged (8.5 hr) workday difference between indoor and outdoor CO_2 concentrations (dCO_2) was calculated and served as a surrogate measure of ventilation rate per occupant. Time averaged indoor minus outdoor CO concentrations (deltaCO) were also calculated for each building. One-day average concentrations of dCO_2, 19 VOCs, formaldehyde, deltaCO, temperature, and relative humidity were available for all 100 buildings.

A thermal exposure variable (°C-hours) was calculated as the integrated difference between 5-minute-average-temperature and 20°C, duration-normalized in to 8.5 hours of exposure. The indoor workday-average relative humidity (RH) was calculated. In addition, climatic/season variables entered into enhanced models included: heating degree days for the building site (HDD, °C-days); cooling degree-days for the building site, (CDD, °C-days), and the season (summer=0; winter=1) in which the building was studied.

Statistical Methods

Multivariate logistic regression (MLR) was used to calculate prevalence odds ratios (OR) and Wald Maximum Likelihood (WML) statistics (SAS, 1989). Crude and adjusted MLR models were constructed using continuous dCO_2 data as an independent variable and an SBS symptom as the dependent variable. Covariates used in the MLR models to control for confounding were age, gender, presence of carpet in workspace, smoking status, thermal exposure, RH, and 1,2,4-TMB concentration. As discussed previously (Apte and Daisey, 1999), 1,2,4-trimethylbenzene (1,2,4-TMB), a VOC measured in infiltrating outdoor air and originating from automotive sources, was found to have statistically significant associations with a number of MM and LResp symptoms. In the following analysis, this variable was used in models where other VOCs were not included. Additionally, the climatic (HDD and CDD) and season variables were added in enhanced models to account for the variability possibly caused by climate during the study. Details regarding model building can be found in Apte et al. (2000).

To evaluate the dose-response relationship between the CO_2 metric and SBS symptoms, additional analyses were conducted where dCO_2 was divided into five categories based upon their distributions across the 100 buildings. The dCO_2 categories reflect the 10^{th} and 90^{th} percentiles of the dCO_2 distribution and three bins evenly split between them. This approach was discussed in Apte et al., 2000. For the purpose of calculating the association between the SBS symptoms and dCO_2 level an analysis of covariance approach was taken (Selvin, 1995): dummy variables were used to represent the four highest CO_2 bins. These regressions were used to evaluate trends in the associations between SBS symptoms and dCO_2 using the building group with the lowest 10^{th} percentile concentrations as the referent.

Additional logistic regression models using a single categorical CO_2 variable with five interval levels discussed above representing the above-defined binned-CO_2 groupings were conducted. These levels were coded using the bin-mean dCO_2 for each dCO_2 level. The WML statistic and associated p-value for this categorical variable was used as a measure-of-fit of the dose-response relationship for the adjusted associations between categorical CO_2 measures and SBS symptoms (SAS, 1989).

The approach using Principal Components Analysis to derive VOC exposure metrics has been discussed thoroughly by Ten Brinke et al. (1998). In brief, PCA converts a set of correlated variables (e.g., measured VOC species in office buildings), into a reduced number of uncorrelated vectors which are linearized sums (principal components) of *standardized* individual variables (i.e., normalized to mean = 0 and standard deviation = 1). These PCs are hypothesized to represent source types or building materials which emit VOCs, since species originating from the same types of sources tend to co-vary in concentration from one building to the next. Some VOC species can originate from more that one source, so it is possible that they will be associated with more than one PC. Thus, the PCA method is useful because it can apportion the VOC contributions from different source groups. It should be noted that since the PCs represent particular groups of sources, it is likely that they correlate with other (possibly unmeasured) compounds emitted from those sources. In these analyses, PCA correlation matrix eigenvalues of the PCs determined the extent of the PCs interpretability, with a cutoff criterion of ≥ 1.0 used to determine which PCs were to be kept in the analysis. Varimax rotation was performed.

MLR (SAS, 1989) was used to evaluate associations between SBS symptoms and both individual VOCs and the PCA-based VOC exposure metrics. Multivariate models contained covariates as described above to adjust for potential confounding. The SBS symptom/environmental exposure associations are presented as prevalence odds ratios (OR). The VOC variable 1,2,4-TMB was not included as a separate variable in models that included the VOC PC vectors.

RESULTS

Comparison of 94-96 and 94-98 BASE datasets

Prior to development of new models, the results of the analysis of dCO_2 association with SBS symptoms in the 94-96 dataset were compared to those in the full 100 building 94-98 dataset. This comparison did not include climatic/season or the environmentally-mediated health condition variables. Table 2 provides calculated summary statistics for environmental and individual-level factors for the participants of the 94-98 BASE survey. Table 3 provides the results comparing the earlier 94-96 dataset with the full 94-98 dataset logistic regression analyses that were unadjusted and then adjusted for GENDER, AGE, CARPET, SMOKER, THERMAL EXPOSURE, RH, and 1,2,4-TMB; these same covariates were used in previously published analyses using the smaller 94-96 dataset (Apte et al., 2000). The dCO_2 ORs are reported in units per 100 ppm. The larger 94-98 BASE dataset analysis yielded similar, but weaker findings as compared with the smaller 94-96 data set, with smaller adjusted ORs ranging from 1.1 to 1.2 per 100 ppm increase in dCO_2 for sore throat, nose/sinus, and wheeze. The effect for dry eyes observed in the 94-96 dataset was not apparent in the 94-98 dataset. Preliminary analyses investigated why the results obtained from the larger 94-98 dataset differed from those obtained from the smaller 94-96 dataset. Mean levels and standard deviations of dCO_2 and the continuous covariates did not differ substantially between buildings for which data were collected in 94-96 compared with buildings for which data were collected more recently (Table 4). Of the dichotomous covariates, only the proportion of females and occupants 40 years of age or older differed between the two data collection periods (Table 5). In terms of SBS symptom prevalence, the 97-98 buildings were slightly lower (see Table 5), though these differences were not statistically significant.

Enhanced modeling

Differences due to climate, regional variability in building codes, design, construction, and operation due to climatic factors could influence the environmental conditions inside office buildings. Thus, in an attempt to control for the variance due to climatic and season in the dataset, variables were added to further adjust the initial models. For simplicity of presentation, Table 6 lists the basic set of variables used in all the models described below. Additionally, variables representing the following selected environmentally-mediated health conditions, or "susceptibilities," were also added into these SBS models: dust allergy, mold allergy, hayfever, eczema, asthma, migraine, sensitivity to (environmental) tobacco smoke, and chemical sensitivity. Table 7 identifies the covariates for which a statistically significant relationship with the SBS symptoms was found. All of the health condition variables showed some statistically significant relationships with symptoms, thus supporting the hypothesis that individuals with these conditions are more susceptible to experiencing SBS symptoms than those without these conditions. In particular, diagnosed asthma (LResp symptoms) and self-reported chemical sensitivity (all symptoms) were consistent predictors.

After including the health condition variables, the dCO_2 variable was not statistically significant with the exception of sore throat (see Table 7). An inspection of the model output suggested that this might be due to reduced statistical power, as many observations had missing values for the health condition variables. To create a more parsimonious model, a new variable was defined such that any individual who reported to have one or more of the environmentally-mediated health conditions was considered to be "susceptible" (SUSCEPT). Results of logistic models, regressing the SBS symptoms on dCO_2, and including the SUSCEPT variable, with the other listed covariates, are outlined in Table 8. The increase in sample size achieved by combining the health condition variables is clear. In these models, associations between dCO_2 and dry eyes, nose/sinus, sore throat, and wheeze symptoms are statistically significant. Table 9 provides a comparison between the crude and adjusted associations, and also provides the ORs and 95% confidence intervals for the FEMALE and SUSCEPT variable in the model. Other statistically significant covariates in these models (see Table 8) were AGE (OR range: 1.2 to 1.4), SMOKER (OR range: 1.4 to 2.2), RH (OR range: 1.6 to 2.0), 1,2,4-TMB (OR = 1.3 for short breath), and CDD (OR range: 0.96 to 0.98 per 100 °C-days).

CO_2 dose-response

Figure 1 presents the results of the analysis of the trend between dCO_2 and symptoms, after adjustment for all of the covariates listed in Table 6 plus SUSCEPT; the data from buildings in the lowest dCO_2 bin serve as the referent. Total sample size for each symptom is also shown (n range: 4108-4225). Visually, the plots suggest possible dose-response relationships, but usually with the OR in one binned group deviating from the expected dose-response pattern. Based on the WML tests for statistically significant trends, the following symptoms or symptom groups were found to have a statistically significant dose response ($p < 0.05$) relationship with dCO_2: MM, dry eyes, sore throat ($p < 0,005$), nose/sinus, and wheeze.

VOC sources in BASE buildings

Table 1 lists the 37 VOCs, formaldehyde, and acetaldehyde (37-VOC set) that are consistently usable for analysis. It is evident from Table 1 that there are 41 buildings for which the entire 37-VOC set is available, and only a 19-VOC set is available for all 100 buildings. Since the focus of this work is on the 100 building dataset, the 19-VOC set is used in the regression models reported here. However, the VOC sets are somewhat related, and information from

the larger VOC sets can be used as a qualitative aid when examining the VOC principal component patterns in the 19-VOC/100-building set – this is particularly useful, although imperfect, for interpreting principal component groupings and source identification.

We discuss the PCA analysis results from the 37-VOC and the 19-VOC sets here. The deltaCO variable was included in each analysis. Due to the large size of the principal components matrix produced by the PCA, it is impractical to tabulate the results for the larger 37-VOC set (includes only 41 buildings). The PCA results for the 19-VOC set (includes all 100 buildings) are shown in Table 10. Table 11 presents a summary of primary (PC loading $\geq$ 0.5) and secondary (0.25 $\leq$loading $<$ 0.5) PCs, as well as possible sources of the measured compounds identified in the 37-VOC set (includes only 41 buildings). Some PC groupings are not attributable, or even similar to known source patterns – these were left unassigned in the Table 11. It should be stressed that the source identifications presented in Table 11 are to be considered tentative and are based upon experience and a review of the literature (references are provided in the Table 11).

Careful inspection of the PCs from the 19-VOC/100-building PCA analysis (Table 10) and comparison with the source identification of the material in Table 11 provides improved certainty in assigning sources to the PCs in Table 10. Table 12 lists possible sources identified in the 19-VOC/100-building PCA. Due to the smaller number of VOCs in this set, these source assignments should be considered even less certain than those from the larger set in Table 11. Tentatively, the 100 building PCA results may represent the following sources: motor vehicle emissions from outdoors (PC1); furniture or wood product coatings (PC2); vinyl products or carpets (PC3); printing processes or printed materials (PC4); air fresheners (PC5); unassigned (PC6); cleaning products, deodorizers (PC7); unassigned (PC8); unidentified formaldehyde sources (PC9); and cleaning products (PC10). Only PC1 – PC7 meet the criterion for eigenvectors $\geq$ 1.0 and only these are used in subsequent regression models.

Logistic regression models with addition of 19-VOC PC vectors

The 19-VOC/100-building PCA vectors PC1 – PC7 were added to the health condition-adjusted logistic regression models discussed above. The purpose was to identify associations between PCA-derived VOC (and CO) sources and the SBS symptoms. The PC vectors were added in a forward stepwise procedure while the original covariates were forced into the models. Table 13 identifies the PCs that are associated ($p \leq 0.05$) with the SBS symptoms. Note that the association pattern for dCO_2 did not change after adding the PC, variables. Of interest is the positive association between PC3, the vinyl or carpet materials vector with MM, dry eyes, and short breath symptoms. Shortness of breath appears to be positively associated with infiltrating motor vehicle emissions. There is also a consistent negative (OR $<$ 1) association between the 19-VOC/100-building PC5 (air fresheners) vector and symptoms (MM, LResp, and cough). The PC6 vector (unassigned) was negatively associated with MM and nose/sinus symptoms.

Logistic regression models with individual indoor VOCs

Adjusted models (including the SUSCEPT variable) were constructed to explore the association between SBS and the individual VOCs from the 19-VOC/100-building set. These models were constructed identically to those that included the PC vectors, with the exception that measured concentrations for VOC were included instead of the PCA vectors. The VOC compounds were entered into the model using the forward stepwise selection procedure described above. Table 14 contains the statistically significant adjusted ORs for dCO_2 (per

100 ppm), the VOCs (per ppb), and deltaCO. Summary statistics for the distributions of measured VOCs are shown in Table 1.

The observed dCO_2–symptom associations remain essentially unchanged with concentrations of individual VOCs in the models. No clear patterns emerge for VOCs positively associated with symptoms. The per-ppb ORs for most of the positively associated VOCs were modest, with the exceptions of o-xylene (OR = 2.0, short breath) and styrene (OR=1.4, cough). A number of VOCs (and deltaCO) were negatively associated with symptoms. The terpene compound d-limonene had a statistically significant per-ppb OR below unity in association with dry eyes, sore throat, LResp, and cough (OR range: 0.91 to 0.97). Formaldehyde was slightly negatively associated with MM, nose/sinus, and LResp (OR range: 0.96 to 0.98). Finally, deltaCO was negatively associated with MM symptoms (OR = 0.81).

Potential for SBS risk reduction

Apte et al. (2000) discussed the Percent Risk Reduction (PRD) method for estimation of the potential for reducing office building SBS symptoms based upon the statistically significant odds ratios at the maximum dCO_2 of 608 ppm. Based upon the adjusted models shown in Table 9, the PRD estimate for the maximum dCO_2 analyses of wheeze is 72% (low prevalence). PRD cannot be used to directly calculate prevalence reduction when the symptom prevalence is greater than 5%. However, as discussed in Apte et al. (2000), a correction can be used to make conservative estimates in these cases. Using a correction of –10%, the PRD for sore throat SBS symptoms (prevalence= 6.6%) through mitigation is about 60%.

DISCUSSION

dCO_2 analyses

It should be re-emphasized here, that there is no direct causal link between exposure to CO_2 and SBS symptoms, but rather CO_2 is a surrogate measure of ventilation rates and is approximately correlated with other indoor pollutants that may cause SBS symptoms. The results of these analyses suggest that there is an association between elevated indoor CO_2 levels and increased prevalence of certain MM and LResp SBS symptoms in the 100 building 94-98 BASE dataset. These findings were evident in the crude regression models and persisted through adjustment for a number of potential confounders.

Analysis of trend indicates that with the fully adjusted model (i.e., the model that include dCO_2, the variables in Table 6, and SUSCEPT), a statistically significant dose-response relationship exists for the relationship between dCO_2 and the MM, dry eyes, sore throat, nose/sinus, and wheeze symptoms in the 94-98 100 building BASE dataset. This is consistent with the findings for the 94-96 BASE dataset as discussed in Apte et al., 2000; however, the 95% confidence intervals around the OR point estimates are considerably tighter in this study as would be expected given the larger dataset.

The odds ratios for the associations of symptoms with the maximum observed difference between indoor and outdoor CO_2 concentrations may indicate the maximum potential to reduce selected SBS symptoms in typical office buildings. As discussed above, the implied potential maximum reduction in prevalence, through increased ventilation for sore throat is roughly 60%, and for wheeze it is about 70%. This reduction could come through large increases in ventilation rates, improved effectiveness in providing fresh air to the occupants'

breathing zone, or through identification of the symptom-causing agents in the indoor air and control of their sources. In no case were the indoor average or the peak indoor CO_2 concentrations extraordinarily high; only two buildings had peak indoor (absolute) CO_2 concentrations routinely above 1,000 ppm.

Susceptible Population

The population of the office buildings with environmentally-mediated health conditions appears to play a very strong role in driving the prevalence of SBS symptoms. The SUSCEPT variable shows itself to be a consistently strong and statistically significant predictor of symptoms in the full 94-98 BASE dataset. The lowest adjusted ORs observed in this study for risk of SBS symptoms for individuals with any of the environmental susceptibilities (i.e., allergies, asthma, migraine, chemical and tobacco sensitivity) are about 1.9. The odds of a susceptible individual for having short breath in the office building are 5.5 times greater than a non-sensitive individual – the odds are 11.4 times greater for tight chest. Interestingly, the prevalence of SUSCEPT in the BASE study building population is very high: 81%, although the prevalence of these lower respiratory symptoms is on the order of a few percent. These observations underscore the importance of controlling the quality of the indoor environments of office workers in order to reduce the environmental conditions that trigger symptomatic responses.

VOCs and VOC sources

Both individual VOC measurements and VOC source PC vectors were used to evaluate the contribution of VOCs to SBS symptom risk in this study. Due to the standardization procedure, the PCA results should be interpreted with caution. The OR is defined by the ratio of odds of having a symptom to the odds of not having it *per unit change* in exposure or risk factor. For the individual VOC analyses, the units are merely per-1 ppb increase in average concentration of a compound. In the case of the PCA-based exposure metrics, where the unit change of the metric is a composite vector of standardized components, the interpretation is less clear. Nonetheless, the observed associations provide one line of evidence regarding the potential influence of specific VOC sources on SBS symptom prevalences. The combination of source identification and analysis of individual compounds emitted from those sources is informative.

In the two VOC analysis types, the compounds that were positively associated with symptoms also belonged to PC source vectors that were positively associated. This is also observed for the negatively associated compounds. An example is the positively associated o-xylene and short breath (OR = 1.95 per ppb), and PC1 (vehicle emissions) and short breath (OR = 1.33). O-xylene is the highest loading compound in the PC1 vector. From Table 1, we see that the average o-xylene concentration was 0.7 ppb and the maximum was 3.1 ppb, distributed across the 100 buildings. At the maximum o-xylene concentration, the adjusted odds ratio for short breath is $e^{(\ln(1.95)*3.1)} = 7.9$. Similarly, Table 14 shows that styrene is associated with cough (OR = 1.39). Interestingly, styrene loads mostly in PC3 (possibly vinyl products) which was not associated with cough. At the maximum measured average styrene level of 3.3 ppb, the odds ratio for cough symptoms is 3.0.

It is noteworthy that the earlier work by Ten Brinke et al. (1998) was conducted in an attempt to account for SBS symptoms associated with sources of highly potent or reactive VOC species not measured by standard techniques. It was thought that if the causal agent could not be identified, at least the source of the agent might be identified through common VOCs

emitted from the same source. Most commonly measured VOCs, by themselves or even in combination, are thought to be less likely to cause sensory irritation at the concentrations typically measured in office buildings. Following this logic, one might expect to find more reactive components of the identified sources to be causative agents for the observed symptoms. Formaldehyde is the one commonly measured VOC that is a sensory irritant. It is of interest that the measured formaldehyde concentrations in this study were slightly protective in association with symptoms. This was not expected for such a reactive compound and deserves further consideration. This observation is further noteworthy since the California Healthy Building Study data that Ten Brinke et al. used in their analyses did not include formaldehyde data – the question was raised as to whether their results would have changed substantially had formaldehyde been available in the data for study

The statistically significant inverse relationships were consistent across the VOC source and individual VOC analyses. Most striking are the d-limonene associations and PC5 associations noted above. The negative association of d-limonene and the MM and LResp symptoms was observed and discussed in Apte and Daisey (1999). At that time, the seemingly protective nature of d-limone was considered questionable. The compound is found in many substances including cleaning products, materials, air fresheners, and tobacco smoke. These PCA results suggest that some portion of it is from an air freshener source.

Current thinking suggests that d-limonene and other terpene compounds readily react with relatively common and low concentrations of ozone entrained from outdoors and produce irritating reaction products including aldehydes and ultrafine particles (Sarwar et al., 2002; Weschler and Shields, 1999; Wolkoff et al., 2000). Thus, rather than d-limonene being protective, it may be that its reaction products are a cause of irritation to the mucosa and respiratory system, leading to the associated symptoms. This tantalizing hypothesis could be tested if ozone data were available; however, these data were not collected in the BASE study.

Epidemiological Considerations

Epidemiological considerations regarding these analyses were discussed in detail in Apte et al., 2000. We refer the reader to that paper for a discussion of bias and confounding, biological plausibility, and consistency of findings in these BASE study analyses. One statistical concern is the potential impact of cross-level bias. This issue has not been addressed in the analyses presented here. The concern relates to the fact that the individual level observations within a building are not truly independent as the environments of the occupants are shared. The extent to which this bias might lead to error in the estimates of the true relationships is thought to be small, but more sophisticated methods would be needed to verify the assumption.

CONCLUSION AND IMPLICATIONS

After adjusting for selected covariates, we found statistically significant associations of mucous membrane and lower respiratory SBS symptoms with increasing dCO_2. Odds ratios for statistically significant associations of dry eyes, sore throat, nose/sinus, and wheeze symptoms with 100-ppm increases in dCO_2 ranged from 1.1 to 1.2. These results suggest that increases in the ventilation rates per person among typical office buildings will, on average, significantly reduce the prevalence of several SBS symptoms, even when these buildings meet the existing ASHRAE ventilation standards for office buildings. The magnitude of the reduction depends on the magnitude of the increase in ventilation rates, improvement in ventilation effectiveness and whether sources of SBS-causing agents are eliminated or

reduced. Very large increases in ventilation rates, sufficient to reduce indoor CO_2 concentrations to approximately outdoor levels, would be expected, on average, to decrease prevalence of selected symptoms by up to 70%. These analyses also indicate that VOC sources may play an important role in causing mucous membrane and lower respiratory irritation both directly by producing irritants and indirectly through indoor chemical reactions with ozone that in turn produce irritating compounds.

A large subset of the office building occupants with selected environmentally-mediated health conditions comprise a large proportion of SBS symptom sufferers. This susceptible subgroup should be considered when planning strategies to reduce SBS symptoms in office environments.

The BASE dataset is a valuable source of U.S building information, providing an opportunity for identification of causal factors of SBS symptoms and for developing solutions to lower their prevalence in buildings.

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TABLES

Table 1. BASE study VOC, aldehyde, and carbon monoxide (deltaCO) summary statistics for the 94-98 BASE Study dataset. A total of 73 VOCs, plus formaldehyde and acetaldehyde, were measured in the BASE study. The list of VOC analytes changed from year to year and many VOC measurements were below detectable limits and measurements for all of the analytes are not available for all of the buildings for the entire study period. The contents of this table include those compounds for which a complete dataset was available (41 buildings).

Compound	Mean (ppb)	Std Dev (ppb)	Median (ppb)	Minimum (ppb)	Maximum (ppb)	# of Buildings
acetaldehyde	4.3	2.1	4.0	1.1	9.5	86
acetone	23	14	19	6.0	92	87
a-pinene	0.2	0.2	0.1	0.03	1.4	100
benzene	1.5	1.2	1.1	0.27	10	100
1-butanol	1.1	1.1	0.7	0.04	4.1	41
2-butanone	2.2	1.5	1.9	0.23	9.8	87
2-butoxyethanol	2.5	3.9	1.3	0.03	18	41
butyl acetate	0.7	1.2	0.3	0.03	6.4	100
chloromethane	1.4	0.8	1.3	0.56	7.7	87
DeltaCO (ppm)	0.1	0.5	0	0.00	4.3	100
1,4-dichlorobenzene	0.5	1.3	0.1	0.03	8.1	100
dichlorodifluoromethane	2.6	5.5	1.4	0.59	49	87
d-limonene	2.0	3.0	1.1	0.06	23	100
dodecane	0.9	1.1	0.5	0.10	6.6	100
ethyl acetate	0.9	1.7	0.5	0.05	13	100
ethylbenzene	0.6	0.5	0.4	0.06	2.6	100
2-ethylhexanol	0.3	0.3	0.2	0.04	2.0	54
4-ethyltoluene	0.3	0.3	0.2	0.03	1.9	87
formaldehyde	13	6.7	12	2.7	36	100
hexanal	1.3	0.8	1.0	0.29	3.5	41
m & p-xylenes	2.0	1.8	1.4	0.24	8.9	100
4-methyl-2-pentanone	0.7	1.8	0.2	0.03	15	87
naphthalene	1.3	4.4	0.2	0.03	34	100
n-decane	0.9	1.2	0.6	0.05	8.0	100
n-hexane	1.7	3.7	1.0	0.06	28	54
nonanal	0.6	0.4	0.5	0.14	2.0	54
nonane	0.5	1.0	0.2	0.05	8.1	87
n-undecane	1.0	1.0	0.6	0.13	5.6	87
octane	0.6	1.7	0.2	0.05	16	100
o-xylene	0.7	0.6	0.5	0.10	3.1	100
pentanal	0.3	0.2	0.2	0.04	0.9	41
phenol	0.6	0.5	0.5	0.11	2.2	41
styrene	0.4	0.5	0.2	0.04	3.3	100
tetrachloroethene	0.6	1.0	0.3	0.04	6.0	100
TMPD-MIB[a]	0.6	0.7	0.3	0.02	2.7	41
Toluene	4.6	8.6	2.5	0.58	82	100
1,1,1-trichloroethane	3.0	15	1.0	.05	147	100
1,2,4-trimethylbenzene	0.8	0.9	0.4	0.05	7	100
1,3,5-trimethylbenzene	0.3	0.3	0.1	0.03	1.6	87
TMPD-DB[b]	0.1	0.1	0.1	0.02	0.6	41

[a] 2,2,4-Trimethyl-1,3-pentanediol monoisobutyrate (combined isomers).

[b] 2,2,4-trimethyl-1,3-pentanediol diisobutyrate

Table 2. Summary statistics for environmental and personal variables calculated at the individual-level in the 100 building 94-98 BASE Study dataset.

Variable	N	Prevalence	Mean	Std. Dev.	Min	Max
Environmental variables						
dCO_2 (ppm/100)	100		2.6	1.3	0.40	6.1
Thermal exposure (°C-hours w/ T>20°C)	100		25	6.8	2.2	43
1,2,4 trimethylbenzene (ppb)	100		0.98	1.1	0.05	6.7
Smoking Building	100	25%				
Season (winter = 1)	100	49%				
Average RH < 20%	100	16%				
Heating degree days (°C-days)	100		2200	1163	114	4616
Cooling degree days (°C-days)	100		801	583	22	2243
Individual-level variables						
Current smoker	4304	15%				
Carpet in workspace	4292	89%				
Female (female=1)	4295	66%				
Age ≥ 40 yrs.	4294	55%				
Dust allergy (diagnosed)	4158	32%				
Mold allergy (diagnosed)	4093	25%				
Hay fever (diagnosed)	4073	29%				
Combined allergy	4208	42%				
Migraine (diagnosed)	4099	21%				
Asthma (diagnosed)	4032	12%				
Eczema	3972	9%				
Sensitive to tobacco smoke	4263	56%				
Sensitive to chemicals	4276	49%				
Combined sensitive	4311	67%				
Any allergy, migraine, eczema, or sensitivity	4316	81%				

Table 3. Crude and adjusted[a] prevalence odds ratios[b] (OR) for the association of dCO_2 with selected MM and LResp SBS symptoms for both the 94-96 and 94-98 BASE dataset analyses.

SBS Symptom	94-96 BASE Dataset dCO_2 OR (per 100 ppm) Crude	Adjusted	94-98 BASE Dataset dCO_2 OR (per 100 ppm) Crude	Adjusted
MM	**1.2 (1.07-1.24)**	**1.1 (1.06-1.25)**	1.0 (0.99-1.09)	1.0 (0.99-1.10)
Irritated eyes	**1.1 (1.04-1.23)**	**1.1 (1.03-1.24)**	1.1 (1.00-1.12)	1.0 (0.98-1.11)
Sore throat	**1.4 (1.21-1.59)**	**1.4 (1.19-1.62)**[c]	**1.1 (1.05-1.25)**[c]	**1.1 (1.05-1.26)**[c]
Nose/sinus	**1.1 (1.04-1.26)**	**1.1 (1.02-1.28)**	1.0 (0.98-1.12)	1.1 (0.98-1.13)
LResp	1.1 (1.00-1.27)	1.1 (0.97-1.26)	1.0 (0.95-1.12)	1.0 (0.94-1.12)
Tight chest	1.1 (0.90-1.41)	1.3 (0.99-1.65)	1.0 (0.89-1.20)	1.1 (0.93-1.28)
Short breath	1.1 (0.87-1.37)	1.2 (0.90-1.56)	1.1 (0.89-1.24)	1.1 (0.91-1.29)
Cough	1.1 (0.91-1.23)	1.0 (0.86-1.20)	1.0 (0.88-1.08)	1.0 (0.86-1.07)
Wheeze	**1.4 (1.14-1.78)**	**1.4 (1.10-1.88)**	**1.2 (1.04-1.42)**	**1.2 (1.03-1.43)**

[a]Adjusted for age, gender, presence of carpet in workspace, smoking status, thermal exposure, RH, and 1,2,4 trimethylbenzene. These models did not include environmentally-mediated health condition variables (e.g., asthma, allergies, chemical sensitivity, etc.).
[b]Values in parentheses are the 95% confidence interval (CI). ORs and CIs given in bold are statistically significant at the 95% confidence level or higher.

Table 4. Means and standard deviations for dCO_2 and continuous covariates.

Variable	94-96 BASE Buildings Mean	SD	97-98 BASE Buildings Mean	SD	P-value[a]
dCO_2 (ppm)	242	142	288	130	0.12
Thermal Exposure (°C-hours)	26.16	6.84	24.37	6.94	0.25
RH (%)	40.28	8.71	44.51	10.97	0.06
1,2,4-TMB[b] (ppb)	1.28	1.31	0.93	0.96	0.17

[a]Student's t-test, 2-sided
[b]1,2,4-trimethylbenzene

Table 5. Percent of occupants reporting selected characteristics and SBS symptoms by study year groups. Total number of buildings studied during each group is shown.

Variable	94-96 BASE Buildings	97-98 BASE Buildings	P-value[a]	94-98 BASE Buildings
% female	68.0	64.8	0.04	65.9
% ≥ 40 years	53.2	57.5	0.01	55.3
% with carpet	89.9	90.5	0.50	89.1
% current smoker	15.5	14.0	0.24	15.2
% MM	26.8	25.7	0.30	26.3
% dry eyes	20.3	18.8	0.32	18.6
% sore throat	7.0	6.9	0.95	6.6
% nose/sinus	13.5	12.8	0.58	13.1
% LResp	8.8	7.7	0.29	7.9
% tight chest	2.4	2.2	0.72	2.2
% short breath	2.3	1.5	0.12	1.8
% cough	5.3	5.4	0.94	5.1
% wheeze	2.4	1.8	0.22	1.8
No. of buildings	44	56	-	100

[a]Chi-square, Fisher's exact test, two-sided comparison of 94-96 building set and 97-98 building set.

Table 6. List of the basic set of covariates included in all enhanced models.

Variable	**Description**
GENDER	0:male; 1:female
AGE	0:age < 40 years; 1:age ≥ 40 years
CARPET	0:no carpet at workstation; 1:carpet on most or all of floor at workstation
SMOKER	0: never or former smoker; 1:current smoker
THERMAL EXPOSURE	8.5 hour workday normalized degree Celsius hours above 20 °C
RH	0: mean RH < 20%; 1: mean RH ≥ 20%
1,2,4-TMB	indoor canister 1,2,4-Trimethylbenzene; automobile exhaust marker
CDD	Cooling degree days (°C-days)
HDD	Heating degree days (°C-days)
SEASON	0: summer; 1: winter

Table 7. Statistically significant ($p<0.05$) covariates in the susceptible-population-adjusted logistic regression model using individual susceptibility variables. A "+" signifies odds ratio point estimates greater than unity while a "-" represents those less than unity.

	SBS Symptom								
Covariate	MM	Dry eyes	Sore Throat	Nose/ sinus	LResp	Tight chest	Short breath	Cough	Wheeze
dCO_2	+		+						
Female	+	+	+	+	+	+	+	+	
Age≥40			+						
Carpet				-					
Smoker									
Therm. Exp							-		
RH < 20%			+			+			
1,2,4-TMB					+		+	+	
CDD[a]									
HDD[a]									
Dust allergy			+	+	+			+	
Mold allergy	+	+		+			+		
Migraine	+	+			+	+			
Asthma					+	+	+	+	+
Eczema					+				
Hay fever	+	+		+					
Tobacco Sens.				-	-	-			
Chemical Sens.	+	+	+	+	+	+	+	+	+
Season	+								
Sample Size	3749	3692	3714	3661	3754	3747	3736	3715	3743

[a]CDD=Cooling degree days, HDD=Heating degree days

Table 8. Statistically significant ($p<0.05$) covariates in the susceptible-population-adjusted logistic regression model using the collapsed variable "SUSCEPT". A "+" signifies odds ratio point estimates greater than unity while a "-" represents those less than unity.

	SBS Symptom								
Covariate	MM	Dry eyes	Sore Throat	Nose/ sinus	LResp	Chest tight	Short breath	Cough	Wheeze
dCO_2	+	+	+	+					+
Female	+	+	+	+	+	+	+	+	
Age≥40	+	+	+	+	+			+	
Carpet				-					
Smoker	+			+	+				+
Therm. Exp		+							
RH < 20%			+	+		+			
1,2,4-TMB							+		
CDD[a]	-	-	-	-					
HDD[a]									
SUSCEPT	+	+	+	+	+	+	+	+	+
Season									
Sample size	4211	4152	4167	4108	4225	4210	4195	4169	4207

[a]CDD=Cooling degree days, HDD=Heating degree days

Table 9. Crude and adjusted prevalence odds ratios[a] (OR) for the associations of dCO_2, gender, and any environmental susceptibility with MM and LResp SBS symptoms for the 94-98 BASE dataset analyses. Statistically significant covariates are identified in Table 8.

	94-98 BASE Dataset			
SBS	dCO_2 OR (per 100 ppm)		Individual risk factors	
Symptom	Crude	Adjusted[b]	FEMALE[d]	SUSCEPT[e]
MM	1.04 (0.99-1.09)	**1.10 (1.03-1.17)**	**2.1 (1.8-2.4)**[c]	**2.1 (1.7-2.5)**[c]
Dry eyes	1.06 (1.00-1.12)	**1.09 (1.02-1.17)**	**2.2 (1.8-2.6)**[c]	**2.1 (1.7-2.7)**[c]
Sore throat	**1.14 (1.05-1.25)**[c]	**1.21 (1.09-1.34)**[c]	**2.1 (1.6-2.9)**[c]	**2.2 (1.5-3.5)**[c]
Nose/sinus	1.05 (0.98-1.12)	**1.11 (1.02-1.20)**	**1.8 (1.5-2.4)**[c]	**2.3 (1.7-3.2)**[c]
LResp	1.03 (0.95-1.12)	1.08 (0.97-1.19)	**1.7 (1.3-2.3)**[c]	**2.7 (1.8-4.0)**[c]
Tight chest	1.03 (0.89-1.20)	1.07 (0.90-1.28)	**1.8 (1.1-3.1)**	**11.1 (2.7-45.5)**[c]
Short breath	1.05 (0.89-1.24)	1.07 (0.87-1.32)	**3.0 (1.5-5.9)**[c]	**5.5 (1.7-17.8)**[c]
Cough	0.98 (0.88-1.08)	1.03 (0.91-1.16)	**1.8 (1.3-2.5)**[c]	**1.9 (1.2 –3.0)**[c]
Wheeze	**1.22 (1.04-1.42)**	**1.23 (1.01-1.48)**	1.7 (1.0-2.9)	**2.4 (1.1-5.4)**

[a]Values in parentheses are the 95% confidence interval (CI). ORs and CIs given in bold are statistically significant at the 95% confidence level or higher.

[b]Adjusted for covariates listed in Table 6 and the susceptible population variable SUSCEPT[e].

[c]$p \leq 0.005$

[d]Adjusted odds ratio for females vs. males of having the SBS symptoms

[e]One or more of the following susceptibilities: dust allergy, mold allergy, hay fever, eczema, asthma, migraine, sensitivity to (environmental) tobacco smoke, chemical sensitivity.

Table 10. Results of Principal Components Analysis of the 100-building 37-VOC set plus deltaCO from the BASE Study. The compounds are sorted by loading from first to last principal component. Values in bold typeface indicate compounds with higher loading in each principal component. Principal components PC1 through PC 7 have Eigenvalues > 1.0.

100 Building 37-VOC set	Rotated Principal Components										
	PC1	**PC2**	**PC3**	**PC4**	**PC5**	**PC6**	**PC7**	**PC8**	**PC9**	**PC10**	**Comm-unality**
o-xylene	**0.94**	0.16	0.22	0.03	0.04	0.03	0.02	0.06	0.02	0.01	0.97
m & p-xylenes	**0.93**	0.12	0.24	0.03	0.00	0.04	0.04	-0.03	0.04	0.00	0.95
ethylbenzene	**0.90**	0.14	0.15	0.01	0.03	0.00	0.03	-0.06	0.03	-0.04	0.87
benzene	**0.58**	0.02	-0.11	**0.48**	0.10	**0.33**	0.16	0.12	0.01	0.09	0.75
ethyl acetate	0.02	**0.90**	0.02	-0.05	0.03	-0.08	0.12	0.01	0.06	0.03	0.83
toluene	**0.47**	**0.70**	0.03	0.13	-0.01	0.03	-0.01	0.10	-0.11	0.01	0.75
butyl acetate	**0.44**	**0.62**	-0.05	-0.11	-0.03	**0.30**	-0.06	**0.26**	0.08	0.00	0.76
Styrene	0.19	0.03	**0.80**	**0.30**	0.22	-0.05	-0.05	-0.10	0.05	-0.10	0.85
1,2,4-trimethylbenzene	**0.46**	0.04	**0.70**	0.08	0.04	0.18	0.14	0.11	-0.07	0.07	0.79
naphthalene	0.03	-0.02	**0.27**	**0.81**	-0.09	-0.07	0.01	-0.10	0.12	-0.01	0.77
d-limonene	-0.02	0.06	0.12	-0.06	**0.86**	0.10	-0.15	-0.03	0.11	-0.10	0.83
dodecane	0.07	-0.07	0.05	**0.59**	**0.64**	-0.08	**0.26**	0.14	-0.12	0.03	0.87
n-decane	**0.28**	-0.11	**0.33**	**-0.29**	**0.43**	0.05	0.20	0.10	0.12	**0.29**	0.63
DeltaCO	**0.31**	0.12	-0.03	-0.09	0.14	**0.72**	-0.08	0.02	-0.22	0.00	0.71
octane	**0.51**	0.20	-0.18	-0.05	0.07	**-0.64**	-0.14	-0.04	-0.25	0.03	0.83
1,4-dichlorobenzene	0.03	0.11	0.04	0.09	-0.04	0.02	**0.87**	-0.12	0.08	-0.09	0.81
a-pinene	-0.03	0.18	-0.02	-0.02	0.03	0.07	-0.13	**0.88**	0.06	-0.07	0.84
tetrachloroethene	0.16	-0.16	**0.43**	-0.07	-0.01	-0.19	**0.42**	**0.47**	-0.25	0.09	0.75
formaldehyde	0.06	0.03	-0.01	0.06	0.08	-0.07	0.05	0.03	**0.94**	0.07	0.92
1,1,1-trichloroethane	-0.02	0.04	-0.01	0.01	-0.05	-0.01	-0.08	-0.06	0.06	**0.95**	0.92
Standardized variance explained:	26%	11%	7%	7%	6%	6%	6%	5%	4%	4%	Total= 82%

Table 11. Possible VOC source identification for 11 principal components (eigenvalues >1) of the 41-building 19-VOC set from the BASE Study. PC groupings without source attributions are have not clearly identifiable pattern of VOCs.

PC	Major contributors (loading ≥ 0.5)	Secondary contributors (loading < 0.5)	Possible source	References
PC1	pentanal, hexanal, phenol, 1-butanol, styrene, 4-methyl-2-pentanone, acetaldehyde	nonanal, TMPD-MIB[a], acetone, formaldehyde, butyl acetate	Furniture coatings, composite wood product sources	[1]
PC2	1,2,4-trimethylbenzene, 1,3,5-trimethylbenzene, 4-ethyltoluene, toluene, benzene	Ethylbenzene, m & p-xylenes, o-xylene, n-undecane, nonane, n-decane, tetrachloroethene, 1,4-dichlorobenzene, deltaCO, naphthalene, butyl acetate, acetaldehyde	Construction materials including ceiling panels and some insulation	[2], [3]
PC3	Ethylbenzene, octane, m & p-xylenes, o-xylene, n-hexane	toluene, 1,1,1-trichloroethane	Motor vehicles (MV), printing, printed matter (Prnt)	MV: [4] Prnt: [5] , [6]
PC4	Dichlorodifluoromethane, d-limonene, dodecane, n-undecane	hexanal, styrene		
PC5	TMPD-DB[b], ethyl acetate, TMPD-MIB[a]	nonanal, 2-butoxyethanol, butyl acetate	Plasticized materials	[2], [7], [8], [9]
PC6	acetone, formaldehyde	1-butanol, hexane, 1,1,1-trichloroethane, acetaldehyde	Draperies fabric coverings, workstation partitions	[10]
PC7	nonane, n-decane		Wood finishing products	[11]
PC8	Tetrachloroethene	hexane, n-undecane		
PC9	4-methyl-2-pentanone, 1,1,1-trichloroethane		Adhesives, automotive products	[12]
PC10	chloromethane	Nonanal	Chlorinated material or tap water	
PC11	2-butanone		Solvents	[13]

[a]2,2,4-Trimethyl-1,3-pentanediol monoisobutyrate (combined isomers). [b] 2,2,4-trimethyl-1,3-pentanediol diisobutyrate

References: [1] Salthammer (1997); [2] Tirkkonen et al. (1993); [3] Park et al. (1996); [4] Chang-Chen et al. 1991; [5] Wolkoff et al. 1993 ; [6] Wadden et al. 1995; [7] Plen (1990); [8] Wilkes et al. (1996); [9] Clausen et al. (1990); [10] Bayer and Papanicolopoulos (1990); [11] Chang and Guo (1992);[12] Sack et al. (1992)

Table 12. PC source vectors with possible sources based on 19-VOC/100-building set. Note that PC1 through PC7 have eigenvalues >1.0.

100 Building PCA	Possible VOC sources
PC1	Motor vehicle emissions
PC2	Furniture or wood product coatings
PC3	Vinyl products or carpets
PC4	Printing processes, printed materials
PC5	Air fresheners
PC6	
PC7	Cleaning products, deodorizers
PC8	Unassigned
PC9	Unidentified formaldehyde sources
PC10	Cleaning products

Table 13. Adjusted[a] prevalence odds ratio point estimates for statistically significant (95% confidence level) associations between dCO_2 and PC vectors PC1 – PC7. . Note that the PC vectors are non-dimensional and therefore the units for these ORs are not well defined.

SBS Symptom /covariate	MM	Dry eyes	Sore Throat	Nose /sinus	LResp	Tight chest	Short breath	Cough	Wheeze
dCO_2	1.09	1.07	1.17	1.09					1.24
PC1							1.33		
PC2									
PC3	1.08	1.08					1.21		
PC4									
PC5	0.90				0.84			0.82	
PC6	0.90			0.86					
PC7									
Sample size	4211	4152	4167	4108	4225	4210	4195	4169	4207

[a] Adjusted for potential confounders listed in Table 6 and the susceptible population variable SUSCEPT

Table 14. Prevalence odds ratio point-estimates for statistically significant (95% confidence level) dCO_2 (per 100 ppm), indoor VOCs (per ppb), and deltaCO (per ppm) for the 100 building VOC set, added to the sensitive-population adjusted[a] logistic regression model. Summary statistics for the observed distributions of VOC and dCO_2 are provided in Table 1.

Compound / Symptom	MM	Dry eyes	Sore Throat	Nose/ sinus	LResp	Tight chest	Short breath	Cough	Wheeze
dCO_2 (ppm)	1.13	1.12	1.2	1.18	1.16				1.24
o-xylene							1.95		
m & p-xylenes									
ethylbenzene									
benzene		0.86							
ethyl acetate									
toluene									
butyl acetate							0.77		
styrene								1.39	
1,2,4-trimethylbenzene									
naphthalene		1.03			1.06				
d-limonene		0.97	0.93		0.94			0.91	
dodecane					1.13				
n-decane									
DeltaCO (ppm)	0.83								
octane				1.07					
1,4-dichlorobenzene									
a-pinene									
tetrachloroethene									
formaldehyde	0.98			0.96	0.98				
1,1,1-trichloroethane	0.98								

[a]Adjusted for potential confounders listed in Table 6 and the susceptible population variable SUSCEPT

FIGURES

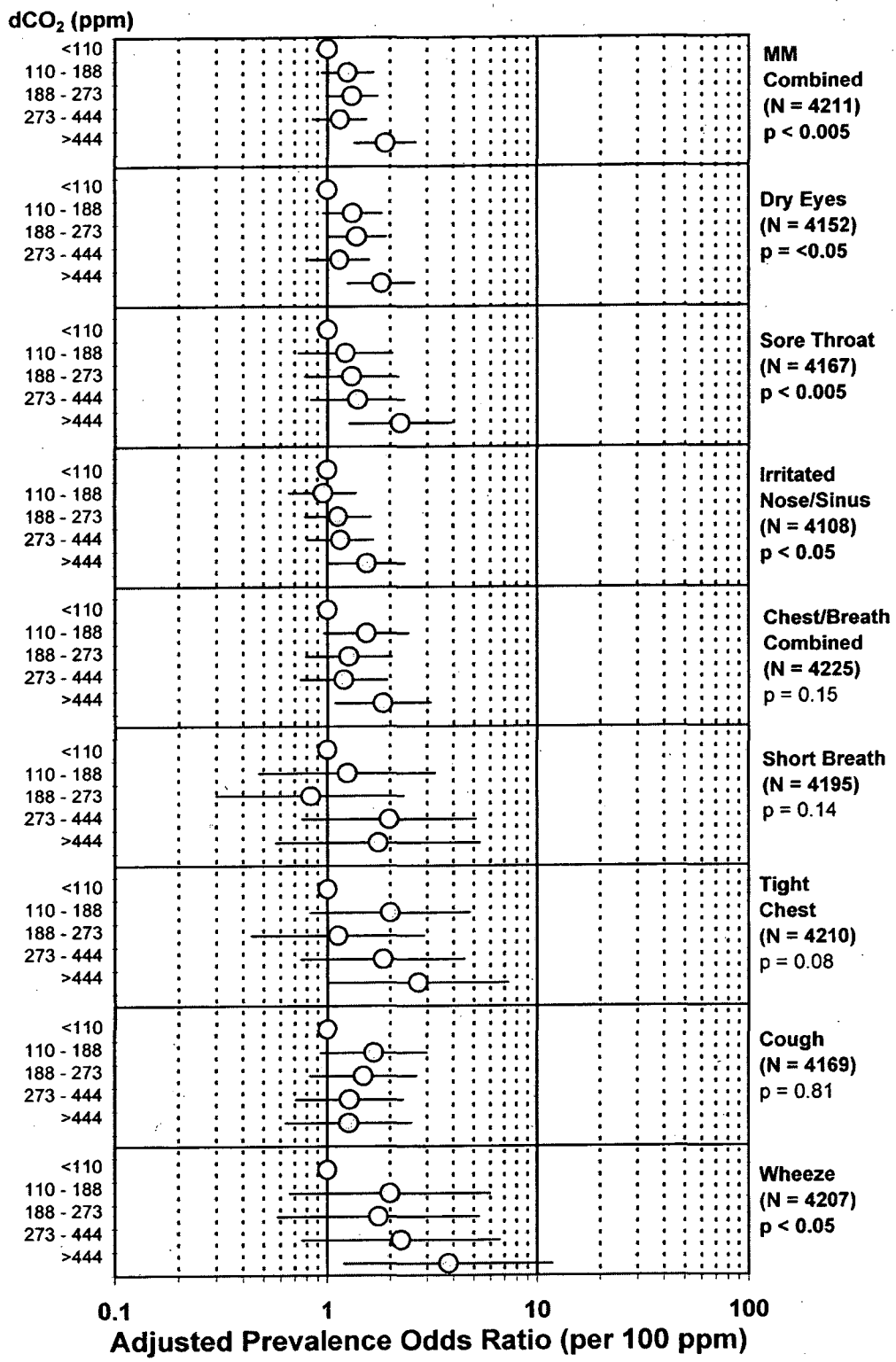

Figure 1. Dose response relationship between binned dCO_2 and MM and LResp symptoms in 100 BASE study buildings. ORs and 95% CIs shown are the results of adjusted models including covariates listed in Table 6 and the SUSCEPT variable. DCO_2 bins reflect the 10^{th} and 90^{th} percentiles of the dCO_2 distribution, and three bins evenly split between them. . P-values shown reflect the fit of the dose-response model with smaller p-values indicating a better fit.

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