

AMBIENT OZONE, HVAC FILTERS, AND BUILDING RELATED SYMPTOMS

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ABSTRACT

Recent studies suggest the reactions between ozone and indoor materials and contaminants can influence human health and perceived indoor air quality within a building. This analysis uses data from the U.S. EPA Building Assessment Survey and Evaluation (BASE) study to determine if there is an association between increasing outdoor ozone concentrations and increased reporting of Building Related Symptoms (BRS) by occupants. Multiple logistic regression (MLR) models, which adjusted for personal, workplace and environmental variables, revealed statistically significant ($p < 0.05$) positive relationships between ozone concentrations and upper respiratory (UR), dry eyes, neurological and headache BRS (odds ratios ranged from 1.03-1.04 per 10 ppb increase in outdoor ozone concentrations). Other BRS had marginally significant relationships with ozone ($p < 0.10$). MLR dose-response analyses indicated a linear increase in UR symptoms with increasing outdoor ozone ($p = 0.03$), while most other symptoms showed consistent but not statistically significant trends with increasing ozone. Importantly, HVAC filter material selection appears to play an important role in the cause of the BRS. Analysis of the BASE data indicate a significant a very relevant increase in BRS in buildings that used polyester and other synthetic (poly/syn) HVAC filter materials. At building locations where average ambient ozone concentrations were above the median during the study day, and poly/syn HVAC filters were in use, adjusted MLR models indicated statistically significant increased odds of LR, cough, UR, dry eyes and neurological symptoms by factors of two to four, relative to buildings with lower ozone and using fiberglass HVAC filters. Although these results should be replicated, they indicate that practical measures to improve occupant health conditions in office and similar building environments in regions with higher ambient ozone levels may require incorporation of effective ozone removal technologies into the outside air intake of ventilation systems, and that filter material selection may become crucial for some locations.

KEYWORDS

Ambient ozone, SBS, BRS, Filter Materials, BASE Study

INTRODUCTION

The materials presented in this conference paper are described in greater detail in two reports (Buchanan et al. 2007 and Apte et al. 2007). What follows is an extended abstract of the findings contained therein. Many of the details of the analyses and results are not included in this short paper but may be found in the referenced full papers.

Building-related symptoms (BRS), more commonly known as sick building syndrome, describe a set of health symptoms with unknown etiology that office workers report experiencing at work, but that improve away from the work environment. These symptoms, which have not been clearly linked to specific causal environmental exposures, can include irritation of the eyes, nose, throat, respiratory tract, and skin, and headaches and fatigue (WHO, 1983). Although the severity or clinical significance of these symptoms is unknown, they affect and may reduce the productivity of a large portion of the

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working population. Fisk (2000) suggests that BRS are responsible for a 2% reduction in productivity, which translates to an economic loss on the order of \$60 billion per year in the United States alone.

Although the causes of BRS are still unknown, low ventilation per person rates (<10 l/s/person) have consistently been associated with BRS (Seppänen et al. 1999). Seppänen et al. (1999) concluded in an extensive review of the literature that ventilation rates of less than 10 l/s per person were associated with relative risks of 1.1-6 for BRS in occupants. Erdmann and Apte (Erdmann and Apte 2004) found in a large random survey of U.S. office buildings that for every 100 ppm increase in indoor minus outdoor carbon dioxide concentrations (dCO₂) office workers experienced 8% to 23% increased odds of having certain mucous membrane or lower respiratory BRS. These findings support the hypothesis that the indoor air quality of a building plays an important role in BRS.

One probable reason for associations of low per-person ventilation rates with BRS is that they act as a proxy or surrogate for increased levels of indoor air pollutants, such as volatile organic compounds (VOCs) and odors generated by buildings, contents, or occupants. This is because provision of less outdoor air for the indoor environment leads to less dilution of air contaminants from indoor sources. Thus, lower ventilation rates imply potentially higher levels of indoor air pollutants, while high ventilation can increase the removal of these indoor contaminants (Weschler et al, 1987; Levin, 1991).

One factor that influences the indoor air quality of buildings is chemical interactions and reactions between oxidizing agents and organic molecules found indoors, such as chemicals used as cleaners (Weschler 2004). One such oxidizing agent is ozone, an indoor contaminant with well established links to morbidity and mortality (Lippmann 1989, Weschler et al. 2006). The dominant source of indoor ozone involved in these reactions is ambient outdoor ozone that penetrates indoors (Weschler 2000). Removal of entrained outdoor ozone occurs because it reacts with compounds on surfaces, in the air, and in building materials or equipment (Weschler et al. 1992, Nazaroff et al. 2006). Even though indoor ozone concentrations are reduced, people spend the majority of their day indoors; therefore a substantial fraction of a person's exposure to ozone occurs indoors (Weschler 2006). Furthermore, health risks are increased not only by low-level chronic exposure to ozone, but also by exposure to the byproducts of ozone reactions, such as formaldehyde, low molecular weight VOCs, and submicron particulate matter, which are often more irritating than their chemical precursors (Weschler and Shields 2000, Mølhavé et al. 2005, Tamas et al. 2006). It is now believed that ozone is responsible for the majority of highly reactive and irritating compounds created indoors (Weschler, 2000 and 2004 and Weschler 2006, Table 1 for thorough summary of ozone reaction products). Formaldehyde, for example, is classified as a carcinogen (Cogliano et al. 2005). Because of their irritancy, it is thought that many of these reaction byproducts have a large impact on the overall indoor air quality of a building (Weschler 2000, 2004). Such "indoor chemistry" may help explain some causes of BRS.

Links between BRS and specific building characteristics, e.g., construction materials, configurations of heating, ventilation and air conditioning (HVAC) systems, and aspects of indoor environmental quality have been investigated (Fisk, 2000; Mendell, 1993). A review of eleven BRS studies (Seppänen and Fisk, 2002), found great consistency in the association between increased prevalence of BRS and presence of air conditioning systems, compared to natural ventilation (a 30%-200% increase). Several studies suggest that HVAC air filters can diminish perceived indoor environmental quality, contribute to BRS, and decrease work performance (Clausen et al. 2002 and Wargocki 2004). Furthermore, several laboratory studies of different air filter types have shown that reactions on filters consume ozone and may produce chemical byproducts that then flow into the building, exposing the occupant to potentially harmful chemicals (Beko et al., 2006; Clausen, 2004; Hyttinen et al., 2003). In addition, the loss of ozone as it passes through ventilation air filters suggests the possibility of an interaction between the air filter and ozone that increases BRS prevalence within a building.

Hypothesis 1. Given the knowledge of indoor ozone-driven reactions and the potential for physiological effects of the products from these reactions, increasing levels of outdoor ozone leads to higher

prevalence of BRS among occupants within a building. This occurs through higher transfer rates of ozone into the indoors increasing the quantity of irritating VOC oxidation products from ozone-VOC reactions indoors. At sufficient levels of exposure to these contaminants, occupants experience irritant and possibly other health symptoms; these symptoms diminish with the removal of exposures, consistent with the definition of BRS.

Hypothesis 2. Air filters can act as a sink for ozone and as possible sources of chemical products that may increase occupant BRS. Certain materials used in the ventilation air filters themselves may increase occupants' risk of BRS, particularly in the presence of elevated ozone concentrations.

Few, if any, field experiments or analyses of field data have been conducted to determine if an ozone and BRS association is detectable. The analyses presented here attempt to identify ozone-BRS relationships and the effects of ozone with HVAC filters on BRS using data obtained from office workers during the US EPA Building Assessment Survey and Evaluation (BASE) study of 100 US office buildings.

METHODS

Data

The data used in this analysis were gathered during the US EPA BASE study that took place from 1994-1998. Each of the 100 randomly selected office buildings was studied for one week either during the winter or summer. The BASE study collected data on environmental factors (e.g. indoor and outdoor temperature, relative humidity, CO₂ concentrations, and selected VOCs), study space ventilation rates, building characteristic (e.g. heating, ventilation, and air conditioning [HVAC] system configuration and maintenance), workplace factors (e.g. cleaning schedules, cleanliness, occupant density) and personal factors (e.g. age, sex, medical conditions, smoking status, health symptoms). Personal data were collected via a confidential self-administered questionnaire distributed to the occupants. Further details of the building selection process and study methodologies have been discussed elsewhere in greater detail (Womble et al. 1993, Womble et al. 1996, EPA 2003).

This analysis uses the weekly definition of BRS; a health symptom was classified as building related if both of the following conditions were met: 1) the symptom occurred on at least 1 day per week during the four weeks prior to administration of the questionnaire and 2) the symptom got better when the occupant was away from his/her work environment. Four individual BRS were analyzed: cough, dry eyes, dry/irritated skin, and headache. Three aggregate BRS categories were constructed: lower respiratory (LR), upper respiratory (UR) and neurological (NEURO), defined as the presence of at least one of the respective symptoms: LR (wheeze, shortness of breath or chest tightness), UR (nose/sinus congestion, sore throat or sneeze) and NEURO (fatigue or trouble concentrating).

Hourly ozone data from the day the questionnaire was taken were used to construct ozone concentration variables. Here we focus on an average late workday (15:00-18:00) concentration variable (LWDOZ) with units of 10 µg m⁻³ although other ozone variables are presented in the above referenced papers.

HVAC filter information in the BASE data were used to address the second hypothesis. Filter-related variables used in this analysis are all based upon the data gathered during the BASE study inspection. The majority of filters were described as being composed of fiberglass, polyester, synthetic, cotton, or cellulose materials; most commonly fiberglass, polyester, and synthetic. Filter categories that we examined included buildings with filters containing any fiberglass vs. none, any polyester or synthetic material vs. none, and any polyester or synthetic material vs. any fiberglass but no polyester or synthetic material. The "any polyester or synthetic material" filters included 100% polyester or synthetic filters as well as blended filters containing polyester or synthetic, such as cotton-polyester and cotton-synthetic filters.

These categories, reflecting any presence of specific materials, allowed inclusion of most or all buildings in analyses. We also constructed a dichotomous variable using “pure” categories of filter medium, restricted to buildings concordant on filter materials, although these included smaller numbers of buildings. For this variable, the reference group was “concordant fiberglass filter” (CFF) buildings (buildings with *only* fiberglass filters), while the comparison group was “concordant polyester or synthetic filter” (CPSF) buildings (buildings with *only* polyester or synthetic filters).

Statistical Methods

The relationship between ambient ozone concentrations and BRS in the BASE study was analyzed using the Multiple Logistic regression with calculated odds ratios (ORs), Wald Maximum Likelihood (WML) statistics, 95% confidence intervals and p-values. Crude (unadjusted, bivariate logistic regression) and adjusted (multivariate logistic regression) models were constructed for each of the four individual symptoms and the 3 aggregate symptom categories.

Adjusted logistic models were controlled for personal, environmental and workplace factors that were suspected to confound the BRS-ozone relationship. Covariates used in the adjusted models included occupant sex, environmental sensitivities, age and smoking status, thermal exposure, indoor minus outdoor carbon dioxide concentration (dCO₂) as an indicator of ventilation per occupant, indoor relative humidity (RH), TMB (a tracer of outdoor automobile pollution), building heating and cooling degree days (HDD and CDD) and the season in which the building was studied.

For the models investigating filter material effects, regression models and general estimating equations were used to estimate odds ratios (OR) and 95% confidence intervals (CI) for the association with BRS of filter medium, ozone, and the joint effect of filter medium and ozone. Crude (bivariate) and adjusted (multivariate) models were constructed for each of the four individual symptoms and the three symptom categories. Primary risk factors of interest were filter material, ozone and filter material*ozone (interaction term). Covariates in adjusted models included filter variables, age, sex, smoking status, sensitivities, dCO₂, RH, season, ThermExp, HDD, CDD and 1,2,4-TMB. The interaction of filter materials with ozone was assessed by including an interaction term (the product of the filter materials variable and the ozone variable) in adjusted logistic regression models. The joint exposure to polyester/synthetic filters and high ozone relative to fiberglass filters and low ozone was calculated from the estimates of the association between filter material, ozone, and their interaction term. Adjusted interaction models were constructed for comparisons of any polyester or synthetic filter material vs. none, and, in a smaller set of buildings, for concordant polyester or other synthetic filter (CPSF) material vs. concordant fiberglass filter (CFF).

For selected risk factors and outcomes, we roughly estimated the attributable risk proportion (ARP), which is the proportion of the risk seen in the total population that is attributable to the specific risk factor, and that would be prevented if the risk factor were removed.

RESULTS AND DISCUSSION

Hypothesis 1

Results from the LWDOZ logistic regression analyses are presented in Table1. In the crude models, significant (p<0.05) ORs for UR, cough, dry eyes, NEURO, and headache BRS ranged from 1.02-1.03 per 10 µg m⁻³. In the adjusted models UR, dry eyes, NEURO and headache were significant at the 95% confidence level. LR was found to be marginally significant (p=0.09). Although the LWDOZ point estimate ORs are identical to or even lower than for AVOZ, the confidence intervals are narrower, making LWDOZ more significant. This observation is discussed below. .

Table 2 shows the Pearson Correlation results for ozone with 20 VOCs with r ≥ 0.10. Nonanal was most strongly associated with increasing outdoor ozone (r = 0.60; p < 0.0001). Other aldehydes (acetaldehyde, pentanal and hexanal), as well as 1-butanol, the texanol isomers, 2-butoxyethanol and

chloromethane also were positively associated with increasing outdoor ozone ($p < 0.05$). In contrast, benzene, ethylbenzene and o-xylene were negatively associated (of these, only benzene had a p -value < 0.05).

When interpreting the ORs in these analyses, it is important to realize that they estimate the average increase in odds of BRS for every $10 \mu\text{g m}^{-3}$ increase in outdoor ozone concentrations, assuming a linear relationship and that the ozone/BRS relationship is causal. The observed ORs translate into roughly a 3-4% increase in BRS risk for every $10 \mu\text{g m}^{-3}$ increase in ambient ozone concentration. If one considers the large range of ozone concentrations present in this analysis ($205 \mu\text{g m}^{-3}$) a 3-4% increase in the odds of having BRS per $10 \mu\text{g m}^{-3}$ increase in ozone becomes a very large increase in overall odds for those occupant in building with high outdoor ozone concentrations. Using the LWDOZ mean ozone concentration ($71 \mu\text{g m}^{-3}$) as the referent, those in buildings with the highest ozone concentration ($210 \mu\text{g m}^{-3}$) have an effective increase in odds of 68%, 49%, 49% and 43% for having UR, dry eyes, neurological, and headache BRS, respectively. If one now uses the occupants from the lowest ozone "exposure" buildings as the reference group, the odds of occupants in the highest ozone "exposure" buildings having BRS increases substantially by 114%, 80%, 80% and 69% for UR, dry eyes, neurological, and headache, respectively.

ARP analyses, assuming that the findings in this study are repeatable with similar results in new research, suggest that, if reductions were made in ambient ozone levels entrained into the building to the lowest level observed in the BASE study ($4.9 \mu\text{g m}^{-3}$), building sites one could expect to see a 48%, 35%, 35% and 33% reduction in UR, dry eyes, NEURO and headache BRS, respectively. These reductions assume that the relationship between ozone and BRS is causal and that all other factors are held constant while ozone reductions are made. This potential to cause large reductions in the BRS indicates another large benefit from reducing outdoor ozone concentrations. More practically, reducing the amount of outdoor ozone that enters into the indoor environment may be a viable alternative. The latter can be accomplished using various types of carbon based filter technologies or absorbent filter materials (Gundel et al. 2002, Shair 1981, Shields et al. 1999, and Kelly and Kinkaid, 1993).

The result of the ozone-VOC correlation should be viewed as qualitative in nature, however, the observed correlation analysis presents evidence that indeed, ozone chemistry is taking place and may be contributing to the observed BRS prevalence in the buildings. In the absence of ozone chemistry, one would expect the indoor concentration of VOCs in the study buildings to vary randomly, without correlation with the indoor or outdoor ozone concentrations. Of interest, formaldehyde, acetaldehyde, pentanal, hexanal and nonanal, which are known products of indoor ozone chemistry, have fairly large, positive r -values, indicating that the relationship between ozone and these compounds track together in a positive direction. The association between ambient ozone and nonanal is particularly strong. Thus with increasing ozone concentrations, and therefore increased ozone reactions with unsaturated hydrocarbons, we would expect to see an increase in aldehyde production, which we do. Three compounds, benzene, ethylbenzene and o-xylene, are all present in motor vehicle exhaust. In many cases outdoor-to-indoor transport is the major source of these compounds in indoor air.

Hypothesis 2

Table 3 shows the numbers of buildings by filter material categories and ozone levels. These included any fiberglass filters vs. none, any polyester/other synthetic filter materials vs. none, and any polyester/other synthetic filter material vs. any fiberglass filter but no polyester/other synthetic filter materials. The relative proportions of buildings with lower ($< \text{median} = 67.6 \mu\text{g/m}^3$) and higher ($\geq \text{median} = 67.6 \mu\text{g/m}^3$) late afternoon average outdoor ozone concentrations for the different sized building sets are also included in the Table.

Tables 4 and 5 show estimates from the adjusted logistic interaction models. Due to missing values in building-level covariates, adjusted models contained a total of only 34 buildings. In low ozone areas,

ORs for occupants in CPSF buildings relative to CFF buildings ranged from 0.79-2.97, but only FTCN had a significant relationship at $p < 0.05$ and only dry skin had an OR < 1 . ORs for high vs. low ozone in CFF buildings ranged from 1.10-1.54, but again, only FTCN had a significant relationship with $p < 0.05$. The joint risk for occupants in CPSF buildings with high ozone, relative to occupants in CFF buildings with low ozone, included ORs ranging from 2.26-5.90 ($p < 0.05$ levels except dry skin).

Table 5 provides the ORs for high vs. low ozone levels within the set of CPSF buildings, and for polyester/synthetic filter risk (relative to fiberglass filter) within the set of high ozone buildings. For high vs. low ozone in CPSF buildings ORs for LR, UR and headache ranged from 2.19-4.08 ($p < 0.05$). For polyester/synthetic filters (relative to fiberglass filters) in high ozone buildings, ORs for LR, UR, dry eyes, FTCN and headache ORs ranged from 1.66-4.01 ($p < 0.05$) and all ORs except dry skin exceeded unity.

We roughly estimated, from the interaction models for CPSF/CFF, the proportion of symptoms that would be prevented (with some assumptions about bias and representativeness), if all entrained outdoor ozone concentrations were lowered to below the $67.6 \mu\text{g}/\text{m}^3$ median and fiberglass filters were substituted for all polyester/synthetic filters. The (ARP) proportional reductions were 62, 38, 29, 26, 33, and 30%, for LR, cough, UR, dry eyes, FTCN and headache BRS, respectively. For skin BRS, which had a nearly significant OR = 0.37, the same formula would estimate a 31% increase in prevalence.

These analyses showed, in a representative sample of U.S. office buildings, that polyester or synthetic air filters alone, or the presence of slightly elevated ambient ozone levels alone, were associated with increases in one or more BRS in occupants, but the joint presence of these two risk factors had a substantially increased risk for several symptoms. CPSF alone was associated with increase in FT/CN, and possibly in cough and dry eyes also, in either low or high ozone environments. Higher ambient ozone alone was associated with an increase in FT/CN in CFF buildings. Buildings with risk factors, CPSF and high ozone, relative to those with neither, were associated with substantial and significant increases in all symptoms except skin. In high ozone areas, increased risk of LR, UR, and headache BRS associated with CPSF relative to CFF was greater than multiplicative, statistically significant such that one cannot consider the risks of polyester/synthetic filters and high ozone separately without considering the joint risks, suggesting an underlying physical interaction between polyester/synthetic filters and ozone with generally adverse health consequences.

CONCLUSIONS

A clear relationship between ambient ozone concentrations and building-related health symptoms has been identified in this study. The hypothesis that the cause of these symptoms is ozone-initiated indoor chemistry is supported by the positive correlation between ozone and aldehydes. Caution must be taken not to place too much credence on this single study, and replication is needed to verify the findings. If additional studies support these findings, the implication is that reduction of ambient ozone entrained into building HVAC systems before it can react with indoor air and surfaces has the potential to significantly reduce building related symptoms.

A clear relationship between polyester/synthetic filters and increased building-related symptoms has been observed in this analysis. In addition, ozone appears to modify this effect leading to large increases in an occupant's odds of have building-related symptoms if they work in buildings with all polyester or synthetic filters, in areas where the mean late workday ambient ozone concentration is greater than $67.6 \mu\text{g}/\text{m}^3$ (about 34 ppb). Before changes to building equipment configurations and maintenance practices occur, the findings presented here need to be replicated and the mechanism by which polyester/synthetic filters increases building-related symptoms needs to be better understood. If the relationship is causal, percent risk reduction analyses indicate that replacing all polyester/synthetic filters with fiberglass filters and reductions in the amount of ozone allowed to enter a building's ventilation system would help to reduce building-related symptoms.

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TABLES

Table 1 Crude and adjusted association per 10 $\mu\text{g m}^{-3}$ between late workday ozone (LWDOZ) and BRS including ORs, 95% Confidence Intervals and p-values.

BRS	Crude Models			Adjusted Models		
	OR	95% CI	p-value	OR	95% CI	p-value
LR	1.03	1.00-1.06	0.08	1.04	1.00-1.08	0.09
Cough	1.02	0.99-1.05	0.23	1.03	0.99-1.07	0.11
UR	1.03	1.01-1.05	<0.001	1.04	1.02-1.06	0.001
Dry eyes	1.02	1.01-1.04	0.01	1.03	1.01-1.05	0.01
NEURO	1.03	1.01-1.05	0.002	1.03	1.01-1.05	0.02
Dry Skin	0.99	0.95-1.02	0.37	0.99	0.95-1.04	0.79
Headache	1.02	1.00-1.04	0.03	1.03	1.00-1.05	0.04

Table 2 Ozone and VOC correlation analysis results ($R \geq 0.10$), sorted by saturation, presence of a carbon-oxygen double bond and r-value.

Compound	r	n	Saturated	C=O	Sampling method
Formaldehyde	0.18+	99	N	Y	DNPH
Acetaldehyde	0.28*	85	N	Y	DNPH
Pentanal	0.40*	40	N	Y	Multisorbent
Hexanal	0.38*	40	N	Y	Multisorbent
Nonanal	0.60**	40	N	Y	Multisorbent
Ethanol	0.49+	13	Y	N	Canister
1-Butanol	0.38*	40	Y	N	Multisorbent
2-Ethylhexanol	0.25	40	Y	N	Multisorbent
Phenol	0.26	40	N	N	Multisorbent
2-Butoxyethanol	0.32*	40	Y	N	Multisorbent
Ethyl Acetate	0.12	69	N	Y	Multisorbent
Texanol 1&3	0.32*	40	N	Y	Multisorbent
TXIB	0.19	40	N	Y	Multisorbent
n-Undecane	0.11	86	Y	N	Canister
Benzene	-0.29*	69	N	N	Multisorbent
o-Xylene	-0.12	69	N	N	Multisorbent
Ethylbenzene	-0.19	69	N	N	Multisorbent
Naphthalene	0.13	69	N	N	Multisorbent
d-Limonene	0.11	99	N	N	Canister
Chloromethane	0.24*	86	Y	N	Canister

+ : $p < 0.10$, * : $p < 0.05$, ** : $p < 0.0001$

Table 3 Initial risk factor categories in entire and selected BASE data sets.

Risk Factor Categories	# (%) of Blds	Total # of Blds
Any fiberglass filter	41 (45)	91
No fiberglass filter	50 (55)	
Any poly/synthetic filter	47 (52)	91
No poly/synthetic filter	44 (48)	
Any poly/synthetic filter	47 (62)	76
Any fiberglass, no poly/synthetic filter	29 (38)	
Only poly/synthetic filter (CPSF)	16	42
Only fiberglass filter (CFF)	26	
Outdoor ozone < 67.6 µg/m ³	42 (46)	91
Outdoor ozone ≥ 67.6 µg/m ³	49 (54)	
Outdoor ozone < 67.6 µg/m ³	22 (52)	42
Outdoor ozone ≥ 67.6 µg/m ³	20 (48)	
Outdoor ozone < 67.6 µg/m ³	15 (44)	34
Outdoor ozone ≥ 67.6 µg/m ³	19 (56)	

Table 4 Adjusted interaction model estimates, 34-buildings, for the effect of filter materials, ozone, and filter materials+ozone. All ORs are relative to fiberglass and low ozone.

a. Occupants in CFF Buildings				b. Occupants in CPSF Buildings			
	BRS	OR		BRS	OR	95% CI	
Low O ₃	LR	1.00		LR	1.45	0.56-3.77	
	Cough	1.00		Cough	2.97	0.83-10.61	
	UR	1.00		UR	1.15	0.53-2.49	
	Dry Eyes	1.00		Dry Eyes	2.07	0.88-4.87	
	FT/CN	1.00		FT/CN	1.93	1.01-3.71	
	Dry Skin	1.00		Dry Skin	0.79	0.25-2.45	
	Headache	1.00		Headache	1.16	0.65-2.06	
c. BRS OR 95% CI				d. BRS OR 95% CI			
High O ₃	LR	1.47	0.58-3.71	LR	5.90	1.73-20.08	
	Cough	1.33	0.56-3.16	Cough	2.67	1.00-7.10	
	UR	1.10	0.65-1.88	UR	2.63	1.36-5.08	
	Dry Eyes	1.37	0.79-2.36	Dry Eyes	2.26	1.17-4.38	
	FT/CN	1.54	1.02-2.35	FT/CN	2.76	1.60-4.76	
	Dry Skin	1.15	0.50-2.62	Dry Skin	0.37	0.14-1.02	
	Headache	1.15	0.69-1.91	Headache	2.54	1.25-5.15	

* p-value <0.05

Table 5 Adjusted interaction model, 34-buildings, relating ozone to BRS in CPSF buildings, and for the risk in high ozone areas in CPSF buildings relative to CFF buildings.

Ozone Risk in CPSF Buildings			CPSF Building Risk (rel. to CFF Building) in high ozone		Interaction test between ozone level and CPSF
BRS	OR	95% CI	OR	95% CI	p-value
LR	4.08	1.24-13.4	4.01	1.94-8.31	0.03
Cough	0.90	0.35-2.28	2.00	0.90-4.48	0.55
UR	2.29	1.24-4.22	2.38	1.59-3.58	0.07
Dry Eyes	1.09	0.58-2.05	1.66	1.12-2.44	0.61
FT/CN	1.43	0.75-2.71	1.79	1.29-2.47	0.82
Dry Skin	0.47	0.18-1.26	0.32	0.14-0.78	0.12
Headache	2.19	1.18-4.07	2.21	1.50-3.26	0.03

* p-value <0.05