PHOTOCHEMICAL SMOG PRODUCTION IN MODERN, SEALED BUILDINGS

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The types and levels of air pollutants found in modern sealed buildings and their effects have increasingly attracted the attention of health scientists. A number of extensive reviews have now documented that public and private structures, especially modern office buildings, contain a wide variety of pollutants, often exceeding levels found outdoors. [1,2,3,4]

Since the mid 1970's government agencies, universities, and independent consulting firms have undertaken over one hundred investigations of building associated epidemics of complaints and illnesses among occupants. Investigators have included government agencies such as the National Institute for Occupational Safety and Health, the Center for Disease Control, and Public Works Canada, university research units such as the Lawrence Berkeley Laboratory and Simon Fraser University, and private consultants such as Geomet Co. of Maryland and TDS Limited of Vancouver. Health complaints have ranged from headaches and eye irritation to reproductive systems and pregnancy problems. Almost all these instances have involved new or refurbished sealed, mechanically ventilated and air conditioned buildings with lighting supplied primarily by fluorescent lights.

Review of these investigations suggests evidence of two generic types of symptomologies.

1) Specific symptoms such as coughing, body rashes and virus caused infections, have frequently been attributed to exposure to specific agents such as residues from carpet shampoos, fibres from materials such as asbestos and fiberglass and viruses coming through the ventilation system.

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2) Nonspecific symptoms similar to those reported for photochemical smog incidents are more common and include eye irritation, fatigue, malaise, and respiratory problems. (Recent studies suggest reproductive system dysfunction may also be symptomatic.)

One likely hypothesis of the source responsible for the nonspecific symptom complex, especially the ever present eye irritation is, in part, a reaction to indoor photochemical smog. Photochemical smog measured outdoors has been shown to be responsible for similar symptom complexes including eye irritation, headaches and respiratory problems. Photochemical smog has also been shown to be related to many of the same vapors found in modern buildings such as formaldehyde (off-gassing from particle board, insulation and other materials), hydrocarbon vapors (from infiltrated auto-exhaust and off-gassing from paints and plastics), peroxyacetyl nitrate (from reactions of hydrocarbon vapors with nitrates from automobile exhaust), benzylic monoalcylbenzenes including toluene and styrene which combine with nitrate (with ingredients coming from glues, solvents and cleaning materials) and even trichloroethylene contained in white-out materials used by typists.[5,6,7] In addition, modern office buildings are lit by fluorescent lights, often around the clock. These lights also give out variable but often not trivial amounts of ultraviolet radiation.

We have undertaken an experimental study to test this hypothesis by varying the antecedent conditions, specifically type of lighting and rate of ventilation in a modern, sealed, air conditioned office building. The study was designed to test the hypothesis that two major factors accounted for perceived environmental problems and Building Illness:

1) Excessive build-up of pollutant products indoors because inadequate dilution of recirculated air by outside air (or by some other source of less polluted air).

2) Enhanced build-up of photochemical oxydants indoors through ultraviolet radiation emitted from sunlight simulating type of lighting impinging on pollutants.

METHOD

A questionnaire of perceived conditions and symptoms was given two times a week to all members of the study office for a control, a test and a final control period. Control periods preceding and following the tests were used to establish a baseline rating for environmental conditions and symptoms when normal ventilation practices were in force.

The office was divided into two areas. Employees in these areas formed two separate experimental groups.

Group 1, consisting of 20 employees, was exposed to a change in air mixture only. For a two-week period the air that ventilated the floor area was mixed to a maximum capacity with outside air. The two-week test period was imbedded in a ten-week period in which the first six and last two weeks were monitored under normal ventilation conditions. Office personnel were not informed that a change in ventilation would occur.

Group 2, consisting of 23 employees, was exposed to changes in both air mixture and lighting. Test periods were preceded by a four-week control period and followed by a two-week control period during which normal conditions of ventilation and lighting prevailed. The initial four weeks of control period were followed by a two-week period during which lighting only was changed. The change was from sunlight simulating to standard cool white fluorescent lamps emitting approximately 5 microwatts per 10 nanometers per lumen of UVA. During the next two-week period, full unrestricted ventilation was introduced in addition to the lighting change. For the last two weeks the sunlight simulating lamps were restored and ventilation was again reduced to its former mixture. Succession of test conditions are schematically presented in Figure 1.

The questionnaire asked if particular environmental or symptomatic conditions existed. Answers were either "yes", or "no", or a blank. Answers were evaluated as indicating improvement, worsening or no change in conditions.

FIGURE 1

SUCCESSION OF TEST CONDITIONS

WEEK OF STUDY	1	2	3	4	5	6	7	8	9	10
GROUP I	•	•	•	•	•	•	V	V	•	•
GROUP II	•	•	•	•	L	L	X	X	•	•

• NORMAL AIR AND LIGHTING CONDITIONS
V VENTILATION ONLY CHANGES
L LIGHTING ONLY CHANGES
X BOTH VENTILATION AND LIGHTING CHANGES

RESULTS

Table I gives the percent change (all in the direction of improvement) during the Group 1 test period. (Only those percent changes are given for which there was at least 5% change in average rating.)

Table I. Percent changes in ratings of quality of ambient air conditions of Group 1 from Control (restricted outside air ventilation) to experimental (full outside air ventilation) phases. Positive values indicate perceived shifts to better quality.

Question	Percent Changes
Is there too much air movement?	--
Is there too little air movement?	+ 57.7*
Is it too cold?	--
Is it too hot?	+ 47.5**
Is there too much humidity?	--
Is there too little humidity?	+ 11.4
Is the air too stuffy?	+ 69.00**
Is there an unpleasant odor?	+ 7.60

* p of rating change by chance <.05

**p of differences by chance <.01

-- changes less than 5%

Dramatic changes were perceived in air movement, heat and stuffiness. These perceptions are not unrelated to each other. A decrease in stuffiness is very likely a summary of the feeling that there is more air movement and less heat. However, it should be kept in mind that in a constant volume ventilation system of this type it is not physically possible for air movement to actually change. The only controlled change was in the content and mixture of the air which now contained more outside air. The slight improvement in perception of odor was to be expected. However, that increase was not statistically significant.

Table II summarizes the changes in rating of lighting quality. (As there were no changes in the perceived light quality for Group 1 which had no lights changed, that group is not included in Table II.) Lighting was felt not to be too bright and, at the same time, adequate. (That is, not too dark.) Perception of glare improved. It is interesting, however, that there was a significant change in the perception of light quality when both light and air changes occurred over that which was perceived when lights only were changed. Differences were tested by analysis of variance and were found to be statistically significant (with $p < .05$).

Table II. Percent changes in ratings of quality of lighting conditions by Group 2 when lighting was changed and when air quality was changed. Positive changes indicate perceived shift to better quality.

Question	Percent Change for Light (but not Air Change)	Percent Change for Light & Air Change
Is the lighting too bright?	+ 19.2	+ 26.7
Is the lighting too dark?	--	--
Is there too much glare?	+ 22.8	+ 28.3

Table III summarizes changes in reported symptomology. Again, changes of less than 5% are not shown.

Table III. Percent decrease in symptoms during periods of full ventilation, light change, and light change plus full ventilation.

	Group 1	Group 2	
Symptom	Full Ventilation	Light Change	Light Change and Full Ventilation
Eye Irritation	6.8	8.0	31.2*
Headaches	--	--	19.3
Dizziness	--	--	--
Nausea	--	--	5.7
Sleepiness	17.4	9.4	10.7
Irritability	--	10.4	11.6
Change of Mood	--	9.3	11.6
Reduced Concentration	14.8	10.3	11.5
Depression	--	--	--
Elation	--	--	--

-- less than 5% change

*p of change, change <.01

Either changing lighting or changing ventilation seems to have had the same effect. While, with one exception, none of the changes were statistically significant, the consistent improvement is an indication that effects were not chance events.

There was a dramatic and statistically significant decrease in eye irritation when the lighting change was accompanied by changes in ventilation. This finding supports our hypothesis that eye irritability in many offices may be due to the build-up of photochemical byproducts and that this build-up is accelerated when light contains ultraviolet emissions. While presence of photochemical smog is difficult to test directly, we feel that the hypothesis is convincing and supported reasonably by our test results.

SUMMARY

In recent years government agencies, universities and independent consulting firms across North America and Europe have responded to complaints of ill health from building occupants with more than 100 epidemiological and industrial hygiene studies of specific buildings. We have reviewed these studies including interviews with a number of the original investigators. Two generic types of symptomologies are evident. Specific symptoms such as coughing and body rashes have frequently been attributed to exposure to specific agents such as residues from carpet shampoos, or fibres coming in through the ventilation system. Non-specific symptoms are more common and have recently been termed Building Illness. Symptoms are similar to those reported for photochemical smog incidents and include eye irritation, fatigue, malaise and respiratory problems. Agents responsible for these symptoms have not yet been determined, however, investigators suspect a combination of reduced ventilation, energy conserving control systems, off-gassing from building materials and office equipment provide the antecedent conditions for the indoor formation of photochemical smog. We have undertaken an experimental study to test this hypothesis by varying the antecedent conditions, specifically lighting and ventilation, in a modern, sealed, air conditioned office building. Results demonstrate a dramatic reduction in building illness symptoms especially eye irritation, with the removal of antecedent conditions for photochemical smog formation. A large number of studies have isolated precursers of photochemical smog in the ambient atmosphere. Many of these same precursers are found in office buildings. Photochemical smog may be a major cause of widespread building illness problems in modern, sealed office buildings.

TABLE I

Average Levels of Pollutants
Measured Most Frequently in Buildings
Investigated for Health Complaints

Pollutant	Buildings with No Smoking Restrictions	Number of Reports	Buildings with Smoking Restrictions	Number of Reports	All Buildings
Aldehydes	.008 mg/m^3	5	-		.008 mg/m^3
Amines	ND	6	-		ND
Ammonia	ND	7	ND	1	ND
Aromatic Hydrocarbons[a]	.006 mg/m^3	35	-		.006 mg/m^3
Carbon Dioxide	615 ppm	18	682 ppm	3	624 ppm
Carbon Monoxide	2 ppm	36	3.5 ppm	10	2.3 ppm
Formaldehyde	.02 ppm	30	.04	4	.022 ppm
Hydrazine	ND	2	ND	2	ND
Hydrogen Sulfide	ND	3	ND	1	ND
Hydrocarbons	.056 mg/m^3	4	ND	1	.056 mg/m^3
Metals	ND	13	ND	1	ND
Nitrogen Oxide	ND	9	13 ppb	2	-
Nitrogen Dioxide	30 ppb	10	-		30 ppb
Ozone	ND	18	.0025 ppm	3	-
Particulates	.134 mg/m^3	6	.015 mg/m^3	1	.100 mg/m^3
Sulphur Dioxide	ND	14	.01 ppm	3	-
Temperature	73°F	17	73°F	5	73°F
Humidity	38%	19	30%	4	36.6%

[a]There were 5 restricted smoking buildings in which levels of Aromatic Hydrocarbons were measured but not detected and 4 hospitals with an average level of 8.5 mg/m^3.

ND: tested but no detectable levels found

- : no data

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