THE IMPLEMENTATION AND EFFECTIVENESS OF AIR INFILTRATION STANDARDS IN BUILDINGS

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BASELINE DATA: HEALTH AND COMFORT IN MODERN OFFICE BUILDINGS

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SYNOPSIS

Reduction of fresh air ventilation is becoming the major means of energy conservation in office buildings. Simultaneously, health and comfort problems experienced by occupants are often suspected to be a direct result of reduced fresh air ventilation. However, there is little data available on health and comfort problems experienced by occupants of buildings operated under normal ventilation rates.

Baseline data needed to compare occupant health and comfort complaints in buildings with reduced ventilation to complaints in "normal buildings" was provided by a survey of 1106 members of the New York local of the Office and Professional Employees International Union in nine office buildings with no prior history of complaints from occupants of health and comfort problems. Buildings were screened for energy conserving retrofits and architectural and ventilation factors.

1. INTRODUCTION

New modes of design, construction, ventilation and energy management have had profound effects on the manner in which pollutants are generated, entrapped or eliminated in buildings. A number of extensive reviews have now documented that sealed, air conditioned buildings, especially modern office buildings, contain a wide variety of pollutants often exceeding levels found outdoors.[1 2 3 4 5] Occupants of these same buildings often also suffer from a complex of symptoms including headaches, burning eyes, irritation of the respiratory system, drowsiness, fatigue and general malaise, now termed Building Illness or Tight Building Syndrome.[6 7] Many public health authorities believe building illness may be reaching epidemic proportions in sealed, air conditioned buildings.

The acceleration of fuel costs in the 1970's placed immediate pressures to conserve energy on the building sector. Building construction, maintenance and service practices and standards were altered to allow energy reduction. Ventilation was drastically decreased and occupant control over ventilation and lighting was reduced. New ventilation standards proposed by the American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE) and the U.S. Department of Energy recommend and permit a reduction of ventilation air by up to 90%.[8 9] For example, the previous ASHRAE "Standard for Natural and Mechanical Ventilation" recommended 25 cubic feet per minute (CFM) per person of fresh air ventilation in general office areas of air conditioned office buildings.[10] However, the new ASHRAE standard "Ventilation for Acceptable Indoor Air Quality" requires only 5 CFM per person of fresh outside air providing smoking is either not allowed or restricted to designated areas.[8] Similar decreased ventilation standards are also being adopted in other countries.

Problems experienced by occupants are often suspected to be a direct result of reduced fresh air ventilation. Without comparative data it is difficult to determine whether the situation experienced by occupants under reduced ventilation conditions is better or worse than under previous conditions. However, baseline data needed to compare occupant health and comfort complaints in buildings with reduced ventilation to complaints in "normal buildings" is now available from a detailed survey of 1106 members of the New York local of the Office and Professional Employees International Union in 9 "normal" office buildings.

2. METHOD

A self-administered Work Environment Survey questionnaire designed to collect perceptions of environmental conditions and prevalence of Building Illness symptoms among office occupants was administered to 1106 office workers in greater New York City (45% men and 55% women). As far as was determined, there was no prior history of health and comfort complaints among the study group, no prior investigations of the office environment, and no major energy conservation retrofits.

The work environment survey questionnaire requested information about:

Environmental conditions: air movement, air quality, lighting, glare, unpleasant odors, temperature, humidity, seating.

Lighting type: fluorescent ceiling light, fluorescent table light, incandescent ceiling light, incandescent table light, natural window light.

Health related symptoms: headache, dizziness, fatigue, sleepiness, nausea, skin rashes, ringing in ears, nose irritation, breathing difficulty, chest pain or tightness, blurred vision, eye irritation, sore throat or cold symptoms.

Control over environmental conditions: windows, illumination, heating, ventilation, air conditioning, smoking.

Questions were so constructed that they could be scored on a 3 point scale, with a 1 indicating a favorable, 2 an intermediate and 3 an unfavorable response. The distribution of responses for health and environment related questions were evaluated by constructing comprehensive indices which combined related and non-conflicting questions.

Table 1 shows the indices used to assess overall effects of working conditions on health related symptoms (visual, cardio-respiratory, musculoskeletal and neurophysiological systems, symptoms common among outbreaks of Building Illness in general, absenteeism and the use of medication) and environmental conditions (lighting, ventilation, temperature, humidity and odor).

Health and environment indices were cross tabulated with responses to individual questions about control of environment (such as opening windows). Cross tabulations were also tested for independence by use of Chi Square statistics.

3. RESULTS

Table 2 presents the percent distribution of complaints about environmental conditions. Seventy-five percent of office workers reported too little air movement as opposed to only 35% reporting too much air movement "Sometime or Often". Unpleasant odor, often used as an indicator of inadequate ventilation, was reported by 40% of respondents as occurring at least "Sometimes" and by 14% as occurring "Often or Always". Temperature was a consistent problem with 77% reporting conditions too cold and 72% reporting conditions too hot "Sometimes or Often". Although 44% of respondents complained of smoky air in the workplace, 74% reported stuffy conditions. These results seem to indicate a need for more appropriate regulations or control by office workers of conditions affecting temperature and air quality. Current air quality regulations[8] are based on restriction of tobacco smoke, however from the survey results it would appear that "stuffy air" rather than "smoky air" would be a better indicator of overall air quality.

Lighting conditions were considered satisfactory. However, responses indicated that brightness and glare could be improved. Fourty-three percent reported that lighting was too dim and 45% reported glare on work surfaces "Sometimes or Often". Lighting conditions are not now a significant problem among office workers, however, with illumination levels and window area being reduced to conserve energy, future problems could result.

Table 3 presents the distribution of Building Illness symptoms commonly reported in the indoor air pollution literature. Headache, fatigue, nose irritation and eye irritation (symptoms indicating general discomfort with environmental conditions) were reported most frequently. Thirty-seven percent of office workers reported headaches, 52% reported fatigue, 32% reported nasal irritation and 37% reported eye irritation more than once a week. Twenty-one percent of respondents reported sore throat or cold symptoms once a week or more.

3.1 Ventilation

Results of the cross tabulation between answers to the question, "In your primary work area do you feel that there is too little air movement?" and the Building Illness Index are shown in Table 4 and the association between "Too Much Air Movement" and Building Illness is shown in Table 5. Table 4 demonstrates a highly significant relation between Building Illness symptoms

and insufficient air movement. (χ^2 = 52.72 and p≤ .001). This is also shown by the approximately four times as many respondents in the insufficient as in the sufficient air movement group who scored "poor" on Building Illness. On the other hand, the responses of "Too much air movement" do not show a significant association to Building Illness (Table 5, χ^2 = 7.41, the value of p is omitted in all tables when the test falls short of reasonable statistical significance). Again this lack of relationship is made obvious by the comparison of the almost equal proportion of respondents in the group that scored low and high on this question. While movement of air by itself does not ensure better fresh air ventilation, it seems to be so perceived and in fact may be the case in buildings that are better ventilated.

Table 6 shows the association between conditions of ventilation in the work place and Building Illness symptoms. There is a highly significant relation between poor ventilation and building illness (χ^2 = 44.72 and p≤ .001). Fourty-four point six percent of office workers with good ventilation as compared to 32.9% with poor ventilation did not complain of Building Illness (i.e. ranked as "good"). As fewer occupants of well ventilated buildings complain of Building Illness symptoms, air movement and quality of ventilation appear to be major determinants of health and comfort among office workers.

3.2 Lighting

Table 7 shows the association between office lighting conditions and Building Illness symptoms. There is a highly significant relation between poor lighting and Building Illness (χ^2 = 45.63 and p≤.001). Twenty-five point two percent of office workers with poor lighting ranked "poor" on Building Illness while only 10.3% with good lighting did so. Table 8 shows the association between lighting conditions and visual health. Again, the relationship is significant and substantial (χ^2 = 74.82 and p≤.001). Eighteen point four percent of office workers with poor lighting also had poor visual health while only 6.4% with good lighting did so.

3.3 Effects Of Smoking

Some of the workers surveyed smoked (57%) and some of them did not (43%). Some of them worked in places where smoking was permitted, some in places where smoking was prohibited, and some in places where smoking was restricted.

Thus a number of groups were constructed for comparison:

- Nonsmokers working in places where smoking was permitted.
- Nonsmokers working in places where smoking was restricted.
- Nonsmokers working in places where smoking was prohibited.

. Smokers working in places where smoking was permitted.
. Smokers working in places where smoking was restricted.
. Smokers working in places where smoking was prohibited.

As responses to questions were almost identical for places where smoking was restricted and where it was prohibited, we combined workplaces where smoking was restricted or prohibited into a single category.

The effect of smoking on nonsmoking office workers is reviewed in the next two tables. Tables 9 and 10 show that there is no significant association between smoking at work and either Building Illness or Visual Health among office workers who either smoke or do not smoke.

Table 11 shows the association between Smoking at Work and the Odor Index. There is no significant difference in the perception of unpleasant odors among nonsmokers or smokers regardless of whether smoking was or was not permitted.

3.4 Control Over Environment

In most modern office buildings, but not in all of them, control of air conditioning and lighting is centralized and thus removed from office occupants. Tables 12 and 13 show the association between control by occupants of air conditioning and lighting on the Building Illness Index. Air conditioning is used here as a generic term referring to the heating, ventilation and air conditioning (HVAC) system. Table 12 shows a significant relationship between control of air conditioning and incidence of Building Illness (χ^2 = 12.17 and $p \leq .005$). Fifteen point nine percent of office workers with no control of air conditioning scored "poor" on the Building Illness Index compared to 4.8% of office workers with control of air conditioning. Table 13 shows a significant relationship between control of lighting and incidence of Building Illness (χ^2 = 8.80 and $p \leq .05$). Fifteen point nine percent of office workers who had no control of lighting scored poor on the "Building Illness Index" compared to 6.7% who had control of lighting conditions. In both cases (Tables 12 and 13) respondents who had control over conditions were approximately three times less likely to suffer symptoms of building illness than those with no control.

4. DISCUSSION

The results indicate that even among occupants of buildings operated under normal ventilation and lighting conditions, there exist problems with environmental conditions as well as a relatively high level of health and comfort complaints. There is a consistent pattern of association of factors relating both ventilation and lighting with frequency of reported illness symp-

toms. Office workers judging their ventilation and lighting environments as poor were more likely to have health complaints than those who considered ventilation and lighting to be good. Office workers with control over environmental and lifestyle factors such as controlling air conditioning, opening and closing windows, switching on and off lighting and smoking had fewer complaints about health and stress symptoms than did office workers with no control over environmental and lifestyle factors.

Very interesting is the lack of significant association between Building Illness, Visual Health and Odor indices and either active or passive smoking. That passive smoking is a known irritant for many nonsmokers is well known. The findings here however do not relate to irritation due to smoking but to the association of smoking to perceived health and/or comfort levels. This lack of association probably is due to two reasons. First, pollutant patterns depend heavily on ventilation factors while, at the same time, byproducts of combustion infiltrate or are generated and entrapped in a building from many sources. In fact, exhaustive reviews of the literature[3] and review of pollutants levels reported in 143 buildings by NIOSH, CDC and other investigators[11] fail to find differences in pollution concentration or patterns in offices with and without smoking restrictions. Second, the manner of administering the questionnaire avoided calling attention to smoking (or any other) factors, besides including questions pertaining to them. It is especially interesting that there were no differences in perception of odors between locations with and without smoking rules (Table 11).

This Work Environment Survey, though limited to office workers in greater New York City, provides some measure of human health and comfort with environmental conditions provided by contemporary office buildings. However, the majority of office buildings may now be designed and built to reduced environmental standards in order to achieve energy conservation goals. Also, many existing contemporary office buildings are being renovated and operated to reduce the amount of energy used. The human costs that may result from reduced environmental standards for energy conservation in office buildings are still unclear. This study presents baseline data showing the relation of environmental parameters to health and comfort of office workers in buildings prior to energy conserving adjustments or modifications. These questionnaire survey results can be used for comparison with similar data collected from occupants of energy conserving office buildings to provide background for prudent standards to ensure that energy efficient buildings are designed, built and operated to provide conditions acceptable for human occupation.

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Health Indices	Environment Indices
Visual . blurred vision . eye irritation . split or double vision . trouble focusing eyes	Lighting . lighting too bright . lighting too dim . glare on work surface
Cardiorespiratory . nose irritation . breathing difficulty . chest pain or tightness . racing heart	Ventilation . too little air movement . too much air movement . air too stuffy
Musculoskeletal . neck ache . sore arms, hands, wrists . backache	Temperature . too cold . too hot
Neurophysiological . headache . dizziness . fatigue . sleepiness . moodiness . depression . lightheadedness . confusion	Humidity . too dry . too moist
Building Illness . headache . fatigue . nose irritation . eye irritation . sore throat or cold symptoms	Odor . unpleasant odor . too smoky
Absenteeism . days absent during past six months . days left work due to illness in past six months	
Medication . aspirin . stomach or digestive aids . cough, cold or sinus medication . stimulants (pep pills) . prescription medicine . laxatives . depressants . sleep inducing aids	

Table 1 - Groups of questions used to construct health and environmental indices

Environmental Condition	Never or Rarely	Sometimes	Often or Always	Total %
Too Little Air Movement	25	39	36	100
Too Much Air Movement	65	29	6	100
Lighting Too Bright	77	15	8	100
Lighting Too Dim	57	28	15	100
Glare on Work Surfaces	55	30	15	100
Unpleasant Odors	46	40	14	100
Temperature Too Cold	23	54	23	100
Temperature Too Hot	28	56	16	100
Air Too Dry	35	43	21	100
Air Too Moist	73	25	3	100*
Air Too Smoky	56	31	13	100
Air Too Stuffy	26	47	27	100
* error due to rounding				

Table 2 - Percent distribution of complaints about environmental conditions

Symptoms	Once a Month or Less	Once a Week	Once a Week or More	Total %
Headache	63	16	21	100
Fatigue	49	24	28	100
Nose Irritation	68	13	19	100
Eye Irritation	63	20	17	100
Sore Throat or Cold	79	13	8	100

Table 3 - Percent distribution of symptoms commonly associated with building illness

BUILDING ILLNESS INDEX	Never	Sometimes	Often	Number of Cases
Good	52.9	45.3	31.1	453
Average	40.8	42.2	46.2	465
Poor	6.3	12.4	22.7	156
Total	100%	100%*	100%	
Number of Cases	272	419	383	
$\chi^2 = 52.72$	$p \leq .001$			

Table 4 - Too little air movement

FUILDING ILLNESS INDEX	Never	Sometimes	Often	Number of Cases
Good	42.8	42.7	43.8	440
Average	41.3	47.0	37.5	439
Poor	16.0	10.3	18.8	149
Total	100%*	100%	100%*	
Number of Cases	664	300	64	
$\chi^2 = 7.41$				

Table 5 - Too much air movement

BUILDING ILLNESS INDEX	Good	Average	Poor	Number of Cases
Good	44.6	50.0	32.9	445
Average	44.6	41.4	45.2	461
Poor	10.8	8.6	21.9	153
Total	100%	100%	100%	
Number of Cases	195	430	434	
$\chi^2 = 44.72$	$p \leq .001$			

Table 6 - Ventilation index

BUILDING ILLNESS INDEX	Good	Average	Poor	Number of Cases
Good	46.7	43.9	30.5	443
Average	42.9	43.9	44.3	459
Poor	10.3	12.1	25.2	156
Total	100%*	100%*	100%	
Number of Cases	687	66	305	

$\chi^2 = 45.63$ $p \leq .001$

Table 7 - Lighting index

VISUAL HEALTH INDEX	Good	Average	Poor	Number of Cases
Good	78.0	62.1	51.5	734
Average	15.6	25.8	30.2	216
Poor	6.4	12.1	18.4	108
Total	100%	100%	100%*	
Number of Cases	687	66	305	

$\chi^2 = 74.82$ $p \leq .001$

Table 8 - Lighting index

BUILDING ILLNESS INDEX	Non Smoker No Smoking Work Zone	Non Smoker Smoking Work Zone	Smoker No Smoking Work Zone	Smoker Smoking Work Zone	Number of Cases
Good	37.9	43.1	43.0	38.9	312
Average	51.5	38.7	44.4	46.5	349
Poor	10.6	18.2	12.6	14.6	112
Total	100%	100%	100%	100%	
Number of Cases	66	137	151	419	

$\chi^2 = 5.30$

Table 9 - Smoking at work

VISUAL HEALTH INDEX	Non Smoker No Smoking Work Zone	Non Smoker Smoking Work Zone	Smoker No Smoking Work Zone	Smoker Smoking Work Zone	Number of Cases
Good	66.7	68.6	70.9	68.3	531
Average	24.2	16.1	17.9	20.5	151
Poor	9.1	15.3	11.3	11.2	91
Total	100%	100%	100%*	100%	
Number of Cases	66	137	151	419	

$^{1}\chi^2 = 4.19$

Table 10 - Smoking at work

ODOR INDEX	Non Smoker No Smoking Work Zone	Non Smoker Smoking Work Zone	Smoker No Smoking Work Zone	Smoker Smoking Work Zone	Number of Cases
Good	28.6	37.9	37.1	33.8	255
Average	58.7	47.7	56.6	53.3	392
Poor	12.7	14.4	6.3	12.9	87
Total	100%	100%	100%	100%	
Number of Cases	63	132	143	396	

$\chi^2 = 7.63$

Table 11 - Smoking at work

BUILDING ILLNESS INDEX	Yes	No	Number of Cases
Good	51.6	40.9	447
Average	43.5	43.2	458
Poor	4.8	15.9	155
Total	100%	100%	
Number of Cases	124	936	

$\chi^2 = 12.17 \quad p \leq .005$

Table 12 - Control air conditioning

BUILDING ILLNESS INDEX	Yes	No	Number of Cases
Good	46.0	41.3	449
Average	47.3	42.8	464
Poor	6.7	15.9	156
Total	100%	100%	
Number of Cases	150	919	

$\chi^2 = 8.80$ $p \leq .05$

Table 13 - Control lighting