Air Recirculation and Sick Building Syndrome: A Blinded Crossover Trial

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ABSTRACT

Objective. This study tested the hypothesis that recirculated air in mechanically ventilated buildings causes symptoms commonly referred to as the sick building syndrome and perceptions of poor indoor air quality.

Methods. A blinded, four-period crossover trial was carried out in two identical buildings, contrasting 70% return air (index phase) with 0% of return air (reference phase). Each period lasted 1 workweek. The study population comprised 75 workers who had reported symptoms related to the work environment or perceptions of poor indoor air quality. Participants reported their ratings of symptoms, their perceptions, and related information in a daily diary. The outcome criteria included aggregative symptom scores for mucosal irritation, skin reaction, allergic reaction, and general symptoms formed of ratings of component symptoms. Perceptions of unpleasant odor, stuffiness, or dustiness were additional outcome criteria.

Results. All 75 participants returned their diaries. For no symptoms did the scores differ between the two phases more than could be expected by chance. Mean rating of unpleasant odor was significantly smaller during the index phase, but mean ratings of dustiness and stuffiness did not differ materially between the two phases.

Conclusions. Our results suggest that 70% recirculated air, when accompanied by an adequate intake of outdoor air, can be used without causing adverse effects. (*Am J Public Health.* 1994;84:422–428)

Introduction

Office workers in North America and Europe have been reported to have symptoms and other health problems attributed to the work environment.[1–12] These symptoms are nonspecific and occur in any population, but several studies indicate that they are more common among the occupants of certain buildings, often referred to as "sick buildings." Thus, the recurrence of these symptoms has given rise to the concept of the sick building syndrome. According to a World Health Organization working group, this syndrome is characterized by eye, nose, and throat irritation; a sensation of dry mucous membranes and skin; erythema; mental fatigue; headache; a high frequency of airway infections and cough; hoarseness; wheezing, itching, and nonspecific hypersensitivity; nausea, and dizziness.[13] There have been several other attempts to define the syndrome as well.[3,14–17]

The indoor environment in a confined space is a complex, dynamic combination of physical, chemical, and biological factors that may affect human health and prompt physical reactions. There is evidence that volatile organic compounds commonly found in office air can cause symptoms typical of the sick building syndrome.[18,19] Exposure to environmental tobacco smoke, which consists of various chemical substances and particulates, has also been related to these symptoms.[4,6,20] Studies in which people subjected to spaces with wall-to-wall carpets,[21] fleecy material,[10] or textile surface material[22] reported more symptoms than people in similar spaces without those materials have provided indirect evidence of the importance of biological particles. In addition, indoor air temperature[5,23] above 22°C and relative humid- ity[24] below 25% have also been assoc- ated with an excess of sick buildin syndrome symptoms in cross-section studies. A six-period crossover trial among office workers was able to sho that symptoms common in low relativ humidity (20% to 25%) can be pre vented by modest air humidification (rai ing relative humidity to 30% to 35%).

In addition to the quality of outdoo air and emissions from the indoo environment and occupants, indoor a quality is affected by type and perfo mance of heating, ventilating, and ai conditioning technology. In mechanic ventilation and air-conditioning system recirculation of air is used to contr temperature and air distribution and t conserve energy. In this type of ventila tion system, a part of the exhaust a from the rooms (return air) is recirc lated back to the supply airflow, which a mixture of return air and outdoor a (Figure 1). Air recirculation can b quantified in terms of the proportion c return air in the total airflow. Propo tions of recirculated air as high as 80 to 90% are common in North Americ whereas, in Finland, they are usual between 30% and 70%.

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The rate of the total and outdoor air upply are other important parameters vhen studying the effects of air recirculaion. It is evident when outdoor airflows ire too low, indoor pollutants can ıccumulate in concentrations that can cause sick building syndrome symptoms. n 1987, a Nordic research meeting considered the use of air recirculation to pe a "risk solution" and recommended igainst it in public buildings.[26] This ecommendation was justified by the risk of spreading indoor air pollutants and by he prevailing poor technology and mainenance of systems involving recirculaion.

We carried out a blinded, fourperiod crossover trial to test the hypothsis that the use of recirculated air in nechanically ventilated office buildings vith sufficient intake of outdoor air exceeding the regulatory recommendaions) and without any unusual internal ources of indoor air pollution causes nucosal irritation, skin reactions, allergic reactions, and general symptoms commonly known collectively as the sick building syndrome), as well as percepions of unpleasant odor, stuffiness, or lustiness.

Methods

Buildings and Study Population

Two identical office buildings in Kilo, 15 km from the center of Helsinki, vere selected as suitable for our study. Constructed in 1974, these buildings ıave eight stories and are 72 m long, 18 n wide, and 35 000 m³ in volume. The tructure of each is concrete, and the vindows can be opened. Each building as a central mechanical ventilation ystem, hot water radiators for heating, nd two identical air handling units, vhich are operated only during office ours, from 7 AM to 5 PM. The roportion of return air, ordinarily 30% o 40% during the heating season, is elected by adjusting the blades of the ampers.

From the source population—the 70 workers in the two buildings—all ıose who met the following eligibility riteria were targeted for recruitment to ıe study population: (1) experience, uring the previous 12 months, of sympıms and/or perceptions of poor indoor r quality, which were attributed to the ork environment generally or to the ıdoor air quality specifically; (2) work in n assigned room on the average of at least 3 days a week; (3) no anticipated absence from work during the study period owing to vacation, trip, or other reason; (4) no doctor-diagnosed asthma; and (5) no regular exposure to environmental tobacco smoke in the office. The resultant study population—the 75 persons who fulfilled these criteria—is described in Table 1.

Recirculation

We tested our hypothesis in a blinded four-period crossover trial in November-December 1988; each period consisted of 1 workweek. For the week just before the experiment, both buildings were ventilated without recirculation, with a total airflow of 20 liters per second (L/s) per person. During the first experimental week, based on random selection, one building (building A) was operated with 70% recirculation while no recirculation was used in the other building (building B). The operation of the recirculation system was then switched during the weekend so that this procedure was reversed during the second week. A similar crossover procedure was carried out two more times. Thus, each participant experienced two periods of exposure to recirculated air (index periods, index phase) and two

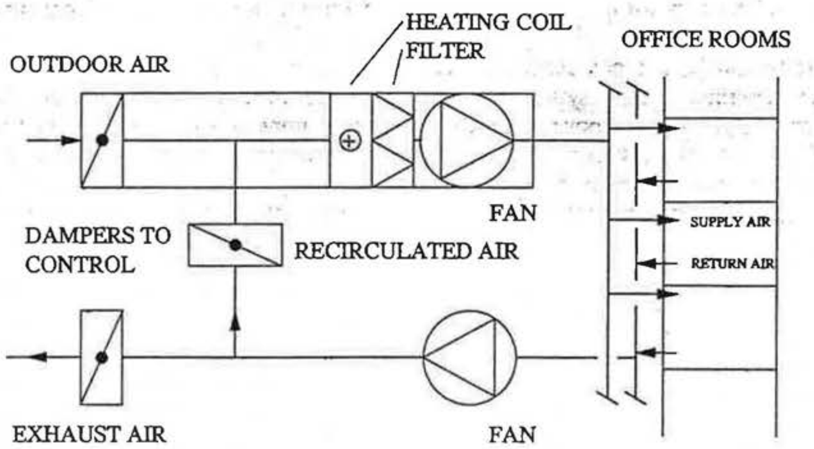

FIGURE 1—A schematic presentation of the air handling system used in the two buildings.

TABLE 1—Characteristics of the Study Population

	Building A (n = 37)		Building B (n = 38)		Total (n = 75)	
	No.	%	No.	%	No.	%
Age						
≤24	3	8	2	5	5	6
25–34	8	22	12	32	20	27
35–44	17	46	13	34	30	40
45–54	7	19	10	26	17	23
≥55	2	5	1	3	3	4
Gender						
Male	15	41	18	47	33	44
Female	22	59	20	53	42	56
Atopic eczema	5	14	8	21	13	17
Hay fever	12	33	17	45	29	39
Allergic conjunctivitis	8	22	11	29	19	25
Smoking						
Current	9	24	12	32	21	28
Ex	12	33	13	34	25	33
Never	16	43	13	34	29	39

periods of no exposure (reference periods, reference phase).

The total supply airflow was kept constant at 20 L/s per person through the experiment. The system was designed to provide outdoor air at the rate of at least 4 L/s per person (the recommended minimum rate in Nordic countries during the study). No air humidification was used in the buildings. The participants were told that ventilation would be adjusted during the study, but neither the objective nor the phase of the study was revealed. Thus, the trial was blinded.

Outcome Criteria

Apart from particular symptoms per se, four outcome scores were defined, based on theories regarding potential health effects of air recirculation, and the reporting of corresponding symptoms (i.e., the symptoms that appear in each outcome score based on the theory) was used in forming them. With a partial overlap of elements, these scores were as follows:

1. *Mucosal irritation score,* based on scores for dryness, itching, or irritation of eyes; nasal dryness; nasal congestion ("stuffy nose"); and pharyngeal irritation
2. *Skin reaction score,* based on scores for dryness, itching, or irritation of skin, and rash
3. *Allergic reaction score,* based on scores for dryness, itching, or irritation of eyes; nasal congestion; nasal excretion ("runny nose"); sneezing; and cough
4. *General symptom score,* based on scores for headache and lethargy

Scores for the perception of unpleasant odor, stuffiness, or dustiness were additional outcome criteria.

Data Collection

During the trial, participants were asked to fill out a diary each day after work recording whether and to what extent they had experienced any of the outcome symptoms (structured answers: no = 0, mild = 1, moderate = 2, severe = 3) and had perceived unpleasant odor, stuffiness, or dustiness (scale from none = 0 to pervasive = 5). A sensation of dryness and of temperature was also requested (scale: all too humid/cold = 1, too humid/cold = 2, acceptable = 3, too dry/warm = 4, all too dry/warm = 5). Extraneous determinants of the outcomes were also inquired about daily. These included symptoms of the common cold (no symptoms = 0, cold and/or sore throat = 1, cold and/or sore throat and fever = 2); sensations of tobacco smoke in a nonsmoking room (scale from none = 0 to extensive odor = 3); the number of cigarettes smoked in the office by participant, roommates, and visitors; the time the window was open, and the reason for opening the window.

Air Measurements

Airflow, temperature, and relative humidity were measured on Tuesdays and Thursdays in all rooms during each period. Airflow was measured in the exhaust air register of each office using a calibrated Wallac anemometer with a relative error of less than 15%. Air temperature and relative humidity were measured with VAISALA HMI-31 capacitive sensors whose accuracy is ±0.3°C for temperature and ±2% for relative humidity. Supply airflow and proportion of return air were measured in the beginning and end of each period using the tracer gas method.

Data Reduction

The detailed data consisted of daily ratings (maximum 20 days) of the component symptoms, and perceptions of and structured answers to the questions on the extraneous factors. The outcome scores were calculated by adding the component symptom ratings and dividing the sum by the number of symptoms. For each participant, the means of the daily outcome scores and the ratings for the component symptoms and the perception of indoor air quality were calculated for both index and reference phases and the difference between these. Days in which less than 2 hours were spent in the office building were excluded. The subjects were also classified, for each item, according to those who reported more, the same number, or fewer symptoms/perceptions of poor indoor air quality during the index phase.

Statistical Methods

The primary hypothesis—that the use of recirculated air causes symptoms and perception of poor indoor air quality—was tested by comparing the means of the outcome criteria in the index, or recirculation, phase with those of the reference phase. In the primary analysis, differences between these means were assessed for statistical significance by using the paired *t* test, and the 95% confidence interval was calculated fo[r] the estimate.[27] The role of period effe[ct] was assessed in a general linear mod[el] using the SAS® computer package (pro[-]cedure *proc glm*), as described by Senn. The probability ratio between experienc[-]ing more and fewer symptoms/percep[-]tions during the index phase as com[-]pared with the reference phase was als[o] estimated. This was done by dividing th[e] number of participants with more symp[-]toms/perceptions during the index phas[e] by the number of participants with fewe[r] symptoms. The statistical significanc[e] was evaluated by means of McNemar['s] test, and the 95% confidence interval fo[r] the probability ratio was calculated b[y] Miettinen's test-based method.[28] Th[e] primary analyses were carried out blinde[d] to the two phases. The analyses wer[e] carried out first for the total stud[y] population and then for the subjects wh[o] had in the baseline questionnaire ind[i-]cated having the corresponding symp[-]tom/perception during the previous 1[2] months.

Results

Experimental Conditions

The proportion of return air durin[g] the study period was achieved reason[-]ably well according to the study design[.] It ranged from 69% to 71% during th[e] index periods and from 1% to 6% durin[g] the reference periods (the result of leak[y] dampers). The total supply airflow in th[e] 67 study rooms was somewhat lowe[r] during the index phase (mean = 20 L/[s] per person, range = 6.3–95.6, SD = 13.2[)] than during the reference phas[e] (mean = 23 L/s per person, range = 6.0[–]77.2, SD = 12.8). Temperature wa[s] somewhat higher during the index phas[e] (23.4°C, range = 21.9–24.8, SD = 0.6[)] than during the reference phase (23.1°C[,] range = 21.8–24.4, SD = 0.6). The rela[-]tive humidity ranged from 23% to 28[%] during the first 3 weeks and from 14% t[o] 20% during the fourth week. The mea[n] relative humidity was 1% greater durin[g] the phase with air recirculation tha[n] during the phase without.

Participation

All 75 members of the study popula[-]tion returned their symptom diarie[s.] Focus on the subjects who were in th[e] office for at least 2 hours on at least 1 da[y] in each of the two phases led to th[e] deletion of three subjects.

Discussion

The possibility that the use of recirculated air causes adverse health effects or discomfort became a public concern at a time when there was no empirical evidence to support or refute it. However, there were two theoretical models according to which the use of recirculated air could cause adverse effects. Berglund and Lindvall[29] suggested that the human sensory system uses a pattern recognition mechanism in the sensation of indoor air with complex environmental adaptation to the inhaled air. Use of a high proportion of recirculated air can lead to extreme homogenization of air, causing sensory confusion and strain on the system when it is trying to interpret the signals. According to the hypothesis, "sensory symptoms tied to 'sick buildings' of the irritant type"[25(p157)] could be related to the homogenization of air. In another theoretical model, which was based on the physical property of recirculation, indoor air pollutants from different point sources are circulated, causing low-level exposure to a mixture of chemical and biological pollutants, which can in turn cause mucosal irritation, skin and allergic reactions, and general symptoms. Thus, the use of air recirculation was hypothesized to produce conditions with adverse health effects; the methods to measure these conditions, however, are poor even with the best of technology.

The sick building syndrome has not been defined properly as a scientific concept, and so far no unifying mechanism has been postulated. We attempted to define the outcome criteria conceptually as biological reactions, mucosal irritation, and allergic reactions. We described the reactions operationally by the chosen symptom scores. The skin reaction score and general symptom score were also used as outcome criteria without any hypothesized mechanism; this was justified because these symptoms have also been attributed to the sick building syndrome.[1–4,8,13–15] General symptoms have also been addressed in earlier studies[8–10,29] without a hypothesized mechanism. The choice of symptoms related to a given mechanism is difficult, and there may be disagreement about the correctness of the choices. In our results, we also showed the occurrence of each component symptom to enable critical readers to evaluate the choice of symptoms or to choose their own combination.

The study population of 75 office workers was recruited from a source population of 470 office workers because they indicated having symptoms or perceived poor air quality related to the work environment at baseline. These subjects thus represented the most sensitive workers, those in whom the effect was most likely to be manifest. Further analyses were carried out focusing on those who had indicated having the corresponding symptom or perception related to the work environment during the previous 12 months when 30% to 40% of recirculated air had been used.

The experimental study design ensured the study's validity because intraindividual comparison of symptoms between different environmental conditions eliminated the potential confounding by personal characteristics. The exact purpose and the phase of the study were not revealed to the study subjects, and thus the information from the index and reference periods was comparable. The length of the periods, 1 week, was deemed adequate for postulated short-term effects. The weekends were considered, a priori, as sufficient washout periods to prevent the effect of exposure in one period to be carried over into a subsequent period. The period effect was found to be negligible in assessing the effect of air recirculation.

The amount of outdoor airflow is directly related to the capability of removing indoor air pollution from a given space. Keeping the total supply airflow constant and varying the proportion of recirculated air, as we did in our study, corresponds to the real-life situation. Our design purpose was to keep room temperature, relative humidity, and total supply airflow similar during the index and reference periods. However, the use of air recirculation had some minor effects on other indoor air factors: the room temperature increased, on average, by 0.4°C; the relative humidity increased by 1%; and the supply air intake rate decreased by 3 L/s per person. Room temperature above 22°C has been shown to increase the symptoms associated with the sick building syndrome.[5] According to an earlier study in Finland,[24,25] an increase in relative humidity in this range is likely to decrease the occurrence of eye and skin symptoms. In the marginal range, a decrease of supply airflow could increase indoor air pollution and thus the symptoms, but during the study the mean supply airflow was 21 L/s per person (minimum was 6 L/s per person) and thus the average decrease was less than 15%. During the index period, the mean outdoor airflow was 6 L/s per person (minimum was 2 L/s per person). In all, the differences in temperature, relative humidity, and supply airflow between the index and reference periods were small and thus were not likely to affect the results.

Uneven distribution of extraneous factors could have affected the validity of the study. To take this potential confounding into account, most important extraneous factors were recorded during the study period. Symptoms of the common cold were slightly more common during the reference phase, which may explain the observed excess in sneezing, nasal excretion, and cough. In all, the differences in the extraneous factors were very small and thus were unlikely to detract from the validity of the study.

The use of 70% recirculated air in the context of sufficient intake of outdoor air appeared not to increase mucosal irritation, skin or allergic reactions, or general symptoms, nor to increase the reporting of poor air quality. Thus, the findings of this study detract from the theory that change in the physical character of air due to recirculation (homogenization) causes the symptoms of the sick building syndrome.[29] Similarly, the use of a high mechanical ventilation rate in another experimental study,[4,6] which was also suggested as a cause of the homogenization of indoor air,[29] appeared not to cause these symptoms.

The present study can also be interpreted as a comparison of the effect of two levels of outdoor air supply (6 vs 20 L/s per person) on the occurrence of sick building syndrome symptoms and perceptions, if the hypothesis of the homogenizing effect of air recirculation, per se, is ignored. The role of air change as a determinant of such symptoms has been assessed earlier at least in five experimental studies.[4,6,30–33] It is evident that too small an air change allows indoor air pollutants to accumulate and that low airflows can thus be indirect determinants of both symptoms and other health problems. In a controlled trial of 46 Canadian office workers in 1980, Sterling and Sterling[30] varied the proportion of outdoor air between 87% (13% return air) and 25% (75% return air) with a constant total airflow, and observed a decrease in the occurrence of

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Nitrogen Dioxide Exposures inside Ice Skating Rinks

Michael Brauer, ScD, and John D. Spengler, PhD, MS

BSTRACT

Objectives. The common opera- of fuel-powered resurfacing pment in enclosed ice skating has the potential for produc- high concentrations of carbon oxide and nitrogen dioxide. osures to these gaseous combus- products may adversely affect health of those inside the rink. e information is available on tant concentrations under nor- operating conditions.

Methods. One-week average ni- en dioxide concentrations in 70 neastern US rinks were mea- d with passive samplers during al winter season conditions.

Results. The median nitrogen de level inside rinks was 180 more than 10 times higher than nedian outdoor concentration. week average nitrogen dioxide entrations above 1000 ppb were ured in 10% of the rinks.

Conclusions. Considering that term peak concentrations were to have reached two to five the measured 1-week aver- our results suggest that nitro- ioxide levels were well above term air quality guidelines onstitute a public health con- of considerable magnitude. *Public Health.* 1994;84:429–

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Introduction

In skating rinks, the operation of gasoline- or propane-powered equipment to clean and resurface the ice can lead to elevated concentrations of combustion products. Reports indicate that high concentrations of carbon monoxide in ice rinks occasionally lead to toxicity.[1–6] Recently, acute respiratory illness due to nitrogen dioxide exposure has also been reported at indoor ice rinks.[7–11]

Acute exposure to nitrogen dioxide concentrations above 5 to 10 parts per million (ppm) may produce severe cough, hemoptysis, chest pain, and pulmonary edema.[12–14] The effects of exposure to lower levels (0.1 to 1 ppm), such as those encountered in homes using gas stoves or kerosene heaters, are more debatable. Controlled exposures of healthy (nonasthmatic) individuals to nitrogen dioxide concentrations above 1000 parts per billion (ppb) (exposure for 1 hour or longer) indicate increased airway responsiveness,[15–17] whereas exposures to lower levels have not produced any effects. On the other hand, controlled chamber studies with asthmatics suggest that small changes occur in spirometric measures and airway responsiveness for short-duration exposures to 100 to 500 ppb nitrogen dioxide.[15,18,19] However, other studies have shown no respiratory effects in asthmatics following exposures to higher levels.[20,21] Consequently, asthmatics are considered to be especially susceptible to respiratory effects of nitrogen dioxide exposure.

Because controlled chamber studies have involved mostly adult subjects, epidemiological studies may have more relevance to the ice skating population since they investigated children. Neas and colleagues report an odds ratio of 1.45 for lower respiratory symptoms in children for an increase in the annual average nitrogen dioxide concentration of 15 ppb.[22] A recent meta-analysis of 11 epidemiological studies yielded similar results, suggesting a 20% increase in the odds of a lower respiratory infection for children with a prolonged increase in exposure to 16 ppb nitrogen dioxide.[23]

Although occurrences are infrequent and are typically associated with resurfacer malfunction, which produces peak nitrogen dioxide concentrations of 1000 to 3000 ppb, reports of acute nitrogen dioxide poisoning in ice rinks demonstrate that an acute exposure in this setting can lead to respiratory illness. In contrast, we sought to examine the potential public health impact of repeated exposures to nitrogen dioxide by investigating the range of concentrations encountered in skating rinks under normal operating conditions. We hypothesized that ice rinks presented the major nitrogen dioxide exposure of users and that, based on comparisons with epidemiological studies of indoor exposures, levels of nitrogen dioxide encountered in ice rinks warrant concern.

Methods

A mail-in survey was conducted in spring 1990. One hundred seven rinks

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