Effect of germicidal ultraviolet light (GUV) installed in the HVAC systems on environmental conditions and, workers health and well being

Overall Findings

Final Performance Report To NIOSH
Technical Report (Option 1)

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May 2002

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List of Abbreviations

HVAC -	Heating Ventilation and Air Conditioning (system)
ACPH -	Air Changes per Hour
GUV -	Germicidal Ultraviolet Light
SBS -	Sick Building Syndrome
BRI -	Building related illness
NSBRI -	Non-specific building related illness
TVOC's -	Total Volatile Organic Compounds
CFMpp -	Cubic feet per minute per person
LSP -	Litres per second per person

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ABSTRACT

Background

Microbial contamination in ventilation systems of modern office buildings has been documented to result in illness among workers. This study was conducted to test whether germicidal ultraviolet (GUV) irradiation of drip pans and cooling coils within ventilation systems of office buildings would reduce occupants work-related symptoms.

Methods

A double-blind multiple crossover design was used. Within three consecutive trials, GUV was off for 12 consecutive weeks, then on for the next four weeks. In the last week with GUV off, or on, workers completed self-administered questionnaires regarding presence of symptoms and environmental satisfaction. Simultaneously, thermal, chemical, and microbial parameters including endotoxin were measured outdoors, within ventilation systems and in occupied spaces.

Results

Operation of GUV lights resulted in significant reduction of microbial and endotoxin concentrations on irradiated surfaces within the ventilation systems, although airborne concentrations of these substances were unchanged. The 771 participants, who appeared to remain blinded, reported significantly fewer work-related overall [within-subject adjusted odds ratio 0.8; (95% confidence interval (0.7,0.99)], respiratory [0.6, (0.4, 0.9)] and mucosal [0.7; (0.6,0.9)] symptoms, when the GUV were operating. Reduction of mucosal symptoms was greatest among atopic workers [0.6, (0.5, 0.8)], and never-smokers [0.7, (0.5, 0.9)]. Never-smokers also had greater reduction of respiratory [0.4, (0.2, 0.9)], and musculo-skeletal symptoms [0.5, (0.3, 0.9)], with GUV on.

Conclusions

GUV was safe, effective in reducing ventilation system surface microbial contamination as well as endotoxin, and associated with significant reduction in respiratory, mucosal and overall symptoms. This effect was greater among workers at risk for allergic or hypersensitivity response to microbial antigens.

Key words: Germicidal ultraviolet light, mechanical ventilation, sick building syndrome, occupational health, building related illnesses, microbes and health effects.

EXECUTIVE SUMMARY

INTRODUCTION:

Non specific building related illnesses, also known as "sick building syndrome" is a poorly understood problem that may affect workers in the office environment. The problem includes respiratory and musculoskeletal symptoms, headache, fatigue, difficulty concentrating, and irritative symptoms of the eyes, nose, throat and skin. The office or office-like indoor environment is now the workplace for approximately 60% of the work force in Northern America and Western Europe, so any occurrence of work related symptoms associated with this indoor environment is likely to have an important impact.

This problem is multi factorial, and there is substantial indirect evidence that microbial contamination in heating ventilation and air conditioning (HVAC) systems contributes to symptoms. Germicidal ultraviolet (GUV) lighting is a low cost practical and feasible technology that could eliminate this microbial contamination. We conducted a study to determine GUV could significantly reduce work related symptoms among office workers.

METHODS:

An experimental study was conducted. The intervention consisted of the installation and operation of germicidal ultraviolet lights (GUV), to irradiate the cooling coils, and drip pans beneath in the heating, ventilation, air conditioning (HVAC) systems supplying selected floors in four study buildings. The study was conducted in 3 blocks of 16 consecutive weeks - within each block GUV was the **off** for 12 consecutive weeks then **on** for 4 following weeks. The study began in August 1999 and continued until the following July, 2000. The study was conducted in a double blind fashion - i.e., workers and data gatherers were not aware whether the ultraviolet lights were on or off.

Four buildings were selected, with sealed windows, mechanical ventilation and central air-conditioning - characteristics which have been associated with building related illnesses. All full time workers on a sample of floors who had fixed identifiable work sites were approached for their written consent to participate. This study was approved by the research ethics committee of the Montreal Chest Institute, of the McGill University Health Centre.

Participating workers completed baseline questionnaires regarding personal and work characteristics. On six occasions - three with GUV off, and three with GUV on, workers completed questionnaires, regarding their satisfaction with the indoor environment, and occurrence of symptoms before or after they arrived at work. At the same time temperature, humidity, air velocity and carbon dioxide were measured at 8-16 work sites per floor, and in the HVAC systems. Viable airborne bacteria and fungi in outdoor air, HVAC return and supply air and at work sites, and on the filters, cooling coils and in the drip pans in the HVAC systems. As

well, carbon monoxide, nitrogen dioxide, formaldehyde, ozone, total volatile organic chemicals, and total airborne particulate (dust) were measured each week that questionnaires were completed.

RESULTS:

In the four buildings, 1021 eligible workers were identified of whom 771 (76%) participated. Overall 45% of all respondents reported at least one work related symptom - most commonly irritation of the mucosal membrane of the eyes, nose and throat, as well as headache or fatigue. Only 10-15% reported symptoms that significantly affected their ability to work. Female gender, younger age, and history of atopic or other illnesses and cigarette smoking were associated with more frequent symptoms.

Temperature, humidity, air movement and carbon dioxide showed substantial variation between buildings. Other indoor parameters including carbon monoxide, TVOC, dust, volatile organic chemicals, ozone, nitrogen dioxide, and formaldehyde were all well below the limits considered acceptable for the indoor office environment, in all buildings. Airborne bacteria and fungi indoors were all well within the range considered acceptable, although they were higher in the warmer months than in winter. Symptoms were increased at higher temperature and lower humidity (especially headache, fatigue, and mucosal irritation), and slightly higher with increased CO_2 and airborne bacteria.

Operation of GUV lights within HVAC systems virtually eradicated bacteria and fungi on directly exposed HVAC surfaces. GUV lights were safe - they did cause any change in concentrations of TVOC's, ozone or formaldehyde, and workers did not note any odour or other problem with them. Environmental satisfaction ratings actually improved slightly when GUV lights were on.

When responses from the same individuals were compared with GUV on or GUV off, and adjusted for work site environmental conditions, GUV resulted in significant reduction in mucosal and respiratory symptoms. Females, non smokers, and workers with an atopic history had greater reduction of mucosal symptoms, and nonsmokers had greater reduction of respiratory and musculoskeletal symptoms.

CONCLUSIONS:

1. Irradiation of cooling coils and drip pans of HVAC systems with Germicidal Ultraviolet lights was safe, eradicated surface micro-organisms, and was associated with significant reduction in work related symptoms - most notably mucosal and respiratory symptoms.

2. The effect of GUV on mucosal symptoms was greatest in nonsmokers, atopic or female workers. The effect of GUV on respiratory symptoms was substantial and not affected by gender or atopic history but was greater in nonsmokers, who also had greater reduction in musculoskeletal symptoms.

3. Low relative humidity and higher temperatures, noted at some work sites were associated with increased reporting of headache, fatigue and mucosal irritative symptoms.

4. This study tested the effectiveness of GUV lights in HVAC systems in a real world setting. We did not identify a causal or pathogenetic mechanism.

5. These results are promising enough to warrant recommendation of continued operation of the GUV lights where they are presently installed. However, these results should be confirmed in an independent study elsewhere. If confirmed, GUV lights could be installed easily and cheaply in HVAC systems of most existing office buildings in North America, and may have considerable public health impact.

USEFULNESS OF FINDINGS

1. Installation of GUV Lamps in HVAC systems proved to be readily feasible in all buildings and was safe. No workers could detect their operation. There no detectable adverse effects, judged by workers' symptoms and environmental ratings, as well as based on measurements of TVOC's and ozone. This means that GUV could readily be applied and acceptable to occupants of most existing North American office buildings.

2. GUV proved highly effective in virtually eliminating surface bacteria, fungi, and endotoxin. The effect was demonstrated in all seasons and on repeated trials including two supplementary trials conducted after the questionnaire gathering was completed. GUV eliminated many different microorganisms identified on non-GUV exposed HVAC surfaces. Some of the identified microorganisms have been previously associated with outbreaks of building related illnesses. GUV was highly effective in eliminating microbial contamination common found on HVAC cooling coil and drip pan surfaces. This suggests that a minimum role for GUV might be the prevention of microbial contamination which can result in outbreaks of building related illnesses.

3. GUV had an important effect on symptoms that have a plausible biologic link with exposure to microbial antigens. In addition the impact of GUV was greatest among individuals with biologic risk factors (such as atopics or non-smokers) for susceptibility to the effect of microbial antigens. This supports the hypothesis that symptoms in these individuals, reported when GUV lamps were off, were related to exposure to microbial antigens emanating from the central HVAC system.

4. The overall reduction of symptoms in this large population of workers was only 4%. Although this overall effect appears modest, if 4% of the total population of workers in similar environments in North America could benefit from this technology, this would mean as many as 3 to 4 million total workers.

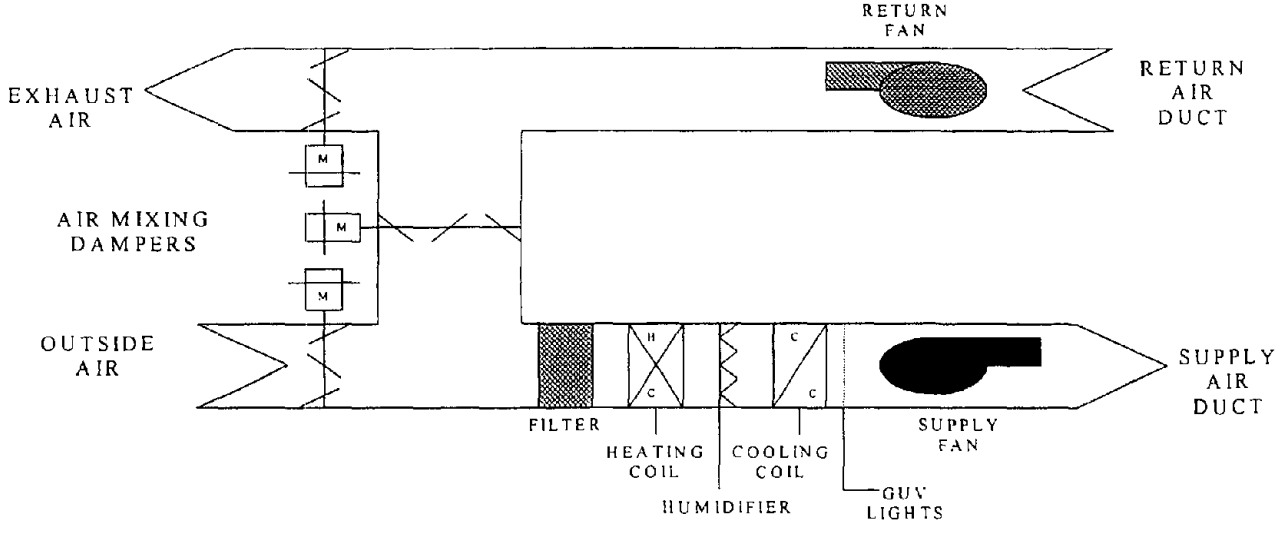
1. INTRODUCTION

Non specific building related illnesses, also known as "sick building syndrome" account for approximately 75% of all outbreaks of illness in the office environment (1). Clinical manifestations include respiratory and musculoskeletal symptoms, headache, fatigue, difficulty concentrating, irritative symptoms of the eyes, nose, throat and skin. The office or office-like indoor environment is now the workplace for approximately 60% of the work force in Northern America and Western Europe (2;3). Between 20-60% of workers report at least one work related symptom and 10-20% report one work related symptom that occurs twice weekly or more often (4). In the United States, the resultant economic loss because of sickness related work absence exceeds 10 billion dollars annually (5). Non specific building related illness is multi factorial. There is substantial indirect evidence that microbial contamination in heating ventilation and air conditioning (HVAC) systems contributes to symptoms. Germicidal ultraviolet (GUV) lighting is a low cost practical and feasible technology that could eliminate this microbial contamination. We conducted a pilot study to assess the feasibility of the installation and experimental operation of GUV in HVAC systems of office buildings. The GUV lights reduced HVAC microbial contamination and were associated with a trend toward symptom reduction and reduced sickness absence. These results warrant a larger study to determine if GUV can significantly reduce symptoms and sickness absence.

2. BACKGROUND

Over the last 40 years, construction and operation of office buildings has changed enormously creating a new man-made indoor ecosystem, and with it new occupational health concerns (1). The majority of modern office buildings have sealed exterior shells with centrally controlled, highly automated, heating ventilation and air conditioning (HVAC) systems which regulate temperature, humidity, air movement, outdoor air supply and removal of contaminants.

Schematic diagram of a typical HVAC system (from (6))



Within large office buildings, there may be more than one thousand workers performing a variety of tasks with different equipment and materials. These occupants and their activities may produce a host of different chemical and microbial contaminants while other contaminants may arise from the building, even the ventilation system itself (7). The interior space may be remodelled, overcrowded, or used for purposes other than that for which the building was designed. In addition, normal wear and tear may lead to dysfunction of the ventilation system (8). Despite this complexity the major - if not the only - means to control this entire indoor environment is the HVAC system, which is itself controlled by only one or two operators (6). Their primary concern is energy conservation, and not the building occupants with whom they have very little contact, or the occupants health - about which they usually know nothing. Given this situation, it is not altogether surprising that health problems related to this indoor environment have arisen.

Since the 1970's outbreaks of several different types of illnesses have been reported among workers in modern office buildings. These can be classified as specific building related illnesses such as legionnaires disease or hypersensitivity pneumonitis, and nonspecific building related illnesses also known as "sick building syndrome" (1). Specific building related illnesses account for approximately 25% of all outbreaks of illness in the office environment (9). In these outbreaks, causative agents can be identified and the clinical manifestations of affected workers are relatively homogeneous.

However, in the majority of outbreaks of illness/environmental dissatisfaction among office workers, no causative agent can be identified and clinical manifestations are both non specific and heterogeneous - including respiratory and musculoskeletal symptoms, headaches, fatigue, difficulty concentrating, and irritative symptoms of the eyes, nose, throat, and skin. As summarized in Appendix 2 - Table 1, symptoms have been associated with female gender (10-18), atopic or allergic history (11-19), psychosocial factors (11;13-16;18;19), work with photocopiers (11;14;15;20), video display terminals (11;14;15;17-19), or carbonless paper (11;14;20;21); and worksite characteristics including crowding (14;18;20), noise (19), surface dust (14;19) and presence of carpets (14;19;20). After accounting for these personal, work, and worksite characteristics the role of indoor air pollution, building ventilation type (18;22-24), and outdoor air supply rate (22-25) remain poorly defined.

2.2 Evidence for the Role of micro-organisms in building related illnesses

2.2.1 - Evidence from outbreaks of specific building related illnesses:

The majority of specific building related illnesses reported to date have been related to microbial contamination. As summarized in Appendix 2 - Table 2, examples include Legionella contamination in water cooling towers resulting in Legionnaires disease or Pontiac fever (26;27), fungal and protozoal contamination of HVAC systems or humidifiers resulting in hypersensitivity pneumonitis (28-31), humidifier fever (32), asthma (33-35) and rhinitis. These specific building related illnesses are important because they demonstrate that microbial contamination does occur and will result in objective health effects if concentrations are high

enough. An important but overlooked finding in many of these outbreaks, was that relatively few workers had objective health abnormalities, and the majority of affected workers had non specific symptoms (30;31). These workers might have been mislabeled as having non-specific building related illnesses, or "functional disorders", had it not been for the few sentinel cases that lead to a specific diagnosis (1). The role that recirculation of microbial contaminants plays in the pathogenesis of illness is unknown. In one study military recruits housed in mechanically ventilated barracks had twice the incidence of respiratory tract infections compared to recruits living in naturally ventilated barracks (36).

2.2.2 - Occurrence of microbial contamination in HVAC system:
Given that outbreaks of specific building related illnesses are uncommon, how often does microbial contamination occur? It appears that some contamination is almost universal because the environmental bacteria, fungi and protozoa commonly found within office buildings require only water and very simple substrates for growth. Substrates are found everywhere as they include dirt, dust and debris, cellulose, building materials, carpets, and furnishings. Water commonly accumulates in the HVAC system from condensation, or humidification (6); as a result bacteria and fungi have been found in large concentrations in HVAC filters (37), drip pans (38), humidifiers (35), air cooling units (28;31;38), even on the cooling coils of air conditioning systems (38), as well as the dust found in ventilation ducts (39;40). In occupied spaces water damage from leaks, spills, and floods can result in contamination of building materials (41), or carpets (42;43). Mycotoxins and endotoxins have been extracted from the dust taken from HVAC system ducts (39;44) as well as from water damaged building materials (41).

2.2.3 - Range of potential health effects of micro-organisms:
A wide variety of bacteria, fungi and protozoa are recognized indoor contaminants ie they may grow somewhere within this indoor environment, and act as a source of indoor airborne microbial pollutants. These may produce health effects through 4 mechanisms (45): (i) direct infection, such as Legionnaire's pneumonia; (ii) allergic, such as rhinitis, asthma or rash; (iii) other immunologic effects, such as hypersensitivity pneumonitis or humidifier fever; or, (iv) toxic effects, although the effects of mycotoxins and endotoxins are less well understood. The likelihood and nature of the health effects depends on the concentration (dose) and type of organism, as well as the host susceptibility (1). Certain organisms such as Alternaria are potent allergens (46-48), while others, such as Stachybotrys produce mycotoxins (45). In some instances, the same agent may result in very different health effects. For example, Legionella pneumophila can cause Legionnaire's pneumonia (49;50), or Pontiac fever (50;51) which is a mild self-limited disorder, similar to humidifier fever. In a few well-characterized outbreaks, exposure to a single agent such as *Penicillium* species resulted in asthma in some individuals, hypersensitivity pneumonitis in others, while yet others had non specific symptoms (31;36).

2.2.4 - Health effects of exposures to micro-organisms - other environments:
In 17 cross sectional or case control studies (Appendix 2 - Table 3) which surveyed more than 50,000 adults and children, a consistent relationship was detected between respiratory symptoms or asthma and self-reported exposure to mold and damp in the home (46;52-66). Although such

self-reports may overestimate exposure. Objectively measured mold levels correlated with symptom status in four studies (52;54;65), but not in two others (55;61). Lung function changes have been correlated with objectively measured mold levels in three studies (52;54;65), but not in two others (58;61). Three studies have demonstrated a close relationship between airborne mold concentrations outdoors and respiratory symptoms (47;67;68). The evidence from home and outdoor environmental studies strongly suggests that fungi or mold play a role in the genesis of respiratory symptoms; it would be logical to assume that the same could occur in office buildings.

2.2.5 - Evidence from epidemiologic surveys in office buildings:
Despite all of the above, there is no consistent relationship between symptoms of non specific building related illnesses and measured levels of fungi and bacteria (see Appendix 2 - Table 4). Yet there is considerable indirect epidemiologic evidence including: (i) the presence of air conditioning is the only building HVAC factor consistently associated with increased symptom prevalence in large scale surveys (18;22-25), (ii) HVAC humidification has been associated in 2 large surveys (18;23), although not in another (25); (iii) carpets (14;19;20), poor cleaning (69;70), surface dust (14;19;71) and debris in the HVAC system (70) are all risk indicators for symptoms - and all in turn are associated with increased microbial levels (42;70-72).

Why are indicators of microbial contamination associated with symptoms when actual measures are not? There are several explanations: **(i)** It is possible that the associations are seen because of unknown contaminant(s) that share characteristics for growth or pollutant production. **(ii)** The number and variety of microbial organisms is enormous, particularly for fungi, and in any office building more than 20 different organisms can be found. The health effects of most of these organisms is unknown. This makes it very difficult to identify health effect related to individual species. **(iii)** Studies attempting to link specific exposures, such as fungi or bacteria, with health outcomes have failed to consider the possibility that susceptibility to these agents does vary substantially. A few workers may manifest health effects even at the very low concentrations usually measured. Experience in other fields of occupational medicine indicate that susceptibility to any given agent will vary substantially in a large population of workers. Therefore it might be predicted, even expected - given the many different microbial contaminants found in the office environment - that a significant number of workers will be affected, although not to the same agents. If susceptibility to different agents were random (i.e., being susceptible to one agent did not affect the chances of susceptibility to another), the cumulative effect of many workers exposed to many microbial pollutants could result in health effects in 10% to 20% of workers, even though all agents were at relatively low concentrations. This would be very difficult to detect. In one epidemiologic survey, approximately 2% of 1100 office workers had symptoms, and allergy skin test reactions that were associated with low level exposure to Alternaria (48). **(iv)** Most of the current measurement methods were developed for the industrial environment; they may not be sufficiently sensitive to detect exposure-response relationships at the low levels of many contaminants in this non-industrial environment. **(v)** Measurement of environmental pollutants is expensive and complex. As a result, most previous investigations have measured environmental parameters in a limited number of locations. In several studies measurements were

taken in as few as 2 to 7 offices per building (10;73-75); this meant that exposures for up to 500 workers were based on a single measurement. There is significant spatial variation in the concentration of pollutants in the office environment because of the effect of local pollutant sources and variation in local effectiveness of the ventilation system in removing these pollutants (17;76-78). Studies with person specific measurements have detected more associations (4;79;80), but even these have been unable to account for temporal variation related to changes in outdoor climate and air pollution levels (81), or changes in indoor activities and occupancy (78). Failure to account for spatial and temporal variation will result in random misclassification of exposure and diminish the likelihood of detecting exposure response relationships. **(vi)** Exposure to airborne endotoxins and mycotoxins have been implicated but dose-response relationships have not been defined. In the rare outbreaks linked to these toxins the health effects have been associated with exposure to endotoxins or mycotoxins producing organisms rather than to measured airborne concentrations of these toxins (45).

2.3 Germicidal ultraviolet light (GUV)

The germicidal effect of sunlight was first discovered in England in 1877 by Downes & Blunt. Since their pioneer work, the effect of ultraviolet radiation on bacteria, molds, fungi, spores and other airborne living organisms has been studied in detail. As can be seen in table no.1, the relation between lethal action and the required ultraviolet dose at a given wavelength is now well known. The relationship between the germicidal effect and wavelength has a maximum effectiveness at 260 nm (nanometer = 10^{-9}m) and falls to practically zero at 320 nm. In a general way, this relationship is similar to the absorption spectrum of a nucleic acid hydrogen bond, the basis of reproduction of any living organism. Within the limits of experimental accuracy, the lethal action appears to be independent of the nature of the bacteria.

About ultraviolet light

The visible light spectrum is relatively small. It goes from 400 nm which we see as violet up to 700 nm wavelength which appears red to our eye. Lower and higher wavelengths are outside the range of our natural sensors and are respectively referred to as ultraviolet and infrared. In pretty much the same way that the visible spectrum is divided into the various colors of the rainbow, the ultraviolet spectrum is conveniently divided into specific regions based on their properties. The first one called UV-A is active in the photosynthesis process in green plants and can be produced artificially with what is commonly called black light. Its wavelength is from 400 nm down to about 330 nm. The second zone ranges from 330 nm down to 290 nm and is called the UV-B. It is the ultraviolet that causes the sun tanning of our skin. The third zone covering a range of 290nm to 220nm is called UV-C and is the one particularly known for its germicidal properties. Finally, the wavelengths lower than 220 nm are called the far ultraviolet or UV-V for vacuum ultraviolet. This denomination comes from the fact that at these wavelengths, the oxygen in the air strongly absorbs the ultraviolet photons to produce a meta-stable oxygen compound known as ozone.

This entire UV spectrum and much more are strongly emitted by the Sun and reaches the Earth's upper atmosphere. Fortunately, they are filtered out by the various atmospheric layers so that only small portions of UV-A and UV-B and practically no UV-C or UV-V reaches the ground.

Effect of GUV on bacteria

When bacteria are subjected to any lethal agent such as heat, disinfectants, x-rays, or ultraviolet, they do not all die at once. A constant fraction of the bacteria present die with each increment of

time. The fraction of the number initially present, which survives at any given time, is called the survival ratio. The fraction killed, is 1 minus the survival ratio. The quantities are expressed as a percent.

The KILLING RATE is an exponential function of the time of exposure and the intensity of the ultraviolet radiation:

$$\text{KILL RATE} = 1 - N/N_o = 1 - e^{-i.t/k}$$

Where:

N_o = the number of bacteria initially present
N = the number of bacteria surviving at time t
t = the exposure time to ultraviolet (sec)
k = a lethal dose depending upon the nature of the organism (microwatt.sec/cm^2)
i = ultraviolet radiation intensity (microwatt/cm^2)

The dose (i x t) required for (i x t / k) to equal 1 has been defined as a "Lethe" and corresponds to a Kill Rate of 63.2%. A given dose results in a given survival ratio, whether the exposure consists of low intensity for a long time, or high intensity for a corresponding shorter time.

GUV artificial sources

Ultraviolet lamps of all kinds are extensively used in hospital operating rooms, meat storage and processing plants, bakeries, breweries, dairies, kitchens, pharmaceutical production, biotech laboratories, water treatment plants, and animal labs - wherever microbial contamination was a concern. Artificial ultraviolet radiation is produced by excitation of mercury atoms. The passage of an electrical current in an ionized gas containing mercury atoms results in an excitation to various energy state of its peripheral electrons. In undergoing transition from one state to another, the electrons emit radiation of definite wavelength. The relative intensity of radiation in different spectral regions depends in part upon the pressure of the mercury vapor, the amount and type of other gases, and the electrical conditions in the discharge. Ultraviolet lamps vary in size and wattage depending upon the application.

In order to insure adequate performance for a given coil size, special attention must be paid to the layout of the number of GUV sources required, their respective position and distance from the coil and alignment on the coil. Adequate performance is defined as the irradiation intensity required so that a living organism requiring a lethal dose of 100,000 microwatt.sec/cm^2 will not survive more than 10 minutes anywhere on the coil. In order to validate the performance of the proposed arrangement for this study, the manufacturer of the GUV system used a computer simulation that computes the irradiation intensity pattern for each individual coil to be irradiated. The two dimensional simulation produces a resulting bacteria kill/time map of the complete coil surface.

Ultraviolet coil irradiation system engineering

Several coils in the same building were irradiated for the purpose of the study. The following is an example of such a coil. The coil to be treated is 96 inches wide by 32 inches high. Four Sanuvox CoilClean™ Model 2020 assemblies were used. Each assembly measures 21.5 inches by 21.5 inches using L-shaped UV lamps, were installed in a layout illustrated in figure 1.

The computer simulation calculates the germicidal UV dose received at every point on the coil. The engineering design criteria for the number of UV lamps and their layout is as follows: within a maximum of 10 minutes of exposure to UV, 99% of the biological contaminants on the surface of the coil must be destroyed.

The survival time of biological contaminants having a lethal dose of 100,000 microwatts.sec/cm^2, which is at the very high end of the UV resistance spectrum, (Ref: Table-1), is computed and plotted on a surface representing the coil.

The results are shown in figure 2. As can be seen, the UV irradiation pattern is concentrated on the side corners and on the bottom of the coil where the condensed water runs down. The survival time there is less than half a minute. At the top of the coil in the center, where the survival map turns to red, the longest survival time is found to be less than 4 minutes.

It is worth noting that the UV lamp/reflector assembly must be installed upstream of the water/steam humidifier injectors. Since the purpose of the UV lamp array is to irradiate the coil surface, the air flow (CFM) plays no part in the design process. In the operation logic of the system, the UV lamp array should be kept on all the time. The design procedure described above can be applied to much larger coil up to 20 ft wide and 20 ft high requiring as much as 16 lamps or more to ensure that the germicidal UV dose is well distributed and sufficient to maintain the coil free of any living organism at all times.

In experimental studies, GUV has been shown to rapidly reduce the airborne concentration of viable micro-organisms (82;83). In field studies, installation of GUV lights has been associated with reduced attack rate of measles in school children (84) and reduced transmission of tuberculosis in congregate settings such as homeless shelters (85). Ultraviolet light poses little health risk although direct exposure may cause conjunctival irritation, and prolonged exposure could theoretically result in skin cancer. However occupants in the offices could not come in direct contact with GUV lights installed in HVAC systems, making such units completely safe.

The problem in the past with use of GUV in ventilation systems has been poor germicidal efficacy because of the low air temperatures and high air flow. Recently developed high intensity lights have made HVAC ultraviolet irradiation feasible and efficacious. The advantages of GUV in HVAC systems is that it is safe, does not produce by-products such as ozone, and is inexpensive to install and maintain in existing buildings. The lights have little energy requirements do not increase resistance to air flow (unlike high efficiency filters). Ultraviolet light installed in HVAC systems could directly sterilize cooling coils, humidifying systems, drip pans, and the "downstream side" of filters, eliminating these as potential sources of organisms, allergens, and toxins.

2.4 Results of a pilot study

To assess the feasibility of an experimental intervention study of the installation and operation GUV in HVAC systems of office buildings, in September 1997, GUV lights were installed in the ventilation systems serving three floor of a downtown office building (NOT selected because of known microbial contamination problems). The objectives of the study were: **(i)** Determine if workers could detect if the GUV were on or off (ie blinding); **(ii)** To ensure no adverse effects were noted; **(iii)** Assess germicidal efficacy within the HVAC system; and, **(iv)** Estimate symptom occurrence in weeks when GUV were off to refine sample size calculations.

Over 12 consecutive weeks the GUV was turned on or off in four 3-week blocks. In the third week of each block, workers completed questionnaires regarding environmental satisfaction ratings, symptoms occurring at work, and sickness absence in the preceding five working days. Detailed environmental measures were made in the ventilation systems and at a sample of work sites. Results of this pilot project are summarized in tabular form in Appendix 3 - Tables 1 to 7. In brief, 107 workers or 87% of the eligible population participated. Environmental satisfaction ratings (Table 3) were not different when the GUV lights were on or off. There was a trend toward fewer work related symptoms (Table 4) when the GUV were on, and fewer hours of work missed due to illness attributed to indoor air quality problems (Table 5). Thermal comfort parameters, and all chemical contaminants including TVOC's, nitrogen dioxide, ozone, formaldehyde, and dust were unchanged by operation of GUV (Table 6). Airborne fungal spores at diffuser and work sites were not different, but in the HVAC system supply air and surface bacterial and fungal levels were much lower with GUV on (Table 7).

From these results, it is possible to conclude that the operation of the GUV could not be detected by the workers, there was no evidence of adverse effects, the GUV lights successfully reduced HVAC microbial contaminants and were associated with a trend toward symptom reduction and fewer hours of work missed attributed to indoor air quality problems. This pilot study attained all objectives successfully, and we believe the results warrant a larger study to determine if GUV can significantly reduce symptoms and sickness absence.

2.5 Summary of background

Non specific building related illnesses is a complex disorder which is probably multi factorial. Fungal and other microbial contaminants can produce a wide variety of different health effects depending upon the concentration and type of organism and the host susceptibility. Microbial contamination throughout office building HVAC systems has been well documented. However there is little direct evidence to link HVAC contamination to health effects. This may be a reflection of methodologic weaknesses of past epidemiologic studies, difficulties of accurately measuring exposure, plethora of contaminants all at low concentrations, heterogeneity of human response to the same agents, and inability to identify the susceptible workers. There is substantial indirect evidence that microbial contamination in HVAC systems contributes to symptoms of non specific building related illnesses. GUV is a low cost, practical and feasible technology that can safely eliminate surface and airborne bacteria and fungi in the central ventilation system. GUV was practical safe and feasible in a pilot study, and was associated with a reduction in reporting of work-related symptoms that are considered typical of non-specific building related illness. These promising pilot study results strengthened the rationale for the large scale study reported here.

3. STUDY METHODS

3.1 Methodologic difficulties in studying nonspecific building related illnesses and reasons for using an experimental design

The majority of previous studies of nonspecific building related illnesses have been cross sectional, although a few have used case control designs. The advantages of such studies are their simplicity and ability to survey a large number of workers and buildings which enhances their generalizability and allow an estimate of the public health impact of this problem. These studies have identified a number of personal, work, worksite, and building characteristics as well as self-reported exposures that are associated with symptoms (see again, Appendix 2 - Table 1). However, the inferences from

such studies are limited, because differences between subjects may account for substantial differences between buildings or work areas, symptomatic workers may overestimate self-reported exposures, and selection bias may inflate estimates of effect because symptomatic workers may be more likely to participate. In their cross sectional studies objective environmental measures have not been able to confirm self-reported exposures, nor have they been consistently associated with symptoms.

Studies that applied experimental interventions using double-blind randomized crossover designs have successfully tested whether changes in temperature (86), humidification (86-89), negative ions (86;90), or outdoor air supply (16;17;86;91) reduce symptoms of nonspecific building related illnesses (summarized in Appendix 2 - Table 5). The advantage of these studies is that a single hypothesis can be tested, eliminating the need to measure all possible causative agents although attainment of the experimental conditions should be confirmed. The double-blind approach reduces the possibility of reporting bias. The crossover design with repeated measures provides a within subject estimate of effect, to reduce the confounding effects of between subject differences in characteristics that affect symptom reporting. (see again Appendix 1 - Table 1).

3.2 Study Design and Rationale

An experimental study was conducted. The intervention consisted of the installation and operation of germicidal ultraviolet light (GUV), in the heating, ventilation, air conditioning (HVAC) systems supplying selected floors in four study buildings. The GUV lights were installed in the supply air main duct just after ("downstream from") the filters in such a way as to irradiate directly the cooling coils, and drip pans usually beneath (see again Schematic of HVAC on Page 2). The heating, cooling, humidification and mix of recirculated with outdoor air in the HVAC system was not controlled experimentally but was measured as these are important covariates. If filters had to be changed according to the building maintenance protocol, this was done between 16-week blocks as otherwise such a change might introduce significant confounding.

GUV in the central HVAC was used as a "blunt instrument" to test whether elimination of all bacteria, fungi and viruses, arising from the central HVAC system itself or in the recirculated air resolves work-related non-specific symptoms. We did not specify which organisms would be eliminated from the HVAC area, (although given the prolonged exposure all should be). While there is sufficient indirect evidence to implicate microbial organisms there is grossly insufficient evidence to implicate any single micro-organism. Intellectually it would be more satisfying to understand why UV worked, if it did. However, establishing specific exposure-response relationships between the many organisms and multitude of health effects has proved impossible in the past. Given that microbial contamination may cause health effects in susceptible individuals through infectious, allergic, immunologic, or toxic mechanisms, we are also not specifying which symptoms will be reduced, although this was of interest for secondary analysis. The study should therefore be considered an effectiveness rather than efficacy study - ie this new technology was tested in a real world setting. The advantage of this approach is that if GUV lights in HVAC systems prove effective, these lights could be installed easily and cheaply in HVAC systems of most existing office buildings in North America. This would have considerable public health impact.

A randomized crossover, block design was used. The study will be conducted in 3 blocks of 16 consecutive weeks - within each block GUV was **on** for 4 consecutive weeks and **off** for the 12 following weeks. The length of time the UV lights were off was maximized to allow re-

contamination to occur. We observed re-contamination, albeit slight, in the ventilation systems 8 weeks after the UV lights were turned off. This occurred in mid-winter when problems of condensation, and contamination from outdoor air were unlikely. The study began in August 1999 and continued until the following July, 2000. In this way, we studied the effect of GUV in different seasons, introducing variation in exposure because of changes in outdoor fungal levels and operation of air conditioning and humidification which affect likelihood of contamination (92), as well as the seasonal occurence of infectious and allergic health problems in this population. Four buildings were studied; in these the GUV intervention was staggered as shown in the schematic below.

Table 1: Study Design Schematic - Timing of Operation of GUV Lights and Outcome Measures (only 2 of the 16-week blocks are shown)

Weeks	Baseline	Block 1				Block 2			
		1-4	5-8	9-12	13-16	17-20	21-24	25-28	29-32
BLDG A	B W + E	ON W+E	OFF	OFF	OFF W+E	ON W+E	OFF	OFF	OFF W+E
BLDG B	B	OFF W+E	ON W+E	OFF	OFF	OFF W+E	ON W+E	OFF	OFF
BLDG C	B	OFF	OFF W+E	ON W+E	OFF	OFF	OFF W+E	ON W+E	OFF
BLDG D	B	OFF	OFF	OFF W+E	ON W+E	OFF	OFF	OFF W+E	ON W+E

ON = UV On; OFF = UV Off
B= Baseline questionnaire W= Weekly questionnaire E= Environmental measurements

Questionnaires were administered in the fourth week when the UV lights are on, and the 12th week when the UV lights are off. The interventions will be staggered in the buildings in such a way that all outcome measures will be taken at the same time in two buildings - one with UV off, the other with UV on. The intervention is staggered in the four buildings to control for temporal effects such as climate changes or major current events. In the pilot study we found that by the third week, there was virtually no viable or culturable microbial contamination within the HVAC system. Therefore, symptoms are measured in the fourth week of UV operation which means that the measures of sickness absence in the preceding five working days will be taken from the third week of operation of GUV (see Appendix 4 - Weekly Questionnaire). Similarly, we will re-measure symptoms and sickness absence in the 12th week after GUV are turned off to allow maximum time for re-contamination to occur. Based on the pilot study in which we found that re-contamination had begun within 8 weeks after the UV lights were turned off in the middle of the winter, we believe that 12 weeks should allow sufficient time for re-contamination to occur.

The study was conducted in a double blind fashion - i.e., workers and data gatherers were not aware whether the ultraviolet lights were on or off. This was feasible because the ultraviolet lights were installed in the central supply air system where they were accessible only to building maintenance and HVAC operators. Blinding is important to eliminate the potential of a placebo effect and resultant reporting bias, which can influence the self reported outcomes to be measured. Repeated

measures of symptoms, environmental satisfaction and sickness absence were taken in the same office workers to provide within-subject estimate of effect. This design provides control of potential confounding related to between-subject differences in personal, medical, work and worksite characteristics.

3.3. Study Buildings

The target population were workers in office buildings with sealed exterior shells and mechanical ventilation with air conditioning. Four buildings were selected. We chose four primarily because of the study design in which symptoms and environmental measures were taken in pairs of buildings at the same time (see again Schematic - Section 3.2). Conducting the study in more buildings would have had the advantage of greater potential generalizability of results, but the disadvantage of greater operational difficulty in actual conduct of the study. Four buildings was a reasonable compromise between generalizability and feasibility. We did not select "sick" buildings, because this is an imprecise term, which does not have an operational definition (1;93;94). Instead buildings with characteristics which have been associated with this problem (1;4;25;80)were selected.

3.4 Workers

All full time workers on the selected floors who had fixed identifiable work sites were considered eligible. Workers were excluded if they had no fixed work site (eg messengers), or were present in the building less than 2 days per week (eg. sales personnel), or were present for less than one full 12-week block because of prolonged sabbatic, training or maternity leave. Before the study began, lists of all eligible workers on the selected floors, as well detailed floor plans showing their work locations (termed work sites) were obtained from management of the companies involved. An on-site census was then conducted by study personnel to verify the identity, location and eligibility of all workers on the selected floors. The precise location of all workers' work site were marked on floor plans. Eligible workers were provided with written information concerning the study, and approached for their written consent to participate.

This study was approved by the research ethics committee of the Montreal Chest Institute, of the McGill University Health Centre (MUHC).

3.5 Sample size considerations

As shown in Table 1 below, we estimated that in order to detect with sensitivity of 95% (alpha = 0.95), and power of 90% (Beta=0.9) a reduction in reporting of any symptoms from 60% in the baseline period to 50% with GUV light would require 632 subjects. This number should have given us 80% power to detect a significant reduction in mucosal symptoms, and 60% power to detect a reduction in systemic or respiratory symptoms. In all previous studies of the health effects of the office environment, we achieved more than 80% participation, which should have minimized selection bias due to non-participation. To account for 80% participation, we estimated we would need 790 eligible workers, and to account for 10% loss to follow-up due to drop-out over the time of the study the number required was increased by $1/(1-R)^2$ (95) to 975, or 240-250 workers per building. Each worker occupies 125-150 square feet, so in each building we estimated need for total floor space of approximately 31,000-38,000 square feet, or 3-4 floors in typical office buildings in downtown Montreal. GUV lights were installed in the HVAC systems which supply these floors.

TABLE 2: SAMPLE SIZES REQUIRED TO DETECT SIGNIFICANT EFFECTS OF GUV LIGHTS

			NUMBER OF WORKERS REQUIRED TO DETECT DIFFERENCE WITH POWER OF[2]		
	Baseline[1]	With Intervention	60%	80%	90%
SYMPTOMS - EXPECTED PREVALENCE					
Any Symptom	60%	50%	382	509	632
Systemic - headache, fatigue, concentration	33%	25%	533	703	869
Mucosal - nasal, throat, eye	42%	33%	469	620	767
Respiratory - cough	10%	5%	526	683	834
SICKNESS ABSENCE - EXPECTED OCCURRENCE					
Any Absence (prevalence)	8%	4%	672	871	1063

[1]expected prevalence of "Symptoms" - average weekly prevalence in weeks with GUV off from pilot study.
"Sickness absence" - Number of workers reporting time missed in the same study.
[2] calculations based on Alpha = 0.95, two-tailed tests of significance for difference in proportions (95)

3.6. Identifying eligible subjects.

Prior to beginning the experimental intervention, a "census" was conducted to identify eligible workers and mark their work site location precisely on floor plans obtained from building management. Workers were provided with written information regarding the study and asked to sign informed consent to participate.

3.7 Questionnaires.

In the baseline period, before the UV lights were turned on in each building, participating workers completed brief self-administered questionnaires regarding demographic characteristics, personal, medical and smoking history, and work and work site characteristics.

One to two weeks before first turning on the GUV, or turning them back on, and in the fourth week when GUV are on, workers completed self-administered questionnaires. These were distributed on Wednesday and Thursday of these weeks and collected at the end of each day up until Friday of that week. To assess potential unblinding, workers were asked whether their work environment was worse compared to the previous month and an open-ended question regarding changes in their work environment in the past month. Workers rated their satisfaction with 9 parameters of the indoor environment. They reported the occurrence of symptoms, whether these symptoms began before (not work-related) or after they arrived at work (if after these were considered work related), as well as how these symptoms affected their ability to work. Self-reported symptoms were the primary outcome measure for a number of reasons. Symptoms are the basis of the World Health Organization definition (96;97), have been the primary outcome measure in all our past studies (17;48;78;98;99), and in virtually all other major epidemiologic studies of this problem (10-12;14;15;18;19;23;25;80), and are associated with sickness absence and other productivity measures (18;100;101). Objective health effects are rarely documented in this illness, and are difficult and intrusive to measure. Any differences in reporting symptoms between individuals should have been controlled by the within-subject estimate of effect since manner of reporting should not have been affected by the

experimental conditions, if workers remained blinded.

To ensure confidentiality (and also thereby enhance accuracy of responses) a code number known only to the participant and study personnel was assigned to each worker. All questionnaires were identified only with this code number. Questionnaires were distributed and collected by direct exchange between study personnel and participants, or were left at the work site of participants, by the McGill study personnel.

Table 3: Time table of experimental interventions and data gathering in each building

Building 35

Baseline Questionnaire - July 9th - August 18th

Trial 1 -

GUV OFF	
Environmental Measurements	August 4th
Questionnaires collected	July 20th to August 24th
GUV ON - Date turned on	August 27th, 1999
Environmental measures taken	September27th to September 29th
Symptoms questionnaires collected	September 27th to October 1st

Trial 2 -

GUV OFF	October 2nd
Environmental Measurements	January 4th to January 7th
Questionnaires collected	January 12th to January 18th
GUV ON	
Date turned on	January 31st, 2000
Environmental measures taken	February 28th
Symptoms questionnaires collected	February 22nd to February 28th

Trial 3 -

GUV OFF	February 29th
Environmental Measurements	May 16th to May 31st
Questionnaires collected	May 18th
GUV ON - Date turned on	May 29th
Environmental measures taken	June 20th to July 06th
Symptoms questionnaires collected	June 20th
Date GUV turned OFF	

Building 36

Baseline Questionnaire - July 21st to July 28th

Trial 1 -

GUV OFF
- Environmental Measurements — September 8th 1999
- Questionnaires collected — September 10th to September 16th

GUV ON
- Date turned on — September 20th 1999
- Environmental measures taken — October 26th
- Symptoms questionnaires collected — October 27th to October 29th

Trial 2 -

GUV OFF — October 30th 1999
- Environmental Measurements — February 14th 2000
- Questionnaires collected — January 24th to February 9th

GUV ON
- Date turned on — February 7th 2000
- Environmental measures taken — March 8th 2000
- Symptoms questionnaires collected — March 8th to March 10th

Trial 3 -

GUV OFF — March 4th 2000
- Environmental Measurements — May 30th
- Questionnaires collected — May 31st to June 6th

GUV ON
- Date turned on — June 12th 2000
- Environmental measures taken — July 5th
- Symptoms questionnaires collected — July 7th to July 11th

Date GUV turned OFF

Building 37

Baseline Questionnaire - July 29th to August 16th 1999

Trial 1 -

GUV OFF
- Environmental Measurements — October 6th 1999
- Questionnaires collected — September 20th to October 8th

GUV ON
- Date turned on — October 11th 1999
- Environmental measures taken — November 4th
- Symptoms questionnaires collected — November 8th

Trial 2 -

GUV OFF — November 13th 1999
- Environmental Measurements — March 6th 2000
- Questionnaires collected — February 6th to March 3rd

GUV ON
- Date turned on — March 6th 2000
- Environmental measures taken — March 29th
- Symptoms questionnaires collected — March 23rd to March 30th

Trial 3 -

GUV OFF — April 4th 2000
- Environmental Measurements — June 14th
- Questionnaires collected — June 7th to June 12th

GUV ON
- Date turned on — June 19th 2000
- Environmental measures taken — July 12th
- Symptoms questionnaires collected — July 12th to July 14th

Date GUV turned OFF

Building 38

Baseline Questionnaire - November 1st to November 15th 1999

Trial 1 -

GUV OFF

Environmental Measurements	November 10th 1999
Questionnaires collected	November 9th to November 15th

GUV ON

Date turned on	November 16th 1999
Environmental measures taken	December 17th
Symptom questionnaires collected	December 14th to December 20th

Trial 2 -

GUV OFF	December 22nd 1999
Environmental Measurements	March 10th 2000
Questionnaires collected	March 14th to March 16th

GUV ON

Date turned on	March 20th 2000
Environmental measures taken	April 14th
Symptom questionnaires collected	April 12th to April 17th

Trial 3 -

GUV OFF	April 18th 2000
Environmental Measurements	June 28th
Questionnaires collected	June 28th to June 29th

GUV ON

Date turned on	July 3rd 2000
Environmental measures taken	July 19th
Symptom questionnaires collected	July 19th to July 27th

Date GUV turned OFF

3.8 Environmental measures

The parameters measured and protocol in regard to timing, number and frequency of sampling are summarized in Table 4. All these parameters were measured in the same weeks as questionnaires were completed, as they may have temporal and spatial variation independent of the study intervention which can affect symptoms.

Table 4: Environmental Sampling Strategy

Parameter	Sites (No/Floor)	No/Bldg/Week	No/Bldg	Total Number
Temperature	OA, RA, SA, worksite (8)	37	222*	888
Humidity	OA, RA, SA, worksite (8)	37	222	888
Air Velocity	--, --, --,, work site (8)	16	96	384
CO_2	OA, RA, SA, work site(8)	37	222	888
CO	OA, RA, SA, work site (8)	37	222	888
TVOC's	OA, SA, work site (1)	9	54	216
NO_2	OA, SA, work site (1)	9	54	216
Ozone	OA, SA, work site (1)	9	54	216
Formaldehyde	OA, SA, work site (1)	9	54	216
Dust	OA, SA, diffuser (1), worksite (1)	13	78	312
Bacteria-airborne	OA, RA, SA, diffuser(8) work site(8)	84	504	2016
Fungi-airborne	OA, RA, SA, diffuser(8) work site(8)	84	504	2016
Bacteria surface	filter, cooling coil, drip pans	24	144	576
Fungi-surface	filter, cooling coil, drip pans	24	144	576

OA = Outdoor Air RA = Return Air SA = Supply Air

*Notes: Generally, outdoor air measures performed once a week if sampling required.

Temperature, humidity and air velocity:

These parameters can have substantial spatial and temporal variability within large office buildings (17;76;78) and have been associated with symptoms consistently in previous studies (10;17;74;86-88;102). They were measured at 8 work sites per floor (generally 2 sites per quadrant - 1 interior/core and 1 perimeter), in the morning and afternoon on the same day as the symptom/environmental rating questionnaires were distributed. Temperature and humidity were measured at the same time in the supply, return and outdoor air for each HVAC system supplying the selected study floors.

Measured with a hotwire anemometer calibrated daily with a psychrometer.

Carbon dioxide (CO_2):
This parameter, considered a proxy of outdoor air supply and recirculation (6;103;104) was measured at the same time and at the same sites as the measures of temperature, humidity and air movement. CO_2 was also measured on the same day in supply, return, and outdoor air in the HVAC system to estimate percent recirculation. This was calculated using the formula:

[(SACO2 - OACO2) / (RACO2 - OACO2)] x 100 = % Recirculation

(Where SA = Supply Air, OA = Outdoor Air, RA = Return Air)

CO_2 was measured using a direct reading infrared non-dispersed detector with digital readout (accuracy ± 10 parts per million).

Airborne biologic contaminants:
Cultures of airborne viral organisms are not feasible, so bacteria and fungi were measured. To assess the efficacy of GUV we sampled for viable micro-organisms in outdoor air, return air, and in supply air post GUV. To assess possible recontamination, we measured micro-organisms in the breathing zone at work sites (implying contamination from workers and sources around the work site).

Fungal spores were collected by impaction on adhesive coated glass slides, using a Burkhard volumetric air sampler operating at 12 litres per minute for 15 minutes, and counted using microscopy. Airborne microbes were collected on Petri dishes containing blood agar media (for all bacteria), Columbia CNA (for gram positive bacteria), Sabhourad media (for fungi - particularly human pathogenic fungi) or Maltose extract (for 'environmental' fungi). These samples were collected with Burkhard volumetric air samplers operating at 12 litres per minute for 15 minutes. All plates were incubated at 37C for 48-72 hours, and colony forming units were counted, and expressed as CFU/cubic metre of air.

Surface biologic contaminants:
Surface growth was assessed using "coupons". These were flat sheet metal pieces measuring 5cm by 5cm, which were sterilized prior to beginning the study, and then placed at three locations within each HVAC system serving the study floors. Coupons were attached to the filters (not exposed to GUV), and on cooling coils and in the drip pans (where they were exposed to the GUV light). At the same time as the airborne biologic samples were taken four coupons were collected from each location using sterile forceps. Coupons were then placed directly on the same four different culture media as for air samples. (Ie Sabhourad, MEA, blood agar and CNA (92;105). The GUV exposed side was placed in contact with the culture media. All plates were incubated at 37C for 48-72 hours, and colony forming units were counted, and expressed as CFU/coupon.

Total volatile organic compounds (TVOC's):
Of all contaminants that are regularly measured in studies of nonspecific building related illness, these are the most difficult and expensive to collect and analyse. The role of TVOC's in nonspecific building related illness is controversial (in part related to these methodologic problems) but there is reasonable evidence to suggest they can contribute (73;74;78;79;106-110). TVOC's may be produced by micro-organisms and so could have been altered by the study intervention, or have varied because of changing sources within the building or outdoors. TVOC's will be measured in outdoor air, supply air, and at worksites. The selected floors will be inspected carefully for potential TVOC sources (eg., printers, wet photocopiers, etc.). If potential sources are found, TVOC's will be measured nearby at least once.

TVOC's were collected on activated charcoal tubes using volumetric air pumps operated at 300 ml per minute over 8 hours for 2 consecutive working days. Total volatile organic compounds were analysed using the flame ionization detection method (FID) - NIOSH method 1501 modified (111).

Formaldehyde:
This parameter was unlikely to have been affected by the study intervention, but was measured nevertheless (as a potential confounder) in outdoor air, supply air after GUV, and at worksites.

Formaldehyde was collected over 24 hours using SKC passive samplers and analysed using ASTM method D5014-89 (112).

Total airborne dust:
Total airborne dust was not expected to be affected by the study intervention but is a marker of filter effectiveness. Airborne dust can be increased at the worksite by human activity disturbing surface dust. Airborne dust was measured in outdoor air, supply air pre-filters and post-filters, and work sites.

Total dust was collected on 1 micron filters using volumetric air pumps operating at 1.5 litres per minute for 8 hours. Total dust was estimated by comparing pre and post dry weights of filters.

Carbon monoxide (CO):
This was measured at the same time and at the same sites as carbon dioxide using a direct reading portable continuous electro-chemical detector (Interscan Model 1142 - accuracy ± .1 parts per million).

Ozone:
This will be collected by bubbling air at 1 litre per minute over 8 hours through ozone absorbency liquid, and analysed using NIOSH method P and CAM 154 (111).

Nitrogen dioxide (NO_2):
Will be collected using SKC volumetric air samplers operating at 75 mls per minute over 8 hours onto a solid sorbent sampling tube containing a triethynolamine (TEA) impregnated molecular surface. This will be analysed using NIOSH method P and CAM 231 (111).

3.9 Interpreting environmental data:

Table 5: Summary of recommended limits (guidelines) for thermal chemical and microbial parameters in the indoor office environment

ENVIRONMENTAL PARAMETER	STANDARDS
Thermal Comfort	
Ambient air temperature	20.0 - 23.6 °C (Winter conditions)
Humidity	20 - 60%
Air velocity	0.15m/s
Air Contaminants	
Carbon dioxide	1000ppm
Carbon monoxide	9ppm
Nitrogen dioxide	0.055ppm
Formaldehyde	0.1ppm
Ozone	0.05ppm
Radon	800 Bq/m^3
Total Volatile Organic Chemical	2400 ug/m^3
Total Airborne Particulates	260 ug/m^3
Fungal contamination	500 CFU/m^3

3.10. Matching environmental data to participants:

To provide the most accurate possible estimate of environmental exposure at their work site for each participant, at the time they completed each symptom questionnaire, environmental measures were matched to participants as follows:

Temperature, humidity, air velocity and CO2 - at work sites.
The test sites at which these parameters were measured were pinpointed on the same floor plans on which all workers' precise work location had been marked. Each worker was assigned to the nearest environmental test site, and matched to all environmental measures taken at that site on the same day, or in the same week as they had completed symptom questionnaires. On floors served by more than one ventilation system, participants were assigned environmental measures taken at the nearest test site, served by the same ventilation system. Mean values (from the morning and afternoon measures) for temperature, humidity, and air velocity, as well the variance (difference divided by the mean) were used as exposure variables in the analysis, while for CO2 the variance and peak afternoon value served as the exposure variables.

TVOC's, formaldehyde, ozone, dust, and NO2 - at work sites:
These chemical parameters were measured at only 1-2 sites per floor. Therefore workers were assigned the average value for all measures of each parameter taken on the same floor and on the same day, or in the

same week as the symptom questionnaires were completed.

Airborne microbial contaminants - at work sites:
These microbial parameters were measured at 4 sites per floor, which were pinpointed on the same floor plans as for thermal test sites. Each worker was assigned to the nearest microbial test site, served by the same ventilation system, and matched to the microbial measures taken at that site on the same day, or in the same week as the symptom questionnaires were completed.

For all microbial measures - 7 different estimates of exposure were used - four were based on growth on the four different culture media, plus total bacteria (sum of CFU on blood agar plus CNA), total fungi (sum of CFU on SAB plus MEA), and total microbes (sum of CFU on all 4 media).

All environmental parameters - surface and airborne microbial, chemical, % Recirculation - in the HVAC systems:
All parameters measured in HVAC systems were assigned to all participants at work sites served by that ventilation system, based on floor plans, and schematic diagrams of the HVAC systems provided by building management. Measures matched were those taken on the same day, or in the same week as the symptom questionnaires were completed.

3.11. Data analysis

Outcomes

(i) Blinding - a dichotomous outcome assessed from the question regarding changes in the environment to indicate whether the participant was aware (correctly) as to whether the GUV lights were on or off.

(ii) Symptoms - our primary outcome was the report, on the symptom questionnaire, of the occurrence of ANY symptom that began after arrival at work.
In addition we examined reporting of work related symptom complexes:
- MUCOSAL - irritation of eyes, nose and throat.
- SYSTEMIC - headache, fatigue or difficulty concentrating.
- RESPIRATORY - feeling of chest tightness, shortness of breath or cough.
- MUSCULO-SKELETAL - aches and pains of muscles and/or joints.

(iii) Environmental satisfaction rating - A total environmental satisfaction score was calculated from the numeric sum of the 9 individual ratings. Individual ratings, scored from 0 meaning terrible, to 4 meaning ideal and total score (from 0 to 36) were analysed. As well groupings of ratings (each ranging from 0-12) were examined: thermal (temperature, humidity, and air movement), physical (lighting, noise and space) and indoor air quality (dust, odours, and overall air quality).

(iv) Sickness absence - this was the numeric sum of all hours reported missed in the previous five working days due to any illness, and attributed to indoor air quality.

Methods of Analysis

To take advantage of the repeated measures of symptoms in the same individuals, we used within-subject analysis. Responses were analysed for individuals who completed at least one questionnaire under each

experimental condition (ie GUV-off and GUV-on). Within each of the three trials, reporting of work related symptoms - ANY or the symptoms complexes defined above, and considered as a dichotomous outcome of occurred / not under the two conditions in the same persons were compared and tested for significance using McNemar's chi square test. Responses in each trial were counted as separate responses. To account for potential confounding effects that varied from week to week during the study including thermal, chemical and microbial parameters conditional logistic regression (generally used for case-control studies) was used to obtain an adjusted estimate of the effect of GUV on symptoms, and standard errors of the estimates were used to calculate 95% confidence intervals (113). CLR was performed using the clogit function in STATA (version 6.0) in which each person was considered a separate strata, and PHREG procedure in SAS (version 6.12) which allows for m:n matching and considered each person a separate strata.

OVERALL RESULTS

As shown in Table 1, of 1011 eligible workers identified, 771(76%) were considered full participants as they completed at least one symptom questionnaire with GUV on and one with GUV off - allowing the within subject estimate of effect. A total of 3,667 symptom questionnaires were completed. Of the 163 who did not respond there was limited information for most except language and gender, although 9 completed baseline questionnaires. Most of the 87 partial participants, who completed up to three symptom questionnaires but all under the same GUV conditions, completed baseline questionnaires. There were no significant differences in the personal and work characteristics of full participants compared to partial participants or non-responders, as shown in table 2A. As well work-related symptoms and environmental ratings were not significantly between the partial and full participants (Table 2B). As shown in table 2C, males and/or non-clerical workers were less likely to complete five or more symptom questionnaires, suggesting that one of the major reasons for non-completion was simply absence at the time of questionnaire distribution. The environmental ratings, and symptom reporting were not significantly different with the exception of systemic symptoms. Therefore inclusion of subjects who completed as few as two questionnaires should not have biased the results.

Overall reporting of symptoms declined over the course of the study - most notably for mucosal symptoms but also for muscular symptoms, as seen in Table 3A. There was no difference in work related systemic symptoms but work related mucosal, respiratory and muscular symptoms were all reduced modestly with GUV on, compared to GUV off (Table 3B). The only changes that were statistically significant were the reduction in mucosal and overall symptoms. Environmental ratings did not improve nor worsen over the course of the study as shown in table 4. Ratings of thermal factors were slightly, and significantly better with GUV on than off, but ratings of all other factors were identical.

Workers' characteristics in the four buildings were strikingly different in terms of the proportion of females, mean age, percent of current smokers, and job type (Table 5A). These differences can result in differences in prevalence of symptoms between buildings, because younger age, female gender, atopic, medical and smoking histories, as well as job type have all been significantly associated with reporting of symptoms in previous cross sectional surveys. As shown in table 5B there were substantial differences between buildings in the environmental ratings and the number and type of work related symptoms, including symptoms affecting work. Some or all of these differences between buildings could be due to the characteristics of the work-forces studied in each building, rather than differences in the indoor environment.

The association of personal and work characteristics with median values of environmental ratings on all symptoms questionnaires was estimated. Individuals were classified as giving environmental ratings above or below the median value for all responses. The characteristics of individuals who rated the environment worse than the median environmental ratings were

compared using multi-variate legistic regression with subject who gave better than median ratings. As shown in table 6A female gender, current smoking, atopic illness and building were associated with worse thermal ratings while other medical problems and building were associated with worse physical ratings. Female gender and building was associated with worst IAQ ratings, and female gender and building were associated with worst overall ratings.

The association of personal and work characteristics with greater than median reporting of symptoms is shown in table 6B. Older age was associated with less reporting of any and systemic symptoms, atopic illness with greater reporting of mucosal, non-clerical workers with more systemic symptoms and respiratory symptoms with one building. Almost all individuals who reported more than average symptoms also rated thermal environment and IAQ parameters worst.

Matched analysis within each trial, for the 771 workers who completed at least one symptom questionnaire under both experimental conditions is shown in Tables 7A-E. In this analysis, responses in individuals without symptoms in either trial or with symptoms in both, are effectively cancelled out. Such individuals can be considered not affected by the experimental intervention. The proportion of individuals with any work related symptoms when the GUV were OFF was significantly higher than when GUV was on. This effect increased with each successive trial. Symptoms ocuuring before or work-related symptoms affecting work were not different with GUV on or off. As shown in table 7B systemic symptoms showed no benefit of the GUV intervention. Work-related mucosal symptoms showed consistent benefit which was greatest in trial 3. Mucosal symptoms before work, or affecting work were not significantly different with GUV on. Respiratory symptom also showed a striking benefit of GUV light although the number of individuals with such symptoms was relatively small. When all three trials were combined (Table 7E), there was a significant reduction in any, mucosal, respiratory, and muscular work related symptoms with GUV on.

Because of the strong confounding effect of personal and work characteristics on symptom reporting, the effect of GUV on work related symptoms was estimated within strata of gender (table 8A) atopic history (table 8B) and building (table 8C). This demonstrated that the effect of GUV light on reduction of mucosal, respiratory, and muscular symptoms was similar in males and females. Interestingly the beneficial effect of GUV on mucosal and respiratory symptoms was substantially larger among atopic individuals, although non-atopic individuals derived some benefit. Reduction of muscular symptoms was similar in atopic and non-atopic individuals. In different buildings, the GUV interventions resulted in reductions of 20% to 50% in all symptoms. Systemic symptoms were reduced in only one building, but there was a reduction in mucosal, respiratory and muscular symptoms in all - although to a variable degree.

The thermal, chemical and microbiologic measurements were merged with results of baseline and symptom questionnaires in order to estimate the effect of GUV on symptoms after adjustment in multivariate analysis for personal, work, thermal and other environmental conditions during the course of the study. As shown in table 9, in week 1 thermal conditions were suboptimal with higher than average temperatures. Humidity also showed substantial,

largely seasonal variation while air velocity was fairly constant. Carbon dioxide also showed seasonal variation with higher values measured during the warmer months. Carbon monoxide was measured at the same sites and times as CO2, but all results were very low, and more than 75% of measures were undetectable, so these results are not shown in tabular form. As shown in table 9B, apart from higher temperature there was no significant difference in the overall thermal conditions with GUV on or off.

Higher worksite temperatures were strongly associated with reporting of systemic, mucosal and overall symptoms. Symptoms reported that day increased steadily, and in a nearly linear relationship with average worksite temperatures as shown in Figure 1. Higher carbon dioxide levels also associated with systemic, mucosal and respiratory symptoms, but the effect was not linear nor as substantial (Figure 2). The worksites of female and/or clerical workers had higher average temperatures, humidity and carbon dioxide levels (Table 10A). Because these thermal conditions have an important impact on work-related symptoms this finding may explain why these personal and work characteristics have been associated with greater symptom reporting in this and other studies. As shown in table 10D, there was no association of thermal conditions with atopic history nor smoking status.

As shown in table 11A average indoor nitrogen dioxide, and ozone concentrations were most closely correlated with outdoor air concentrations, and the levels of these two contaminants were generally lower indoors than outdoors in most weeks. By contrast TVOC and formaldehyde concentrations were higher indoors than outdoors in most weeks. Chemical contaminants were not higher in photocopy rooms than at work sites, on average, suggesting that these rooms are not a major source of indoor air contaminants - at least on the floors and in the buildings studied. Average levels of all contaminants were generally low and within the range considered acceptable by ASHRAE. As well there appeared to be no effect of the GUV lights on indoor contaminant concentrations (see table 11B).

In the complex indoor environment of a modern office building there are many environmental parameters that can affect human health and well being. As shown in table 11C these different parameters also have complex interrelationships. For example temperature and humidity were positively correlated - expected since the major determinant of these parameters are outdoor temperature and humidity. Similarly indoor temperature and humidity were correlated with higher indoor CO_2 which may be a reflection of a greater crowding, and sources of heat from humans and their associated work activities - especially computers. Other associations such as the strong positive correlation between ozone and TVOC's or negative correlation between NO_2 and formaldehyde are unexplained but demonstrate the complexity of the indoor office environment - which is still poorly understood. These interrelationships may result in adverse effects on human health and well being, even though all individual contaminants measures appeared to be within limits considered safe by authoritative agencies such as ASHRAE.

When the chemical contaminant concentrations measured in HVAC supply air or at work sites were matched to the results of symptom questionnaire completed on the same day or at least in

the same week, then a number of important relationships were detected. Nitrogen dioxide levels were significantly higher in HVAC supply air, or at worksites of workers with any, systemic or mucosal symptoms. Higher ozone concentrations were not associated with symptoms (The finding that ozone and TVOC concentrations were higher for workers who did not have symptoms was probably spurious). These results are shown in table 12 A and B. Female workers were exposed to a higher concentrations of nitrogen dioxide in the HVAC system supplying their worksites and at their work sites, and higher TVOC's in the HVAC supply air, although not at their worksites. Males were exposed to higher concentrations of formaldehyde at their work site. Atopic status was not associated with worksite environmental conditions, but clerical workers were exposed to higher nitrogen dioxide and TVOC concentrations than management, or professional workers. Since nitrogen dioxide and TVOC's may result in symptoms considered typical of sick building syndrome, the higher concentrations of these contaminants at the worksites of female and clerical workers may help explain the association of these characteristics with symptoms in this and earlier cross sectional surveys.

As seen in Table 13, airborne bacteria and fungi at worksites and HVAC supply air were notably lower in weeks 3 and 4 - in the coldest winter months. Concentrations of airborne bacteria and fungi at work sites and ventilation supply air were not altered by the operation of the GUV lights. Airborne bacteria and fungi at work sites were positively correlated with higher worksite humidity. Airborne bacteria were also positively correlated with higher indoor temperatures and carbon dioxide levels, as shown in table 13C. Worksite airborne fungal concentrations were positively correlated but airborne bacteria were negatively correlated with TVOC concentrations. This typifies the interrelationships of airborne microbial concentrations with the chemical parameters at work sites- these interrelationships also differed in supply and return air making interpretation very difficult.

The association of symptoms with airborne concentrations of bacteria and fungi in the HVAC systems and at work sites, are shown in table 14A and B. Airborne bacteria particularly gram positive bacteria at work sites were associated with reporting of any, mucosal and muscular work related symptoms. Female workers were exposed to higher airborne bacterial concentrations at their work sites and higher fungal concentrations were detected in the return air from their work sites (Tables 14C and 14D). Air borne microbial contamination was not associated with smoking nor atopic status but was strongly associated with job category. Clerical workers were exposed to much higher airborne concentrations of bacteria at their work sites and the return air fungal concentrations were also higher although supply air concentrations fungal and bacterial concentrations were not significantly different.

Fungal and bacterial contamination of surface coupons was much greater in weeks when GUV were off compared to when GUV lights were on (Table 15A), but differences in the contamination on coupons taken from filters were much less - since in most buildings these were not exposed to GUV lights. There was very litttle surface contamination in week 1 in all buildings because the coupons were placed in the HVAC systems only a few weeks before the first set were removed again for Week 1 samples. The coupons therefore had insufficient time to

aquire surface contamination at levels commensurate with adjacent parts of the HVAC system. This phenomenon is demonstrated in table 15B; in the final trial the concentrations on cooling coils and in drip pans showed a much greater reduction than was demonstrated for all trials combined. As shown in table 15C, surface fungal contamination on the cooling coils and drip pans correlated with levels of airborne fungi in HVAC supply air, although this was not true for bacteria. None of the HVAC surface measures correlated with airborne measures at work sites. When the results of surface microbial measures for each week were matched with the symptom questionnaires for the same week surface microbial contamination were not associated with any of the target symptoms or symptoms complexes. There was no significant, or substantial association between these concentrations and potentially confounding personal or work characteristics (tables 16 C and D).

Table 16E summarises all environmental parameters by GUV condition. The most notable findings in this table, were the relatively small differences in all parameters under the conditions. Temperature was slightly warmer when GUV was OFF, but relative humidity was higher. Since symptoms were more often reported with higher temperature, but also with lower humidity, these effects may have balanced out. The percent recirculation was lower with GUV OFF, implying greater outdoor air supply, yet mean CO2 was higher. This suggests greater number of occupants in the building, when GUV was OFF. None of the chemical parameters were significantly different under the two conditions. Airborne microbial levels in the HVAC systems and at worksites were not significantly different whether GUV was ON or OFF. By contrast viable microbial levels were substantially lower on GUV exposed surfaces, although samples from the HVAC filters which were not exposed to UV light, were not different. Endotoxin levels were also substantially and significantly reduced on GUV exposed samples but were not significantly different on surface samples not exposed to GUV light. Airborne endotoxin levels were not different at worksites (although almost undetectable there) nor in the HVAC systems before the filter. There was a trend to reduction of airborne endotoxin after the filters and after the cooling coils, ie "downstream" from the GUV lamps, when they were on.

As shown in Table 16 F there was a wide range and large number of organisms detected on HVAC surface samples while GUV were turned OFF. Interestingly many of these organisms have been associated with building related illnesses in other studies. When GUV was turned ON the number and variety of organisms detected declined substantially and significantly.

Overall assessment of the impact of GUV on work related symptoms is shown in Table 17. For this matched paired univariate analysis, odds ratios were calculated for discordant pairs using a within subject analysis. Overall, mucosal and musculoskeletal symptoms declined significantly. These estimates are not adjusted for environmental covariates. Symptoms that had onset before arrival at work were not significantly affected by GUV; if anything these were increased when GUV was ON compared to OFF.

Two analytic methods were used to estimate the effect of GUV light on work-related symptoms after adjustment for all known, and measured potentially confounding personal, work and

environmental characteristics. In the first method, summarized in tables 17A to 17E, each symptom questionnaire completed by respondents was treated as an independent response. These were matched with baseline characteristics and all thermal, chemical and microbial environmental conditions measured at the nearest work site or in the ventilation system serving their work site. In multi-variate logistic regression, the effect of GUV was estimated after adjustment for personal and work characteristics, and in a second model also for environmental characteristics. As shown in table 17D the building, younger age, female gender, and atopic history were all significantly associated with reporting of mucosal, respiratory, muscular and overall symptoms. Musculo-skeletal symptoms were associated with other medical history and female gender but not with age. Cigarette smoking was not associated with any symptom complex while job type was associated only with systemic symptoms.

After adjustment for these personal and work characteristic mean temperature was significantly associated with systemic and mucosal but not respiratory or muscular symptoms. Lower humidity was associated with greater reporting of mucosal and respiratory symptoms, while higher CO_2 was associated with respiratory, mucosal and systemic symptoms. After adjustment for personal, work, and thermal environmental factors, chemical contaminants and surface or airborne bacteria and fungal measurements at work sites and in HVAC systems were not significantly associated with any symptom complexes, and operation of GUV was associated with a 20 % reduction in mucosal and 33% reduction in respiratory symptoms.

In the second method, conditional legistic regression was utilized to obtain a within subject estimate of the effect of GUV adjusted for covariates such as environmental conditions. This method utilized each individual as their own control, and allowed a variable number of responses (i.e. anywhere from 2-6 responses per individual could be analyzed). As shown in table 18A, with GUV on, reporting of overall symptoms was significantly reduced. Higher temperatures, lower humidity and higher CO_2 were also associated significantly with greater likely of reporting of any symptom. With GUV on, mucosal symptoms and respiratory symptoms were substantially reduced.

Conditional legistic regression compares symptoms in the same individual under different environmental conditions so fixed characteristics such as atopic history, gender or job type, can not be analyzed. Therefore regression was conducted within strata defined by atopic history, gender or building, adjusted for the same environmental factors. As also shown in table 18A reduction of mucosal symptoms was greater in persons with an atopic history and females, but reduction of respiratory symptoms was similar irrespective of gender, building or atopic history. The effect of GUV was seen in all buildings, but was strongest in two. In overall, and stratified analysis systemic systems were not significantly reduced with the operation of GUV lights. The possibility of a temporal effect was examined as shown in table 18B. The largest reduction of mucosal and musculoskeletal symptoms was seen in the first and third trials while the least effect was seen in the second trial (during winter time conditions).

In summary, operation of GUV lights for one month at a time was associated with substantial

reduction in surface bacterial and fungal contamination from samples that were exposed to UV light. However GUV did not result in any significant reduction in airborne bacteria or fungi either in supply air nor at work sites. Despite this, operation of GUV was associated with a significant reduction in work-related mucosal, respiratory and muscular symptoms, which may be considered building related. This reduction was seen in unadjusted analysis, and after adjustment for simultaneously measured worksite temperature, humidity and carbon dioxide.

DISCUSSION

STRENGTHS OF THE STUDY:

A major strength of this study was the large scale, as over 1,000 eligible workers were identified of whom 771 participated. This was more than was originally estimated as required to provide sufficient power to detect a significant difference if the reduction of symptoms was only 20%. The actual estimate of effect was surprisingly close to that originally anticipated in the sample size calculations. This explains why a relatively modest reduction in all work-related symptoms with operation of GUV lights could be successfully detected. An additional strength of the study was the high degree of participation of those eligible for the study. This is important to reduce the possibility of selection bias, which could, for example, result in an over-estimate of symptoms, if only symptomatic individuals completed questionnaires!

In this, and other studies, factors such as gender, atopic history, and job type have a profound impact on symptom reporting. As a result differences in the characteristics of the work-force populations can contribute to differences between buildings in occurrence of building-related symptoms. Therefore the repeated measures design providing a within-subject estimate of effect was another major strength, as it controlled the potential confounding influence of personal and work characteristics.

A further strength was that respondents were not aware of whether the GUV lights were on or off. This blinding to the study intervention limited the possibility of response bias due to personal beliefs that GUV would, or would not help.

Differences in environmental exposure related to substantial temporal as well as spatial variation may also contribute to differences in symptom occurrence. Accordingly, a key feature of the study design was the measurement of all known potentially confounding environmental covariates at multiple sites at the same time as symptom questionnaires were completed. This allowed adjustment of the estimate of effect of GUV in multi-variate within-subject regression, termed conditional logistic regression. Temperature, humidity, air velocity and carbon dioxide are known to have considerable temporal and spatial variation within buildings and can strongly influence symptom reporting. Therefore these important factors were measured twice daily at 8-16 work sites on each floor to provide the most precise possible estimation of these factors. Chemical factors were measured each study week, although at only one or two sites per floor so that average values for each floor were assigned to all workers on that floor. This method of estimation was less precise than for thermal factors, but nevertheless temporal variation was accounted because these measures were taken at the same that symptom questionnaires were completed.

To enhance the accuracy of microbial assessment, measurements from air and surface samples

were taken on 4 different media at multiple work sites and throughout the ventilation systems. Four different culture media were used to identify the relative contribution of gram positive bacteria vs total bacterial counts, without having to resort to much more labor intensive and expensive methods of identification. Similarly, samples for fungal culture were grown on Sabhourad agar to capture human pathogenic fungi which grow best on this richer media, as well maltose extract agar for the more common environmental fungi, identified in other investigations of building related illnesses. The measurement of endotoxin strengthened the microbial measurements by providing some evidence as to a possible pathogenetic mechanism by which GUV lights may have been effective.

LIMITATIONS OF THE STUDY:

Despite these strengths the study had several important limitations. First only a limited number of buildings were studied, which reduces potential generalizability of results to other buildings. However the large number of workers with both public and private employers, enhances the generalizability to all office workers, even if not to all buildings. The major factor limiting the number of buildings was the cost, logistic complexity, and intensity of data gathering - of questionnaires from workers, and environmental measures, as well as the cost and complexity of bacteriologic monitoring of the GUV lights. Therefore the selection of 4 buildings was a compromise between maximizing generalizability (more buildings) and feasibility (fewer buildings).

A criticism of the study might be the lack of objective measures, as our primary outcome measure was self reported symptoms. Reported work-related symptoms may be non specific, in that a significant prportion may be unrelated to the indoor environment, so that only a fraction of all symptomatic individuals would feel improvement. However, the sample size was adjusted upward to account for this. The primary reason that self-reported symptoms was selected as the primary outcome measure is that self-reported symptoms have been the primary outcome measure in virtually all cross-sectional, longitudinal, and experiemntal studies of health effects of the office environment. Different individuals may interpret questionnaires, and/or report symptoms differently, creating potential mis-classification bias. However this would have been controlled by the within subject estimate of effect based on repeated responses to the same questionnaire by the same individual.

The failure to identify a consistent relationship between surface or airborne fungal or bacterial measures and symptoms is disappointing. This may reflect the difficulties of estimation of microbial contamination, which is why several different approaches were taken. It may also be that quantifying the total number of bacteria and fungi, even with use of different culture media was not accurate enough to characterize microbial exposure. A more qualitative approach with identification of all bacteria and fungi may have provided more information. However given the number and complexity of microbial organisms found in the indoor environment, and with over 1,000 different microbial samples taken for culture, a qualitative approach would have been prohibitively complex and expensive. AS well, there is no evidence to suggest specific fungal or

bacterial organisms as causative organisms - so any attempt to correlate symptoms with individual microbial species would have resulted in a prolonged "fishing expedition". GUV was effective in eliminating virtually all bacteria and fungi on surfaces directly exposed to GUV, but had no impact on airborne microbial contamination even in the supply air systems. Nevertheless the sterilization of surfaces of HVAC cooling coils and drip pans appeared to be sufficient to cause a substantial reduction in symptoms.

IMPLICATIONS OF THE FINDINGS:

The strong association between higher temperatures and increased reporting of systemic and mucosal symptoms provides an important lesson for building operators and managers. When workers are exposed to temperatures above the range considered optimal for prolonged times this will cause greater discomfort and in time result in symptoms of fatigue, headache and mucosal irritation. Although we did not demonstrate any economic impact in this study, other studies have consistently demonstrated a strong relationship between work related symptoms in the office environment and lost productivity. Therefore the higher temperatures noted in certain buildings in certain weeks should be examined, and the underlying causes corrected for future years. Similarly, very low levels of humidity noted in some buildings in winter months were associated with significantly increased rates of symptom reporting, after adjustment for other potentially confounding factors. Winter time humidity levels varied considerably between buildings - reflecting differences in effectiveness of the building's HVAC humidification systems. Given the strong relationship between work related symptoms and low humidity, building owners and operators should ensure that HVAC humidification systems maintain humidity above 20% at all times.

The association of female gender and clerical job type with worse environmental condition is important for 2 reasons. First such workers are often located in large open areas. One reason for this choice of work location is the apparent efficiency in use of space. However, environmental conditions may be more difficult to control in these areas, and the resultant adverse conditions may result in more discomfort, and work-related symptoms. These will inevitably result in reduced work performance and productivity, offsetting any gains in efficiency. Therefore building owners and operators should ensure that discrepancies in environmental conditions are corrected, to ensure the most comfortable and healthy work environment possible for all workers.

Operation of germicidal ultraviolet light in the central HVAC system was associated with significant reduction in work-related mucosal and respiratory symptoms, as well as overall symptoms. Musculo skeletal symptoms were somewhat although not significantly reduced, and systemic symptoms were not changed. Respiratory symptoms were uniformly reduced in all buildings, irrespective of gender or atopic history. Reduction of mucosal symptoms with GUV lights was greater in females, atopic individuals, and in certain buildings.

Confounding due to personal or work characteristics is very unlikely to have resulted in effect of GUV seen, because this was a within-subject estimate of effect, and because the stratified

analysis demonstrated that the effect was simply stronger within certain strata such as females and atopic persons.

Could the beneficial effect of GUV have been due to confounding with other environmental contaminants? It was because of concern of potential confounding with other environmental factors that the indoor environment was measured in great detail in the same weeks that symptom questionnaires were completed. These measurements were then used in multivariate analysis, to obtain the adjusted estimate of the effect of GUV on symptoms, which was, if anything strengthened by this adjustment.

Could the benefit of GUV have been simply a temporal effect? Past studies of similar design symptom have noted that symptoms tend to decline over time. However, in unadjusted analyses the effect of GUV actually increased from the 1st to the 2nd and from the 2nd to the 3rd trials while in adjusted analyses the effect was seen in all 3 trials and was not significantly different in the third trial compared to the first. This suggests that any temporal effect was minimized by the study design of multiple repeated questionnaires over the course of a full year.

If GUV works what might be the pathogenetic mechanisms? GUV consistently reduced surface bacteria and fungal contamination on the surface coupons directly exposed to the GUV, attached to cooling coils and in drip pans. GUV was also associated with reduction in endotoxin on the same surface coupons. Exposure to endotoxin has been associated with building related symptoms in other studies, so this could represent one plausible mechanism by which GUV reduced symptoms. The reduction in respiratory symptoms of cough, chest tightness and difficulty breathing could suggest these symptoms had been due to an allergic or hypersensitivity reaction to airborne allergens, endotoxins, or other products of microbial contamination. The greater reduction of mucosal symptoms in individuals with an atopic history suggests that these symptoms were mediated through an allergic mechanism.

There was a reduction in musculo-skeletal symptoms - although not significant. Earlier cross-sectional studies noted an association between microbial levels and musculo-skeletal symptoms. Several outbreak reports have demonstrated an association between airborne microbial and the occurrence of "humidifier fever" which is characterized by muscle aches and pains along with feverishness. Therefore it is plausible that muscular aches and pains could be reduced through use of GUV lights if they reduced the occurrence of sub-clinical cases of humidifier fever.

What are the importance of these findings? First GUV lights are safe. They were not associated with increased production of TVOC's, formaldehyde nor ozone. Workers ratings of the indoor environment, particularly odours and overall air quality were not changed. If anything environmental ratings were slightly better with GUV lights on. GUV light installation is feasible as these lamps can be retrofitted to almost all HVAC system in existing office buildings throughout North America. Although the bulbs are relatively expensive, their installation is simple and so should not be costly, and subsequent energy and maintenance costs are low. Therefore GUV lights could be safely and easily installed in many existing office buildings.

What could be the impact of these lights? Before extrapolating from these findings to make optimistic projections of the potential impact of GUV lights on the occurrence of building related illness in other buildings, these findings MUST be confirmed by an independent study. Only then could a recommendation be made regarding the installation of GUV lights in HVAC systems in other buildings. However if these findings are confirmed then GUV lights could result in a substantial reduction of work related symptoms among office workers who are in similar mechanically ventilated buildings equipped with central air conditioning. Given that occurrence of any symptom was reduced by approximately 20% and that over half of all workers reported at least symptom then overall 10% of workers may benefit from this intervention.

CONCLUSIONS

1. Operation of GUV lamps in central HVAC systems resulted in significant and substantial reduction of viable bacteria and fungi, as well as endotoxin on the irradiated surfaces. There was also a trend to reduction in endotoxin in the HVAC supply air "down stream" from the GUV lamps. There were no differences in airborne endotoxin levels at worksites (although these were virtually undetectable) nor airborne viable microbes in HVAC systems or occupied spaces.

2. Operation of Germicidal Ultraviolet Light in central HVAC systems of mechanically ventilated office buildings was associated with a significant reduction in work related symptoms.
   - Reduction in mucosal and respiratory symptom complexes were particularly significant.
   - Reduction in mucosal symptoms was greater in females, and atopic individuals.
   - Reduction in respiratory symptoms was similar in all sub-groups in all buildings.

3. GUV installed in central HVAC systems appears to be safe. There was no evidence of increased production of TVOC's, ozone nor formaldehyde. Workers were not aware when the GUV lamps were operating, and did not report any odors nor perceive other adverse effects on the indoor air quality.

4. Work related symptoms were increased with higher work site temperature, lower relative humidity and higher CO_2.
   - These parameters were often outside the recommended limits or optimal range suggested by authoritative agencies for human comfort and well being.

5. Environmental conditions notably temperature, carbon dioxide,TVOC's, nitrogen dioxide and microbial contaminants were worse for female and/or clerical workers than their counterparts
   - Symptoms were increased in these workers.
   - Symptoms were also associated with many of these environmental parameters.
   - This suggests that increased symptoms in certain worker sub-groups may be related to worse local environmental conditions.

RECOMMENDATIONS

1. The apparent beneficial effect of GUV on work related symptoms in office workers should be confirmed in an independent study conducted elsewhere.

2. For now it would seem prudent to keep the germicidal ultraviolet lights in the HVAC systems of buildings where they have already been installed, and turn them on, at least during warmer months when air conditioning systems are in operation.

3. UV lamp life may be prolonged through intermittent use. On the basis of these results no recommendation can be made regarding intermittent use, to achieve the optimal balance between lamp life and sterilization of the surfaces of the cooling coils and drip pans of HVAC systems.

4. In specific buildings, increased temperature and reduced humidity outside the ranges considered ideal for human comfort and well being should be corrected by building owners and operators. Higher then average CO_2 concentrations may reflect greater crowding and should be corrected through improved ventilation to those areas.

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ACKNOWLEDGMENTS

Funding for this project was provided by the Medical Research Council (Grant # MA-15142) and the National Institute of Occupational Safety and Health - NIOSH (Grant # R01-0HO03693-01A1). In kind financial contribution was made by Sanuvox Incorporated of Montreal who provided the germicidal ultraviolet lights and installed them in the HVAC systems of the buildings involved. Dr. Menzies was supported by an Medical Research Council scientist award.

The investigators thank the building owners and operators for their systems in the conduct of the study as well as the management officials of the employers involved. The investigators wish to acknowledge the help and collaboration of the workers involved - without their participation there would have been no results to report.

The investigators thank Mme's Javahari, Lustig and Michaud for assistance in preparation of this report.

LIST OF PUBLICATIONS:

1. "Effect of Germicidal Ultraviolet (GUV) lights within HVAC systems of office buildings on environmental conditions in workers health and well being". J. Popa, D. Menzies, D. Milton, T. Rand, American Journal Respiratory and Critical Care Medicine, 165;(8): A527

2. "Impact of Germicidal Ultraviolet lights installed in the ventilation systems of office buildings on workers health and well being" D. Menzies, J. Popa, J.A. Handley, T. Rand, D. Milton. Submitted (New England Journal of Medicine)

REPORT OF EQUIPMENT PURCHASED WITH GRANT

No Equipment was purchased with this grant.

REPORT OF INVENTIONS FOSTERED BY GRANT

No invention was made through or because of funding by this grant.

Table 2A : Characteristics of Participants *

	Non Participants	Partial	Full
Number	163	87	771
Personal Characteristics			
Age (Mean SD)	-	42.9(10.5)	43.1 (8.5)
Females (N,%)	95 (59%)	41 (47%)	465 (60%)
French mother tongue (N, %)	131 (80%)	68 (78%)	616 (80%)
Smoking Never (N,%)	-	28 (42%)	328 (45%)
Ex-smoker (N,%)	-	22 (33%)	208 (28%)
Current Smoker (N,%)	-	17 (25%)	194 (27%)
Medical			
Atopic Illness (N,%)	-	30 (45%)	308 (42%)
Other Medical (N,%)	-	15 (22%)	167 (23%)
Work Characteristics			
Job Type Clerical (N,%)	-	21 (31%)	275 (38%)
Manager (N,%)	-	25 (37%)	288 (39%)
Professional (N,%)	-	21 (31%)	168 (23%)
Years worked same employer (mean, SD)	-	13.8 (10.9)	13.7 (9.6)
Hours worked at worksite per day (Mean, SD)	-	7.1 (1.6)	7.1 (1.9)
Hours worked on computer per day (mean, SD)	-	4.9 (2.6)	5.4 (2.3)

* None of the differences in personal and work characteristics between the 3 groups were statistically significant.

Table 2B: Symptom and environment ratings - by participation status
(155 with no symptom questionnaires excluded)

	Partial (1-3 Same GUV)	Full (2-6 Diff GUV)	(P value)
Number	85	771	
Env ratings - (mean values)			
Thermal	1.3	1.2	(NS)
Physical	1.0	0.8	(.06)
IAQ	1.7	1.8	(NS)
Total	1.3	1.3	(NS)
Total no. of symptoms - (mean values)			
Before work	0.42	0.52	(NS)
After work	1.28	1.12	(NS)
Affecting work	0.2	0.22	(NS)
Symptoms			
ANY - Before work	31%	53%	(<.001)
- After arriving at work	52%	53%	(NS)
- Affecting	12%	35%	(<.001)
SYSTEMIC - at work	31%	51%	(<.001)
MUCOSAL - at work	45%	53%	(NS)
MUSCULAR - at work	9%	22%	(<.01)
RESPIRATORY - at work	8%	13%	NS

Table 2C: Symptoms and environmental ratings - by response status
(155 no response, 85 partial - excluded)

	Number of symptom questionnaires			
	2	3-4	5-6	(P value)
Number of participants	54	237	471	
CHARACTERISTICS				
Age - mean	43	43	43	(NS)
Gender - % male	48%	47%	35%	(.005)
Job - Clerical (%)	25%	34%	41%	(.06)
- Management (%)	40%	40%	39%	
- Professional (%)	35%	26%	20%	
Smoking - Current (%)	25%	29%	26%	(NS)
- Ex (%)	29%	28%	29%	
- Never (%)	46%	43%	46%	
Atopy - (% yes)	41%	40%	42%	(NS)
Other medical (% yes)	24%	25%	22%	(NS)
ENVIRONMENTAL RATINGS (mean)				
- Thermal	1.4	1.2	1.2	(NS)
- Physical	0.8	0.8	0.7	(NS)
- IAQ	1.9	1.8	1.9	(NS)
- Total	1.4	1.3	1.3	(NS)
SYMPTOMS - Total values (mean)				
- Before work	0.6	0.5	0.5	(NS)
- After work	1.2	1.2	1.1	(NS)
- Affecting work	0.3	0.3	0.2	(NS)
SYMPTOMS				
- Any	63%	52%	53%	(NS)
- Mucosal	43%	54%	50%	(NS)
- Systemic	52%	66%	46%	(<.001)

Table 3A: Overall % reporting symptoms by week
(unpaired analysis)

	GUV					
	OFF	ON	OFF	ON	OFF	ON
	WEEK					
	1	2	3	4	5	6
Total subjects	746	634	608	593	587	515
ANY SYMPTOMS						
Before work	28%	31%	27%	28%	23%	25%
After arrival at work	50%	48%	46%	40%	39%	34%
Affecting work	13%	15%	12%	12%	11%	10%
SYSTEMIC SYMPTOMS						
Before work	8%	8%	5%	8%	8%	10%
After arrival at work	28%	29%	25%	24%	21%	21%
Affecting work	10%	12%	9%	9%	7%	7%
MUCOSAL SYMPTOMS						
Before work	19%	24%	22%	21%	15%	16%
After arrival at work	40%	36%	36%	32%	29%	25%
Affecting work	5%	6%	6%	5%	4%	6%
RESPIRATORY SYMPTOMS						
Before work	4%	5%	3%	4%	4%	4%
After arrival at work	14%	4%	5%	4%	9%	8%
Affecting work	1%	0%	1%	1%	1%	1%
MUSCULAR SYMPTOMS						
Before work	8%	7%	7%	7%	6%	6%
After arrival at work	10%	7%	7%	7%	6%	5%
Affecting work	2%	1%	2%	1%	2%	1%
AVERAGE NO. OF SYMPTOMS						
Before work	0.5	0.6	0.5	0.5	0.4	0.5
After arrival at work	1.3	1.2	1.2	1.1	0.9	0.9
Affecting work	0.2	0.3	0.2	0.2	0.2	0.2

Table 3B: Overall number and % reporting by GUV intervention
(Unpaired analysis)

	GUV				
	ON		**OFF**		(P value)
	N	(%)	N	(%)	
Total questionnaires	1744		1941		
ANY SYMPTOMS					
Before work	496	(28%)	513	(26%)	NS
After work	719	(41%)	881	(45%)	.01
Affecting work	219	(13%)	236	(12%)	NS
SYSTEMIC SYMPTOMS					
Before work	148	(8%)	138	(7%)	NS
After work	435	(25%)	488	(25%)	NS
Affecting work	175	(10%)	175	(9%)	NS
MUCOSAL SYMPTOMS					
Before work	360	(21%)	359	(19%)	NS
After work	544	(31%)	687	(35%)	.007
Affecting work	79	(4%)	99	(5%)	NS
RESPIRATORY SYMPTOMS					
Before work	71	(4%)	71	(4%)	NS
After work	62	(4%)	93	(5%)	.06
Affecting work	13	(1%)	15	(1%)	NS
MUSCULAR SYMPTOMS					
Before work	123	(7%)	143	(7%)	NS
After work	113	(6%)	155	(8%)	.08
Affecting work	20	(1%)	35	(2%)	.1
AVERAGE NO. OF SYMPTOMS	mean	(SD)	mean	(SD)	
Before work	0.5	(1.1)	0.5	(1.0)	NS
After work	1.1	(1.7)	1.1	(1.7)	NS
Affecting work	0.2	(0.7)	0.2	(0.7)	(NS)

Table 4A: Environmental ratings (0 = ideal, 4 = terrible)
Average ratings in each week

	WEEK					
	1	2	3	4	5	6
(Number of respondents)	(746)	(636)	(608)	(593)	(587)	(515)
Thermal factors	1.2	1.2	1.4	1.2	1.2	1.0
Physical factors	0.8	0.8	0.7	0.8	0.8	0.7
Indoor air quality	1.6	1.7	1.9	1.9	2.0	2.0
Overall ratings	1.2	1.2	1.3	1.3	1.3	1.3

4B- Average ratings under each experimental condition

	GUV ON	GUV OFF	P value
(Number of questionnaires)	1744	1941	
Thermal factors	1.16	1.23	.04
Physical factors	0.8	0.8	NS
Indoor air quality	1.9	1.8	NS
Overall ratings	1.3	1.3	NS

Table 5A: Mean + Median values of symptoms and environmental ratings

Ratings	Mean	Median
Thermal	1.2	1.11
Physical	0.79	0.67
IAQ	1.84	1.87
Total	1.28	1.24

SYMPTOM COMPLEXES	Before work		After work		Affecting work	
	Mean	Median	Mean	Median	Mean	Median
Symptoms sum	0.51	0.25	1.13	0.67	0.22	0
Any	0.28	0.2	0.44	0.4	0.13	0
Mucosal	0.20	0	0.34	0.25	0.05	0
Systemic	0.08	0	0.25	0.20	0.10	0
Muscular	0.07	0	0.07	0	0.01	0
Respiratory	0.04	0	0.04	0	0.01	0

Table 5B: Symptoms and environmental ratings - by buildings

	A	M	R	S	(P value)
Number of participants	147	140	245	240	
CHARACTERISTICS					
Age - mean	43.4	43.2	41.7	44.3	(.01
Gender - % male	76%	36%	16%	43%	(<.001)
Smoking - % current	19%	18%	33%	29%	(.04)
- % ex-smoker	32%	33%	25%	27%	-
Atopic history - %	35%	47%	38%	46%	(.08)
Job - Clerical (%)	8%	20%	74%	27%	(<.001)
- Management (%)	33%	72%	24%	41%	-
- Professional (%)	59%	8%	1%	32%	-
ENVIRONMENTAL RATINGS (mean)					
- Thermal	1.2	0.9	1.3	1.2	(<.001)
- Physical	1.0	0.5	0.8	0.7	(<.001)
- IAQ	1.9	1.6	1.9	1.9	(<.001)
- Total	1.4	1.0	1.4	1.3	(<.001)
SYMPTOMS - mean number					
- Before work	0.5	0.5	0.5	0.5	(NS)
- After work	1.2	0.7	1.2	1.2	(.002)
- Affecting work	0.2	0.1	0.3	0.2	(.005)
SYMPTOMS - complexes					
- Any	53%	43%	55%	57%	(.08)
- Mucosal	54%	43%	55%	55%	(NS)
- Systemic	52%	38%	53%	54%	(.01)
- Muscular	22%	22%	24%	19%	(NS)
- Respiratory	12%	7%	19%	11%	(.004)

Table 6A: Association of personal and work characteristics with environmental ratings

	Thermal		Physical		IAQ		Overall	
Characteristics	OR*	(95% CI)	OR*	(95% CI)	OR*	(95% CI)	OR*	(95% CI)
Older age (per 10 years)	1.1	(0.9, 1.3)	1.0	(0.9, 1.1)	1.0	(0.8, 1.2)	1.1	(0.9, 1.4)
Female gender	**2.8**	**(2.0, 4.1)**	0.9	(0.7, 1.3)	**3.6**	**(2.5, 5.3)**	**2.7**	**(1.9, 3.9)**
Current smoker (vs never)	**1.5**	**(1.04, 2.2)**	1.1	(0.8, 1.6)	0.9	(0.6, 1.3)	1.2	(0.9, 1.8)
Ex-smoker (vs never)	0.8	(0.6, 1.2)	1.1	(0.7, 1.5)	1.3	(0.9, 1.8)	1.1	(0.8, 1.6)
Atopic illness	**1.5**	**(1.1, 2.0)**	1.1	(0.8, 1.4)	1.0	(0.8, 1.4)	1.2	(0.8, 1.6)
Other medical	1.3	(0.9, 1.8)	**1.5**	**(1.01, 2.1)**	0.9	(0.6, 1.3)	1.3	(0.9, 1.8)
Job - Clerical vs Prof.	0.9	(0.6, 1.5)	0.8	(0.5, 1.3)	1.2	(0.8, 2.0)	1.1	(0.7, 1.8)
Mgmt vs Prof.	1.0	(0.7, 1.5)	0.6	(0.4, 0.8)	1.1	(0.7, 1.6)	0.9	(0.6, 1.3)
Building A (vs M)	**3.1**	**(1.8, 5.5)**	**2.9**	**(1.7, 4.9)**	**2.8**	**(1.6, 4.8)**	**4.8**	**(2.7, 8.4)**
R (vs M)	**2.0**	**(1.2, 3.3)**	**1.9**	**(1.2, 3.1)**	1.1	(0.7, 1.8)	**1.8**	**(1.1, 3.0)**
S (vs M)	**2.1**	**(1.3, 3.4)**	1.4	(0.9, 2.3)	1.4	(0.8, 2.1)	**1.8**	**(1.1, 2.9)**

* OR: Odds ratio - expressing odds that characteristic associated with ratings (in all weeks reported), worse than median value for all respondents.

Table 6B: Association of personal and work characteristics with greater reporting of symptoms

	Any*		Systemic*		Mucosal*		Respiratory†	
	OR	(95% CI)	OR	(95% CI)	OR	(95% CI)	OR	(95% CI)
Older age - per 10 years	**0.8**	**(0.6, 0.9)**	**0.7**	**(0.6, 0.9)**	1.0	(0.9, 1.1)	1.2	(0.9, 1.4)
Female gender	1.3	(0.8, 1.9)	1.1	(0.7, 1.6)	1.0	(0.6, 1.4)	0.8	(0.5, 1.4)
Current smoker	0.9	(0.6, 13)	1.1	(0.8, 1.7)	1.2	(0.8, 1.8)	1.1	(0.7, 2.0)
Ex-smoker	1.0	(0.7, 1.5)	1.3	(0.9, 1.9)	1.1	(0.7, 1.6)	1.3	(0.8, 2.2)
Atopic illness	**1.8**	**(1.2, 2.5)**	1.3	(0.9, 1.7)	1.8	(1.3, 2.5)	1.4	(0.9, 2.2)
Other med-illness	1.0	(0.6, 1.5)	**1.5**	**(1.0, 2.2)**	1.1	(0.7, 1.6)	0.9	(0.5, 1.5)
Job - Clerical (vs Prof.)	**0.6**	**(0.3, 0.98)**	**0.5**	(0.3, 0.9)	0.8	(0.5, 1.4)	0.9	(0.4, 2.0)
- Management (vs Prof.)	0.7	(0.5, 1.1)	0.6	(0.4, 0.99)	0.8	(0.5, 1.2)	1.2	(0.6, 2.3)
Building - A (vs M)	1.1	(0.6, 1.9)	1.3	(0.7, 2.3)	1.0	(0.6, 1.9)	1.4	(0.5, 3.5)
- R (vs M)	1.1	(0.7, 2.0)	1.5	(0.9, 2.5)	1.0	(0.6, 1.7)	**2.7**	**(1.2, 6.1)**
- S (vs M)	1.3	(0.8, 2.2)	1.5	(0.9, 2.4)	1.0	(0.7, 1.8)	1.3	(0.6,3.0)
Thermal rating (per unit)	**4.2**	**(3.0, 5.9)**	**2.6**	**(1.9, 3.4)**	**3.6**	**(2.6, 5.0)**	**2.2**	**(1.5, 3.2)**
IAQ rating (per unit)	**1.7**	**(1.2, 2.4)**	**1.6**	**(1.1, 2.1)**	**1.7**	**(1.2, 2.3)**	1.2	(0.8, 1.9)

Notes: OR -*Odds that characteristics associated with reporting of more than the median number of any systemic, or mucosal symptoms.
† Odds ratio that characteristics associated with ever reporting of respiratory symptoms in any week.

Table 7A: Reporting of any symptoms in 3 trials (ANY)
771 who completed at least one symptom questionnaire under both experimental conditions

	No symptom in either trial		Symptoms in both trials		Symptoms only GUV OFF		Symptoms only GUV ON		Odds ratio GUV ON : OFF
Before work									
Trial 1	329	(56%)	79	(13%)	73	(13%)	103	(18%)	103/73= 1.4
Trial 2	294	(58%)	67	(13%)	69	(14%)	79	(16%)	79/69= 1.1
Trial 3	273	(61%)	45	(10%)	65	(15%)	62	(14%)	62/65= 0.95
After arrival at work									
Trial 1	196	(33%)	188	(32%)	105	(18%)	99	(17%)	99/105= 0.94
Trial 2	205	(40%)	137	(27%)	98	(19%)	69	(14%)	69/98= 0.70
Trial 3	213	(48%)	109	(24%)	80	(18%)	43	(10%)	43/80= 0.5
Affecting work									
Trial 1	451	(77%)	28	(5%)	49	(8%)	60	(10%)	60/49= 1.2
Trial 2	409	(80%)	18	(4%)	40	(8%)	42	(8%)	42/40= 1.05
Trial 3	371	(83%)	20	(4%)	28	(6%)	26	(6%)	26/28= 0.93

Table 7B: Reporting systemic symptoms in 3 trials
771 who completed at least one symptom questionnaire under both experimental conditions

	No symptom in either trial		Symptoms in both trials		Symptoms only GUV OFF		Symptoms only GUV ON		Odds ratio GUV ON : OFF
Before work									
Trial 1	482	(86%)	17	(2%)	44	(7%)	46	(8%)	46/44= 1.04
Trial 2	439	(88%)	8	(1%)	23	(4%)	39	(7%)	39/23= 1.7
Trial 3	364	(83%)	14	(2%)	31	(7%)	36	(8%)	36/31= 1.2
After arrival at work									
Trial 1	336	(54%)	66	(12%)	95	(16%)	92	(18%)	92/95= 0.97
Trial 2	330	(65%)	47	(11%)	73	(14%)	59	(14%)	59/73= 0.8
Trial 3	313	(70%)	43	(11%)	51	(12%)	38	(10%)	38/51= 0.7
Affecting work									
Trial 1	496	(84%)	11	(2%)	36	(6%)	46	(8%)	46/36= 1.3
Trial 2	449	(88%)	9	(2%)	27	(5%)	24	(5%)	24/27= 0.9
Trial 3	393	(88%)	12	(3%)	20	(4%)	20	(4%)	20/20= 1

Table 7C: Reporting of mucosal symptoms in 3 trials
771 who completed at least one symptom questionnaire under both experimental conditions

	No symptom in either trial		Symptoms in both trials		Symptoms only GUV OFF		Symptoms only GUV ON		Odds ratio GUV ON : OFF
Before work									
Trial 1	416	(71%)	38	(6%)	54	(9%)	81	(14%)	81/54= 1.5
Trial 2	357	(70%)	35	(7%)	60	(12%)	57	(11%)	57/60= 0.95
Trial 3	341	(77%)	23	(5%)	40	(9%)	41	(9%)	41/40= 1
After arrival at work									
Trial 1	266	(46%)	129	(21%)	93	(16%)	101	(17%)	101/93= 1.09
Trial 2	259	(51%)	104	(20%)	81	(16%)	65	(13%)	65/81= 0.8
Trial 3	262	(59%)	74	(17%)	67	(15%)	42	(9%)	42/67= 0.6
Affecting work									
Trial 1	505	(86%)	15	(3%)	30	(3%)	39	(7%)	39/30= 1.3
Trial 2	435	(85%)	8	(2%)	30	(6%)	36	(7%)	36/30= 1.2
Trial 3	400	(90%)	6	(1%)	18	(4%)	21	(5%)	21/18= 1.2

Table 7D: Reporting of respiratory symptoms in 3 trials ...
771 who completed at least one symptom questionnaire under both experimental conditions

	No symptom in either trial		Symptoms in both trials		Symptoms only GUV OFF		Symptoms only GUV ON		Odds ratio GUV ON : OFF
Before work									
Trial 1	488	(83%)	16	(3%)	38	(6%)	47	(8%)	47/38= 1.2
Trial 2	426	(84%)	10	(2%)	35	(7%)	38	(7%)	38/35= 1.09
Trial 3	384	(86%)	7	(2%)	33	(7%)	21	(5%)	21/33= 0.9
After arrival at work									
Trial 1	471	(80%)	12	(2%)	57	(10%)	49	(8%)	49/57= 0.9
Trial 2	422	(83%)	14	(3%)	36	(7%)	37	(7%)	37/36= 1.03
Trial 3	375	(84%)	19	(4%)	30	(7%)	21	(5%)	21/30= 0.7
Affecting work									
Trial 1	575	(98%)	0	(0%)	7	(1%)	7	(1%)	7/7= 1
Trial 2	493	(98%)	1	(<1%)	8	(1%)	7	(1%)	7/8= 0.9
Trial 3	437	(99%)	1	(<1%)	3	(1%)	4	(1%)	4/3= 1.3

Table 7E: Reporting of symptoms in all 3 trials combined
771 who completed at least one symptom questionnaire under both experimental conditions

	No symptom in either trial		Symptoms in both trials		Symptoms only GUV OFF		Symptoms only GUV ON		Odds ratio GUV ON : OFF
ANY									
Before work	290	(38%)	220	(29%)	124	(16%)	137	(18%)	137/124= 1.1
After arrival at work	**175**	**(23%)**	**371**	**(48%)**	**138**	**(18%)**	**87**	**(11%)**	**87/138= 0.6**
Affecting work	503	(65%)	91	(12%)	92	(12%)	85	(11%)	85/92= 0.9
SYSTEMIC									
Before work	531	(69%)	59	(8%)	81	(11%)	100	(13%)	100/81= 1.23
After arrival at work	**339**	**(44%)**	**171**	**(22%)**	**150**	**(19%)**	**111**	**(14%)**	**111/150= 0.74**
Affecting work	582	(75%)	51	(7%)	72	(9%)	66	(9%)	66/72= 0.8
MUCOSAL									
Before work	421	(55%)	126	(16%)	108	(17%)	116	(15%)	116/108= 1.07
After arrival at work	**245**	**(32%)**	**283**	**(37%)**	**147**	**(19%)**	**96**	**(12%)**	**96/147= 0.65**
Affecting work	581	(75%)	49	(6%)	69	(9%)	72	(9%)	72/69= 1.04
RESPIRATORY									
Before work	553	(72%)	50	(6%)	90	(12%)	78	(10%)	78/90= 0.9
After arrival at work	**553**	**(72%)**	**67**	**(9%)**	**89**	**(12%)**	**62**	**(8%)**	**62/89= 0.7**
Affecting work	733	(95%)	2	(0.3%)	19	(2%)	17	(2%)	17/19= 0.9
MUSCULAR									
Before work	602	(78%)	51	(7%)	64	(8%)	54	(7%)	54/64= 0.8
After arrival at work	**601**	**(78%)**	**45**	**(6%)**	**78**	**(10%)**	**47**	**(6%)**	**47/78= 0.6**
Affecting work	724	(94%)	4	(1%)	30	(4%)	13	(2%)	13/30= 0.4

Table 8 A: Effect of confounding factors on response to GUV
Gender

	No Symptoms in either trials		Symptoms in both trials		Symptoms only with GUV Off		Symptoms only with GUV ON		Odds Ratio ON:OFF
	N	%	N	%	N	%	N	%	
ANY									
Before Work Females	167	(36%)	144	(31%)	68	(15%)	86	(10%)	86/68= 1.3
Males	123	(40%)	76	(25%)	56	(18%)	51	(17%)	51/56= 0.9
After Work Females	79	(17%)	249	(54%)	86	(18%)	51	(11%)	51/86= 0.6
Males	96	(31%)	122	(40%)	52	(17%)	36	(12%)	36/52= 0.7
SYSTEMIC									
Before Work Females	308	(66%)	36	(8%)	53	(11%)	68	(15%)	68/53= 1.2
Males	223	(73%)	23	(8%)	28	(9%)	32	(10)	32/28= 1.4
After Work Females	175	(38%)	110	(24%)	102	(22%)	78	(17%)	78/102= 0.8
Males	164	(54%)	61	(20%)	48	(16%)	33	(11%)	33/48= 0.7
MUCOSAL									
Before Work Females	226	(49%)	85	(18%)	72	(15%)	82	(18%)	82/72= 1.1
Males	195	(64%)	41	(13%)	36	(12%)	34	(11%)	34/36= 0.9
After Work Females	121	(26%)	186	(40%)	97	(21%)	61	(13%)	61/97= 0.6
Males	124	(41%)	94	(32%)	50	(16%)	35	(11%)	35/50= 0.7
RESPIRATORY									
Before Work Females	330	(71%)	34	(7%)	50	(11%)	51	(11%)	50/51= 0.98
Males	223	(73%)	16	(5%)	40	(13%)	27	(9%)	27/40= 0.7
After Work Females	307	(66%)	53	(11)	62	(13%)	43	(9%)	43/62= 0.7
Males	246	(80%)	14	(5%)	27	(9%)	19	(6%)	19/27= 0.7
MUSCULAR									
Before Work Females	368	(79%)	33	(7%)	35	(7%)	29	(6%)	29/35= 0.8
Males	234	(76%)	18	(6%)	29	(9%)	25	(8%)	25/29= 0.9
After Work Females	348	(75%)	36	(8%)	50	(11%)	36	(8%)	36/50= 0.7
Males	253	(83%)	9	(3%)	28	(9%)	16	(5%)	16/28= 0.6

Table 8 B: Effect of confounding gender factors on response to GUV
Atopic History

		No Symptoms with either trials		Symptoms in both trials		Symptoms only with GUV Off		Symptoms only with GUV ON		Odds Ratio ON:OFF
		N	%	N	%	N	%	N	%	
ANY										
Before Work	Non atopic	188	(44%)	104	(24%)	68	(16%)	69	(16%)	68/69= 1.01
	Atopic	87	(28%)	105	(34%)	56	(18%)	60	(19%)	60/56= 1.07
After Work	Non atopic	115	(27%)	178	(41%)	78	(18%)	58	(14%)	58/78= 0.7
	Atopic	51	(17%)	178	(58%)	54	(18%)	25	(8%)	25/54= 0.5
SYSTEMIC										
Before Work	Non atopic	299	(70%)	25	(6%)	48	(11%)	57	(13%)	57/48= 1.2
	Atopic	208	(68%)	31	(10%)	32	(10%)	37	(12%)	37/32= 1.2
After Work	Non atopic	209	(44%)	77	(18%)	82	(19%)	61	(14%)	61/82= 0.7
	Atopic	115	(37%)	84	(27%)	64	(21%)	45	(15%)	45/64= 0.7
MUCOSAL										
Before Work	Non atopic	264	(62%)	52	(12%)	56	(13%)	57	(13%)	57/56= 1.01
	Atopic	138	(45%)	66	(21%)	50	(16%)	54	(18%)	54/50= 1.08
After Work	Non atopic	159	(37%)	133	(31%)	77	(18%)	61	(14%)	61/77= 0.8
	Atopi	77	(25%)	137	(44%)	64	(21%)	30	(10)	30/64= 0.5
RESPIRATORY										
Before Work	Non atopic	337	(79%)	17	(4%)	41	(10%)	34	(8%)	34/41= 0.8
	Atopic	195	(63%)	27	(9%)	48	(16%)	38	(12%)	38/48= 0.8
After Work	Non atopic	338	(79%)	25	(6%)	42	(10%)	24	(6%)	24/42= 0.6
	Atopic	190	(62%)	39	(14%)	43	(13%)	36	(12%)	36/43= 0.8
MUSCULAR										
Before Work	Non atopic	335	(78%)	28	(7%)	35	(8%)	31	(7%)	31/35= 0.9
	Atopic	239	(78%)	20	(6%)	29	(9%)	20	(6%)	20/29= 0.7
After Work	Non atopic	347	(81%)	24	(6%)	36	(8%)	22	(5%)	22/36= 0.6
	Atopic	228	(74%)	19	(6%)	38	(12%)	23	(7%)	23/38= 0.6

Table 8C: Effect of confounding factors on response to GUV - building
(only symptoms reported after arrival at work are shown)

		No Symptoms with either trials		Symptoms in both trials		Symptoms only with GUV Off		Symptoms only with GUV ON		Odds Ratio ON:OFF
SYMPTOM	BUILDING	N	%	N	%	N	%	N	%	
ANY										
	A	35	(24%)	70	(47%)	24	(16%)	19	(13%)	19/24= 0.8
	M	46	(35%)	47	(36%)	22	(17%)	16	(12%)	16/22= 0.7
	R	47	(19%)	124	(50%)	51	(21%)	26	(10%)	26/51= 0.5
	S	47	(19%)	130	(58%)	41	(17%)	26	(11%)	26/41= 0.6
SYSTEMIC										
	A	71	(48%)	35	(24%)	21	(14%)	22	(15%)	22/21= 1.05
	M	80	(61%)	13	(10%)	21	(16%)	17	(13%)	17/21= 0.8
	R	91	(37%)	64	(26%)	56	(23%)	37	(15%)	37/56= 0.7
	S	97	(40%)	59	(24%)	53	(22%)	35	(14%)	35/53= 0.7
MUCOSAL										
	A	47	(32%)	55	(37%)	27	(18%)	19	(13%)	19/27= 0.7
	M	54	(41%)	32	(24%)	30	(23%)	15	(11%)	15/30= 0.5
	R	72	(29%)	96	(39%)	49	(20%)	31	(12%)	31/49= 0.6
	S	72	(40%)	100	(31%)	41	(17%)	31	(13%)	31/41= 0.8
RESPIRATORY										
	A	108	(73%)	10	(7%)	21	(14%)	9	(6%)	9/21= 0.4
	M	102	(78%)	6	(5%)	10	(8%)	13	(10%)	13/10= 1.3
	R	169	(68%)	29	(12%)	26	(10%)	24	(10%)	24/26= 0.9
	S	174	(71%)	22	(9%)	32	(13%)	16	(7%)	16/32= 0.5
MUSCULAR										
	A	115	(78%)	9	(6%)	14	(9%)	10	(7%)	10/14= 0.7
	M	102	(78%)	5	(4%)	16	(12%)	8	(6%)	8/16= 0.5
	R	186	(75%)	21	(8%)	26	(10%)	15	(6%)	15/26= 0.6
	S	198	(81%)	10	(4%)	22	(9%)	14	(6%)	14/22= 0.6

Table 9 A: Thermal conditions at floor sites by week

		GUV					
		OFF	ON	OFF	ON	OFF	ON
		Week					
		1	2	3	4	5	6
Temperature							
	Mean (°C)	26.1	24.7	24.3	23.4	23.8	23.7
	Variation	0.04	0.03	0.04	0.03	0.02	0.04
Humidity							
	Mean (%)	42%	30%	21%	22%	44%	44%
	Variation	0.10	0.09	0.15	0.07	0.05	0.08
Air Velocity							
	Mean	0.97	0.98	0.92	0.88	0.83	0.85
	Variation	0.85	0.85	0.96	0.80	0.80	0.81
Carbon Dioxide							
	Mean (PPM)	671	647	557	570	583	536
	PM	688	678	582	595	594	553
	Variation	0.14	0.12	0.11	0.11	0.08	0.10
Ventilation System							
% Recirculating	AM	78%	85%	80%	79%	76%	82%
	PM	78%	81%	81%	82%	80%	81%
	Mean	78%	83%	81%	80%	78%	81%

Note:

Variation - Differences between AM and PM Values divided by the mean of AM and PM values

Table 9B : Thermal conditions at floor sites - by GUV experimental conditions

		GUV	
		OFF	ON
Temperature			
	Mean (°C)	24.7	23.9
	Variation	0.03	0.03
Humidity			
	Mean (%)	36%	32%
	Variation	0.10	0.08
Air Velocity			
	Mean	0.90	0.91
	Variation	0.87	0.82
Carbon Dioxide			
	Mean (PPM)	601	584
	PM	619	609
	Variation	0.11	0.11
Ventilation System			
Recirculating	AM	78%	82%
	PM	80%	81%
	Mean	79%	82%
	PM CO_2 in return Air (PPM)	614	572

Note:

Variation - Differences between AM and PM Values divided by the mean of AM and PM values

Table 10A: Relation of thermal conditions to symptoms
(Independent/unpaired analysis)

	ANY			SYSTEMIC		
	Present	Absent	(PValue)	Present	Absent	(PValue)
Floor Sites:						
Temperature						
Mean (°C)	24.7	24.4	(<.001)	24.8	24.4	(<.0001)
Variation*	0.03	0.03	[NS]	0.03	0.03	[NS]
Humidity						
Mean (%)	34%	34%	[NS]	35%	34%	[NS]
Variation	0.08	0.09	[NS]	0.09	0.09	[NS]
Air Velocity						
Mean	0.91	0.91	[NS]	0.92	0.90	[NS]
Variation	0.90	0.95	[NS]	0.92	0.86	(.03)
Carbon Dioxide						
Mean(PPM)	600	594	[NS]	605	595	(.01)
Peak PM(PPM)	620	612	(.05)	625	614	(.01)
Variation	0.10	0.10	[NS]	0.11	0.10	[NS]
Ventilation System						
% Recirculating	79%	79%	[NS]	80%	80%	[NS]
AM PM	81%	81%	[NS]	82%	81%	[NS]
Mean	80%	80%	[NS]	81%	81%	[NS]

Note:

*Variation - Differences between AM and PM Values divided by the mean of AM and PM values

Table 10B: Association of thermal conditions with SYMPTOMS
(Independent unpaired analysis)

		MUCOSAL			RESPIRATORY		
		Present	Absent	(PValue)	Present	Absent	(PValue)
Floor Sites:							
Temperature							
	Mean (°C)	24.7	24.4	(<.001)	24.7	24.5	(.05)
	Variation*	0.03	0.03	[NS]	0.03	0.03	[NS]
Humidity							
	Mean (%)	34%	34%	[NS]	33%	34%	[NS]
	Variation	0.09	0.09	[NS]	0.10	0.09	[NS]
Air Velocity							
	Mean	0.91	0.90	[NS]	0.93	0.90	[NS]
	Variation	0.90	0.87	[NS]	0.97	0.87	[NS]
Carbon Dioxide							
	Mean(PPM)	601	596	[NS]	609	596	(.05)
	Peak PM	621	614	[NS]	629	615	(.01)
	Variation	0.10	0.10	[NS]	0.10	0.10	[NS]
Ventilation System							
% Recirculating	AM	79%	79%	[NS]	79%	79%	[NS]
	PM	81%	81%	[NS]	82%	82%	[NS]
	Mean	80%	80%	[NS]	81%	80%	[NS]

Note:

* Variation - Differences between AM and PM Values divided by the mean of AM and PM values

Table 10C: Association of thermal conditions with potentially confounding personal characteristics

		GENDER			JOB TYPE			
		Male	Female	(Pvalue)	Clerical	Manager	Professional	(PValue)
Floor Sites:								
Temperature								
	Mean (°C)	24.4	24.6	(<0.0001)	24.8	24.3	24.4	(<0.0001)
	Variation*	0.03	0.03	[NS]	0.03	0.03	0.03	[NS]
Humidity								
	Mean (%)	33%	34%	(<0.01)	34%	34%	32%	(.0002)
	Variation	0.10	0.08	(0.0001)	0.07	0.09	0.11	(<0.0001)
Air Velocity								
	Mean	0.89	0.92	[NS]	0.94	0.90	0.88	(0.001)
	Variation	0.87	0.88	[NS]	0.91	0.85	0.87	[NS]
Carbon Dioxide								
	Mean(PPM)	588	602	(<0.0001)	610	594	577	(<0.0001)
	Peak PM	612	618	[NS]	619	619	604	(.001)
	Variation	0.11	0.10	(<0.0001)	0.09	0.11	0.11	(<0.0001)
Ventilation System								
% Recirculating	AM	79%	80%	[NS]	79%	79%	79%	[NS]
	PM	82%	82%	[NS]	81%	81%	81%	(<0.001)
	Mean	81%	81%	[NS]	80%	80%	80%	[NS]

Note:

* Variation - Differences between AM and PM Values divided by the mean of AM and PM values

Table 1. Participation at 4 sites

	A	M	R	S	Total
INITIALLY IDENTIFIED	292	214	373	439	1318
Eligible	214	166	323	308	1011
Refused/No response	41	28	42	45	155
Partial	25	7	33	19	85
Full participant	148	131	248	244	771
(% full)	(69%)	(78%)	(76%)	(79%)	(76%)
BY WEEK					
1	151	112	234	243	740
2	129	106	209	187	631
3	112	100	203	192	607
4	113	105	187	187	592
5	100	98	207	179	584
6	85	85	171	172	513
Total	690	606	1211	1160	3667
Average no. of weeks	3.2	3.8	3.8	3.8	3.7

Table 10 D: Association of thermal conditions with potentially confounding personal characteristics

		ATOPIC			SMOKING			
		YES	NO	(Pvalue)	NEVER	EX-SMOKER	CURRENT	(PValue)
Floor Sites:								
Temperature								
	Mean (°C)	24.5	24.5	[NS]	24.5	24.5	24.6	[NS]
	Variation*	0.03	0.03	[NS]	0.03	0.03	0.04	[NS]
Humidity								
	Mean (%)	34%	34%	[NS]	34%	34%	35%	[NS]
	Variation	0.08	0.09	[NS]	0.09	0.09	0.09	[NS]
Air Velocity								
	Mean	0.90	0.91	[NS]	0.90	0.91	0.92	[NS]
	Variation	0.87	0.89	[NS]	0.87	0.90	0.87	[NS]
Carbon Dioxide								
	Mean(PPM)	595	597	[NS]	595	599	596	[NS]
	Peak PM	617	614	[NS]	614	620	614	[NS]
	Variation	0.11	0.10	[NS]	0.10	0.11	0.10	[NS]
Ventilation System								
% Recirculating	AM	79%	80%	[NS]	80%	80%	80%	[NS]
	PM	82%	82%	[NS]	81%	82%	82%	[NS]
	Mean	81%	81%	[NS]	81%	81%	81%	[NS]

Note:

* Variation - Differences between AM and PM Values divided by the mean of AM and PM values

Table 11A: Airborne chemical contaminates
A - Average measures by week

	GUV					
	OFF	ON	OFF	ON	OFF	ON
	WEEK					
	1	2	3	4	5	6
Nitrogen Oxide (NOx)						
Outdoor Air	55	42	52	94	43	38
Supply Air	40	48	54	51	31	26
Work sites	39	43	54	46	32	26
Photocopy rooms	36	44	65	49	35	21
Ozone (O_3)						
Outdoor Air	4.7	4.1	13.5	22.5	12.7	10.1
Supply Air	1.5	2.3	4.0	5.7	9.4	5.2
Work sites	1.6	1.2	1.5	2.2	5.7	3.3
Photocopy rooms	1.7	2.2	3.1	1.4	5.2	3.0
Volatile Organic Compounds (VOC)						
Outdoor Air						
Supply Air	40	52	40	29	99	324
Work sites	141	112	97	85	174	283
Photocopy rooms	107	89	131	113	165	287
	175	104	92	92	138	219
Formaldehyde						
Outdoor Air	0.040	0.078	0.016	0.021	0.023	0.025
Supply Air	0.031	0.029	0.022	0.041	0.029	0.089
Work sites	0.015	0.028	0.025	0.057	0.049	0.031
Photocopy rooms	0.015	0.022	0.052	0.138	0.025	0.031

Table 11B: Airborne chemical contaminates
B - Average measures by GUV interventions

	GUV	
	OFF	ON
Nitrogen Oxide (NOx)		
Outdoor Air	49	57
Ventilation Supply Air	42	41
Work sites	42	38
Photocopy rooms	45	38
Ozone (O_3)		
Outdoor Air	11.4	13.0
Ventilation Supply Air	4.9	4.4
Work sites	3.0	2.2
Photocopy rooms	3.2	2.2
Volatile Organic Compounds (VOC)		
Outdoor Air	61	135
Ventilation Supply Air	137	161
Work sites	134	163
Photocopy rooms	135	139
Formaldehyde		
Outdoor Air	0.026	0.041
Ventilation Supply Air	0.027	0.053
Work sites	0.030	0.039
Photocopy rooms	0.032	0.063

Table 11C: Correlation of chemical and thermal parameters at work sites

	Humidity	Air Velocity	CO_2	NO_x	O_3	TVOC	FORM
Temperature	**+0.26**	+0.05	**+0.14**	**+0.19**	**-0.29**	**-0.36**	**-0.12**
Humidity	-	-0.01	**+0.19**	**-0.28**	**+0.44**	**+0.27**	**-0.13**
Air Velocity		-	+0.08	**+0.15**	-0.10	**-0.20**	-0.04
CO_2			-	**-0.18**	**-0.15**	**-0.39**	-0.10
NO_x				-	-0.06	**-0.36**	**-0.32**
O_3					-	**+0.51**	-0.04
TVOC						-	-0.03
Formaldehyde							-

Table 12 A: Airborne chemical contaminants
Association with work related symptoms

	ANY			ANY-AFFECTING WORK			SYSTEMIC		
	Present	Absent	PValue	Present	Absent	PValue	Present	Absent	PValue
Number of respondents	(1594)	(2073)		(455)	(3212)		(850)	(2817)	
Nitrogen Oxide (NOx)									
Ventilation Supply Air	54.7	51.1	(.005)	56.7	52.1	(.020	56.8	51.4	(.001)
Average on Floor	46.8	44.3	(.003)	47.6	45.1	[NS]	47.6	44.7	(.01)
Work sites	46.5	43.8	(.002)	47.5	44.6	(.03)	467.4	44.2	(.01)
Ozone (O_3)									
Ventilation Supply Air	5.4	5.6	[NS]	5.1	5.6	[NS]	5.3	5.6	[NS]
Average on Floor	2.5	2.7	[NS]	2.6	2.7	[NS]	2.5	2.7	[NS]
Work sites	2.4	2.6	(.02)	2.4	2.5	[NS]	2.4	2.6	[NS}
Volatile Organic Compounds (VOC)									
Ventilation Supply Air	122	136	(.001)	125	130	[NS]	120	133	(.01)
Average on Floor	128	143	(.001)	122	138	(.001)	124	140	(.001)
Work sites	132	146	(.001)	130	141	(.02)	130	143	(.001)
Formaldehyde									
Ventilation Supply Air	0.031	0.034	[NS]	0.033	0.032	[NS]	0.030	0.034	[NS]
Average on Floor	0.033	0.035	[NS]	0.032	0.035	[NS]	0.032	0.035	[NS]
Work sites	0.030	0.032	[NS]	0.029	0.031	[NS]	0.029	0.032	[NS]

Table 12 B: Airborne chemical contaminants
Association with work-related symptoms

	MUCOSAL			RESPIRATORY			MUSCULAR		
	Present	Absent	PValue	Present	Absent	PValue	Present	Absent	PValue
Number of respondents	(1255)	(2412)		(370)	(3297)		(267)	(3400)	
Nitrogen Oxide (NOx)									
Ventilation Supply Air	54.8	51.5	(.01)	53.6	52.5	[NS]	51.1	52.8	[NS]
Average on Floor	46.9	44.6	(.02)	45.6	45.4	[NS]	45.8	45.4	[NS]
Work sites	46.7	44.1	(.01)	45.4	44.9	[NS]	45.6	44.9	[NS]
Ozone (O_3)									
Ventilation Supply Air	5.4	5.6	[NS]	5.7	5.5	[NS]	5.3	5.5	[NS]
Average on Floor	2.5	2.7	[NS]	2.6	2.7	[NS]	2.3	2.7	(.05)
Work sites	2.4	2.6	(.01)	2.4	2.5	[NS]	2.2	2.6	(.01)
Volatile Organic Compounds (VOC)									
Ventilation Supply Air	121	134	(.001)	120	131	[NS]	124	130	[NS]
Average on Floor	128	140	(.001)	129	137	[NS]	123	137	(.01)
Work sites	132	144	(.001)	132	141	[NS]	123	141	(.001)
Formaldehyde									
Ventilation Supply Air	0.031	0.034	[NS]	0.032	0.033	[NS]	0.034	0.033	[NS]
Average on Floor	0.033	0.035	[NS]	0.035	0.034	[NS]	0.033	0.034	[NS]
Work sites	0.030	0.032	[NS]	0.031	0.031	[NS]	0.031	0.031	[NS]

Table 12 C: Assessment of potential confounding
Association of personal and work characteristics with airborne chemical contaminants

	GENDER			SMOKING		
	Male	Female	PValue	Never	Current	Ex-Smoker
Number of respondents	(1419)	(2248)		(1560)	(926)	(988)
Nitrogen Oxide (NOx)						
Ventilation Supply Air	48	55	(.0001)	52	56	52
Average on Floor	41	48	(.0001)	45	48	44
Work sites	40	48	(.0001)	44	48	43
Ozone (O_3)						
Ventilation Supply Air	6	5	(.005)	5	6	6
Average on Floor	3	3	[NS]	3	3	3
Work sites	3	3	[NS]	2	3	3
Volatile Organic Compounds (VOC)						
Ventilation Supply Air	116	138	(.0001)	126	135	131
Average on Floor	137	135	[NS]	136	135	138
Work sites	145	136	(.006)	138	141	141
Formaldehyde						
Ventilation Supply Air	0.03	0.03	[NS]	(0.03)	(0.03)	(0.04)
Average on Floor	0.04	0.03	(.0001)	(0.04)	(0.03)	(0.03)
Work sites	0.04	0.03	(.0001)	(0.03)	(0.03)	(0.03)

Table 12 D: Assessment of potential confounding
Association of personal and work characteristics with airborne chemical contaminants

	ATOPY			JOB CATEGORY			
	Atopic	Non-Atopic	PValue	Clerical	Management	Professional	PValue
Number of respondents	(1474)	(2029)		(1350)	(1345)	(780)	
Nitrogen Oxide (NOx)							
Ventilation Supply Air	54	53	[NS]	59	48	50	
Average on Floor	45	46	[NS]	52	41	41	
Work sites	45	45	[NS]	53	40	41	
Ozone (O_3)							
Ventilation Supply Air	5	6	[NS]	5	5	6	
Average on Floor	3	3	[NS]	3	3	3	
Work sites	3	2	[NS]	2	3	3	
Volatile Organic Compounds (VOC)							
Ventilation Supply Air	134	126	[NS]	140	135	103	
Average on Floor	141	133	(.01)	123	149	136	
Work sites	145	136	(.01)	125	148	151	
Formaldehyde							
Ventilation Supply Air	0.03	0.03	[NS]	0.03	0.04	0.03	
Average on Floor	0.03	0.03	[NS]	0.03	0.04	0.04	
Work sites	0.03	0.03	[NS]	0.03	0.03	0.04	

Table 13 A: Airborne bacteria and fungi - by study week

			GUV					
			OFF	ON	OFF	ON	OFF	ON
			WEEK					
Location in HVAC	Microbe	Medium	1	2	3	4	5	6
Outdoor Air								
	Fungi	SAB	49	30	5	9	9	18
		MEA	60	42	0	0	21	14
	Bacteria	ALL	90	100	33	12	75	134
		GRAM NEG	20	27	13	2	52	16
Ventilation Return air								
	Fungi	SAB	4	30	1	4	6	3
		MEA	2	159	2	1	1	5
	Bacteria	ALL	27	35	14	10	19	29
		GRAM NEG	24	17	7	7	8	13
Ventilation Supply Air								
	Fungi	SAB	2	5	4	5	4	2
		MEA	1	3	3	0	2	1
	Bacteria	ALL	76	61	17	12	27	29
		GRAM NEG	39	28	7	11	8	12
Work sites								
	Fungi	SAB	1	6	4	0	5	8
		MEA	1	0	0	0	0	1
	Bacteria	ALL	302	152	106	76	124	107
		GRAM NEG	196	55	43	36	67	41

Table 13 B: Airborne bacteria and fungi - by GUV experimental condition

			GUV	
Location in HVAC	Microbe	Medium	OFF	ON
Outdoor Air				
	Fungi	SAB	21	19
		MEA	27	19
	Bacteria	ALL	66	82
		GRAM NEG	28	15
Ventilation Return air				
	Fungi	SAB	4	13
		MEA	1	57
	Bacteria	ALL	20	25
		GRAM NEG	13	12
Ventilation Supply Air				
	Fungi	SAB	3	4
		MEA	2	1
	Bacteria	ALL	40	34
		GRAM NEG	18	17
Work sites				
	Fungi	SAB	3	5
		MEA	0	0
	Bacteria	ALL	82	112
		GRAM NEG	15	44

Table 13C: Correlation of airborne bacteria and fungi
with the environmental factors

In Ventilation System Location in HVAC	Microbe	Medium	**NO_x**	**Ozone**	**TVOC**	**Formaldehyde**
Supply Air						
	Fungi	SAB	**-0.24**	+0.14	-0.08	**+0.22**
		MEA	-0.10	+0.03	-0.04	-0.09
	Bacteria	ALL	-0.09	**-0.30**	-0.05	-0.12
		GRAM NEG	+0.01	**-0.24**	-0.06	+0.04
Return Air						
	Fungi	SAB	+0.07	+0.03	+0.03	+0.07
		MEA	**+0.15**	-0.07	+0.06	-0.01
	Bacteria	ALL	+0.11	**-0.15**	+0.08	-0.01
		GRAM NEG	**+0.18**	-0.13	+0.01	+0.03

Work site	Temperature	Humidity	Air Veloc.	CO_2	NO_x	O_3	TVOC	FORM
Fungi SAB	-0.10	+0.12	-0.03	-0.15	+0.06	**+0.38**	**+0.29**	-0.10
MEA	**-0.16**	**+0.21**	-0.08	-0.13	-0.10	+0.16	**+0.42**	-0.01
Bacteria ALL	**+0.66**	**+0.41**	**+0.23**	**+0.33**	**+0.25**	**-0.20**	**-0.45**	**-0.25**
GRAM NEG	**+0.66**	**+0.47**	**+0.19**	**+0.44**	**+0.17**	-0.12	-0.41	**-0.28**

Table 14 A: Association of symptoms with airborne concentrations of bacteria and fungi

			ANY			SYSTEMIC		
Location in HVAC	Microbe	Medium	Present	Absent	PValue	Present	Absent	PValue
Number of respondents			(1594)	(2073)		(850)	(2817)	
Ventilation Systems Supply Air								
	Fungi	SAB	5	5	[NS]	5	5	[NS]
		MEA	2	2	[NS]	1	2	[NS]
	Bacteria	ALL	52	45	(.001)	54	46	(.01)
		GRAM POS	27	24	[NS]	28	25	[NS]
Return Air								
	Fungi	SAB	10	10	[NS]	11	10	[NS]
		MEA	38	31	[NS]	40	32	[NS]
	Bacteria	ALL	33	31	[NS]	35	31	(.002)
		GRAM POS	22	19	(.003)	23	19	(.005)
Floors								
	Fungi	SAB	4	4	[NS]	4	4	[NS]
		MEA	1	1	[NS]	1	1	[NS]
	Bacteria	ALL	193	177	(.001)	201	179	(.001)
		GRAM POS	102	89	(.001)	107	91	(.001)
Work sites								
	Fungi	SAB	4	4	[NS]	4	4	[NS]
		MEA	0.2	0.2	[NS]	0.2	0.2	[NS]
	Bacteria	ALL	181	161	(.001)	189	164	(.001)
		GRAM POS	101	86	(.001)	103	89	(.001)

Table 14 B: Association of symptoms with airborne concentrations of bacteria and fungi

			MUCOSAL			RESPIRATORY			MUSCULAR		
Location in HVAC	Microbe	Medium	Present	Absent	PValue	Present	Absent	PValue	Present	Absent	PValue
Number of respondents			(1255)	(2412)		(370)	(3297)		(267)	(3400)	
Ventilation Systems											
Supply Air											
	Fungi	SAB	5	5	[NS]	4	4	[NS]	5	5	[NS]
		MEA	2	2	[NS]	2	2	[NS]	2	2	[NS]
	Bacteria	ALL	51	46	(.02)	52	48	[NS]	51	48	[NS]
		GRAM POS	26	25	[NS]	26	25	[NS]	30	25	[NS]
Return Air											
	Fungi	SAB	11	10	[NS]	11	10	[NS]	11	10	[NS]
		MEA	40	31	[NS]	45	33	[NS]	37	34	[NS]
	Bacteria	ALL	33	32	[NS]	33	32	[NS]	30	32	[NS]
		GRAM POS	22	20	[NS]	23	20	[NS]	21	20	[NS]
Floors											
	Fungi	SAB	4	4	[NS]	4	4	[NS]	3	4	[NS]
		MEA	1	0.6	[NS]	1	1	[NS]	0.6	0.6	[NS]
	Bacteria	ALL	190	181	[NS]	195	183	[NS]	211	182	(.004)
		GRAM POS	100	92	(.01)	105	94	(.03)	113	93	(.001)
Work sites											
	Fungi	SAB	4	4	[NS]	4	4	[NS]	3	4	(.05)
		MEA	0.3	0.3	[NS]	0.2	0.2	[NS]	0.3	0.2	[NS]
	Bacteria	ALL	177	166	(.03)	181	168	[NS]	197	168	(.005)
		GRAM POS	99	89	(.005)	104	91	(.02)	112	91	(.002)

Table 14 C: Association of exposure to airborne bacteria and fungi with potentially confounding personal and work characteristic

			GENDER			SMOKING		
Location in HVAC	Microbe	Medium	Male	Female	PValue	Never	Current	Ex-Smoker
Number of respondents			(1419)	(2248)		(1560)	(926)	(988)
Ventilation Systems								
Supply Air								
	Fungi	SAB	7	4	(.0001)	5	4	5
		MEA	2	1	(.0001)	2	1	2
	Bacteria	ALL	49	47	[NS]	47	50	49
		GRAM POS	27	25	[NS]	25	26	25
Return Air								
	Fungi	SAB	9	11	(.001)	11	11	9
		MEA	15	46	(.0001)	34	40	31
	Bacteria	ALL	34	31	(.01)	32	34	31
		GRAM POS	21	20	[NS]	21	21	19
Floors								
	Fungi	SAB	5	3	(.0001)	4	4	4
		MEA	0.5	0.6	[NS]	0.6	0.6	0.5
	Bacteria	ALL	174	190	(.001)	180	196	179
		GRAM POS	86	100	(.0001)	93	102	93
Work sites								
	Fungi	SAB	6	3	(.0001)	4	4	4
		MEA	0.2	0.2	[NS]	0.2	0.2	0.2
	Bacteria	ALL	157	178	(.0001)	167	181	164
		GRAM POS	85	97	(.0001)	90	99	90

Table 14 D: Association of exposure to airborne bacteria and fungi with potentially confounding personal and work characteristic

			ATOPY			JOB CATEGORY			
Location in HVAC	Microbe	Medium	Atopic	Non-Atopic	PValue	Clerical	Management	Professional	PValue
Number of respondents			(1474)	(2029)		(1350)	(1345)	(780)	
Ventilation Systems									
Supply Air									
	Fungi	SAB	5	5	[NS]	3	5	8	
		MEA	1.4	2	(.04)	1	2	3	
	Bacteria	ALL	47	49	[NS]	52	43	52	
		GRAM POS	27	25	[NS]	24	24	30	
Return Air									
	Fungi	SAB	9	11	(.02)	15	7	8	
		MEA	31	37	[NS]	64	22	5	
	Bacteria	ALL	34	31	(.04)	29	32	39	
		GRAM POS	22	20	(.04)	18	20	25	
Floors									
	Fungi	SAB	3	4	(.05)	2	3	7	
		MEA	0.6	0.6	[NS]	0.6	0.5	0.6	
	Bacteria	ALL	178	188	[NS]	218	158	171	
		GRAM POS	91	98	(.03)	119	80	81	
Work sites									
	Fungi	SAB	4	4	[NS]	2	4	8	
		MEA	0.3	0.2	(.04)	0.2	0.3	0.3	
	Bacteria	ALL	165	173	[NS]	204	147	152	
		GRAM POS	91	94	[NS]	113	79	82	

Table 15 A: Concentration of fungi and bacteria on surfaces within HVAC systems by week

			GUV							
			OFF	ON	OFF	ON	OFF	ON	OFF	ON
			WEEK							
Location in HVAC	Microbe	Medium	1	2	3	4	5	6	7	8
Cooling Coil										
	Fungi	SAB	0	1	4	0	1	0	12	0
		MEA	0	1	4	1	3	0		
	Bacteria	ALL	1	2	28	1	16	1	38	1
		GRAM POS	1	1	6	0	8	0		
Drip Pan										
	Fungi	SAB	0	2	3	1	2	1	16	0
		MEA	0	1	6	0	1	0		
	Bacteria	ALL	2	2	22	2	21	2	11	0
		GRAM POS	4	1	7	1	14	1		
Filters †										
	Fungi	SAB	0	5	4	2	2	1	10	16
		MEA	0	4	6	2	2	1		
	Bacteria	ALL	1	22	44	18	17	10	41	11
		GRAM POS	1	10	22	9	8	4		

†Filters - HVAC filters not exposed to the GUV light

Table 15 B: Concentration of fungi and bacteria on surfaces within HVAC systems by operation of GUV lights

			GUV - (all weeks)		GUV - (Week 5-6 only)	
Location in HVAC	Microbe	Medium	OFF	ON	OFF	ON
Cooling Coil						
	Fungi	SAB	4	0	2	0.1
		MEA	3	0.2	4	0.1
	Bacteria	ALL	42	1	22	1.1
		GRAM POS	5	0.1	7	0.1
Drip Pan						
	Fungi	SAB	5	0	3	0.7
		MEA	2	0.1	3	0.1
	Bacteria	ALL	16	1	22	1.8
		GRAM POS	8	0.6	10	0.5
Filters†						
	Fungi	SAB	4	6	3	2
		MEA	3	2	4	1
	Bacteria	ALL	26	15	31	14
		GRAM POS	10	8	15	6

†Filters - HVAC filters not exposed to the GUV light

Table 15C: Correlation of surface microbial contaminants with other environmental parameters

	Air Borne Microbial									
	Supply Air				Air Borne			Work Site		
Location in HVAC / Microbe / Medium	Fungi SAB	Fungi MEA	ALL Bacteria	GRAM POS.	Fungi SAB	Fungi MEA	ALL Bacteria	Temperature	Humidity	CO_2
Cooling Coil										
Fungi SAB	**0.30**	**0.33**	-0.18	-0.11	-0.13	-0.10	-0.10	0.04	**-0.37**	**-0.36**
Fungi MEA	**0.19**	**0.60**	-0.15	-0.08	-0.07	-0.08	-0.09	-0.08	-0.14	-0.11
Bacteria ALL	0.09	**0.34**	-0.22	-0.16	-0.09	-0.13	-0.16	-0.05	**-0.16**	**-0.23**
GRAM POS	0.10	**0.19**	-0.17	-0.12	-0.05	-0.10	-0.15	-0.08	0.03	-0.12
Drip Pan										
Fungi SAB	**0.19**	**0.30**	-0.22	-0.13	-0.10	-0.10	-0.15	**-0.16**	**-0.26**	**-0.25**
Fungi MEA	**0.20**	**0.74**	-0.09	-0.04	-0.07	-0.05	-0.03	0.01	**-0.24**	**-0.24**
Bacteria ALL	0.09	0.05	-0.16	-0.15	-0.10	-0.11	-0.08	-0.04	0.03	**-0.25**
GRAM POS	0.07	0.25	-0.03	-0.11	-0.05	-0.06	-0.07	0.02	0.14	0.02
Filters										
Fungi SAB	**0.27**	**0.23**	-0.24	-0.14	-0.12	-0.12	-0.22	-0.13	**-0.36**	-0.25
Fungi MEA	**0.39**	**0.43**	-0.16	-0.10	-0.11	-0.09	-0.11	-0.05	**-0.32**	**-0.30**
Bacteria ALL	-0.06	-0.03	-0.24	-0.19	-0.10	-0.14	-0.18	**-0.19**	-0.10	0.04
GRAM POS	-0.05	-0.02	-0.14	-0.07	-0.08	-0.10	-0.09	-0.10	**-0.18**	-0.07

Table 16 A: Association of work related symptoms with the concentration of bacteria and fungi on surfaces in HVAC systems

			ANY			SYSTEMIC			MUCOSAL		
Location in HVAC	Microbe	Medium	Present	Absent	PValue	Present	Absent	PValue	Present	Absent	PValue
Number of respondents			(1594)	(2073)		(850)	(8176)		(1255)	(2412)	
Cooling Coil											
	Fungi	SAB	1	1	[NS]	1	1	[NS]	1	1	[NS]
		MEA	2	2	[NS]	2	2	[NS]	2	2	[NS]
	Bacteria	ALL	11	10	[NS]	10	10	[NS]	11	10	[NS]
		GRAM POS	3	3	[NS]	3	3	[NS]	3	3	[NS]
Drip Pan											
	Fungi	SAB	2	2	[NS]	2	2	[NS]	2	2	[NS]
		MEA	2	2	[NS]	1	2	[NS]	2	2	[NS]
	Bacteria	ALL	12	12	[NS]	12	12	[NS]	11	12	[NS]
		GRAM POS	7	6	[NS]	6	6	[NS]	6	6	[NS]
Filters											
	Fungi	SAB	2	2	[NS]	2	2	(.04)	2	2	[NS]
		MEA	3	2	[NS]	2	3	[NS]	3	3	[NS]
	Bacteria	ALL	14	16	(.01)	14	16	[NS]	14	16	[NS]
		GRAM POS	8	9	(.04)	8	9	[NS]	8	9	[NS]

Table 16 B: Association of work related symptoms and concentration of bacteria and fungi on surfaces in HVAC systems

			RESPIRATORY			MUSCULAR		
Location in HVAC	Microbe	Medium	Present	Absent	PValue	Present	Absent	PValue
Number of respondents			(370)	(3297)		(267)	(3400)	
Cooling Coil								
	Fungi	SAB	1	1	[NS]	1	1	[NS]
		MEA	2	2	[NS]	2	2	[NS]
	Bacteria	ALL	11	10	[NS]	10	10	[NS]
		GRAM POS	3	3	[NS]	3	3	[NS]
Drip Pan								
	Fungi	SAB	1	2	[NS]	1	2	[NS]
		MEA	1	2	[NS]	1	2	[NS]
	Bacteria	ALL	15	12	[NS]	10	12	[NS]
		GRAM POS	7	6	[NS]	7	6	[NS]
Filters								
	Fungi	SAB	2	2	[NS]	2	2	(.04)
		MEA	2	2	[NS]	2	3	[NS]
	Bacteria	ALL	15	15	[NS]	14	15	(.02)
		GRAM POS	8	9	[NS]	8	9	(.04)

Table 16 C:Association of concentration of bacteria and fungi on surfaces in HVAC systems with potentially confounding personal and work characteristics.

			GENDER			SMOKING		
Location in HVAC	Microbe	Medium	Male	Female	PValue	Never	Current	Ex-Smoker
Number of respondents			(1419)	(2248)		(1560)	(926)	(988)
Cooling Coil								
	Fungi	SAB	1	1	[NS]	1	1	1
		MEA	2	2	[NS]	2	2	2
	Bacteria	ALL	11	10	[NS]	9	10	12
		GRAM POS	4	3	(.05)	3	3	4
Drip Pan								
	Fungi	SAB	2	2	[NS]	2	2	2
		MEA	2	2	[NS]	2	2	2
	Bacteria	ALL	13	11	(.03)	12	12	12
		GRAM POS	7	6	(.02)	6	6	7
Filters								
	Fungi	SAB	2	2	(.05)	2	2	3
		MEA	3	2	[NS]	3	2	3
	Bacteria	ALL	15	16	[NS]	16	15	15
		GRAM POS	9	8	[NS]	9	8	8

Table 16 D: Association of concentration of bacteria and fungi on surfaces in HVAC systems with potentially confounding personal and work characteristics.

			ATOPY			JOB CATEGORY*			
Location in HVAC	Microbe	Medium	Atopic	Non-Atopic	PValue	Clerical	Management	Professional	PValue
Number of respondents			(1474)	(2029)		(1350)	(1345)	(780)	
Cooling Coil									
	Fungi	SAB	1	1	[NS]	1	1	1	
		MEA	2	2	[NS]	2	2	2	
	Bacteria	ALL	10	11	[NS]	11	9	12	
		GRAM POS	3	3	[NS]	3	3	4	
Drip Pan									
	Fungi	SAB	2	2	[NS]	2	2	2	
		MEA	2	2	[NS]	1	2	2	
	Bacteria	ALL	13	12	[NS]	11	11	15	
		GRAM POS	6	6	[NS]	6	5	8	
Filters †									
	Fungi	SAB	2	2	[NS]	2	2	3	
		MEA	3	2	[NS]	2	3	3	
	Bacteria	ALL	16	15	[NS]	15	17	14	
		GRAM POS	9	9	[NS]	7	9	10	

* For 192 respondents baseline questionnaires not available

† Filters - main filters HVAC not exposed June 11, 2001June 11, 2001 to GUV

Table 16E: Environmental Conditions

		GUV OFF		GUV ON		P value*
		MEAN	(SD)	MEAN	(SD)	
Thermal Conditions - Worksites †						
Temperature (°C)		24.5	(1.7)	23.8	(1.4)	(<.001)
Relative Humidity (%)		36%	(13%)	32%	(11%)	(<.001)
Air Velocity (M/sec)		0.90	(0.44)	0.90	(0.33)	(NS)
HVAC Re-circulation (%)		79%	(4%)	82%	(6%)	(.02)
Chemical Parameters - Worksites ††						
CO2	At Worksites (ppm)	604	(104)	584	(83)	(.01)
TVOC's	At Worksites (mcg/m3)	134	(83)	163	(126)	(NS)
	In outdoor air (mcg/m3)	69	(112)	157	(199)	(NS)
Formaldehyde:	at Worksites (ppm)	0.030	(0.033)	0.039	(0.045)	(NS)
	In outdoor air (ppm)	0.026	(0.032)	0.041	(0.073)	(NS)
Ozone:	at Worksites (ppm)	3.0	(3.57)	2.2	(2.0)	(NS)
	In outdoor air (ppm)	8.8	(6.4)	11.1	(10.6)	(NS)
Nitrogen oxides:	at Worksites	41.9	(28.1)	38.1	(27.3)	(NS)
	In outdoor air	52.8	(36.1)	62.9	66.7	(NS)
Microbial Parameters †††						
Fungi (average CFU from MEA and Sabouraud)						
HVAC Surfaces: Filters (CFU/coupon)		6.5	(17)	6.4	(16)	(NS)
Drip Pans (CFU/coupon)		8.7	(33)	1.4	(4.3)	(<.001)
Cooling Coils (CFU/coupon)		6.4	(16)	0.7	(2.1)	(<.001)
HVAC Airborne:	Outdoor Air (CFU/M^3)	21	(35)	19	(28)	(NS)
	Return Air (CFU/M^3)	4	(6)	13	(32)	(.05)
	Supply Air (CFU/M^3)	3	(7)	3	(13)	(NS)
Worksite Airborne: (CFU/M^3)		3	(10)	4	(8)	(NS)

* P values for comparison of results:
For thermal, chemical and airborne microbial results – from T-tests.
For surface bacteriologic, and endotoxin results - from non-parametric Wilcoxon and Kruskal-Wallis tests.

† 2400 measures each for temperature, humidity, air velocity and CO_2

†† 318 measures each of TVOC, formaldehyde, ozone, and NO_2

††† 1240 measures each of bacteria and fungi

†††† 284 samples assayed for endotoxin

Table 16E: Environmental Conditions (continued)

	GUV OFF		GUV ON		P value*
	MEAN	(SD)	MEAN	(SD)	
Bacteria (CFU from blood agar plates)					
HVAC Surfaces: Filters (CFU/coupon)	22	(29)	16	(24)	(NS)
Drip Pans (CFU/coupon)	15	(24)	1.8	(2.5)	(.005)
Cooling Coils (CFU/coupon)	15	(22)	1.4	(3.8)	(<.001)
HVAC Airborne:Outdoor Air (CFU/M^3)	66	(43)	82	(84)	(NS)
Return Air (CFU/M^3)	20	(22)	25	(28)	(NS)
Supply Air (CFU/M^3)	40	(54)	34	(49)	(NS)
Worksite Airborne (CFU/M^3)	173	(206)	111	(89)	(NS)
	MEDIAN	(IQR)	MEDIAN	(IQR)	
Endotoxin *††††*					
Ventilation system surfaces – (EU/coupon)					
Filters	17	(6-48)	21	(10-42)	NS
Drip pans	32.5	(15-260)	3	(0-11)	(<.001)
Cooling Coils	8.0	(0-24)	0	(0-8)	(.007)
Airborne - (EU/M^3)					
Outdoor Air	0.23	(0.05-0.28)	0.15	(0-0.35)	NS
Worksites	0	(0-0.07)	0	(0-0.08)	NS
Ventilation system – Total	0.075	(0-0.23)	0.04	(0-0.165)	NS
Before Filter	0.16	(0-0.33)	0.08	(0-0.18)	NS
After Filters	0.07	(0-0.32)	0.0	(0-0.05)	(.06)
After Cooling Coils	0.065	(0-0.14)	0.02	(0-0.18)	NS

* P values for comparison of results:
For thermal, chemical and airborne microbial results – from T-tests.
For surface bacteriologic, and endotoxin results - from non-parametric Wilcoxon and Kruskal-Wallis tests.

† 2400 measures each for temperature, humidity, air velocity and CO_2

†† 318 measures each of TVOC, formaldehyde, ozone, and NO_2

††† 1240 measures each of bacteria and fungi

†††† 284 samples assayed for endotoxin

Table 16F: Organisms detected on surface (coupons) before and after GUV exposure

Organism	GUV OFF		GUV ON		Health Effects Associated	(REF)
	Coupons* with organisms	Mean CFU †	Coupons* with organisms	Mean CFU †		
Alternaria - alternata	11	15	2	2	Asthma	(19) (58) (57)
Cladosporium cladosporoides	11	12	1	1		
Yeasts	11	31	4	3		
Epicoccum nigrum	10	8	1	1	Sinusitis	
Aureobasidium pullulans	9	4	4	1	Hypersens pneumonitis Humidifier Fever	(56) (10) (21) (22)
Penicillium species	9	3	0	--	Asthma, sinusitis Hypersens, Pneumonitis	(12) (11) (56)
Aspergillus species	3	4	0	--	Respiratory symptoms Sinusitis	(63) (56)

* With GUV OFF all 12 coupons were "unexposed". With GUV ON only 8 coupons were exposed so-results from these 8 exposed coupons only are shown.

† Mean CFU per coupon on which at least one colony with the given species was identified.

Table 17: Matched Analysis of Work Related * Symptoms

	No Symptoms Either Condition	With Symptoms Both Conditions	Symptoms Only with GUV **OFF**	Symptoms Only with GUV **ON**	Odds Ratio GUV ON:OFF
	N (%)	N (%)	N (%)	N (%)	OR (95% CI)
Trial 1 (Aug-Nov)					
Any	196 (33%)	188 (32%)	105 (18%)	100 (17%)	0.95 (0.7, 1.3)
Systemic	317 (54%)	70 (12%)	95 (16%)	107 (18%)	1.13 (0.9, 1.5)
Mucosal	273 (46%)	125 (21%)	103 (17%)	88 (15%)	0.85 (0.6, 1.1)
Respiratory	550 (93%)	7 (1%)	16 (3%)	16 (3%)	1.0 (0.5, 2.0)
Musculo-skeletal	497 (84%)	13 (2%)	49 (8%)	30 (5%)	**0.61 (0.4, 0.96)**
Trial 2 (Dec-March)					
Any	205 (40%)	137 (27%)	98 (19%)	69 (14%)	**0.70 (0.5, 0.95)**
Systemic	312 (61%)	54 (11%)	73 (14%)	70 (14%)	0.96 (0.7, 1.3)
Mucosal	266 (52%)	106 (21%)	74 (14%)	63 (12%)	0.85 (0.6, 1.2)
Respiratory	461 (91%)	5 (1%)	24 (5%)	19 (4%)	0.79 (0.4, 1.4)
Musculo-skeletal	447 (88%)	15 (3%)	26 (5%)	21 (4%)	0.84 (0.5, 1.5)
Trial 3 (April-July)					
Any	213 (48%)	109 (24%)	80 (18%)	43 (10%)	**0.54 (0.4, 0.8)**
Systemic	298 (67%)	47 (11%)	55 (12%)	45 (10%)	0.82 (0.6, 1.2)
Mucosal	267 (60%)	70 (16%)	69 (16%)	39 (9%)	**0.56 (0.4, 0.8)**
Respiratory	418 (94%)	5 (1%)	16 (4%)	6 (1%)	**0.38 (0.1, 0.97)**
Musculo-skeletal	403 (91%)	9 (2%)	19 (4%)	14 (3%)	0.74 (0.4, 1.5)
Total for all trials					
Any	614 (40%)	434 (28%)	283 (18%)	212 (14%)	**0.74 (0.6, 0.9)**
Systemic	927 (60%)	171 (11%)	223 (14%)	222 (14%)	0.99 (0.8, 1.2)
Mucosal	806 (52%)	301 (20%)	246 (16%)	190 (12%)	**0.77 (0.6, 0.9)**
Respiratory	1429 (93%)	17 (1%)	56 (4%)	41 (3%)	0.73 (0.5, 1.1)
Musculo-skeletal	1347 (88%)	37 (2%)	94 (6%)	65 (4%)	**0.69 (0.5, 0.9)**
Before Work † *(Total for all trials)*					
Any	887 (58%)	190 (12%)	205 (13%)	242 (16%)	1.18 (0.98, 1.4)
Systemic	1306 (86%)	25 (2%)	86 (6%)	107 (7%)	1.24 (0.9, 1.6)
Mucosal	1045 (69%)	113 (7%)	162 (11%)	204 (13%)	**1.26 (1.03, 1.5)**
Respiratory	1415 (93%)	10 (1%)	47 (3%)	52 (3%)	1.11 (0.7, 1.6)
Musculo-skeletal	1345 (88%)	35 (2%)	68 (4%)	76 (5%)	1.12 (0.8, 1.6)

*Work related - defined as a symptom that began after arrival at work.

†Before work - defined as a symptom that began before arrival at work – considered not work related.

Table 17 A: Adjusted estimates of association of personel, work and environmental characteristics and **ANY** work related symptoms

Factors (comparison)	1- Personal and Work Characteristics*		2- Personal and work characteristics & environmental measures**	
	OR	(95% CI)	OR	(95% CI)
GUV ON	**0.84**	**(0.74, 0.96)**	0.87	(0.76, 1.01)
Building				
A vs M	**2.1**	**(1.6, 2.7)**	**2.0**	**(1.6, 2.6)**
R vs M	**1.5**	**(1.3, 1.9)**	**1.5**	**(1.2, 1.8)**
S vs M	**1.9**	**(1.5, 2.3)**	**2.0**	**(1.5, 2.5)**
Age (per increase of 10 years)	**0.9**	**(0.8, 0.98)**	**0.9**	**(0.8, 0.99)**
Gender - Female	**1.7**	**(1.5, 2.0)**	**1.7**	**(1.5, 2.0)**
Atopic History	**1.5**	**(1.3, 1.7)**	**1.5**	**(1.3, 1.7)**
Mean Temperature (per increase of 1°C)	--	--	**1.08**	**(1.03, 1.1)**
Mean Humidity (per increase of 10%)	--	--	**0.94**	**(0.88, 0.99)**
Peak CO_2 (per increase of 50 PPM)	--	--	**1.07**	**(1.03, 1.11)**

* Smoking, other medical illness, type of work not significant and dropped from both final models 1 and 2

** Work site, TVOC, Formaldehyde, NOx, ozone as well as air borne and surface bacteria and fungi - at work sites or in HVAC not significant and dropped from final model

Table 17 B: Adjusted estimates of association of personal, work and environmental characteristics and **systemic work related** symptoms

Factors (comparison)	1- Personal and Work Characteristics*		2- Personal and work characteristics & environmental measures**	
	OR	(95% CI)	OR	(95% CI)
GUV ON	0.9	(0.8, 1.1)	1.0	(0.9, 1.1)
Building				
A vs M	**2.0**	**(1.5, 2.7)**	**2.0**	**(1.4, 2.7)**
R vs M	**2.3**	**(1.8, 3.1)**	**2.2**	**(1.6, 2.9)**
S vs M	**2.1**	**(1.6, 2.7)**	**2.1**	**(1.5, 2.8)**
Job				
Clerical vs Professional	**0.7**	**(0.5, 0.9)**	**0.7**	**(0.5, 0.9)**
Management vs Professional	**0.9**	**(0.7, 1.1)**	**0.9**	**(0.7, 1.1)**
Age (Per increase of 10 years)	**0.9**	**(0.8, 1.02)**	**0.9**	**(0.8, 1.03)**
Gender - Female	**1.4**	**(1.2, 1.8)**	**1.4**	**(1.2, 1.7)**
Atopic History	**1.4**	**(1.2, 1.6)**	**1.4**	**(1.2, 1.7)**
Other Medical History	**1.3**	**(1.1, 1.6)**	**1.3**	**(1.1, 1.6)**
Mean Temperature (per increase of 1°C)	--	--	**1.1**	**(1.02, 1.14)**
Mean Humidity (per increase of 10%)	--	--	0.96	(0.9, 1.03)
Peak CO_2 (per increase of 50 PPM)	--	--	**1.06**	**(1.02, 1.1)**

* Smoking, other medical illness, type of work not significant and dropped from both final models 1 and 2

** Work site, TVOC, Formaldehyde, NOx, ozone as well as air borne and surface bacteria and fungi - at work sites or in HVAC not significant and dropped from final model

Table 17 C: Adjusted estimates of association of personal, work and environmental characteristics and **MUCOSAL** symptoms

Factors (comparison)	1- Personal and Work Characteristics*		2- Personal and work characteristics & environmental measures**	
	OR	(95% CI)	OR	(95% CI)
GUV ON	**0.9**	**(0.8, 1.04)**	**0.9**	**(0.8, 1.06)**
Building A vs M R vs M S vs M	 **2.0** **1.5** **1.7**	 **(1.5 2.6** **(1.2, 1.8)** **(1.3, 2.1)**	 **2.0** **1.4** **1.8**	 **(1.5, 2.6)** **(1.1, 1.8)** **(1.4, 2.3)**
Age (Per increase of 10 years)	0.97	(0.9, 1.06)	0.98	(0.9, 1.08)
Gender - Female	**1.6**	**(1.4, 1.9)**	**1.6**	**(1.3, 1.8)**
Atopic History	**1.4**	**(1.2, 1.7**	**1.4**	**(1.2, 1.6)**
Other Medical History Cigarettes - current smoker	1.3 1.2	(1.1 ,,1.5 (1.01, 1.4)	1.3 1.2	(1.1, 1.5) (1.01, 1.4)
Mean Temperature (per increase of 1°C)	--	--	1.06	(1.01, 1.1)
Mean Humidity (per increase of 10%)	--	--	**0.91**	**(0.86, 0.97)**
Peak CO_2 (per increase of 50 PPM)	--	--	**1.06**	**(1.02, 1.10)**

* Smoking, other medical illness, type of work not significant and dropped from both final models 1 and 2

** Work site, TVOC, Formaldehyde, NOx, ozone as well as air borne and surface bacteria and fungi - at work sites or in HVAC not significant and dropped from final model

Table 17 D: Adjusted estimates of association of personal, work and environmental characteristics and **Respiratory** symptoms

Factors (comparison)	1- Personal and Work Characteristics*		2- Personal and work characteristics & environmental measures**	
	OR	(95% CI)	OR	(95% CI)
GUV ON	0.85	(0.7,1.06)	**0.83**	**(0.7,1.06)**
Building				
A vs M	**2.0**	**(1.3,3.1)**	**2.2**	**(1.4,3.3)**
R vs M	**1.5**	**(1.0,2.2)**	**1.6**	**(1.1,2.4)**
S vs M	**1.4**	**(0.99,2.1)**	**1.8**	**(1.2,2.7)**
Age (Per increase of 10 years)	**1.1**	**(0.9,1.3)**	**1.1**	**(0.9,1.2)**
Gender - Female	1.9	(1.4,2.6)	1.9	(1.4,2.5)
Atopic History	2.1	(1.7,2.6)	2.1	(1.7,2.6)
Cigarettes - current smoker	1.5	(1.2,2.0)	1.5	(1.2,1.9)
Mean Temperature (per increase of 1°C)	--	--	1.02	(0.9,1.1)
Mean Humidity (per increase of 10%)	--	--	**0.9**	**(0.8,1.1)**
Peak CO_2 (per increase of 50 PPM)	--	--	**1.12**	**(1.02,1.22)**

* Other medical, job type not significant so dropped from final models 1 and 2

**Formaldehyde, NO_x, TVOC, Ozone at work site and all surface and air borne measures of bacteria and fungi at work sites and in HVAC DP BAC†

Table 17 E: Adjusted estimates of association of personal, work and environmental characteristics and **Muscular** symptoms

Factors (comparison)	1- Personal and Work Characteristics*		2- Personal and work characteristics & environmental measures**	
	OR	(95% CI)	OR	(95% CI)
GUV ON	**0.79**	**(0.6, 1.01)**	0.81	(0.6, 1.07)
Building				
A vs M	**1.7**	**(1.1, 2.6)**	**1.6**	**(1.03, 2.6)**
R vs M	1.1	(0.8, 1.6)	1.1	(0.7, 1.6)
S vs M	0.7	(0.5, 1.1)	0.7	(0.5, 1.2)
Age (Per increase of 10 years)	1.0	(0.9, 1.1)	1.0	(0.9, 11)
Gender - Female	**1.6**	**(1.2, 2.2)**	**1.6**	**(1.2, 2.2)**
Atopic History	1.3	(0.97, 1.6)	1.3	(0.99, 1.7)
Other Medical History	**1.8**	**(1.4, 2.4)**	**1.8**	**(1.4, 2.4)**
Mean Temperature (per increase of 1°C)	--	--	1.07	(0.97, 1.2)
Mean Humidity (per increase of 10%)	--	--	0.95	(0.85, 1.07)
Peak CO_2 (per increase of 50 PPM)	--	--	1.05	(0.99, 1.13)

* Job style and smoking not significant so dropped from final models 1 and 2

** Work site formaldehyde, Ozone, NO_x, TVOC, and all airborne plus surface bacterial and fungi measures at work sites and in HVAC **not** significant so dropped from final model 2

Table 18A - Within subject estimates of effect of GUV on Symptoms, adjusted for environmental covariates measured at work sites(From Matched multivariate analysis using conditional logistic regression)

	ANY	Systemic	Mucosal	Respiratory	Musculo-skeletal
	OR (95%CI)	OR (95%CI)	OR (95%CI)	OR (95%CI)	OR (95%CI)
GUV ON (vs OFF)	**0.8 (0.7,0.99)**	1.1 (0.9, 1.3)	**0.7 (0.6, 0.9)**	**0.6 (0.4, 0.9)**	0.8 (0.6, 1.1)
Higher worksite temp(per°C)	**1.1 (1.05,1.2)**	**1.1 (1.03,1.2)**	**1.1 (1.0, 1.1)**	1.0 (0.9, 1.1)	1.1 (0.9, 1.2)
Higher Humidity(Per10%)	0.9 (0.8,1.0)	1.0 (0.9, 1.1)	**0.9 (0.8, 1.0)**	1.0 (0.9, 1.1)	1.0 (0.9, 1.1)
Higher CO2 (per 50PPM)	**1.1 (1.02, 1.15)**	1.0 (1.0, 1.1)	**1.1 (1.0, 1.2)**	1.0 (1.0, 1.1)	1.0 (1.0, 1.1)
Within Subgroups * (Odds shown for GUV ON vs OFF)					
Atopic	**0.7 (0.5,0.9)**	1.1 (0.8, 1.5)	**0.6 (0.5, 0.8)**	0.6 (0.3, 1.1)	0.7 (0.4, 1.1)
Non Atopic	0.9 (0.7, 1.2)	1.0 (0.8, 1.3)	0.8 (0.6, 1.1)	0.6 (0.3, 1.2)	0.9 (0.6, 1.4)
Females	**0.7 (0.5, 0.9)**	1.0 (0.8, 1.2)	**0.6 (0.5, 0.8)**	0.6 (0.3, 1.01)	0.8 (0.5, 1.1)
Males	1.1 (0.8, 1.5)	1.2 (0.9, 1.7)	1.0 (0.7, 1.3)	0.5 (0.2, 0.9)	0.8 (0.5, 1.5)
Smoking					
Current Smoker	1.1 (0.8, 1.6)	1.3 (0.9, 1.9)	0.9 (0.7, 1.4)	0.7 (0.3, 1.5)	1.5 (0.8, 2.7)
Ex-Smoker	0.7 (0.5, 1.01)	1.0 (0.7, 1.4)	**0.7 (0.5, 0.9)**	0.7 (0.3, 1.6)	0.7 (0.4, 1.3)
Never Smoked	0.8 (0.6, 1.01)	1.0 (0.8, 1.4)	**0.7 (0.5, 0.9)**	**0.4 (0.4, 0.9)**	**0.5 (0.3, 0.9)**

*Estimates of effect for GUV ON vs OFF within subgroups are all adjusted for temperature, humidity and CO^2 at worksites.

†The following environmental parameters, when added to a model including GUV, temperature, humidity and CO^2 were not significantly associated with symptoms: worksite NO_2, TVOC, Formaldehyde, Ozone, and airborne fungi or bacteria, HVAC surface bacteria and fungi.

Table 18 B: Within subject estimate of effect of GUV on work related symptoms by trial (all estimates adjusted for thermal conditions (T, RH, CO2) at work sites)

	ANY		SYSTEMIC	
	OR	(95% CI)	OR	(95% CI)
Overall	**0.8**	**(0.7, 0.99)**	0.9	(0.8,1.1)
(1371) Trial 1 (1199) Trial 2 (1097) Trial 3	0.7 0.8 **0.6**	(0.4, 1.3) (0.5, 1.2) **(0.4, 1.0)**	0.8 0.9 0.7	(0.5,1.4) (0.5,1.4) (0.4,1.3)
(2296) Trial 2 and 3	**0.7**	**(0.6, 0.9)**	0.9	(0.7,1.2)

	MUCOSAL		RESPIRATORY		MUSCULAR - SKELETAL	
	OR	(95% CI)	OR	(95% CI)	OR	(95% CI)
Overall	**0.86**	**(0.7,1.02)**	**0.81**	**(0.6,1.06)**	0.8	(0.6, 1.1)
Trial 1 Trial 2 Trial 3	0.7 0.8 0.78	**(0.4,1.1)** (0.5,1.3) (0.5,1.3)	0.4 1.1 0.9	(0.2,0.8) (0.6,2.2) (0.4,1.7)	0.4 0.8 1.0	(0.2, 1.1) (0.4, 1.6) (0.4, 2.7)
Trial 2 and 3	**0.8**	**(0.6,0.95)**	0.87	(0.6,1.3)	0.8	(0.5, 1.2)

Memorandum

Date: May 23, 2002

From: Adele M. Childress, Ph.D., Program Official
Office of Extramural Programs, NIOSH, E-74

Subject: Final Report Submitted for Entry into NTIS for Grant 5 R01 OH003693-02.

To: William D. Bennett
Data Systems Team, Information Resources Branch, EID, NIOSH, P03/C18

The attached final report has been received from the principal investigator on the subject NIOSH grant. If this document is forwarded to the National Technical Information Service, please let us know when a document number is known so that we can inform anyone who inquires about this final report.

Any publications that are included with this report are highlighted on the list below.

Attachment
cc: Sherri Diana, EID, P03/C13

List of Publications

Popa J, Menzies D, Milton D, Rand T: Effect of Germicidal Ultravioloet (GUV) Lights Within HVAC Systems of Office Buildings on Environmental Conditions in Workers Health and Well Being. American Journal Respiratory and Critical Care Medicine, 165:8
Menzies D, Popa J, Handley JA, Rand T, Milton D: Impact of Germicidal Ultraviolet Lights Installed in the Ventilation Systems of Office Buildings on Workers Health and Well Being. Submitted, New England Journal of Medicine

Publications

Popa J, Menzies D, Milton D, Rand T: Effect of Germicidal Ultravioloet (GUV) Lights Within HVAC Systems of Office Buildings on Environmental Conditions in Workers Health and Well Being. American Journal Respiratory and Critical Care Medicine, 165:8

Menzies D, Popa J, Handley JA, Rand T, Milton D: Impact of Germicidal Ultraviolet Lights Installed in the Ventilation Systems of Office Buildings on Workers Health and Well Being. Submitted, New England Journal of Medicine

Title:	Ultraviolet Lights In HVAC Systems-Effect On Health Well and Being
Investigator:	Richard Menzies, M.D.
Affiliation:	McGill University
City & State:	Montreal, QC
Telephone:	(514) 398-8122
Award Number:	5 R01 OH003693-02
Start & End Date:	9/30/1999–9/29/2001
Total Project Cost:	$48,935
Program Area:	Indoor Environment
Key Words:	airborne contaminants, intervention, indoor air quality

Abstract:

Background

Microbial contamination in ventilation systems of modern office buildings has been documented to result in illness among workers. This study was conducted to test whether germicidal ultraviolet (GUV) irradiation of drip pans and cooling coils within ventilation systems of office buildings would reduce occupants work-related symptoms.

Methods

A double-blind multiple crossover design was used. Within three consecutive trials, GUV was off for 12 consecutive weeks, then on for the next four weeks. In the last week with GUV off, or on, workers completed self-administered questionnaires regarding presence of symptoms and environmental satisfaction. Simultaneously, thermal, chemical and microbial parameters including endotoxin were measured outdoors, within ventilation systems and in occupied spaces.

Results

Operation of GUV lights resulted in significant reduction of microbial and endotoxin concentrations on irradiated surfaces within the ventilation systems, although airborne concentrations of these substances were unchanged. The 771 participants, who appeared to remain blinded, reported significantly fewer work-related overall (within-subject adjusted odds ratio 0.8: [95% confidence interval (0.7, 0.99)], respiratory [0.6, (0.4, 0.9)] and mucosal [0.7; (0.6, 0.9)] symptoms, when the GUV were operating. Reduction of mucosal symptoms was greatest among atopic workers [0.6, (0.5, 0.8)], and never-smokers [0.7, (0.5, 0.9)]. Never-smokers also had greater reduction of respiratory [0.4, (0.2, 0.9)], and musculo-skeletal symptoms [0.5 (0.3, 0.9)], with GUV on.

Conclusions

GUV was safe, effective in reducing ventilation system surface microbial contamination as well as endotoxin, and associated with significant reduction in respirator, mucosal and overall symptoms. This effect was greater among workers at risk for allergic or hypersensitivity response to microbial antigens.