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The effects of electric fields on charged molecules and particles in individual microenvironments

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Abstract

Measurements of small air ion concentrations, electrostatic potential and AC electric field strengths were taken in an office setting to investigate the link between electric fields and charged molecule and particle concentrations in individual microenvironments. The results obtained indicate that the electromagnetic environments individuals can be exposed to whilst indoors can often bear little resemblance to those experienced outdoors in nature, and that many individuals may spend large periods of their time in "Faraday cage"-like conditions exposed to inappropriate levels and types of electric fields that can reduce localised concentrations of biologically essential and microbiocidal small air ions. Such conditions may escalate their risk of infection from airborne contaminants, including microbes, whilst increasing localised surface contamination. The degree of "electro-pollution" that individuals are exposed to was shown to be influenced by the type of microenvironment they occupy, with it being possible for very different types of microenvironment to exist within the same room.

It is suggested that adopting suitable electromagnetic hygiene/productivity guidelines that seek to replicate the beneficial effects created by natural environments may greatly mitigate such problems.

Keywords: Air ions; Electric fields; Microbes; Charged ultrafine particles

1. Introduction

The nature of the electromagnetic environments that most humans are now regularly exposed to has changed dramatically over the past century and often bears little resemblance to those created in nature. In particular, the increased masking/shielding of individuals from beneficial types of natural electromagnetic phenomena, the presence of synthetic materials that can gain strong charge and increased exposures to inappropriate electric field levels and polarities have greatly altered the electromagnetic nature of the microenvironments many individuals usually occupy.

Considerable electrostatic and alternating current (AC) electric fields, poor specification of materials and relative humidity (RH)/dew-point temperature levels, "Faraday cage"-like conditions plus failure to appropriately ground conductive objects

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(including humans), can create highly localised incidents of electromagnetic pollution capable of significantly reducing concentrations of biologically vital and microbiocidal small air ions (SAI), such as charged oxygen. Evidence (Ghaly and Teplitz, 2004; Altmann, 1974, 1969; Barron and Dreher, 1964; Lang, 1972a, b; Kritzinger, 1957) indicates that if the body is exposed to poorly designed electromagnetic environments it is more prone to demonstrate reduced activity levels, oxygen uptake and performance, whilst potentially increasing stress and likelihood of succumbing to degenerative illnesses. Research by Cohen et al. (1998) also suggests that in certain instances electromagnetic pollution can increase the body's alveolar burden of potentially harmful particulate matter by enhancing retention rates of contaminants when inhaled.

2. Background

2.1. Charged molecules (small air ions)

These are also known as fast air ions or cluster ions and are charged gaseous molecules that can possess complex geometries. Negative cluster ions are 0.36–0.85 nm in size with mobilities of 1.3–3.2 $cm^2\,V^{-1}\,s^{-1}$, whilst positive cluster ions are 0.85–1.6 nm in size with mobilities of 0.5–1.3 $cm^2\,V^{-1}\,s^{-1}$. Their average lifetime is between 50 and 250 s, depending on the aerosol content of the air. They have a complicated and varied chemical nature, usually independent of nearby aerosols, which normally changes several times a second. They each possess a single elementary charge of 1.6×10^{-19} C, and their direction of movement is greatly influenced by electric fields, with a large degree of attraction being shown towards opposite or ''mirror'' charges. They are repelled by charges of similar polarity and attracted to those of opposite polarity. Both small negative and small positive air ions have been shown to be microbiocidal, further details are given in Jamieson and Jamieson (2006). Whilst prolonged long-term exposure to unipolar negative ionisation appears capable of shortening life-span (Kellogg and Yost, 1986), experiments by Goldstein and Arshavskaya (1997), indicate that charged oxygen appears vital to life and that animals can die within weeks of being completely deprived of this form of SAI.

2.2. Charged particles

2.2.1. Intermediate and large air ions

These are solid or liquid charged aerosol particles/ultrafine particles. Both long- and short-term exposures to elevated concentrations of such particles are associated with raised admissions to hospital and premature death. At present, they are seldom measured in air pollution or air ion studies. Intermediate air ions are 1.6–7.4 nm in size with mobilities of 0.034–0.5 $cm^2\,V^{-1}\,s^{-1}$ and are normally present in far lower numbers than large air ions. There are two main types of large air ions (also known as slow ions because of their lower mobility). Light large air ions are 7.4–22 nm in size and have mobilities of 0.0042–0.034 $cm^2\,V^{-1}\,s^{-1}$, whilst heavy large air ions (charged Aitken particles) are 22–79 nm in size and have mobilities of 0.00087–0.0042 $cm^2\,V^{-1}\,s^{-1}$. Both follow air-stream flows like uncharged aerosols unless very large electric fields are present. Their chemical nature is similar to that of uncharged aerosols, and they can possess more than one elementary charge. Increasing charge increases their likelihood of deposition on oppositely charged surfaces (Dolezalek, 1985).

2.2.2. Charged ultrafine particles

These are charged particles of particulate matter $<0.1\,\mu m$ (100 nm) in size and are classed as $PM_{0.1}$. Ultrafine particles can induce greater cytotoxicity and epithelial damage than fine particles composed of similar materials, partially due to their far greater surface area per given mass, a factor which can also increase their ability to carry toxic co-pollutants.

2.2.3. Charged fine particles

These are charged particles from 0.1 to $<2.5\,\mu m$ in size. Electrical effects can predominate as a transport and deposition mechanism for particles $\leqslant 1\,\mu m$ in size (McMurry and Rader, 1985).

Particles $\leqslant 1\,\mu m$ in size can greatly exacerbate health problems. In excess of 90% of PM_{10} particles can be in this size range (Rao et al., 2005). Such particles can be composed of dust, lint, tobacco smoke, diesel soot, fresh combustion particles, ozone and terpene-formed aerosols, nitrates and sulphates, heavy metals, mineral fines, respiratory droplets, skin squamae and a variety of other substances. Airborne biological contaminants in this size range include allergens, bacteria, fungal spores and viruses. The greater the charge they possess the higher the likelihood of their deposition.

2.3. Alternating current (AC) electric fields

AC fields are measured in volts per metre ($V\,m^{-1}$) and can be created by high-voltage power lines, electrical wiring and items of electrical equipment. They increase in strength as voltage is raised. Whilst electrical equipment has to be switched on before magnetic fields are registered, electric fields can be detected even if the equipment is switched off but not unplugged from the mains power socket. Frequencies within the range being measured in the present case study (10–2000 Hz $\pm$ 3 dB) can be biologically active (Lang, 1972a, b).

2.4. Electrostatic fields

Under natural fair weather conditions an electrostatic vertical potential gradient of 100–200 $V\,m^{-1}$ can exist near the ground, with the positively charged ionosphere acting as an anode and the earth as a cathode causing a transfer of negative ions from the earth to the sky and positive ions from the ionosphere to the earth along electrostatic lines of force. When poor weather conditions, such as thunderstorms, arise this situation is reversed and triboelectric inversion occurs, with the air below positively charged clouds becoming more negatively charged than the ground underneath, causing the vertical electric current to flow in the opposite direction—in such situations fields of 3000–10,000 $V\,m^{-1}$ can be encountered (Sulman, 1980; Sheppard and Eisenbud, 1977; Bach, 1967). Distorted current flow and higher fields than this can however be created indoors, particularly when conditions of low RH or dew-point temperature exist.

2.5. Standards and guidelines

2.5.1. Standards regarding air ion concentrations

The Ministry of Health of the Russian Federation's 'Sanitary and Epidemiologial Norms' guidelines (SanPiN, 2003) stipulate mandatory maximum and minimum levels of bipolar air ion concentrations in the computer workplace. SAI concentrations must not be <600 negative (NSAI) and 400 positive small air ions (PSAI) cm^{-3}, and levels must not exceed 50,000 NSAI or PSAI cm^{-3}. These regulations state that optimum recommended ion concentrations to reduce fatigue and enhance capacity for work are 3000–5000 NSAI and 1500–3000 PSAI cm^{-3}. These air ion concentrations are also required to have a factor of unipolarity Y, with a minimum and maximum ratio of positive to negative ions being given by $0.4 \leqslant Y \leqslant 1.0$.

Though the recommended optimal and mandatory maximum small air ion concentrations suggested by the Russian SanPiN guidelines are far higher than often found in nature, such levels can help to reduce incidences of excess charge.

Though no formal legislation appears to exist in the western world, in the USA, the Federal Aviation Authority (F.A.A.) acknowledged that both very low SAI concentrations, and high ion concentrations with a factor of unipolarity with a strong imbalance of positive air ions can produce detrimental effects (Rosenberg, 1972).

2.5.2. Standards regarding AC fields

Whilst International Commission on Non-Ionising Radiation Protection (ICNIRP, 1998) guidelines stipulate that 60 Hz AC electric fields encountered by members of the general public should be $\leqslant 4200\,V\,m^{-1}$, Russian and Swedish guidelines for computer users advocate AC field levels of $\leqslant 25$ and $\leqslant 10\,V\,m^{-1}$, respectively, at 0.5 m from computers in the ELF 5–2000 Hz (Band I) range (SanPiN, 2003; TCO, 2003).

AC fields may partially influence ion deposition, coagulation rates along with localised contamination levels if they are sufficiently strong.

2.5.3. Standards regarding electrostatic fields

The Russian guidelines for computer users stipulate that the electrostatic potential at 0.5 m from computers should be $\leqslant 500$ V (SanPiN, 2003), whilst the Swedish guidelines specify a maximum surface potential of ± 500 V (TCO, 2003).

However, whilst such standards can be of great use in reducing incidences of electrostatic discharge, induced charge and surface contamination, they do not take into account the fact that the body appears to function best when exposed to constant vertical electrical fields and that exposure to distorted field regimes and "Faraday-cage" conditions may actually prove detrimental to health (Jamieson et al., 2006).

2.6. Hypothesis and scientific evidence

The presence of inappropriate levels and types of electric fields in individual microenvironments may greatly reduce localised concentrations of SAI, whilst increasing localised concentrations of charged ultrafine particles, such as large air ions (LAI).

The possible presence of high concentrations of LAI in the room being assessed for the case study is indicated by the fact that the air is highly conductive whilst having low concentrations of SAI—large air ions normally add little to the air's conductivity apart from when SAI are absent (Wait and Parkinson, 1951). Note: though LAI are categorised as being $\leqslant 79$ nm in size, electrical effects can predominate as a transportation and deposition mechanism for ultrafine particles and fine particles up to 1 μm in size.

3. Case study

Measurements of SAI concentrations, electrostatic potential and AC electric field strengths were taken in an office environment. It was intended that this work would indicate the link between inappropriate levels and types of electric fields, low concentrations of SAI and high concentrations of LAI, whilst also showing how the electromagnetic environments individuals can be exposed to when indoors often have little resemblance to that generally experienced in nature. This work was also undertaken in conjunction with a critical literature review.

3.1. Methodology

3.1.1. Room description

The office studied was a computer work-suite, with both natural ventilation and air conditioning, which is situated in a reinforced-concrete building in Bergen, Norway. Data were collected on separate days in July 2005 whilst the main workstation was occupied. A listing of the materials and finishes found in this room are given in Table 1, and a plan, section and photograph of it are shown in Fig. 1.

Table 1
Materials and finishes specifications

Items	Comments
Room dimensions	2.4 m × 4.4 m × 2.8 m
Ceiling	Paint finish on plasterboard
Cabinets	2 No. metal construction
Chairs (synthetic covering)	2 No.
Cathode ray tube (CRT) monitors with hard drives	5 No. plus grounded laptop
Timber door	1 No. with paint finish
Flooring	Vinyl
Plastic letter trays	3 No.
Main lighting—fluorescent and incandescent	Not used during measurements period as low light levels preferred by normal occupants
Anglepoise desk-light	1 No. used during measurements
Oscillating desk fan	1 No. used during measurements
Printer	1 No.
Walls	Paint finish on plastered block
Windows	Double-glazed external window with blinds and curtains. Observation window from indoor passageway
Heating/ventilation	Natural, fan and air-conditioning
Work-stations	2 No. with wood veneer finish and metal framework
Telephone	1 No. DECT digital phone unit
Miscellaneous (including personal items and paraphernalia)	Plastic-finish Lever Arch files, plastic filing-pockets and cardboard magazine files on shelving

3.1.2. Measurement procedures

For the vertical sections created through the room used for this work, continuous measurements were taken at 0.1 m increments from a height of 2.1 m to a height of 0.1 m, with further readings being taken 0.05 m from the finished floor level in each instance. These were taken at 0.35 m intervals along a line that passed diagonally directly through the sitting area occupied by the main computer operative and the 0.25 m horizontal grid-work used for measuring the horizontal sections. Two hundred and seventy-six individual sampling points were used for constructing the vertical isopleths of this room, and 202 sampling points for the creation of the horizontal isopleths. As the measurements were taken at grid points, it was possible to miss maximum and minimum readings that appeared off-grid.

3.1.2.1. Ion measurements. The concentrations of SAI present were measured using an air ion counter by Alpha Lab Inc., which had accuracy guaranteed to $\pm 25\%$ for ions in this range (mobility $>0.8\,\mathrm{cm^2\,V^{-1}\,s^{-1}}$) though the unit itself is calibrated to an accuracy of $\pm 5\%$. The lowest characterisable mobility for the unit is $0.5\,\mathrm{cm^2\,V^{-1}\,s^{-1}}$. It had been intended to extend this work to include the measurement of large air ions, but this part of the project was postponed due to lack of equipment/funding.

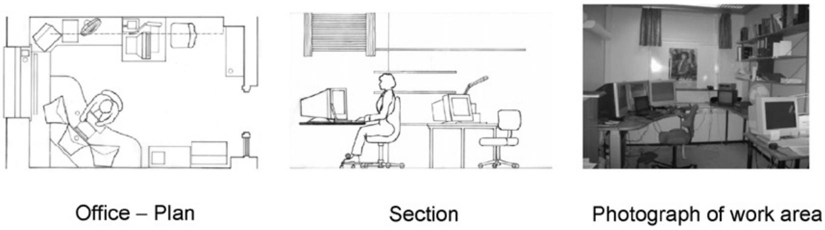

Fig. 1. Case study: office.

Whilst undertaking measurements of NSAI concentrations, a period of between 10 and 15 s was allowed between switching grid-points before the maximum and minimum concentrations were logged at each location. These were each taken over a minimum period of 15 s and up to a maximum period of 30 s in cases where large fluctuations in values were noted. When these occurred, due to the presence of clouds of high or low ion concentrations in sections of poorly mixed air in individual microenvironments, the most regular maximum and minimum SAI concentrations noted were logged. Due to time limitations, it was not possible to create isopleths of PSAI concentrations, though spot measurements, and additional studies by the authors (Jamieson et al., 2005), indicate that the concentrations and distribution of this type of ion throughout the room would have been very similar to that found with the NSAI.

3.1.2.2. AC electric field measurements. Single measurements were undertaken at each grid-point using an EMFields Professional AC Electric and Magnetic Field Metre by Perspective Scientific Ltd., which has an expected accuracy of $>\pm10\%$ in the 50–500 Hz range and can measure from 0 to 1999 V m^{-1}, RMS, with a frequency response of 10–2000 Hz $\pm$ 3 dB. The metre is calibrated for hand-held use and provides a strong indication of the *E*-fields a person would experience at the location being measured. A truly accurate reading cannot be achieved as perturbed electric fields vary greatly due to the presence of conductive objects, including the instrument's operator in the environment being assessed.

3.1.2.3. Electrostatic potential measurements. Measurements of electrostatic potential (D) were taken in the X-, Y- and Z-axis at each grid-point using a JCI Static Monitor 140F by John Chubb Instrumentation to allow "3D-measurements" to be obtained. This was undertaken using the following formula:

$$D = \sqrt{X^2 + Y^2 + Z^2}.$$

The monitor used to measure the electrostatic potential had a 1 and 10 V resolution, a response of -3 dB at $\approx$400 Hz, and an accuracy $\pm2\%$ full-scale deflection.

3.1.2.4. Additional measurements. The number and type of measurements taken were primarily determined by equipment availability and access periods. Spot checks of temperature and relative humidity (RH) variations were taken throughout the course of the measurements. Isopleths were also created of the light levels measured during the course of the assessment period but are omitted from the current discussion. It was not possible to measure wind speeds or air pressure variations.

4. Results and discussion

Access periods limited the amount of data that could be collected and the number of complete data sets that could be formed. The results shown below in Table 2 were taken on two separate days when the laptop computer used on the main workstation was grounded. There was a large variation between the temperature and RH/dew-point temperature levels recorded indoors on these days but the measurements taken indicated that low levels of SAI were normally detected in areas where high electric fields occurred. Access periods limited the amount of data that could be collected and the number of complete data sets that could be formed.

4.1. Air ion concentrations

4.1.1. Vertical section

Analysis of the data taken at 276 sampling points for this section determined an arithmetic mean of 361 negative small air ions cm^{-3} (SNAI cm^{-3}), with

Table 2
Synopsis of results

Location	Measurements	Sampling points	Arithmetic mean	S.D.	Median	Minimum	Maximum
Vertical plane (Section A16-L5)	Average negative air ions cm^{-3a}	276	361	263	302.5	10	930
	Lower bound	276	288	257	230	0	870
	Upper bound	276	434	279	420	20	1070
	AC fields ($V\,m^{-1}$)[a]	276	19.5	49.0	4.5	1.0	452.0
	Electrostatic potential (V)[b]	276	104.9	495.2	27.9	2.2	7705.8
Horizontal plane at 1.10 m (Grids 0A-18L)	Average negative air ions cm^{-3b}	202	433	205	435	35	910
	Lower bound	202	372	204	375	10	960
	Upper bound	202	494	224	500	50	1060

[a] 19.3 ± 0.3 °C, with 66.7 ± 4.2% RH (dew-point temperature 12.96 °C).
[b] 26.8 ± 0.6 °C, 29.1 ± 3.6% RH (dew-point temperature 7.35 °C).

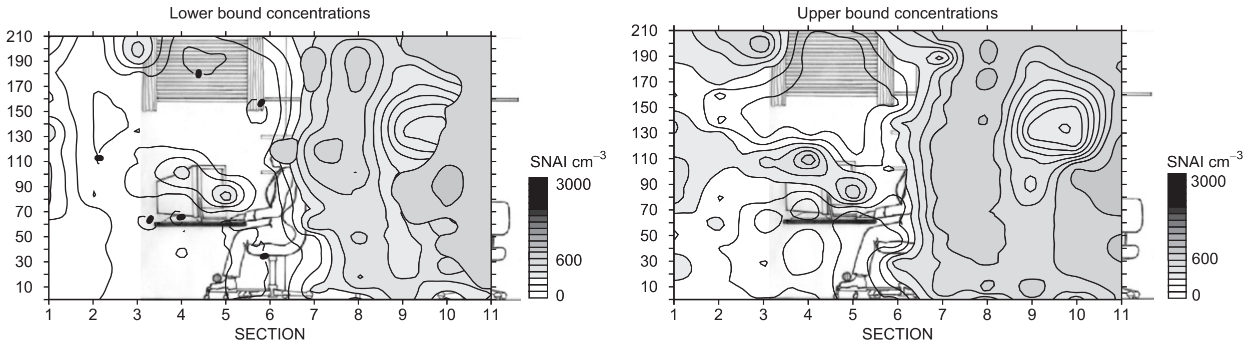

Fig. 2. Vertical section showing concentrations of small negative air ions cm^{-3}.

average maximum and minimum values of 930 and 10 SNAI cm^{-3} being found. The lowest actual value detected in several areas was 0 SNAI cm^{-3} and the highest value 1070 SNAI cm^{-3}. The isopleths created from these measurements are shown in Fig. 2, which indicates that very low SAI concentrations were found in the microenvironments where the operative was sitting and where high electric fields occurred. In the personal breathing zone of the computer operator concentrations of 10–280 SNAI cm^{-3} were detected, whilst the influence of inappropriate types and levels of fields on SAI concentrations was also clearly seen for the anglepoise desk-light located on grid-line 10 where concentrations of 0–40 SNAI cm^{-3} were registered.

4.1.2. Horizontal section

Measurements were taken to create horizontal isopleths at a height of 1.1 m when the laptop computer on the main workstation was both grounded and ungrounded, though only those taken whilst it was grounded are shown in Fig. 3. On the day these measurements were taken the weather was far warmer than when the data for the vertical ion isopleths were collected, see Table 2, necessitating the continual use of an oscillating fan unit within the room, and natural ventilation provided by an opened high-level external window, in addition to the sporadically operating air conditioning unit.

Analysis of the data taken at the 202 sampling points used determined an arithmetic mean of 433 SNAI cm^{-3} for this section, with average maximum and minimum values of 910 and 35 SNAI cm^{-3}, respectively, being found. The lowest actual value detected was 10 SNAI cm^{-3} and the highest value 1060 SNAI cm^{-3}. The isopleths created from these measurements are shown in Fig. 3.

The measurements taken clearly indicate that concentrations of negative small air ions measured in the room used for the case study were well below the minimum acceptable level of 600 SNAI cm^{-3} given in the Russian SanPiN (2003) guidelines. As

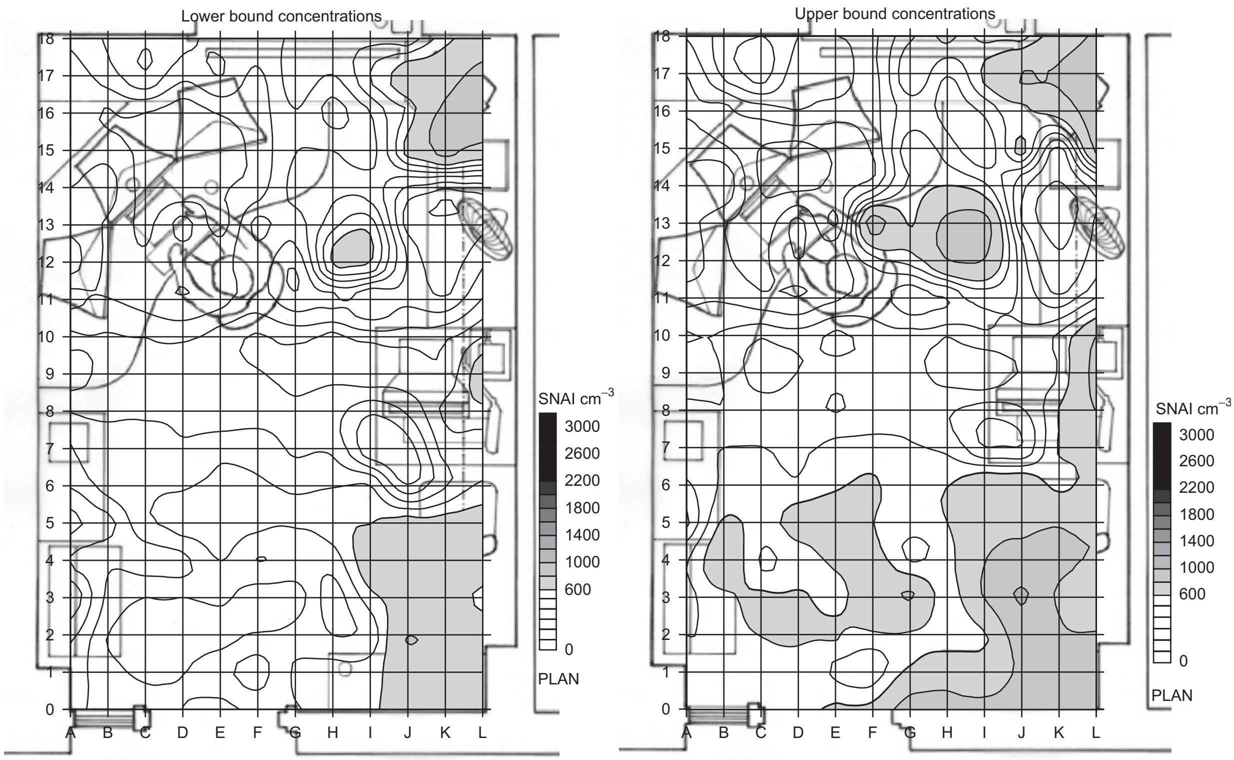

Fig. 3. Plan section at height of 1.1 m showing concentrations of small negative air ions cm^{-3}.

very low concentrations of SAI are detected in the main work area, the concentrations of charged oxygen molecules must also have been greatly reduced.

It is suggested that the presence of inappropriate levels and types of electric fields in individual microenvironments within the room may greatly increase both the localized concentrations of charged sub-micron particles, such as large air ions, in those areas and the risk of contamination and respiratory problems.

4.2. AC electric fields

4.2.1. Vertical section

Natural vertical atmospheric fields are often almost completely prohibited from entering many modern buildings due to the type of construction methods used. Even if such fields had been able to penetrate the room being measured; they would often have been masked by the high levels of AC electric and electrostatic fields present that would have distorted the direction of current flow.

This section was measured on the same day as the vertical isopleths showing NSAI concentrations. The arithmetic mean for the AC fields measured at the 276 sampling points was 20.9 V m^{-1}, with actual maximum and minimum values of 452.0 and 1.0 V m^{-1}, respectively, being obtained. The isopleth created from the data collected is shown in Fig. 4, and when studied in conjunction with Fig. 2 visually demonstrates the link between high AC electrical fields and low SAI concentrations.

Though the AC fields emitted from the monitors complied with both Russian and Swedish guidelines, the fields emitted by the junction box on the workstation and the anglepoise desk-light exceeded those suggested guidance levels for computers, thereby preventing the creation of low-field conditions in those microenvironments and creating high local concentrations of charged sub-micron particulates.

4.3. Electrostatic potential

4.3.1. Vertical section

This was measured on the same day as the ion measurements taken for the horizontal section, and is shown in Fig. 5. The average electrostatic potential measured was 104.9 V, with maximum

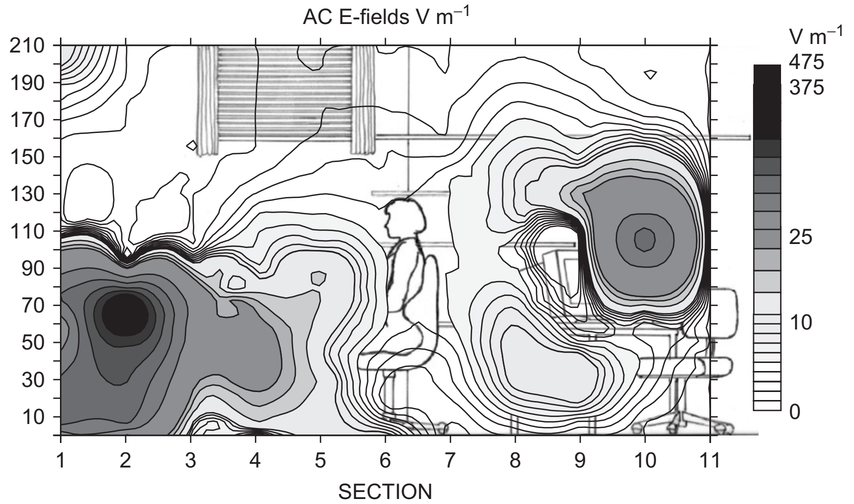

Fig. 4. AC electric field strengths in $V\,m^{-1}$.

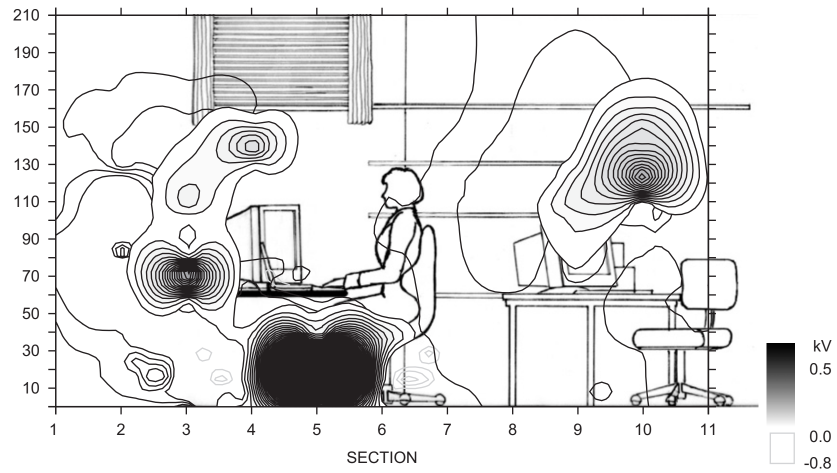

Fig. 5. Electrostatic potentials in kilovolts (kV).

and minimum values of 7705.8 and 2.2 V also being noted. Field readings in excess of 500 V were also recorded off-grid above the CRT monitor.

It can be clearly seen in Fig. 5 that the electrostatic field in this room does not resemble fair weather field conditions and that the room's occupant is constantly exposed to distorted current flow regimes. It is suggested that such conditions may greatly reduce the operator's biological and work efficiency.

Moreover, the influence of tribolectric charging in creating high electrostatic potentials is clearly demonstrated in Fig. 5, with the greatest potential measured in the room being created by frictional charging of the footrest of the computer operative's chair by the user (concentrations of 0–40 SiNAI cm^{-3} being noted there). Again low concentrations of SAI were found where high fields from electrical equipment and wiring existed.

In addition to the electric fields created by the items of electrical equipment and cabling in the room, high body voltages can be created through frictional charging, particularly when individuals wear insulative footwear, or come into contact with insulative materials such as are often used for clothing and furnishings. The most notable cause of this in the room was the insulative footrest which curtailed charge dissipation from the computer operative. Such charging leads to a high body potential being created by frictional charging and retention of charge, with the excess charge being dissipated when a conductive surface is touched. The problems encountered from electrostatic charging in such situations are much exacerbated in wintertime when lower RH/dew-point temperature leads to higher potentials being generated. As an example of this, Moss (1987) showed that walking on a floor finish similar to the one in the surveyed room at 20% RH at 21 °C (−2.5 °C dew-point temperature) could generate 12,000 V whilst the same action at 80% RH at 21 °C (17.4 °C dew-point temperature) generated only 250 V.

4.4. Temperature, RH and dew-point temperature

Indoor temperatures on the first measurement day were 26.8 ± 0.6 °C, necessitating the continual use of an oscillating fan unit within the room, in addition to the air conditioning unit (which was sporadically in operation) and natural ventilation provided by the opened external window. 29.1 ± 3.6% RH was also recorded during that period, giving an average dew-point temperature of 7.35 °C. On the final measurement day the temperature was 19.3 ± 0.3 °C, with 66.7 ± 4.2% RH (12.96 °C dew-point temperature). The air conditioning was still in sporadic operation, though the fan was no longer in use and the external window shut.

Furthermore, large seasonal variations can occur with regard to charge generation in buildings, with higher charges generally being generated in winter months (even when external RH levels are >50%). This is primarily due to the reduction in indoor RH levels due to the operation of heating systems with RH being halved for every 10 °C increase in temperature over the outdoors. Vonnegut (1973) noted that in a hypothetical situation where 100% RH was encountered at −20 °C, indoor temperatures of 20 °C would reduce RH to <10%. Low humidities can greatly increase the deposition and retention of contaminants as they encourage the generation of higher electric fields.

5. Effects of electrostatic and AC electric fields on charged molecules and particles

Both fair weather and poor weather field conditions can significantly influence biological processes, with poor-weather fields tending to be seen as detrimental and fair weather fields beneficial. Building occupants can often be screened from these however due to many buildings acting like Faraday cages. Constant vertical electrostatic fields can significantly influence a number of physiological parameters in comparison to controls under Faraday conditions. These include breathing rate, oxygen uptake, activity levels and immune system functioning (Möse and Fischer, 1975; Altmann, 1974, 1969; Lang, 1972a, b; Kritzinger, 1957; Hahn, 1956). It is suggested by the present authors that exclusion and/or masking of individuals from such phenomena, or artificial simulations of them, may significantly influence their health, performance and well-being.

In indoor environments where large concentrations of aerosols exist, the main cause of decay of SAI can be collision with neutral or oppositely charged particles. When this occurs, the result of the collision can be the creation of an intermediate or large air ion. SAI can also be lost due to plate-out on surfaces, this situation being greatly exacerbated when the surfaces themselves obtain a high degree of charge and when there is <20–30% RH. As previously mentioned, high electric fields can also be created from electrical items and wiring, and through frictional charging, as was demonstrated by the measurements taken next to the footrest of the computer operative's chair in this present study.

Recombination of oppositely charged cluster ions in the air can additionally occur and result in their neutralisation, though this is more likely to occur in areas where there is little aerosol pollution. High levels of unipolar charge in particular, such as are noted in the case study, can affect the concentrations of different sizes of aerosols, with droplet disintegration occurring when the repellent forces that unipolar charges apply to each other exceed the droplet's surface tension, causing the creation of smaller particles (Wehner, 1969). Such situations may further exacerbate contamination and health risks by creating higher concentrations of charged ultrafine particles. Excess electrical charges may often play a key part in contamination incidences by significantly increasing the coagulation, charging and deposition of microbes, contaminated airborne droplets and particulate matter on the skin, surroundings and airways of those exposed. The greater the degree of charge that such contaminants receive, the greater the likelihood of infection and contamination, as high electric fields can also significantly raise the deposition velocity and localised deposition rate of charged and charge-neutralised dielectric particles $\leqslant 1$ μm in diameter.

This is because increased potential linearly increases their deposition onto oppositely charged objects.

As demonstrated in the case study, high electrical fields can often be created in everyday life. The presence of inappropriate charging regimes in individual microenvironments may greatly increase incidences of skin and surface contamination and the likelihood of contaminants, including pathogens, being retained by the body when inhaled, though there are many ways in which excess charge can be reduced (Jamieson et al., 2006).

Past research by Wedberg (1991, 1986, 1987) found that in office environments the deposition of particulate matter $>0.07\,\mu m$ in size on individuals' faces was significantly influenced by electrical field regimes, with precipitation rates increasing markedly as the magnitude of applied voltages increased—facial deposition rates of ≈ 100 particles $mm^{-2}\,h^{-1}$ at 0 kV increasing to ≈ 1000 particles $mm^{-2}\,h^{-1}$ when the body was charged to a potential of ± 5–6 kV. This is because though such particles have drift velocities far lower than normal indoor (and outdoor) wind velocities, they are likely to be captured when passing sufficiently close to suitably charged surfaces. High charging will also increase contaminant deposition onto other areas of exposed skin, such as the hands, thereby increasing the risk of contamination spread. Research by Rao et al. (2005) indicates that $>90\%$ of airborne particles may be $<1\,\mu m$ in size. Electrostatic attraction between airborne ultrafine particles and charged surfaces is often a greater determinant of localised contaminant deposition than aerodynamic forces or gravity. Unlike gas molecules and millimetre-sized molecules, aerosols strongly adhere to surfaces they contact (Hinds, 1999; Yost and Steinman, 1986).

Electrical forces can greatly increase the deposition of charged particles in the respiratory tract since whilst its surface, is uncharged, it is electrically conductive, and when a suitably charged particle approaches the alveolar surface the particle induces an image charge of opposite polarity on its surface, thereby attracting the particle. Work by the International Commission on Radiological Protection (ICRP, 1994) modelling particle deposition in the respiratory tract indicates that maximum alveolar deposition in humans may occur with singlet ultrafine particles of approximately 20 nm ($0.02\,\mu m$) diameter. Research by Cohen et al. (1998) has indicated that this size of particle when singly charged may deposit 5.3 ± 0.3 times more readily than uncharged particles, and 3.4 ± 0.3 times more readily than charge-neutralised particles. Creating conditions where such particles gain charge may greatly increase risk of infection and respiratory problems.

6. Conclusions

The measurements discussed within this document, and taken during additional surveys by the main author, indicate that many individuals may spend the majority of their time indoors in "Faraday cage"-like conditions exposed to (unnecessarily) high electrostatic and AC electric fields. Such conditions can reduce available concentrations of biologically-essential SAI, whilst increasing their likelihood of inhaling and retaining airborne contaminants, such as charged ultrafine particles and being exposed to higher levels of difficult-to-remove surface contamination. The degree of "electro-pollution" that individuals are exposed to is very much determined by the type of microenvironment they occupy, with inappropriate levels and types of electric field normally resulting in low concentrations of SAI and high concentrations of LAI. Very often, different types of microenvironment can exist within the same room, with the location occupied by individuals for prolonged periods greatly influencing the levels of pollution they are exposed to. Therefore, where possible, future research studying the link between particulate pollution and health should include measurements of concentrations (and charge) of small, intermediate and large air ions and sub-micron particles in such areas.

The cost to national economies of poor indoor air/indoor environmental quality (IAQ/IEQ) practices is immense and may be significantly reduced by introducing suitable electromagnetic hygiene/productivity guidelines. It was estimated by Mendell et al. (2002) that respiratory illnesses due to poor building management and practices in the USA alone may cost $32 billion dollars annually in terms of absenteeism, health-care costs and reduced work efficiency, whilst Clements-Croome and Baizhan (1997) suggest that improving indoor air quality may increase the productivity of office staff by $\approx 10\%$. It is suggested by the current authors that creating indoor environments which more closely enhance/simulate beneficial natural electromagnetic phenomena and reduce incidences of excess charge, whilst exposing individuals to constant vertical electrical fields and suitable concentrations of balanced bipolar small air ionisation, may greatly improve their productivity and biological functioning at the same time as significantly reducing incidences of contamination and infection. Further research in this relatively unexplored area is urgently required.

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