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Building Health: The Need for Electromagnetic Hygiene?

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Abstract. Whilst the electromagnetic nature of the built environment has changed considerably over the past century, little thought is at present given to the possible advantages of creating electromagnetic microenvironments that more closely resemble those found in nature and/or developing biologically-friendly technology aligned more closely to its operating principles.

This review paper examines how more natural exposures to a variety of electromagnetic phenomena could be re-introduced into the built environment, possible benefits that might arise, and discusses the extent to which there may be tangible benefits obtainable from introducing more rigorous properly considered electromagnetic hygiene measures. Amongst the matters discussed are: the effects of different materials, finishes and electrical items on charge generation (*and the effects of excess charge on contaminant deposition*); the possible benefits of suitably grounding conductive objects (*including humans*) in order to reduce excess charge and contaminant deposition; how the presence of vertical electric field regimes, similar to those found in nature, may enhance biological performance; and possible pitfalls to avoid when seeking to introduce appropriate electromagnetic hygiene regimes.

1. Introduction

This paper investigates the beneficial and detrimental effects that a variety of natural (predominately electromagnetic) phenomena may have on health and wellbeing. It also discusses the extent to which exposure to such phenomena may be altered indoors, and how beneficial natural phenomena (or simulations of them) might, where appropriate, be introduced to improve environmental quality and biological functioning. It is proposed that increased knowledge in this multidisciplinary field may lead to the refinement of the principles under which present day technology and environments are designed and operated.

Several key factors are considered in this work: vertical potential gradients; distorted field regimes; triboelectric charging; charge and particle deposition; grounding regimes; bipolar ionisation; and humidity levels. The effects of different types of natural and artificial lighting regimes are not discussed, though they too can have key roles to play, and will be discussed in detail in a later paper by the lead author.

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2. Vertical Potential Gradients (VPG)

A positive vertical potential gradient (VPG) exists in nature during fair-weather periods, with the positively charged ionosphere acting as an anode and the Earth as a cathode. During such conditions, VPGs of 80-150 V/m can occur in low-lying areas [1], and VPGs of ≤5,000 V/m on high elevations such as on mountains [2]. During 'poor-weather' conditions, triboelectric inversion can occur as a result of air below positively charged areas of clouds becoming negatively charged in relation to the ground directly beneath it causing the direction of current flow to reverse [3, 4].

Some buildings, for instance those predominantly of timber construction, can allow the passage of VPGs into their interiors to a high degree. As an example, traditional rural timber housing can allow ≈70-75% transmission of such fields through their structure [5, 6]. In comparison to this, most modern buildings, particularly those of steel and concrete construction, tend to act as 'Faraday cages' substantially shielding/masking individuals from such fields. The biological effects of shielding from such fields are seldom taken into consideration.

Even centuries old buildings can register zero-fields if electrical conductors and/or large metal uprights are added to them [5]. Indoor environmental factors too can have a role to play. Measurements undertaken by the present lead author indicate that the presence of electrical equipment and materials that gain high charge can also mask such fields (Figure 1).

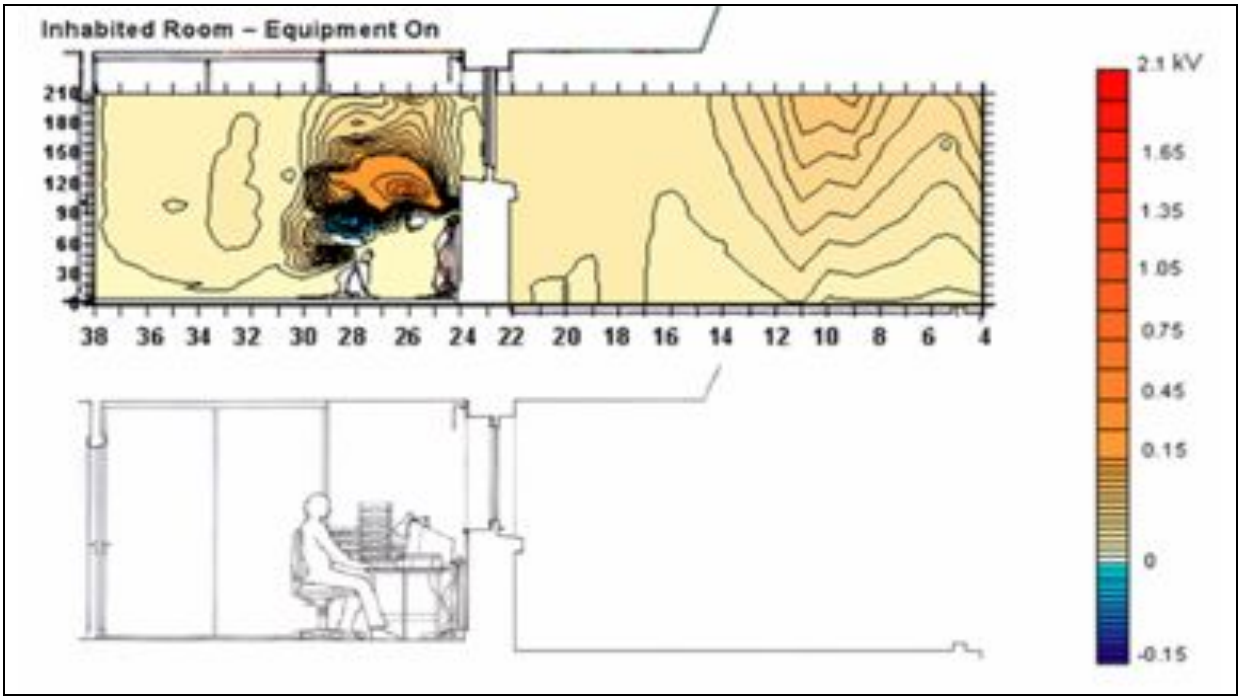


Figure 1. Electrostatic potentials measured indoors and outdoors. (Jamieson – unpublished research).

At present some individuals further shield themselves from VPGs through deliberately creating 'Faraday cage' conditions indoors in an attempt to protect themselves from manmade fields, such as those from mobile phone base stations which can readily penetrate most buildings. Such measures may in part prove counterproductive.

2.1 VPGs and Immune System Functioning

Past research on mice by Möse et al. [7] and Fischer [8] indicate that the screening of VPGs can have pronounced effects on immune system functioning, with exposure to constant vertical DC field

protocols significantly altering the operating efficiency of the immune system compared to immune responses provided under Faraday cage and control environments (Table 1).

In that research, the plaque count method devised by Jerne & Norlin [9] was used to determine the degree of immunity exhibited by animals exposed to different field regimes, with higher plaque counts indicating more efficient immune system response. It was revealed that a VPG of only 40 V/m could significantly increase immune system response over true Faraday cage conditions, with further improved immune system responses being noted at the further increased field strengths shown. As mentioned earlier, fair-weather fields of 80-150 V/m are regularly encountered outdoors in nature but are often blocked from ingress indoors.

Number of investigations per exposure	VPG Field strength (V/m)	Plaque counts (indicating degree of immunity)		
		Constant DC field	Control chamber (normal conditions)	Faraday cage conditions
10	40 V/m	210.2 ± 24.1	232.3 ± 13.2	111.6 ± 11.0
10	200 V/m	608.0 ± 55.1	384.0 ± 31.7	199.2 ± 16.5
15	1,000 V/m	572.4 ± 112.8	161.6 ± 31.5	76.0 ± 34.0

Table 1. Plaque Counts after 15-day exposure to various field levels [7, 8].

It is proposed by the present authors that similar improvements in the immune system functioning of humans (and other animals) might occur if exposed to comparable regimes in otherwise low field microenvironments. Whilst improved versions of such regimes might be of particular benefit in hospital environments to improve patient recovery and staff wellbeing, the possibility of introducing them into other building types such as schools, offices and homes should also be considered, especially if electrical items used therein were designed to be more compatible with such systems.

Evidence indirectly supporting possible health benefits that may occur through the adoption of VPG protocols is given by Hahn, who noted dramatic recoveries in sick animals (cows, goat, pigs and a chicken with avian influenza) after exposure to enhanced VPGs. Interestingly, over an 8-year test period, none of the people exposed to those fields (whilst managing the animals on a regular basis) succumbed to colds, influenzas or any another type of infectious disease. Reduced incidents of infection and improved recovery rates were additionally noted in hospital areas with VPG systems installed on their ceilings [10].

2.2 Airborne Contaminants, Microbes and Vertical Electric Field Regimes

The creation of vertical electric fields indoors (*in low field environments* – present authors' emphasis), to replicate those found in nature, has additionally been shown to help reduce concentrations of airborne contaminants and surface deposition in individual microenvironments, and might it is proposed be used as a component in future electromagnetic hygiene initiatives to help substantially reduce individuals' exposures to contaminants whilst increasing general wellbeing.

Past research trials by Hahn [10] demonstrated additionally that VPG regimes could prevent odours and mould growth that had previously occurred in individual offices, and could reduce the airborne concentrations of microbes found in hospital wards by ≈95%. Stersky et al. [11] also demonstrated that VPGs could significantly reduce airborne concentrations of microbes.

The effects of VPG regimes on removing non-biological airborne particulates were investigated by Sandberg & Mellin [12]. Their tests (on a 3.8 m^3 model room) found that the use of a charged ceiling, in situations where there was no ventilation, could reduce concentrations of airborne particulate matter (<250μm) by ≈60% in comparison to control conditions. Additionally, the use of VPGs in conjunction with natural ventilation was shown to reduce particulate concentrations with greater efficiency than that achievable by using natural ventilation alone.

They also investigated the effectiveness of VPG regimes in removing environmental tobacco smoke (ETS). Typically after < 1 hour, concentrations of ETS were less than they would have been in the control situation where such measures were not been applied. Whilst no quantification was given in their results for that test, such regimes have been used successfully in the past to reduce exposure to ETS in West German restaurants [10], as electric fields are able to act as a major transport and deposition mechanism for submicron particles [13]. A partial listing of contaminants within this size range is shown in Table 2.

Viruses (also arise in larger droplet nuclei)	<0.01–0.31 µm
Diesel soot	0.01–1 µm
Bacteria (also arise in larger droplet nuclei)	0.05–10 µm
Fresh combustion particles	<0.1 µm
Metal fumes	<0.1 µm
Ozone and terpene formed aerosols	<0.1 µm
Environmental tobacco smoke	0.1–0.8 µm
Outdoor fine particles (metals, sulphates)	0.1–2.5 µm
Asbestos	0.25–1 µm
Fungi	0.5–30 µm
Cat dander	1–3 µm
Skin flakes	1–40 µm

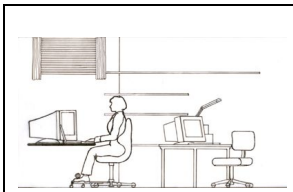
Table 2. Common Indoor Particles with Size Range ≤ 1µm diameter [14, 15, 16].

As increased exposures to submicron contaminants are associated with increased prevalence of cardiovascular problems and respiratory diseases, such as asthma and chronic obstructive pulmonary disease (COPD) [17], and may lead to increased likelihood of infection from pathogens, investigation into the possible benefits of applying vertical field protocols in standard indoor situations would appear warranted. It is proposed that the introduction of appropriate VPG regimes indoors could help remove many contaminants from the air whilst improving human performance and wellbeing.

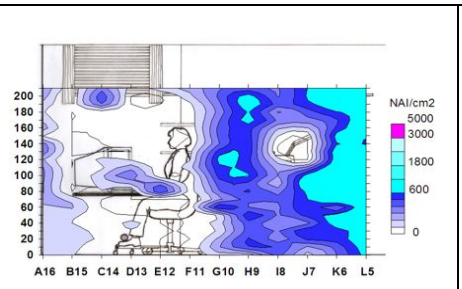
3. Distorted Field Regimes

Even in instances where (natural or artificial) VPGs exist indoors, their presence may be masked in some microenvironments within rooms by highly localised incidences of 'electromagnetic-pollution' as a result of fields created by equipment, finishes and/or materials as indicated in Figure 1.

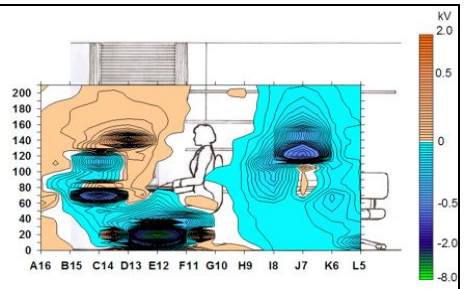
Research by Jamieson et al [18, 19] suggests that areas which exhibit poor 'electromagnetic hygiene' may often exhibit higher concentrations of charged sub-micron contaminants than low field areas within individual rooms. For the examples shown - of offices measured in Norway and the United Kingdom - a marked reduction in small air ions (SAI) levels occurs in sectors where raised electric fields exist (Figure 2a,b).



Office



Lower bound of negative small air ion (NAI) levels



Electrostatic potentials in kilovolts (kV)

Figure 2a. Vertical Section through Office Environment. Adapted from [18].

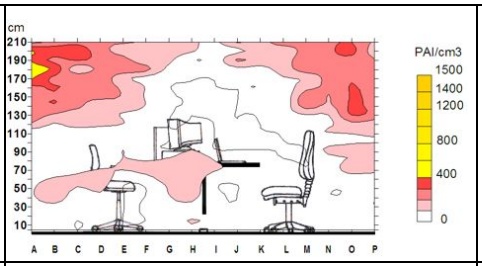
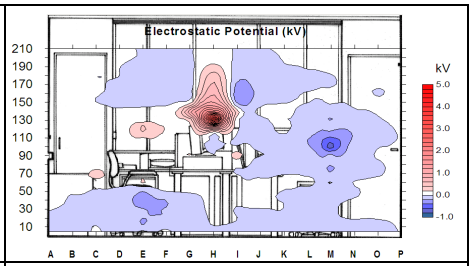
		
Office	Lower bound of positive small air ion (PAI) levels	Electrostatic potentials in kilovolts (kV)

Figure 2b. Vertical Section through Office Environment. Adapted from [19].

Such conditions are generally indicative of the presence of increased [local] concentrations of harmful charged ultrafine particles (which contribute little to air's conductivity except when SAI are greatly reduced in number). Greater local concentrations of charged neutralised submicron particles that can also cause negative health effects will also occur under such circumstances.

The indication that raised fields, at levels well below those normally considered injurious to health, can increase local concentrations of submicron contaminants (and their localised deposition) appears important, as even small differences in pollutant levels within sections of individual rooms may be vital to medical hygiene and general wellbeing, particularly if exposures to such regimes are prolonged. Often exposures to inappropriate fields regimes (and levels of pollutants) may be easily mitigated.

In addition to optimising the levels and types of fields created, appropriate zoning of field sources may also be undertaken to help improve the electromagnetic character of individual microenvironments [20]. In general, where possible, electrical items that can emit raised fields should be located in areas where individuals are unlikely to spend prolonged periods of time (Figure 3), and/or replaced with suitably designed units that emit low fields. Appropriate finishes and/or materials should also be specified to reduce the likelihood of excess charge.

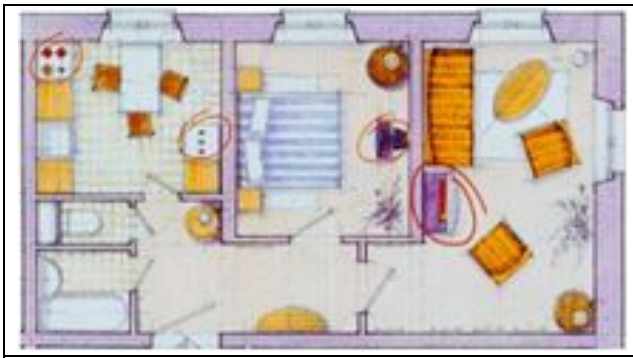
	
a) Typical room layouts	b) Improved low exposure room layouts

Figure 3. Inappropriate layouts/specification may increase both field and contaminant exposures [20]. (Reproduced with kind permission from the Russian National Committee of Non-Ionising Radiation Protection).

4. Triboelectric Charging of Humans

In the past the human body was often at ground potential for prolonged periods of time. Nowadays, however, high body-potentials can often be readily induced on individuals through exposure to raised potentials from electrical items which have not been designed to take improved electromagnetic hygiene measures into account. Humans and the actions they undertake too are often now a prime

cause of excess DC body-potentials, primarily through the triboelectric/contact charging of inappropriately combined/specified modern materials. Tests have shown that the inappropriate use and combination of materials can create charges > 60 kV DC on individuals [21] (Figure 4).

Electrostatic discharge (ESD) incidents can often occur indoors when individuals readily gain potential whilst undertaking many common activities. ESD events can both damage computers and increase local surface contamination and skin contamination rates.

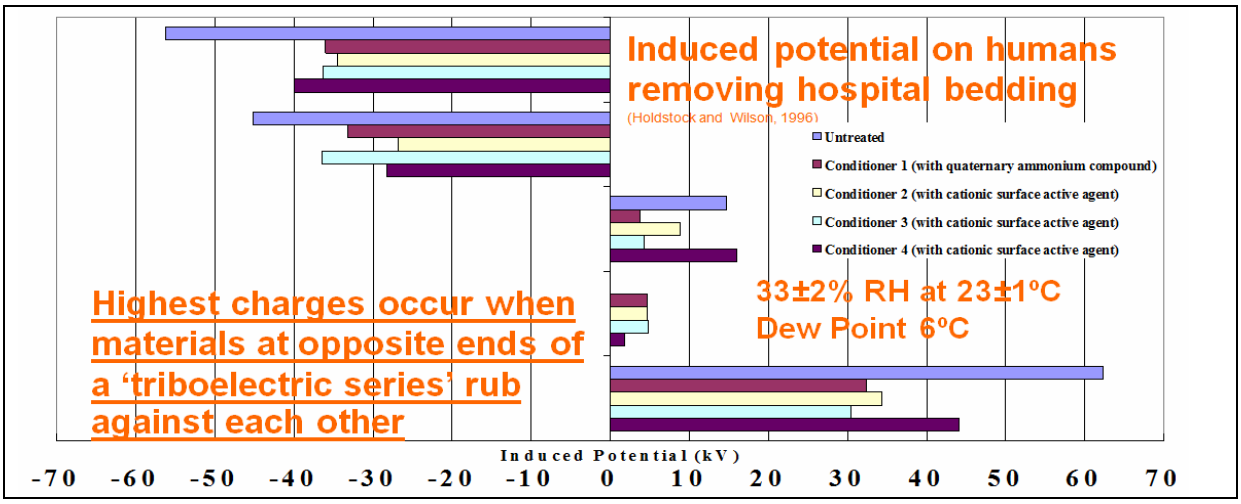


Figure 4. Inappropriate use and combination of materials can create charges >60 kV DC on individuals. (After Holdstock & Wilson [21], with kind permission of the ESD Association).

As the highest incidence of ESD events in hospitals are often found in ward areas [22], and sensitive computer data can be easily lost through ESD events, it appears important as a matter of best practice to ensure that 'mission critical' design measures are followed on hospital wards where computers are used. Another benefit from introducing such measures would be the reduction in localised deposition of submicron contaminants that would otherwise occur through the presence of raised fields.

Allen (23), and Allen et al (24, 25, 26) when conducting research on hospital infections, demonstrated that the size of local electrostatic fields could strongly influence microbe deposition. In one test, deposition was ≤ 20 times greater than control conditions after a 4-day exposure period using voltages ≤ ± 4kV. It was also demonstrated in that work that being in close proximity to highly charged plastic nurses' aprons could greatly increase microbial deposition onto patients.

The raised fields from electrical wiring and equipment (such as televisions and ungrounded laptop computers) that are often found in hospital wards, and elsewhere, should also be taken into consideration when wishing to mitigate against microbial contamination and deposition. In addition to the triboelectric properties of materials and finishes and raised fields from inappropriately designed electrical equipment; poor grounding, humidity levels and air-ion regimes can also contribute to the level of charge created.

5. Influence of Charge on Particle Deposition

As many pathogens, including adenovirus (which causes respiratory infections), influenza A, B and C, SARS-CoV and MRSA [27], are in the submicron range for which electric fields can act as a major transport and deposition mechanism [13], and > 90% of airborne particles in hospitals can be in this size range [28], it appears sensible to discuss the possible influence of charge on particle deposition and how likelihood of infection might be reduced.

5.1 Infectious droplets and droplet nuclei

Gain of charge, particularly unipolar charge, can directly influence the size of infectious droplets (*such as those containing influenza virons – present authors' comment*), with their disintegration occurring whenever the repellent forces that such charges exert on each other exceed droplet surface tension [29, 30].

The amount of charge held by droplets will greatly determine their behaviour when exposed to electric fields. Whenever the mutual repulsion of charges contained within liquid particles exceeds that of the bonding force of their surface tension, the droplets break-up to form smaller droplets with significantly higher cumulative surface area and overall charging limit. The smaller the particles, the more readily the charge that they hold will influence their deposition. As influenza A tends to infect the lower respiratory system, reduced particle size will aid its deposition in that location.

5.2 Effect of Charge on Respiratory Deposition

Space charge is an important mechanism for increasing respiratory deposition of charged airborne contaminants where high concentrations of charged particles exist. Research by Cohen et al. [31], indicates that singly charged 0.02 μm particles may deposit 5 times more readily than uncharged particles, and 3 times more readily than charge-neutralised particles.

It appears highly likely that areas where raised electric fields occur - such as those shown in [18, 19] - will have higher concentrations of such particles than microenvironments where lower fields are found. It is hypothesised by the present authors that areas with poor electromagnetic hygiene, which can be highly location specific within different microenvironments, can exhibit higher concentrations of charged submicron aerosols and charged-neutralised submicron aerosols thereby increasing the likely deposition rates of such particles in the respiratory tract. Past research has already suggested that improved electromagnetic hygiene in homes may reduce respiratory deposition, with low field environments being shown to help prevent incidents of asthma [32].

5.3 Effect of Charge on Skin Deposition

An indication of how differences in potential can influence the deposition of particulate matter (PM) onto the skin is provided by Wedberg [33, 34, 35] who demonstrated that at body voltages of 0 kV DC, deposition of PM >0.07μm was ≈100 particles/mm^2/hr, compared to ≈1,000 particles/mm^2/hr under moderately high body voltages of ±5-6 kV DC which can be readily achieved in some indoor environments. Deposition rates of >10,000 particles/mm^2/hr were recorded under larger fields.

When it is taken into consideration that excess charge can increase the likelihood of microbial deposition, indications that poor electromagnetic hygiene may greatly increase their localised deposition and deposition onto individuals give cause for concern, particularly when wishing to minimise hospital acquired infections and the spread of infections in other environments. The infective dose required to cause infection varies between microbes; research by Caul [36], for example, showed that the infective dose for Norwalk-like viruses (NLVs) may be ≥ 10–100 infected particles, while Ward et al. [37] noted that for rotavirus (which can cause diarrhoea in young children), the infective dose may be ≤ 10 infected particles.

5.4 Effect of Charge on Surface Deposition

Excess fields increase surface contamination by increasing plate out of submicron contaminants, and by makes them harder to remove, as aerosol deposition velocity increases in proportion to field strength, thereby causing them to exhibit greater deformation and adhesion on impact [38, 39].

Tests have shown that both the particle deposition velocity and the solidity of the materials involved greatly influence final area of the contact site that is achieved by particles, and the strength of adhesive force created. It was noted by Tsai et al. [38], in their research on elastic flattening and particle adhesion, that flattening can significantly enhance adhesive forces, by a factor of ≤ 15 times in soft metals and a factor of > 100 in plastics. The deposition velocity of sub-micron particles, and

hence their degree of adhesion, is greatly determined by both field-strength and the net-charge that individual particles hold.

As mentioned previously, the research of Allen [23] and Allen et al (24, 25, 26) demonstrates how excess charge can influence microbial deposition.

6. Grounding to Reduce Excess Charge

In most instances local surface-charge should be decreased wherever practicable, as this can reduce the retention and degree of contamination that occurs from sub-micron contaminants in individual microenvironments. In some situations grounding can be used to reduce excess surface-charge, however, the electrical conductivity of the materials being assessed should be taken into account, as electrons can flow freely throughout conductors but not through insulators (Figure 5). Conductors are more likely to gain excess charge through induction whist insulators are most likely to gain it through triboelectric charging and are often a major source of charge generation experienced indoors.

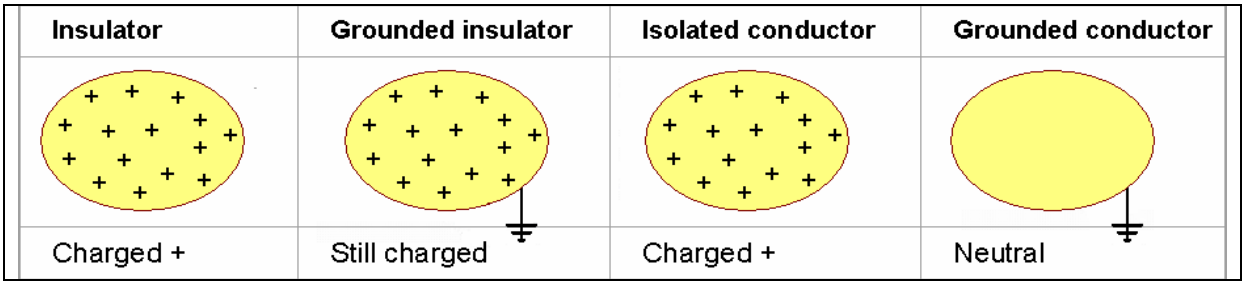


Figure 5. Insulators, conductors & surface charge

Whilst grounding can reduce excess charge on conductive objects, including humans, grounding the human body to reduce excess charge may not always be sufficient to adequately reduce contaminant deposition (including that of microbes) on it when individuals are in microenvironments that have raised electric fields. The potential difference between field sources and individuals is a major factor in determining both deposition-rates and deposition-velocities of sub-micron particulate matter onto the skin. Even when an individual is at zero-potential, a potential difference between the individual and a field-emitter can cause enhanced deposition. The same is true of other conductive objects [40] (Figure 6). If the subject is charged to a potential of opposite polarity to the field source deposition velocities can also be enhanced.

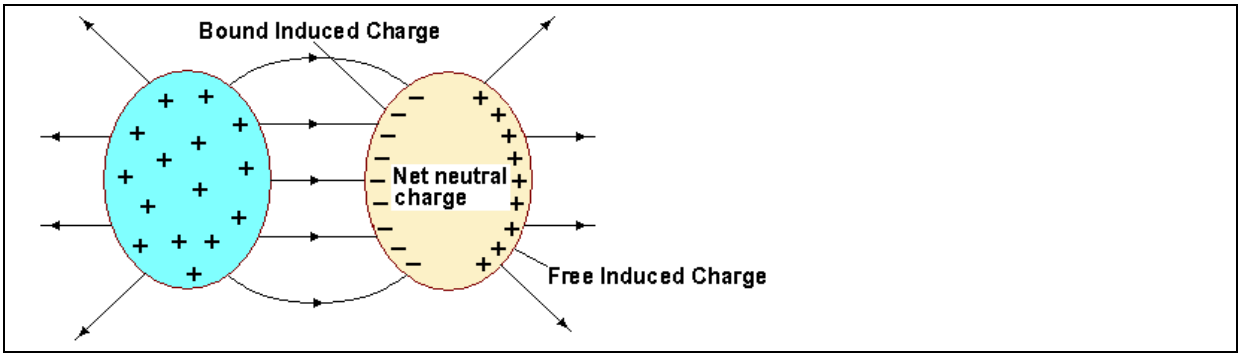


Figure 6. Isolated (ungrounded) conductor exposed to field from charged insulator (After Jonassen [40], with kind permission of Springer Science and Business Media).

Suitably grounding individuals in low field environments can minimise deposition of contaminants onto skin (and it is proposed may also reduce deposition in the airways). In some instances grounding

may provide additional health benefits such as stress reduction. As examples of this latter factor, Ghaly &Teplitz [41] found grounding could cause the normalisation of circadian cortisol secretion profiles in some individuals tested, whilst Chevalier & Mori [42] reported that test-subjects appeared less stressed and more attentive when grounded. They also noted improvements in test-subjects' muscle tone when grounded, and that subjects' beta, SMR (slow beta), alpha, theta and delta brainwaves demonstrated abrupt changes after grounding with the right and left hemispheres of the brain coming into synchronicity to a greater degree.

7. Ionisation to Reduce Excess Charge

Bipolar SAI as found in nature can help neutralise excess charge, and the charges on insulators and isolated conductors found indoors can both be neutralised using artificial bipolar ionisation [43] and passive air ionisation measures (such as the specification of appropriate materials that do not gain excess charge readily and the grounding of electrical equipment and conductive items). Even simple "Prudent Avoidance" practices such as occupying lower field microenvironments, and re-zoning electrical equipment within individual rooms, can help improve individuals' exposures to SAI. No direct assessment appears to have been made on how balanced bipolar ionisation - at levels similar to those stipulated in the Russian guidelines for areas where computers are used [44] (Table 3) - may affect the likelihood of deposition of sub-micron contaminants in the airways, or onto the clothing and skin of individuals in comparison to areas with low SAI concentrations.

Minimum	600 NSAI/cm^3	400 PSAI/cm^3
Optimal	3,000 – 5,000 NSAI/cm^3	1,500 – 3,000 PSAI/cm^3
Maximum	50,000 NSAI/cm^3	50,000 PSAI/cm^3

Table 3. Russian Guidelines stipulating mandatory bipolar SAI Exposures for computer workplaces [44].

In addition to being able to reduce excess charge and surface contamination, work by Krueger & Reed [45] has indicated that bipolar ionisation may help reduce the mortality rates of animals infected with influenza (Figure 7). Interestingly, the levels of 2,500-3,500 ions/cm^3 used in that research corresponds closely with the optimum levels stipulated in mandatory Russian guidelines. The levels of <60 NSAI/cm^3 and <100 PSAI/cm^3 used to represent low SAI ion conditions in that research are similar to those sometimes measured at computer workstations in the western world (*present authors' comments*).

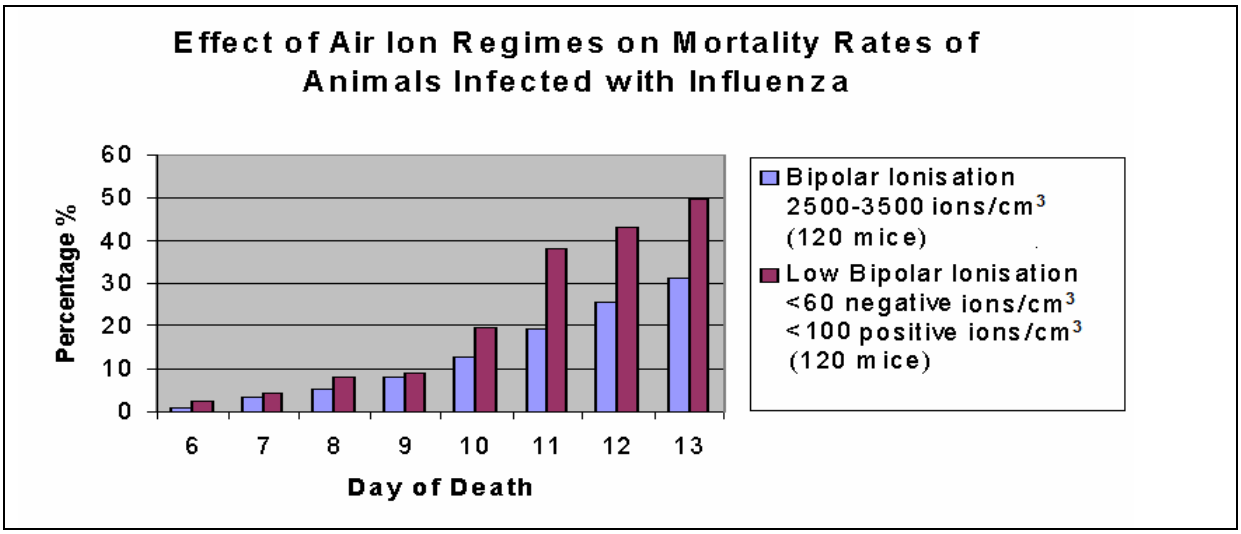


Figure 7. Effect of air ion regimes on mortality rates of animals infected with influenza [45]. (After Krueger & Reed [45], with kind permission of Springer Science and Business Media).

Whilst short-term exposures to standard *unipolar* ionisation have been indicated as being beneficial in some instances, long term exposures to such regimes are not recommended for health reasons [46, 47, 48], with its use actually being prohibited in Russian workplaces [44]. Animal tests in the United States have shown that long-term *unipolar* exposures can result in exposed animals having significantly shorter life-spans than those under non-enhanced conditions [47]. For reasons such as this, SAI regimes more closely resembling those found in nature, such as those recommended in Russia [44], are recommended by the present authors for areas where people spend large periods of time.

8. The Role of Humidity in Electromagnetic Hygiene

Higher levels of charging often occur when the moisture content of the air is <20-30% RH (≈4ºC dewpoint temperature), as low humidity reduces surfaces' conductivity (ability to transfer electrical charge), thereby making charge dissipation more difficult [49].

Under such conditions, the higher local electric-field strengths that can be encountered on surfaces that act as insulators or isolated conductors (and the presence of ungrounded electrical equipment) can increase the deposition rate and deposition velocity of many airborne contaminants, including microbes. Low levels of humidity can also make air a component of the charge build-up mechanism as it flows over such surfaces, with dry particles and dust becoming charged to a greater degree on removal from surfaces.

Low humidity levels (though often avoidable with suitable foresight) often occur when air-conditioning is used during summer and winter months, especially in buildings that are not actively humidified [50]. In Scandinavian countries, where low humidity can be a problem (particularly during wintertime), there are often more pronounced cases of screen dermatitis, dry irritated throats and eyes, and cases of electro/chemical-sensitivity due to increased deposition of contaminants onto the eyes, skin and airways of individuals. Reduced humidity can also cause a drying of the skin, making it more conductive [51].

8.1 Humidity and Charge Mitigation

As dewpoint temperature is a more accurate predictor of charge generation than relative humidity (RH) alone [52], it is proposed that dewpoint temperatures should be specified instead of RH, whenever practical, to help mitigate excess charge. Jamieson et al. [19] hypothesise that an 'ideal' average dewpoint temperature for general indoors purposes may be approximately 12ºC, and that ≥ 4ºC dewpoint temperature might be permissible where this is not possible.

It is further suggested that the application of that proposed 'ideal' dewpoint temperature indoors may help prevent the spread of pathogens such as influenza, particularly during the winter season, as influenza outbreaks normally occur when conditions of low temperature and low RH co-exist [16].

An illustration of the effects that different humidity levels can have on triboelectric charge generation is given by this paper's second author (Figure 8). In this instance, body voltages were measured on an individual after getting up from a desk's main chair, its chair provided for visitors, and walking along a carpet at 11.6ºC dewpoint temperature and at ≥ 4ºC dewpoint temperature. Marked differences in potential can be seen under the different regimes. As mentioned earlier, increased potential can significantly influence the deposition rates of PM onto the skin [33, 34, 35]. It has also been shown to increase microbial deposition [23]. Optimising humidity levels, along with the other measures discussed, can help to cost effectively reduce such problems.

Low humidity levels can be improved in a number of ways in individual microenvironments, including the use of suitable HVAC systems, commercial humidifiers and/or greenery to help locally regulate the air's moisture content and reduce excess charge. Excessively high humidity levels should be avoided.

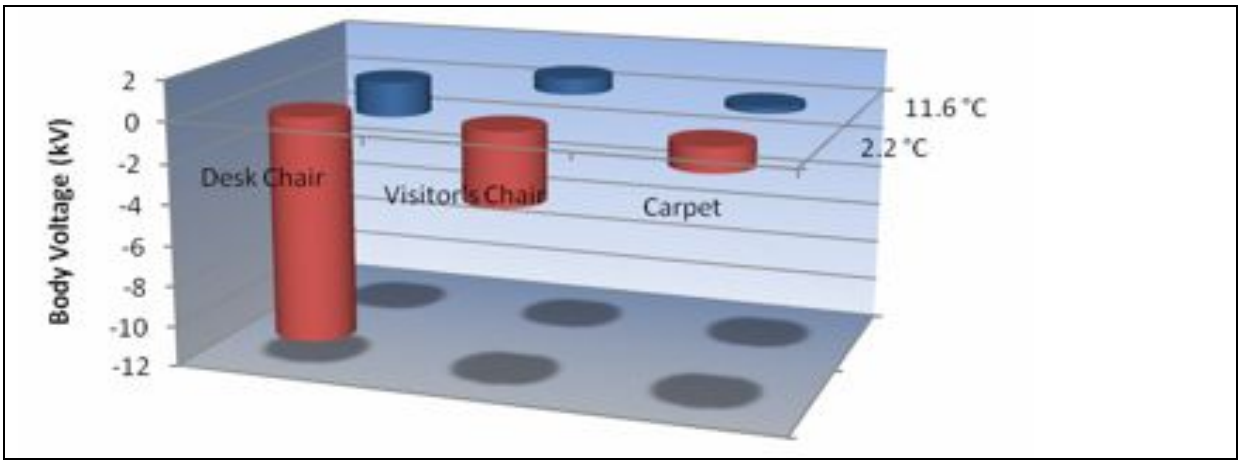


Figure 8. Effects of different dewpoint temperatures on generation of triboelectric charge. (Holdstock – unpublished research).

9. Conclusion

From this review, it appears that there may be a number of substantial benefits achievable for healthcare, industry, general businesses, telecommunications, the general public and other end-users alike through seeking to work with and understand the electromagnetic properties and cues of nature more closely.

The need for further research into electromagnetic hygiene and its related fields appears long overdue, with rapid progress and development of novel (often low cost) technologies and techniques appearing possible in many areas, which could dramatically reduce the socio-economic burden of hospital acquired infections whilst also increasing the wellbeing and work-efficiency of society in general.

Whilst rigorous research is required - and there is a need for caution to ensure that the results of such studies are correctly interpreted and acted upon - the potential rewards for healthcare, businesses, countries, individuals and sustainable technological innovation alike appear great, creating a situation where everyone can gain.

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