Electromagnetic Environments and Health in Buildings

Edited by
Derek Clements-Croome

Electromagnetic Environments and Health in Buildings

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Contributors

Professor Derek Clements-Croome

Professor of Construction Engineering and director of research in the School of Construction Management & Engineering at the University of Reading. With industry set up an undergraduate course in Building Services Engineering Design and Management in 1989. Set up new MSc in Intelligent Buildings in 1996 funded by EPSRC. Past Chairman and founder of the South East Centre of the Built Environment in Construction. Chairman of European Intelligent Building Group. Visiting Professor at five universities in China. Member of EPSRC Innovative Construction Research Centre at Reading University.

Author of several books: including *Airconditioning and Ventilation of Buildings,* Pergamon Press, 1981(Second Edition), also published in Chinese and Russian; *Noise, Buildings and People*, Pergamon Press, 1977; Editor and part author of *Naturally Ventilated Buildings* Spon (1997) and *Creating the Productive Workplace (2000)* Spon; published over 200 papers on various aspects of his research and education projects.

The University of Reading
School of Construction Management and Engineering
Whiteknights, PO Box 219
Reading, RG6 6AW
UK
E-mail: d.j.clements-croome@reading.ac.uk

Professor Ross Adey

William Ross Adey received degrees of M.B & B.S. (1943) and M.D. (1949) University of Adelaide, Australia. Royal Australian Navy, 1944-1946. Reader in Anatomy, University of Adelaide 1947-49. University of California, Los Angeles and UCLA Brain Research Institute, 1954-1977. Chief of Research Svc., Veterans Affairs Med. Centre, Loma Linda CA 1977-1997. University Calif. Riverside 1997-2000.

Since 1965, he has studied cell and molecular, physiological and behavioural effects of nonthermal environmental electromagnetic field exposures with emphasis on RF/microwave low-frequency modulation. These studies support a key role for field transduction in cooperative processes at cell membranes that may involve free radicals and calcium-dependent enzymatic mechanisms, organised hierarchically. Nuffield Foundation Fellow, University of Oxford, 1950-51. D'Arsonval Medallist, Bioelectromagnetics Soc., 1989. Sechenov Medallist, Russian Acad. Medical Sciences, 1996. Wellcome Trust Visiting Professor, Royal

Society of Medicine, 1996. Hans Selye Medallist, American Institute of Stress, 1999.

Distinguished Professor of Physiology
School of Medicine
Loma Linda University
31866 Third Avenue
Redlands, California 92373
USA
E-mail: Radey43450@aol.com

Dr Cyril Smith

Cyril was born in London in 1930. His career started in Radar at T.R.E. Malvern; his Ph.D was on X-Ray image intensification at Imperial College, London; He taught physics before moving to Salford in 1964. With over 100 publications and the book Electromagnetic Man, there have been four mainstreams of his research: instrument technology, dielectric liquids, bio-medical electronics; electromagnetic hypersensitivity and electromagnetic effects in living systems, bio-molecules and water. Since retiring in 1990, he has continued writing, research and lecturing.

Honorary Senior Lecturer
University of Salford
School of Acoustics and Electronics
Manchester, M30 9EA
UK
E-mail: cyril.smith@which.net

Professor Andrew Marvin

A Lecturer and Senior Lecturer at the University of York from 1979 – 1995. Appointed Professor of Applied Electromagnetics 1995. Founder and Leader of the Applied Electromagnetics Research Group, Department of Electronics, University of York. Technical Director of York EMC Services Limited. Research interests are Electromagnetic Compatibility Measurements and Metrology, Associate Editor of IEEE Trans EMC. Chairman of Cost 261, EMC in Complex and Distributed to Systems.

Applied Electromagnetics
Department of Electronics
University of York
Heslington, York, YO10 5DD
UK
E-mail: acm@ohm.york.ac.uk

Alan Meyer

Alan Meyer has been a practising lawyer in Westminster since the early 1960s and from 1976 to 2001 was the Senior Partner of a medium sized Private Client firm. He is now a full time Consultant with the large Private Client firm, Bircham Dyson Bell.

In 1997 he was instructed to oppose a mast application on behalf of Mr Mohammed Al Fayed. This led to a judicial review which found that the planning process was flawed. However, it was necessary to appeal the decision to the Court of Appeal with regard to the High Court Judge's discretion. At that Court of Appeal hearing, it was stated by the Court of Appeal that it was common ground that genuine public fear and concern was a material planning consideration.

Alan Meyer acted initially as Legal Adviser for NIFATT (Northern Ireland Families Against Television Towers) and in that capacity gave evidence in both Belfast and London to the Stewart Independent Expert Group on mobile telecommunications. Since then, he has been involved in the government/ industries link further research programme. From December 2000 he became Legal Director of Mast Action UK and in legalistic terms would be best described as an objector's lawyer although he has assisted more than one local planning authority with regard to the law and how it affects planning guidance.

Senior Consultant, Legal Director of Mast Action UK
Bircham Dyson Bell (Solicitors)
50 Broadway
London, SW1H OBL
UK
Web site: www.mastaction.co.uk

Dr Gerard Hyland

Honorary Associate Fellow of the University of Warwick, UK, and a member of the International Institute of Biophysics, in Neuss-Holzheim, Germany specialising in biophoton research. During the last 6 years, a particular concern has been potential health hazards associated with non-thermal influences of the low intensity, pulsed microwave radiation used in GSM telephony, and how to render this technology more electromagnetically biocompatible.

He is regularly invited to speak on these subjects at international conferences, and gave evidence to the IEGMP. Recent publications include a review article for The Lancet (November 2000) – Physics and Biology of Mobile Telephony – and a report commissioned by the Scientific and Technological Options Assessment (STOA) Programme of the Directorate General for Research – The Physiological and Environmental Effects of Non-ionising Electromagnetic Radiation – which was published by the European Parliament in March 2001.

Physicst Department
University of Warwick
Coventry, CV4 7AL
UK
E-mail: gjhyland@hyland.demon.co.uk

Simon Pearl

A Partner at Davies Arnold Cooper with 25 years practice experience in product liability litigation including the leading cases of the Whooping Cough Vaccine test case and HIV/AIDS and Hepatitis C virus in blood. He is currently working on the MMR Vaccine litigation.

Partner
Davies Arnold Cooper (Solicitors)
6-8 Bouverie Street
London, EC4Y 8DD
UK
Web site: www.dac.co.uk

Dr Philip Chadwick

Philip Chadwick has worked on the interaction of EMF with the human body since 1985, within the University system, at NRPB and at the Department of Health. He is currently Technical Director of MCL, an independent research and consultancy organisation. He is Chairman of CENELEC TC106X and four of its sub-committees, a member of IEEE SCC28 and is a Consulting Member of ICNIRP.

Technical Director
Microwave Consultants Limited
17B Woodforsd Road
London E12 2EL
UK
E-mail: phil.chadwick@mcluk.org
Web site: www.mcluk.org

Dr Zenon Sienkiewicz

Dr Sienkiewicz is from the Radiation Effects Department of the NRPB and has an interest in behavioural effects of power frequency magnetic fields and radio frequency fields. He has written many papers, reviews and articles on the subject of electromagnetic fields. He is also a consultant to AGNIR and a member of the UK MTHR programme management committee.

National Radiological Protection Board (NRPB)
Chilton, Didcot, Oxon, OX11 ORQ
UK
E-mail: Zenon.Sienkiewicz@nrpb.org.uk
Web site: www.nrpb.org

Dr Magda Havas

Magda Havas is an Associate Professor in Environmental and Resource Studies, Trent University, Peterborough, Canada. She received her B.Sc. and Ph.D. at the University of Toronto and then did PostDoctoral Research at Cornell University.

Her research, on the biological effects of environmental pollutants, includes acid rain, metal pollution (aluminum, copper, nickel), drinking water quality, and electromagnetic fields both low frequency and radio frequency. She also has a keen interest and has published in the area of environmental education.

Environmental & Resource Studies
Trent University
Peterborough
Ontario, K9J 7B8
Canada
E-mail: mhavas@trentu.ca

Dr Ing Dietrich Moldan

Graduated in 1987 at the University of Aachen.worked from 1986-2001 in different construction material producing companies. Until end of 2001, he had been Head of the Department of Environment and Health at Gebr. Knauf Westdeutsche Gipswerke, Germany. Since 1996 he has a consulting office for environmental analysis (technical fields and waves; indoor air pollution). His paper entitled Reduction and Shielding of RF and Microwaves in the Building Industry was written with co-author Prof. Dipl.-Ing Peter Pauli from the German Armed Forces University Munich.

Consulting Office for Environmental Analysis
Baubiologe IBN, Am Henkelsee 13
D-97346 Iphofen
Germany
E-mail: dietrich.moldan@dr-moldan.de

Alasdair Philips

Alasdair is a professional EMC engineer and scientist and is widely recognised as one of the few truly "independent" UK experts on the possible adverse health effects of non-ionising radiation. He started working in the telecommunications industry in 1969.

He has been studying and writing on the subject of the possible biological effects of electromagnetic fields since 1986. He has given professional advice to many local authorities and presented Expert Evidence on these matters to the High Court, local Courts, Public Inquiries and Hearings and has been on Regulator committees. In 1987 he was a founder member of Powerwatch, a consumer information service on the possible adverse health effects of non-ionising radiation.

UK Powerwatch
2 Tower Road, Sutton, Ely
Cambridgeshire, CB6 2QA
UK
E-mail: aphilips@gn.apc.org
Web Site: www.powerwatch.org.uk

Dr Jean Monro

Dr Monro has a background in hospital general medicine and worked at the National Hospital for Nervous Diseases, London, researching migraine and multiple sclerosis. She entered full-time practice in Environmental Medicine in 1982 and in 1988 established the Breakspear Hospital for Allergy and Environmental Medicine. She has many publications to her name and regularly speaks at conferences worldwide. Her primary areas of interest are nutrition, medicine and immunology, metabolic function and environmental medicine.

Breakspear Hospital
Lord Alexander House
Waterhouse Street
Hemel Hampstead, Herts, HP1 1DL
UK
E-mail: jmonro@breakspear.org

Anne Silk

Anne Silk is an environmental health researcher with special interest in Electromagnetic Fields. She is a retired contact lens practitioner with 30 years experience with referred patients, many with allergies and atypical ocular conditions.

The Bostons
Optician Health Researcher
Vice Chairman of Electromagnetic Biocompatibility Association
Thorn Close
Whiteleaf
Princess Risborough, HP27 OLU
UK
E-mail: annesilk@waitrose.com

Professor Denis Henshaw

Professor Henshaw holds a Medical Research Council Programme Grant leading a team specialising in the effects of low level radiation on the human body. Although much of this work has concerned with low level ionising radiation, more recent work has concentrated on the ability of high voltage powerline electric fields to mediate increased exposure to air pollution. The findings suggest that people living near high voltage powerlines are at increased risk of illnesses known to be associated with air pollution.

HH Wills Physics Laborotary
University of Bristol,
Tyndall Avenue, Bristol, BS8 1TL
UK
E-mail: d.l.henshaw@bris.ac.uk

Professor Barry Michael

PhD in Radiation Physics. Professor Michael has been mainly interested in radiation biophysics (ionising and non-ionising), radiation and cancer treatment, radiation risk, DNA damage, micro-irradiation techniques. He is a visiting Professor at Queen Mary and Westfield College, London and a Member International Commission on Radiation Units and Measurement.

Joint Executive, Head of Cell and Molecular Biophysics Group,
Gray Cancer Institute,
PO Box 100,
Mount Vernon Hospital,
Northwood, Middlesex, HA6 2JR
UK
E-mail: michael@gci.ac.uk
Web site: www.graylab.ac.uk

Professor Jeffrey Hand

Jeff Hand is Head of the Radiological Sciences Unit within the Imaging Directorate at Hammersmith Hospitals NHS Trust and Professor in Imaging Physics within the Faculty of Medicine at Imperial College, London. He has worked on medical applications of RF and microwave fields for 25 years and authored more than 170 scientific papers. He has PhD and DSc degrees from the University of Newcastle upon Tyne, and has worked at Stanford University and the University of Arizona in the USA, and at Shimane Medical University at Izumo in Japan. He is a Fellow of the Institute of Physics, a Fellow of the Institution of Electrical Engineers and a Fellow of the Institute of Physics and Engineering in Medicine. He is also a Chartered Engineer, a Chartered Physicist and a registered Clinical Scientist.

Head of Radiological Sciences Unit
Hammersmith Hospital
Due Cane Road,
London, W12 OHS
UK
E-mail: j.hand@ic.ac.uk

Dr Neil Cherry

Dr Neil Cherry was the Associate Professor of Environmental Health at Lincoln University, New Zealand. This academic position involves using his experience of research and teaching or climate change, wind and solar energy resources, energy efficiency, human biometeorology, biophysics, environmental epidemiology in health effects weather, air pollution, viruses and electromagnetic radiation health effects. For his advanced and innovative work in this area of integrative environmental health science, Dr Cherry was awarded a Royal Honour in 2002, Officer of the New Zealand Order of Merit. He was a well-known independent international academic presenter of over 30 papers to international conferences on the health effects of EMR/EMF. Dr Neil Cherry died on 24 May 2003, aged 56, from motor neurone disease.

Dr Jeremy Smallwood

After seven years in electronics R&D, Jeremy Smallwood worked on contract research in the Electrostatics Research Group at the University of Southampton from 1987 to 1994, studying electrostatic discharge measurements and ignition risks, which became the subject of his PhD. He subsequently worked for ERA Technology Limited as Electrostatics Section Leader before forming his specialist R&D and consultancy company Electrostatic Solutions Ltd.

Dr Smallwood is Chairman of the Institute of Physics Statics Electrification Group, and the International Electrotechnical Committee TC101 (Electrostatics).

Electrostatic Solutions Limited
13 Redhill Crescent,
Bassett, Southampton,
Hampshire, SO16 7BQ
UK
E-mail: jeremys@static-sol.com
Web site: www.static-sol.com

Professor Olle Johansson

Olle Johansson works in the field of basal and clinical neuroscience at the Karolinska Institute in Stockholm. He is the head of the Experimental Dermatology Unit in the Department of Neuroscience and he specialises in radiobiology, ionising and non-ionising radiation. He is particularly interested in the effects of microwaves on the human body as well as the clinical issue of electrosenstivity. Author of more than 450 articles within the field of neuroscience and dermatoscience.

Experimental Dermatology Unit,
Karolinska Institute,
17177 Stockholm, Sweden
E-mail: olle.johansson@neuro.ki.se

Dr Vladimir Binhi

Dr V.N. Binhi graduated form the Moscow Physical Technical Institute in 1977; he was awarded his PhD (maths & physics) degree at the P.N. Lebedev Physical Institute, USSR Academy of Sciences in 1982. From 1982 to 1994 he worked in the General Physics Institute USSR Academy of Sciences and other physics institutes. From 1994–2000 he was Head of Biophysics department in the International Institute of Theoretical and Applied Physics, Moscow, and then from 2000 – Head of GPI RAS Laboratory. Research expertise: magnetic processes in molecular systems, theoretical modelling of biological effects of electromagnetic fields, proton dynamics and structure defects in liquid water, magnetic measurements.

Head of Radiobiology Laboratory
General Physics Institute,
Russian Academy of Sciences,
38 Vavilova Street, Moscow, 119991
GSP-1 Russian Federation
E-mail: infor@biomag.info

Professor Alan Preece

Alan Preece is a professor in Oncology and Medical Physics at the University of Bristol. He specialises in radiobiology, non-ionising radiation and physiological measurement and is particularly interested in the interactions of microwaves and with the human body.

Bristol Haematology and Oncology Centre
University of Bristol,
Level C, Horfield Road
Bristol, BS2 8ED
UK
E-mail: a.w.preece@bristol.ac.uk

Alastair Speare-Cole

Alastair Speare-Cole graduated from Oxford in 1981 having read geology. His expertise lies in: liability reinsurance, motor reinsurance, alternative risk transfer, E.M.F., subsidence, pollution and property.
History: FCII Chartered Insurance Institute, Fellow of Geological Society, M.A. Oxon: Geology and Mineralogy.

Managing Director
AON Limited
8 Devonshire Square
London, EC2M 4PL
UK
E-mail: alastair.speare-cole@aon.co.uk
Web site: http://www.aon.co.uk

Professor Ray Kemp

Prof. Ray Kemp BA, MSc, PhD, MRTPI is Head of the Risk Management Group at Galson Sciences Limited. He holds an honorary visiting professorship in Risk Management and Communication at the University of Surrey, Guildford, UK. Ray has 20 years research and consulting experience in corporate risk assessment, risk management and risk communication for controversial projects. He was President of the Society for Risk Analysis in Europe from 1995 to 19996. Prof. Kemp's most recent work has been in relation to risk communication regarding the health risks of mobile phone base stations. He has provided guidance on environmental planning, consultation and professional training in risk communication both in the UK and in Europe. He has acted as chairman and independent facilitator of a series of stakeholder roundtable meetings on the mobile phone health issue for the UK mobile phone sector. Ray is also an advisor to the World Health Organisation in Geneva, chairing an international expert group on risk communication in relation to the health risks of electromagnetic fields.

Head of Risk Management Group
Galson Sciences Limited
5 Grosvenor House
Melton Road, Oakham
Rutland, LE 15 6AX
UK
E-mail: rvk@galson-sciences.co.uk
Web site: www.galson-sciences.co.uk

Michael Dolan

Michael Dolan is Director of the Mobile Telecommunications Advisory Group (MTAG) within the Federation of the Electronics Industry (FEI), which represents he UK mobile manufacturers and network operators on health and related issues including planning. Michael has held this position since 1 September 1999. He was formerly Deputy Director of the Electricity Supply Association of Australia where he was responsible over a period of nine years for electricity industry management of the power frequency health issue. A lawyer by profession, Michael has extensive experience in issues management and media interface.

Director
Mobile Telecoms Advisory Group,
Federation of the Electronics Industry,
London,
UK
E-mail: mdolan@fei.org.uk

Nicole Hughes

Nicole Hughes joined the FEI in October 2001 as Public Affairs Manager. The FEI represents the five mobile phone companies in the UK on health and planning related matters. During her time with the FEI, Ms Hughes has presented at numerous conferences on the issue of risk management and the precautionary principle relating to mobile health.

Ms Hughes has extensive experience in public affairs, journalism and issues management. She currently works on policy development and public affairs interface.

Public Affairs Manager
Mobile Telecoms Advisory Group
Federation of the Electronics Industry
London,
UK
E-mail: nhughes@fei.org.uk
Web site: http://www.fei.org.uk

Dr Sakari Lang

He was awarded an MSc in Environmental Sciences (1988) and a PhD in Radiation Biology (1994), both from the University of Kuopio, Finland. Post-doctoral fellow at the Department of Radiological Health Sciences, Colorado State University 1995-1996. Assistant professor in radiation biology at University of Kuopio 1997-1998. Principal scientist and research manager (responsible for bioelectromagnetics research and radiation and safety issues at Nokia) at Nokia Research Centre, Helsinki, Finland, from 1998 to date. Sakari Lang has studied effects of both ionising and non-ionising radiation.

Research Manager
Nokia Research Centre
PO Box 407, FIN-0045 Helsinki
Finland
E-mail: sakari.lang@nokia.com

Mike Smith

Mike Smith initially trained in the Royal Air Force as an engineering technician. His subsequent technical and management career within the RAF spanned 22 years and covered a variety of engineering, management, quality and health & safety roles. During his last 4 years within the RAF he fulfilled the role of Ministry of Defence HS&Q Manager (Cryogenics) for mainland Europe. Upon retirement from the RAF, he joined the Defence Evaluation & Research Agency's (now under

PPP renamed QinetiQ) Tactical Communications Division working in a variety of project management roles before taking up the post of Health, Safety & Environment Manager. For the past two years, Mike has been seconded to Quintel S4 Ltd with the post of Project Director for Health, Safety, Environment & Planning with specific responsibility for liaising with local and central government, regulators, the general public, pressure groups and others both in the UK and abroad. He is a corporate member of the Institute of Occupational Safety and Health and the International Institute of Risk and Safety Managers.

Project Director of Health and Safety, Environment & Planning
Quintel S4 Ltd
Building A57
Cody Technology Park
Farnborough
Hants, GU14 0LX
UK
E-mail: mike.smith@quintels4.com
Web site: www.quintels4.com

Dr Peter Grainger

Peter Grainger is a graduate of the University of Bristol and London. He has been researching the effects of non-ionising electromagnetic energy and health for seven years. Recent work has included mathematical modelling of personal exposure to magnetic fields.

Bristol Haematology and Oncology Centre
Medical Physics University Research Centre
Bristol University
Horfield Road
Bristol, BS2 8ED
UK
E-mail: drpetergrainger@yahoo.co.uk

B. Blake Levitt, Journalist

Blake Levitt is an award-winning medical and science journalist. A former New York Times writer, she is the author of Electromagnetic Fields, A Consumer's Guide to the Issues and How to Protect Ourselves (Harcourt Brace 1995) for which she won an Award of Excellence from the American Medical Writers Association. She is also the editor of Cell Towers, Wireless Convenience? or Environmental Hazard? Proceedings of the Cell Towers Forum, State of the Science/State of the

Law (New Century Publishing, 2001). She lectures widely on environmental energy issues.

355 Lake Road
P.O. Box 2014,
New Preston
CT. 06777
USA.
E-mail: Blakelevit@cs.com

Preface

Electromagnetic fields are an intrinsic part of the universe. Animals and plants conduct electricity and with this there are associated magnetic fields. Over the last hundred years there has been a rapid rise in the use of electrical equipment inside and outside buildings. Does the rapid increase in electropollution affect the health of people? We do know some people are hypersensitive to electromagnetic fields, referred to in this book as electrosensitive people. We do not however understand the mechanisms which underlie this phenomenon. Knowledge on the subject is very fragmented. Our education at school about hybrid areas such as bio-physics and electro-medicine is relatively poor.

The *Electromagnetic Environments and Health in Buildings Conference* took place on 16th and 17th May 2002 at the Royal College of Physicians in London. About 150 people attended including scientists, people from various professions, various manufacturers, electromagnetic field networkers, private individuals and representatives from the media. The main aim of the conference was to bring people from different disciplines and all walks of life together, to discuss many different points of view and hear from those that carry out research, those that design buildings, those medics that treat patients, as well those who collect knowledge and distribute it internationally via various networks.

The problem of hypersensitivity is making us think deeply about the validity of the knowledge that we have. On one hand some scientists are saying that there are no known mechanisms for understanding the interaction of the human body with electromagnetic fields. But there are others who believe that there are known mechanisms, which have been developed and replicated by others. The book *Magnetobiology* by Binhi (2002) gives detailed scientific explanations of such mechanisms. There are a number of people who suffer from electrosensitivity and we need to look at their problems sympathetically even though they describe what scientists usually term *anecdotal (or case study) evidence*, which many scientists dismiss. There is the possibility that different issues are being confused. Case study evidence clearly does not propose a mechanism for the problem and so the cause of electromagnetic hypersensitivity still eludes us. On the other hand the effect exists; this is no different from a patient going to the doctor with some illness and describing the symptoms for which the doctor may be able to give some help. The fact that a condition may be ameliorated does not mean that the doctor understands the mechanisms behind the illness in all cases. It is quite possible to have an effect demonstrated without understanding the cause but this does not mean the effect should be dismissed. One recalls that initially the health effects of smoking, asbestos or repetitive strain injury from working with computers were all dismissed. Several leading scientists have supported the September 2002 Catania Resolution which basically states electromagnetic fields do adversely affect health (see Appendix).

In general we are better at dealing with reductionist ideas and analysis but not so confident when dealing with holistic ideas requiring a synthesis of knowledge from a range of disciplines. However, scientists should acknowledge that even physics and mathematics have limitations. Confucius wrote that:

To be uncertain is uncomfortable
To be certain is ridiculous

Government bodies tend to be cautious and manufacturers tend to be profit oriented. We need to beware of being so excited by the opportunities afforded by new technologies that matters of health are forgotten. In the November issue of Physics World 2002 some research is reported that has developed miniature antennae which produce a much lower energy density than current devices. Mobile phones and computers are used in the workplace and by very young children in the home as well as in school. People want to communicate with anyone they like wherever they are. The limitations of technology are also becoming apparent. Ultimately face to face communication is preferable but many times this is not possible, and understandably the technology which makes communication possible is therefore welcomed, but then possibly overused in situations where it is not necessary.

This book is largely based on the Conference with subsequent additions and covers health effects of electromagnetic fields; emissions and standards; and offers some glimpses into the future. It concludes that there is much more valid scientific knowledge available but it is fragmented. There is clearly a need for much more research using a range of methodologies. Physicists, biologists, medics, physiologists, epidemiologists and sociologists need to work together on scientific research programmes.

There remains the problem of who pays for the research. The health of nations is partly a responsibility of governments but the computer, mobile phone and multi-media industries are developing high technology products to sell in vast volumes to young and the old alike. The convenience of communication offered by their products is seductive and attractive. Health issues however are given scant attention. There is a need for public-private sector financed research programmes to ensure health is not endangered.

I would like to thank my colleagues Anne Silk (Vice Chairman of the Electromagnetic Biocompatibility Association, EMBA), Dr Peter Grainger (formerly at the Department of Oncology at the University of Bristol), Dr Cyril Smith (formerly at the University of Salford) who helped me plan the programme. Additional thanks to other peer reviewers Professor Anthony Barker (Royal Hallamshire Hospital); Professor Lawrie Challis (University of Nottingham); Dr Zenon Sienkiewicz (National Radiological Protection Board); ABACUS for undertaking the administrative arrangements and the financial risk for the conference under the leadership of Peter Russell; all the speakers who gave their time at and after the conference to help produce this book; to the audience that attended the Conference and for the many who wrote to me afterwards about how they had found it valuable and enjoyable; to EMBA for supporting the marketing

of the book. My special thanks to Gülay Ozkan for preparing the camera-ready copy for the publishers with such care, diligence and dedication; to Maureen Taylor and Göksenin Inalhan for manuscript preparation; to Anne Silk Vice-Chairman of EMBA for proof reading.

Professor Derek Clements-Croome
School of Construction Management and Engineering
University of Reading
October 2002

Part I

Setting the Scene

CHAPTER 1

Healthy Buildings

Derek Clements-Croome

1.1 BACKGROUND

What do we mean by a healthy building? There are health and safety regulations but these merely set a basic threshold for environmental safety conditions. They define nothing about the real quality of the human sensory experience.

We live through our senses which continually receive stimuli from the world around us, from which particular ones are selected to deal with the activity being undertaken at a particular time. The remaining stimuli still exist but our mind, whilst aware of them, places them in the background. Stimuli can be thought of as packets of information received by the body's receptors and processed from them via the nervous system to the brain which results in our perceived experiences or so-called qualia.

There are *moving* and *static* elements in our environment. Air, light and sound patterns vary in space and time, in other words they *flow* through the space. Structural elements such as walls and floors are usually *fixed* but the way they are arranged, the materials from which they are made, their colours, their textures affect the sound and the visual environments. Materials can emit gases or particulates to the air so they can also affect the air quality. There are moveable components such as furniture which affect our skeletal comfort.

Pollutants are formed from dust and gases in the air; these arise from people, clothing, furnishings, coverings of objects, air entering the space from outside or even the dirty air from poorly maintained ventilation systems.

The effects of electromagnetic fields are less understood hence the reason for this book (Binhi, 2002; Brune *et al.*, 2001). Visible light is a very small but important part of the electromagnetic spectrum. Non-ionising and ionising radiations are important too although the latter are usually at a negligible level in most buildings. Non-ionising radiation is emitted from computers, mobile phones and power equipment, which are an increasingly prominent part of our living and working environments. It is important to increase our understanding of the interaction between the body's internal electromagnetic fields and those around the outside of the body.

Health means good well-being and refers to the states of mind and the physical body. There must be an overall satisfaction and awareness of the environment with a degree of comfort and freshness, but also a keenness to concentrate on the task in hand. It is easy to disturb this balance by stuffy air conditions, bland surroundings, shabby decor, lack of daylight or non-ergonomic furniture. Of course the nature of the work being undertaken, the organisation and the social ambience are also key factors.

Our responses are conditioned by our past experiences and our expectations which arise from them within particular situations. They are partly physiological and partly psychological so that there is an adaptive physical objective context but also a more elusive fuzzy subjective one. Environment can affect our mood, our feelings as well as our physical reactions.

Poor quality environments – physical, social and organisational – can disturb or distract the mind and lead to negative stress. Stress can weaken the body's defence system (i.e. the immune system) and thus increase the likelihood of building sickness symptoms taking root. These symptoms include respiratory ailments; skin irritations; tired eyes; headaches; and lethargy.

1.2 ARCHITECTURE AND THE SENSES

The idea of taking into account the senses of a building occupant has led to our research into how we smell, touch and see a building, as well as our psychological interactions with it. Architecture deals not only with the materials and form but also with people, emotion, space and relationships between them (Clements-Croome, 2000). Buildings should be a multi-sensory experience. Pallasmaa (1996) elegantly describes this belief in his book *The Eyes of the Skin* and also in association with Holl and Perez-Gomez (1994) in the book *Questions of Perception.*

During the Renaissance, the five senses were understood to form a hierarchical system from the highest sense of vision down to touch. It is by vision and hearing that we acquire most of our information from the world around us. But one should not underestimate the importance of the other senses. Olfactory enjoyment of a meal or the fragrance of flowers, and responses to temperature provide a bank of sensory experience which help to mould our attitudes and expectancies about the environment. The senses not only mediate information for the judgment of the intellect, they are also channels which ignite the imagination. This aspect of thought and experience through the senses, which trigger the body and mind, is stimulated not only by the environment and people around us but when inside a building, it is the architecture of the space which sculpts the outline of our reactions. Merleau-Ponty (1964) said that the task of architecture was to make visible how the world touches us.

At the heart of architecture is the fundamental question of how buildings in their design and use can confront the questions of human existence in space and time and thus express and relate to man's being in the world. If this question is ignored the result is soulless architecture which is a disservice to humanity. There is a danger, for example that the ever-increasing pace of technology is distorting natural sociological change. Such distortion makes it difficult for modern architecture to be coherent in human terms.

Buildings must relate to the language and wisdom of the body. If they do not they become isolated in the cool and distant realm of vision. But in assessing the value of building, how much attention is made to the quality of the environment inside the building and its effects on the occupants? The qualities of the environment affect human performance inside a building and these should always be given a high priority. This can be considered as an invisible aesthetic that together with the visual impact makes up a total aesthetic.

Buildings should provide a multi-sensory experience for people and uplift the spirit. A walk through a forest is invigorating and healing due to the interaction of all sense modalities; this has been referred to as the polyphony of the senses. Architecture is an extension of nature into the man-made realm and provides the ground for perception, a basis from which one can learn to understand the world. Buildings filter the passage of light, air and sound between the inside and outdoor environments; they also mark out the passage of time by the views and shadows they offer to the occupants. Pallasmaa (1996) gives as an example to illustrate this point. He believes that the Council Chamber in Alvar Aalto's Säynätsalo Town Hall recreates a mystical and mythological sense of community where darkness strengthens the power of the spoken word. This demonstrates the very subtle interplay between the senses and how environmental design can heighten the expression of human needs within a particular context.

Although the five basic senses are often studied as individual systems covering visual, auditory, taste - smell, orientation and the haptic sensations, there is interplay between the senses. Sight, for example, collaborates with the other senses. All the senses can be regarded as extensions of the sense of touch because the senses as a whole define the interface between the skin and the world. The combination of sight and touch allows a person to get a scale of space, distance or solidity.

However, qualitative attributes in building design are often only considered at a superficial level. For example, in the case of light the level of illuminance, the glare index and the daylight factor are normally taken into account. But in great spaces of architecture there is a constant deep breathing of shadow and light; shadow inhales, whereas illumination exhales light. The light in Le Corbusier's Chapel at Ronchamps for example gives the atmosphere of sanctity and peace. How should we consider hue, saturation and chroma in lighting design for example? Buildings provide contrast between interiors and exteriors. The link between them is provided by windows. The need for windows is complex. It includes the need for an interesting view and for contact with the outside world; at a fundamental level, it provides contrast for people working in buildings. Much work today is done at computers in close quarters and requires eye muscles to be constrained to provide the appropriate focal length, whereas when one looks outside towards the horizon the eyes are focused on infinity and the muscles are relaxed. There are all kinds of other subtleties, such as the need to recreate the wavelength profile of natural light in artificial light sources, which need to be taken into account. Light affects mood. How can this be taken into account in design?

The surfaces of the building set the boundaries for sound. The shape of the interior spaces and the texture of surfaces determine the pattern of sound rays throughout the space. Every building has its characteristic sound of intimacy or monumentality, invitation or rejection, hospitality or hostility. A space is conceived and appreciated through its echo as much as through its visual shape, but the acoustic concept usually remains an unconscious background experience. It is said that buildings are composed as the architecture of space, whereas as music represents the architecture of time. The sense of sound in buildings combines the threads of these notions. Without people and machines, buildings are silent. Buildings can provide sanctuary or peace and isolate people from a noisy fast moving world.

The ever increasing pace of change can temporarily be slowed down by the atmosphere created in a building. Architecture emancipates us from the embrace of the present and allows us to experience the slow healing flow of time. Again buildings provide the contrast between the passing of history and the pace of life today.

The most persistent memory of any space is often its odour. Every building has its individual scent. Our sense of smell is acute, and strong emotional experiences are awakened by the olfactory sense. Odours can influence cognitive processes that affect creative task performance as well as personal memories. Creative task performance is influenced by moods, which odours can also affect (Warren and Warrenburg, 1993; Erlichman and Bastone, 1991; Baron, 1990).

Various parts of the human body are particularly sensitive to touch. The hands are not normally clothed and act as our touch sensors. The skin reads the texture, weight, density and temperature of our surroundings. There is a subtle transference between tactile, taste and temperature experiences. Vision can be transferred to taste or temperature senses; certain odours, for example, may evoke oral or temperature sensations. The remarkable, world-famous percussionist Evelyn Glennie is deaf but senses sound through her hands and feet and other parts of her body. Architectural experience brings the world into intimate contact with the body.

The body knows and remembers. The essential knowledge and skill of the ancient hunter, fisherman and farmer, for example, can be learnt at any particular time, but more importantly, the embodied traditions of these trades have been stored in the muscular and tactile senses. Architecture has to respond to behaviour that has been passed down through the genes. Sensations of comfort, protection and home are rooted in the primordial experiences of countless generations. The word "habit" is too casual and neglects the history embedded in us.

The interaction between humans and buildings is more complex than we imagine. As well as simple reactions that we can measure, there are many sensory and psychological reactions that are very difficult to understand and quantify.

1.3 HEALTHY BUILDINGS

Indoor environment can be defined by physical features of the environment such as lighting, colour, temperature, air quality and noise. These factors have been studied extensively with regard to their impact on task performance and satisfaction. Sundstrom (1987) reports laboratory studies that show with high consistency that ambient conditions do have real and meaningful influences on behaviour in 150 out of a total of 185 experiments. A complete analysis of indoor environmental quality would take into consideration not only indoor air quality and thermal comfort but also lighting, floor lay-out, colour scheme, building materials, noise level, disruption, weather, management styles, space, employee and customer backgrounds employee/customer satisfaction and employee motivating factors. Any field study must account for all of these factors.

Interior finishes can have a marked effect on air quality. Lisbet (1994) shows that occupants working in offices with carpets complained significantly more about the sensation of dry and stuffy air than occupants working in offices with linoleum flooring, Research by Rundnai (1994) shows the prevalence of the most frequent symptoms among people living in buildings with different types of construction in Budapest. Brick construction shows a lower incidence of sick building syndrome (SBS) than concrete; the brick buildings were warmer and drier, whereas the concrete ones had poor heating control and possibly low infiltration. People living in mixed concrete and breeze block homes suffered from higher concentrations of formaldehyde. Clearly, materials and construction are important.

Ricci-Bitti (1994) distinguishes between SBS and mass psychogenic illness (MPI). The former is a temporary failure to cope with the environment whereas the latter represents a collective stress response. Building related illness (BRI) and Neurotoxic disorders (NTD) are deemed to be caused by environmental pollution, although minor forms of the these syndromes may be related to stress. The principal difference between these phenomena is that neurotoxic disorders and building related illness (such as legionnaires disease) persist whether the person is in the workplace or away from it, but in the case of sick building syndrome and mass psychogenic illness the effects only occur in the working environment and tend to decay quickly on leaving it. Most attention has been given to the sick building syndrome.

The World Health Organisation (WHO, 1983) describes the term sick building syndrome as a collection of non-specific symptoms expressing a general malaise associated with occupancy of the workplace. Symptoms include irritations of the eyes, respiratory system, skin rashes, as well as mental discomforts due to lethargy or headaches. The ancient Chinese believed that invisible lines of energy, known as *chi* run through our bodies and the environment. A smooth flow of chi means wellbeing, but if it is blocked then ill health, expressed in various ways results. Feng Shui is the art of freeing and circulating chi. Equipment such as computers emit electromagnetic fields and these together with underground water and geological faults can disturb the earth's natural electromagnetic field. There remains the possibility that geopathic stress could be partially responsible for sick building syndrome.

There have been numerous studies on *sick building syndrome*, but a lack of coordinated research means the methodology of investigation has varied, making it difficult to compare results. Research by Jones (1995), together with the work on a standard questionnaires by Raw (1990, 1995), Burt (1997), Baldry (1997) and Berglund (2000), will allow future investigations to be carried out in a more consistent manner. Sick building syndrome conditions are prevalent in the work environment but disappear when people leave it.

It is, for example, very difficult to make any strong conclusions about the effect of ventilation with respect to sick building syndrome. According to work by Jaakkola (1991) and also Sterling (1983) ventilating a building with 25% or 100% outdoor air makes little difference. Likewise other work referred to by Hedge

(1994) quotes work where the ventilation rate has been increased from 10 l/s per person to 25 l/s per person with no beneficial effects on SBS symptoms; Sundell (1994) and also found that ventilation rates above 10 l/s per person have no discernable effect on the symptoms.

Jones (1995) classifies healthy offices as those which average 1-2 symptoms per worker, while relatively unhealthy offices have 4-5 symptoms per worker. Headaches and lethargy appear to be nearly always the most frequently reported symptoms.

Hedge (1994) carried out an investigation in six office buildings and found that the prevalence of eye, nose and throat symptoms were higher in airconditioned offices than naturally ventilated ones, but headaches did not show any consistent pattern. Other studies by Burge *et al.* (1987); Mendell and Smith (1990); Wilson and Hedge (1987) confirmed that SBS symptoms were less prevalent in naturally ventilated buildings than airconditioned ones, but some mechanically ventilated buildings did not give rise to any problems either. Robertson *et al.* (1985) compared SBS symptoms in adjacent air-conditioned and naturally ventilated offices and found that the symptoms were more prevalent among workers in the airconditioned offices, although measurement of a variety of physical environmental factors failed to show any significant differences in the environmental conditions between buildings. Other work described by Hedge (1994) confirms these findings.

However, care should be taken to ensure that the concentrations of volatile organic compounds are measured and compared. Some studies have found that symptoms maybe associated with suspended particulate matter, but there is contrary evidence about this issue also. The lack of a consistent association between symptoms and they physical environment suggests that building sickness syndrome remains elusive and so maybe there are a number of other factors like geopathic stress, individual factors, perceived control and occupational factors are more important. Again psychosocial factors are probably not directly related to the SBS symptoms, but Hedge (1994) argues that psychosocial variables may trigger off patterns of symptom reporting. Hedge (1994) describes a large study that he has undertaken in 27 air-conditioned offices. Dry eyes and headaches were found to be weakly associated with formaldehyde; mental fatigue was found to be weakly associated with formaldehyde and particulate concentrations; complaints about stale air were associated with carbon dioxide levels. The building users age, job grade and smoking status was not associated with SBS symptoms. Results showed that more SBS were reported by women; full-time computer users; building occupants with high job stress or low job satisfaction; people who perceived the indoor air quality to be poor; the 18-35 years old age group; occupants who have allergies; people who have migraines; users who wore spectacles or contact lenses, and finally smokers. Hedge (1994) concluded that reports about sick building syndrome symptoms are influenced by several individual and occupational interacting factors. Other studies by Hedge (1994) attempted to establish if a certain personality type was susceptible to sick building syndrome but did not establish any connection. Likewise the effect of circadian rhythms did not appear to be important. Sick buildings syndrome appears to arise from a set of multiple risk factors, some of which are environmental, but biological, perceptual and occupational aspects are also important. The general conclusion can be made that environmental, occupational and psychosocial factors interact to induce sick building syndrome symptoms.

Jones (1995) considers health and comfort in offices and states that the symptoms commonly referred to as sick building syndrome (SBS) show a wide range of variation in reported symptoms between buildings and also between zones in any one building. Only about 30% of the variation in symptoms has been explained by the built environment, by an individuals characteristics or by the job.

In common with other work he concludes that the symptoms of SBS arise from a combination of factors such as building environment, nature of the work being undertaken, as well as the individual characteristics of the person. One important conclusion reached by Jones (1995) is that when thermal conditions are perceived as comfortable, the office is not necessarily healthy. This is also in some ways analogous to earlier work, already discussed, which suggests that the most productive environments are slightly less than comfortable. He calls for improved standards of maintenance, spatial simplicity and flexibility, as well as adaptability of services, good management and recognition that the building, its environment and activities all interact dynamically.

The Health and Safety Executive published a booklet in 1995 entitled How to Deal with Sick Building Syndrome. This booklet helps building owners to identify and investigate buildings, besides giving advice on how to create a good work environment. As regards productivity, it is pointed out that although the SBS symptoms are often mild they do not appear to cause any lasting damage. They can affect attitudes to work and can result in reduced staff efficiency; increased absenteeism; staff turnover; extended breaks and reduced overtime; lost time due to complaining. Advice is offered in the HSE Booklet on building services and indoor environment; finance; and job factors, including management systems and work organisation.

Whitely *et al.* (1995b) suggests *equity theory* may explain the range of individual differences in symptom reporting in the same building and between buildings. Equity theory suggests that the way workers are treated may affect productivity. If this is true then a person in an organisation may intuitively assess their level of reward from the organisation and put the amount of effort in which is related to this. The physical environment in which a person works, can be seen as part of the reward system. The organisation can influence people's attitudes depending on whether any attempt is made to improve conditions in the workplace.

Whitely *et al.* (1995a) describes a well established, relatively stable, personality measure which is related to perceived control called locus of control, which measure the general tendency to attribute outcomes of behaviour due to internal or external causes and goes on to conclude that, the locus of control and job satisfaction appear to explain the perceptions of people to the environment as a whole. These factors also significantly influence the way people report sick building syndrome, environmental conditions and productivity. Whitely states that self reports of productivity change due to the physical environment must be treated with extreme caution, as job satisfaction is a major factor also. Research has already been described which shows that the perception of control over the environment is important with regard to productivity.

1.4 WELL-BEING AND PRODUCTIVITY

Myers and Diener (1997) have been carrying out systematic studies about awareness and satisfaction with life among populations. Psychologists often refer to this as *subjective well-being.* Findings from these studies indicate broadly that those who report well-being have happy social and family relationships; are less self-focused; less hostile and abusive; and less susceptible to disease. It appears also that happy people typically feel a satisfactory degree of personal control over their lives, whether in the workplace or at home. It is probably fair to assume that it is more likely that the work output of a person will be higher if their well-being is high. A study by Jamison (1997) reviews research which links manic-depressive illness and creativity. Many artists, such as the poets Blake, Byron and Tennyson, the painter Van Gogh and the composer Robert Schumann, are well-known examples of manic-depressives. The work output from such people is distinguished but lacks continuity. Mozart and Schubert were not classified as manic-depressives, and their work output was consistently high throughout their short lives. In contrast, Robert Schumann, who suffered hypo-mania throughout 1840 and 1849, was prolific during 1839 - 41 and 1845 - 53. Between these periods he suffered from severe depression; and before 1838 and after 1853, he made suicide attempts.

In the workplace one does not expect creativity at such levels of genius. Rather, it is hoped there will be a consistently high standard of work performance. Townsend (1997), in an article *How to Draw Out All the Talents*, states that 25% of us enjoy our work but the rest of us do not. Productivity suffers when the workplace is a site of conflict and dissatisfaction. Lack of productivity shows up in many ways, such as absenteeism, arriving late and leaving early, over-long lunch breaks, careless mistakes, overwork, boredom and frustration with the management and the environment. Townsend believes that we are all capable of focusing completely on the task at hand and that when we succeed in doing this the whole body feels different. Townsend also says that people in the workplace can be encouraged to use both halves of their brain. The left side is concerned with logic, whereas the right side is concerned with feeling, intuition and imagination (Ornstein, 1973). When logic and imagination work together, problem-solving becomes more enjoyable and more creative.

It is from the body that we orient ourselves in the world. Many measurements used in architecture are originally derived from measurements of parts of the body – a foot, a stride of three feet (a yard), or the size of a brick according to the hand. Many abstract structures for thinking and understanding also originate in bodily experiences of perception, movement and interaction with physical objects. We experience these structures when encountering the environment, and then we project them onto other situations, which helps us to organise shared understanding and knowledge. Our ways of inhabiting the world physically, as well as psychologically and intellectually, extend from our bodies outward. There are information exchanges between us and our surroundings, which are defined by nature, the built environment and people. These form physical and social environments. Their impact on our system is physiological, psychological, emotional and social.

Well-being reflects feelings about oneself in relation to the world. Warr (1998) proposes a view of well-being which comprises three scales: pleasure to displeasure; comfort to anxiety; enthusiasm to depression. There are work and non-work attributes which characterise one's state of well-being at any time, and these can overlap with one another. Well-being is only one aspect of mental health; other factors include personal feelings about one's competence, aspirations and degree of personal control. Good architecture extends and enhances human capacities. Buildings moderate climates, which help to keep the body healthy and enhance well-being. Some buildings demand closely controlled environments, and various equipment can be installed in order to achieve this but many buildings can take advantage of the body's ability to adapt and interact in a compensatory way with other senses.

We all have circadian rhythms, physiologically and psychologically, and these change as we carry out different activities during the course of a day. There is a large variation in these needs, and also behaviour patterns, between one individual and another. It is important that when people are within buildings they have contact with the outside world throughout their working day, and also have the means to adjust their environment according to changing needs. The built environment therefore has to be sensitive to these requirements and allow individuals to control their surroundings, as well as provide adaptability to changing needs.

Architecture is given life and spirit by all the qualities that touch the human senses *and* the human soul. If the functional nourishes our physical needs, the poetic nourishes our soul. This nourishing has been referred to by Franck and Lepori (2000) as *the animism of architecture.*

Stone, marble, brick and concrete create solidity and mass, as well as darkness and enclosure within. Glazed openings bring in light, and provide views and contact with the outside world. Materials have character. Glass is transparent and a mirror extends space by reflection. Brick suggests absorption rather than reflection because of its permeable and porous nature and its closeness to earth. Marble seems to be more aloof because of its coolness, hardness and exotic beauty. In contrast, concrete is a much more plastic building material that allows ease of construction through malleability. Steel structures provide the bones and skeleton of buildings and can be sculpted to different shapes to support or contain structures or spaces.

Lightweight structures that have been developed in the last decades remind us that the skins of buildings are like another layer of clothing. Tents of nomadic tribes or the *ger* of Mongolia are perfect examples of how lightweight materials have been used in everyday living in various parts of the world, whether cold or hot, over many centuries.

Wood is very special because it reminds us of trees and nature. It is flexible and responds to the vibrations of sound, in addition to providing a natural source of colour and pattern. String instruments like the violin, the viola, the cello and the double-bass demonstrate this perfectly.

Architecture supports our living activities and also provides an important ingredient in our perception of the world. We are surrounded by many examples of souless architecture, but there are also some buildings which exhibit great sensitivity to the human senses. The Kiasma Museum of Contemporary Art in Helsinki, designed by Steven Holl, and the lecture hall at the Institute of Technology in Otaniemi, Finland, by Alvar Aalto are two examples. Other examples are the Ronchamp Chapel by Le Corbusier; the Pyramid at the Louvre by IM Pei; the Philharmonie in Berlin by Hans Scharoun; and the house Falling Water, in Pennsylvania, by Frank Lloyd Wright. The work of Hassan Fathy also provides a rich source of human architecture. In all these examples their richness is demonstrated by an imaginative combination of function, form and aesthetics. Buildings are designed for the soul and the spirit not just the function, convenience and form.

A good working environment helps provide users with a good sense of well-being, inspiration and comfort. The main advantages of good environments are reduced investment in upgrading facilities, reduced sickness absence, an optimum level of productivity and improved comfort levels. Individuals respond very differently to their environments, and research suggests a correlation between worker productivity, well-being, environmental, social and organisational factors.

Research shows occupants who report a high level of dissatisfaction about their job are usually the people who suffer more work and office environment related illnesses which affect their well-being, but not always so. Well-being expresses overall satisfaction. There is a connection between dissatisfied staff and low productivity; and a good sense of well-being is very important as it can lead to substantial productivity gain (Clements-Croome 2000). If the environment is particularly poor, people will be dissatisfied irrespective of job satisfaction.

Health is the outcome of a complex interaction between the physiological, psychological, personal and organisational resources available to individuals and the stress placed upon them by their physical and social environments, work and home life. A deficiency in any area increases stress and decreases human performance. Weiss (1997) suggests that the mind can affect the immune system. Stress can decrease the body's defences and increase the likelihood of illness, resulting in lowering of well-being. Stress arises from a variety of sources: *the organisation*, *the job, the person* and *the physical environmental conditions*. It can affect the mind and body, weaken the immune system and leave the body more vulnerable to environmental conditions. In biological terms, the hypothalamus reacts to stress by releasing the hormone ACTH; then the hormone cortisol in the blood increases to a damaging level possibly affecting the brain cells involved in memory. This chain of events interferes with human performance, and productivity falls as a consequence.

1.5 INDOOR ENVIRONMENT AND PRODUCTIVITY

Typical mental health factors related to a job include: stress (which may cause physical symptoms or emotional and psychological difficulties); dissatisfaction with the job itself or with organisational design and structure; unhappiness with achievement and growth; problems with personal relationships; and overall dissatisfaction with the physical indoor environment (Clements-Croome and Li, 2000).

Traditionally thermal comfort has been emphasised as being necessary in buildings but is comfort compatible with health and well-being? The mind and body need to be in a state of health and well-being for work and concentration, which are a prime prerequisite for productivity. Good productivity brings a sense of achievement for the individual as well as increased profits for the work organisation. The holistic nature of our existence has been neglected because knowledge acquisition by the classical scientific method has dominated research and is controlled but limited in application, whereas the world of reality is uncontrolled, subjective and anecdotal but nevertheless is vitally important if we are to understand systems behaviour. It is possible to reconsider comfort in terms of the quality of indoor environment and employee productivity.

Dorgan (1994) has analysed some 50,000 offices in the USA. He found (i) 20% were *Healthy Buildings* (always met ASHRAE Standards 62-1989 and 55-1992 during occupied periods); (ii) 40% *Generally Healthy Buildings* (meet ASHRAE Standards 62-1989 and 55-1992 during most occupied periods); (iii) 20% were *Unhealthy Buildings* (fail to meet ASHRAE Standards 62-1989 and 55-1992 during most occupied period); (iv) 20% were *Buildings with Positive SBS* in which more than 20% of occupants complain of more than two SBS symptoms, and frequently 6 of the more common 18 SBS symptoms.

Health is the outcome of a complex interaction between the physiological, personal and organisational resources available to the individual and the stress placed upon them by their physical environment, work, and home life. Symptoms occur when the stress on a person exceeds the ability to cope and where resources and stress both vary with time so that it is difficult to predict outcomes from single causes. Sickness building syndrome is more likely with warmer room conditions and this can lead to decreased productivity. Higher temperatures also mean wasteful energy consumption. When the temperature reaches uncomfortable levels, output is reduced. On the other hand, output improves when high temperatures are reduced by air-conditioning. When temperatures are either too high or too low, error rates and accident rates increase. While most people maintain high productivity for a short time under adverse environmental conditions, there is a temperature threshold beyond which productivity rapidly decreases. Mackworth (1946) stated that overall the average number of errors made per subject per hour increased at higher temperatures and showed that the average number of mistakes per subject per hour under the various conditions of heat and high humidity was increased at higher temperatures especially above 32°C.

Vernon (1936) demonstrated relative accident frequencies for British munitions plant workers at different temperatures; the accident frequency was a minimum at about 20°C in three munition factories.

Pepler (1963) showed that individual productivity fell as indoor air temperature increased. His work shows that variations in productivity in a non-airconditioned mill were influenced by temperature changes, although absenteeism was apparently not related to the thermal conditioning. On average an 8% productivity increase occurred with a 5°C decrease in temperature (Pepler, 1963).

Factors, such as poor lighting, both natural and artificial, poorly maintained or designed air conditioning, and poor spatial layouts are all likely to affect performance at work. This may be evidenced by lower performance. In a survey of 480 UK offices occupiers, Richard Ellis (1994) states that 96% were convinced that the design of a building affects productivity and when asked an open ended question on how aspects of design tend to lead to this effect; 43% used words such as attractive, good visual stimulus, colours and windows; 41% mentioned good morale, 'feel good' factor and contented happy staff; 19% said more comfortable, relaxing, restful conditions to work; 16% said increases in motivation and productivity; 15% said improved communications; 3% or less said reduced stress. All these aspects help to promote a well designed building. The importance of various factors are summarised in the following table and it can be seen that natural daylight and ventilation are rated highly, but green issues and the use of atria are also significant.

Table 1.1 Importance ratings of various design factors (Ellis, 1994)

Feature	Very	Quite	Not very	Not-at-all
Best use of natural daylight	57%	31%	10%	1%
Ventilation using windows	30%	41%	25%	3%
Thermal design for building	12%	40%	36%	6%
Energy-saving green design	15%	36%	37%	8%
use of atria & glazed streets	4%	20%	52%	18%

Clearly any building that does not maximise its natural daylighting is likely to be unpopular with office occupiers. The high value attributed to the use of windows rather than air-conditioning partly reflects the generally low level of effectiveness achieved by air-condtioning in many buildings, but also more fundamentally the inherent need for natural light and good views out of the building.

Wilkins (1993) reports that good lighting design practice, particularly the use of daylight, can improve health without compromising efficiency. Concerns about the detrimental effects of uneven spectral power distribution and low-frequency magnetic fields are not as yet substantiated. Wilkins states that several aspects of lighting may affect health, including (i) low-frequency magnetic fields; (ii) ultra-violet emissions; (iii) glare; and (iv) variation in luminous intensity; and (v) flicker frequency. The effects of low-frequency magnetic fields on human health are uncertain. The epidemiological evidence of a possible contribution to certain cancers cannot now be ignored, but neither can it be regarded as conclusive but the effect of electromagnetic fields on cognitive functions may be significant.

The ultraviolet light from daylight exceeds that from most sources of artificial light. Its role in diseases of the eye is controversial, but its effects on skin have been relatively well documented.

The luminous intensity of a light source, the angle it subtends at the eye, and its position in the observer's field combine to determine the extent to which the source will induce a sensation of discomfort or impair vision. Glare can occur from the use of some lower intensity sources, such as the small, low-voltage, tungsten-halogen lamps. It is reasonable to suppose that in the long-term, glare can have secondary effects on health and that is visibly flickering can have profound effects on the human nervous system. At frequencies below about 60 Hz it can trigger epileptic seizures in those who are susceptible. In others it can cause headaches and eyestrain. Wilkins concludes that the trend towards brighter high-efficiency sources is unlikely to affect health adversely, and may indeed be advantageous. The trend could have negative consequences for health were it to be shown that the increasing levels of ambient light at night affect circadian rhythms. Improvements in brightness and the evenness of spectral power may be beneficial. In particular, the move towards a greater use of daylight is likely to be good for both health and efficiency.

In many buildings, users report most dissatisfaction with temperature and ventilation, while noise, lighting and smoking feature less strongly. The causes lie in the way temperature and ventilation can be affected by changes at all levels in the building hierarchy, and, most fundamentally, by changes to the shell and services. In comparison, noise, lighting and smoking are affected mainly by changes to internal lay out and work station arrangements which can often be partly controlled by users.

There are some indications that giving occupants greater local control over their environmental conditions improves their work performance and their work commitment and morale which all have positive implications for improving overall productivity within an organisation. Building users are demanding more control at their workstations of fresh air, natural light, noise and smoke. Lack of control can be significantly related to the prevalence of ill health symptoms in the office environment, and there is widespread agreement that providing more individual control is beneficial. Work by Burge *et al.* (1987) demonstrates the relationship between self-reports of productivity and levels of control over temperature, ventilation and lighting.

Intervention to ensure a healthy working environment should always be the first step towards improving productivity. There are very large individual differences in the tolerance of sub-optimal thermal and environmental conditions.

Even if the average level of a given environmental parameter is appropriate for the average worker, large decrements in productivity may still be taking place among the least tolerant. Environmental changes which permit more individual adjustment will reduce this problem. Productivity is probably reduced more when large numbers work at reduced efficiency than when a few hypersensitive individuals are on sick leave. Wyon (1993) states that commonly occurring thermal conditions, within the 80% thermal comfort zone, can reduce key aspects of human efficiency such as reading, thinking logically and performing arithmetic, by 5-15%.

Lorsch and Abdou (1993) summarise the results of a survey undertaken for industry on the impact of the building indoor environment on occupant productivity, particularly with respect to temperature and indoor air quality. They also describe three large studies of office worker productivity with respect to environmental measurements, and discuss the relationship between productivity and building costs.

It is felt in general that improving the work environment increases productivity. Any quantitative proof of this statement is sparse and controversial. There are a number of interacting factors which affect productivity, including privacy, communications, social relationships, office system organisation, management, as well as environmental issues. It is a much higher cost to employ people who work than it is to maintain and operate the building, hence spending money on improving the work environment may be the most cost effective way of improving productivity. In other words if more money is spent on design, construction and maintenance and even if this results in only small decreased absenteeism rates or increased concentration in the workplace, then the increase in investment is high cost effective (Clements-Croome, 2000).

In one case study reported by Lorsch and Abdou (1994b) it is not clear if the drop in productivity was due to a reduction in comfort, by the loss of individual control of frustration due to being inconvenienced. According to Pepler and Warner (1968), people work best when they are slightly cool, but perhaps not sufficiently so to be termed discomfort, and should not be cool for too long.

Lorsch and Abdou (1994b) conclude that temperatures which provide optimum comfort may not necessarily give rise to maximum efficiency in terms of work output. The difficulty here is that this may be true for relatively short periods of time, but if a person is feeling uncomfortable over a long period of time it may lead to a decrement in work performance. However, there is a need for more research in this area. It almost seems that for optimum work performance a keen sharp environment is needed which fluctuates between comfort and slight cool discomfort.

According to a report by the National Electrical Manufacturers Association in Washington (1989) increased productivity occurs when people can perform tasks more accurately and quickly over a long period of time. It also means people can learn more effectively and work more creatively, and hence sustain stress more effectively. Ability to work together harmoniously, or cope with unforeseen circumstances, all point towards people feeling healthy, having a sense of well-being, high morale and being able to accept more responsibility. In general people will respond to work situations more positively. At an ASHRAE Workshop on Indoor Quality held at Baltimore in September 1992 the following productivity measures were recommended as being significant.

- Absence from work or workstation. Health costs including sick leave, accidents and injuries.

- Interruptions to work.
- Controlled independent judgements of work quality.
- Self assessments of productivity.
- Speed and accuracy of work.
- Output from pre-existing work groups.
- Cost for the product or service.
- Exchanging output in response to graded reward.
- Volunteer overtime.
- Cycle time from initiation to completion of process.
- Multiple measures at all organisational levels.
- Visual measures of performance, health and well-being at work.
- Development of measures and patterns of change over time.

Rosenfeld (1989) describes that when airconditioning was first conceived it was expected that the initial cost of the system would be recovered by an increased volume of business. He quotes an example where the initial cost of the airconditioning system for an office building is about £100 per m^2, so that if the average salary is £3,000 per m^2 and there is an occupancy of 10 m^2 per person, then adding 10% to the cost of the system is justified if it increases productivity by as little as 0.33%. Such small differences are difficult to measure in practice. Rosenfeld shows the relationship between the savings in working hours and the incremental initial cost of the system for a range of salaries.

Rosenfeld (1989) shows that improvement in indoor air quality can be more than offset by modest increases in productivity. This leads to the conclusion that in general, high quality systems which will have higher capital costs can generate a high rate of return in terms of productivity. In addition systems will be efficient, be effective, have low energy consumptions and consequently achieve healthier working environments in buildings with a low $C0_2$ emission.

Holcomb and Pedelty (1994) attempt to quantify the costs of potential savings that may accrue by improving the ventilation system. The increase in cost can be offset by the gain in productivity resulting from an increase in employee work time. Higher ventilation rates generally result in improved indoor air quality. Collins reported that over half of all acute health conditions were caused by respiratory conditions due to poor air quality. Cyfracki (1990) reported that a productivity increase of 0.125% would be sufficient to offset the costs of improved ventilation. It should be mentioned again that some studies have shown a decrease in SBS symptoms with increased ventilation rates while others have not conclude that although there is some inconsistency there is still sufficient evidence to suggest that there is an association between ventilation rates, indoor air quality, sick building syndrome symptoms and employee productivity.

It is easier to assess the effects of temperature on physical performance, but much more difficult to test the effects on mental performance. For example, the lowest industrial accident rate occurs around 20°C and rises significantly above or below this temperature. The other problem is the interaction with other factors which contribute towards the productivity. Motivated workers can sustain high levels of productivity even under adverse environmental conditions for a length of time which will depend on the individual.

Lorsch and Abdou (1994c) analyse several independent surveys which show that when office workers find the work space environment comfortable, productivity tends to increase when air-conditioning is introduced by as much as 5-15%, in the opinion of some managers and researchers. These are however, only general trends and there is little hard data and some findings are contradictory. Kobrick and Fine (1983) conclude that it is difficult to predict the capabilities of groups of people, never mind individuals, in performing different tasks under given sets of climatic conditions.

A study for the Westinghouse Furniture Systems Company in Buffalo, New York, entitled The Impact of the Office Environment on Productivity and the Quality of Working Life suggested that the physical environment for office work might count for a 5-15% variation in employee's productivity. And the general conclusion was that people would do more work on an average workday if they are physically comfortable.

Woods (1987) reported that satisfaction and productivity vary with the type of heating, ventilation or air-conditioning system. Central systems appeared to be more satisfactory than local ones, the most important factor being whether there was cooling or not. In one study on user controlled environmental systems by Drake, the ability to have local control was important in maintaining or improving job satisfaction, work performance and group productivity, while reducing distractions from work. For example, some users reported that they wasted less time taking informal breaks compared to times when environmental conditions were uncomfortable. They were also able to concentrate more intensively on their work. The gain in-group productivity from the user controlled environmental system amounted to 9%. A number of studies suggest that a small degree of discomfort is acceptable, but it has to be confined to a point where it does not become a distraction.

Work by Kamon ((1978) and others shows that heat can cause lethargy which can increase the rate of accidents, and also affect productivity. Bedford (1949) concluded that there was a close relationship between the external temperature and the output of workers. Deteriorating performance is partially contributable to insomnia due to heat. Schweisheimer (1962) carried out some surveys concerned with establishing the effect of air-conditioning on productivity at a leather factory in Massachusetts, an electrical manufacturing company in Chicago and a manufacturing company in Pennsylvania. In all cases after the installation of air-conditioning the production increased by between 3-8.5% during the Summer months. On the basis of these investigations Schwisheimer concluded that the average performance of workers dropped by 10% at an internal room temperature of 30°C, by 22% at 32°C and by 38% at 35°C. Konz and Gupta (1969) investigated the effects of local cooling of the head on mental performance in hot working environments. The subject had to create words in ten minutes from one of two sets of 8 letters, which were type printed on a blank form. Poor conditions without cooling resulted in the creation of works dropping by some 20% in the hot condition, whereas with cooling the reduction was only some 12%.

Abdou and Lorsch (1994) studied the effects of indoor air quality on productivity. It was concluded that productivity in the office environment is sensitive to conditions leading to poor indoor air quality and this is linked to sick building syndrome. It is recognised that any stress is also influenced by management and other factors in the workplace. Occupants having local control over their environment generally have an improvement in their work effort, but in a more general way there is a synergistic effect of a multitude of factors which effect the physical and mental performance of people. Abdou and Lorsch (1994) conclude that in many case studies occupants have been highly dissatisfied with their environment, even though measurements have indicated that current standards were being met. This highlights the need to review standards and the basis on which they are made. Exactly the same conclusion is made by Donnini *et al.* (1994).

Although, it is difficult to collect hard data which would give a precise relationship between the various individual environmental factors and productivity there is sufficient evidence to show that improved environment decreases peoples complaints and absenteeism, thus indirectly enhancing productivity. The assessment of problems at the work place, using complaints is unreliable, because there is little mention of issues that are working well, and also the complaints may be attributable to other entirely different factors. Abdou and Lorsch (1994) contend that the productivity of 20% of the office work force in the USA could be increased simply, by improving the air quality of offices, and this is worth approximately $60 billion per year.

Work by Vernon (1936) shows that there is a clear relationship between absenteeism and the average ventilation grading for a space, which was judged by the amount of windows on various walls, so that windows on 3 sides had the highest grading and windows on one side only had the lowest. Abdou and Lorsch (1994) give the following causes as being the principal ones contributing to sick building syndrome:

- Building occupancy higher than intended.
- Low efficiency of ventilation.
- Renovation using the wrong materials.
- Low level of facilities management.
- Condensation or water leakage.
- Low morale and lack of recognition.

In this case lower efficiency of ventilation means that the supply air is not reaching the space where the occupants are, hence the nose is breathing in recirculated stale air. It is important to realise that even if the design criteria are correct for ventilation, the complete design team are responsible for ensuring that the systems can be easily maintained; the owner and the facilities manager also need to ensure that maintenance is carried out effectively. The tenant and occupants should use the building as intended. When new pollutant sources are introduced, such as new materials or a higher occupancy density, then the ventilation will become inadequate.

Burge (1987) conducted a study of building sickness among 4373 office workers in 42 office buildings having 47 different ventilation conditions in the United Kingdom. The data was further analysed by Raw (1990). The principal conclusions were that as individuals reported more than two symptoms, the subjects reported a decrease in productivity; none of the best buildings in this survey were airconditioned and these had fewer than two symptoms per worker on average, whereas the best airconditioned buildings had between two and three symptoms; women recorded more symptoms than men, but there was no overall difference in productivity; individual control of the environment has a positive effect on productivity; the productivity is increased by perceived air quality; productivity, however, only increases with perceived humidity up to a certain point and then appears to decrease again. Evidence supporting the importance of individual control of environment is again provided by Preller (1990). It should be said that some contrary evidence exists concerning some of these factors, which points to the need for a systems approach to studying the effects of environment in buildings such as that proposed by Jones (1995).

Productivity can be related to quality and satisfaction of the service or functional performance. Studies have shown that productivity at work bears a close relationship to the work environment. Burge demonstrates that there is a strong relationship between self-reports of productivity and ill health symptoms related to buildings: productivity decreases as ill health symptoms increase. There is a slightly less marked trend relating productivity and air quality but there is a significant effect.

Dorgan (1994) defines productivity as the increased functional and organisational output including quality. This increase can be the result of direct measurable decreases in absenteeism, decreases in employees leaving work early; or reductions of extra long breaks and lunches. The increase can also be the result of an increase in the quantity and quality of production while employees were active; improved indoor air quality is an important consideration in this respect. There is general agreement that improved working conditions, and the office environment is certainly one of the more important working conditions, tend to increase productivity. However, determining a quantitative relationship between environment and productivity proves to be highly controversial. While some researchers claimed they reliably measured improvements of 10% or more, others present data showing that no such relationships exist. Since the cost of the people in an office is an order-of magnitude higher than the cost of maintaining and operating the building, spending money on improving the work-environment may be the most cost-effective way to improve worker productivity.

In 1994, the energy use in an average commercial office building in the United States costs approximately \$20/m^2/year, whereas the functional cost is approximately \$3,000/m^2/year. The functional cost includes the salaries of employees, the retail sales in a store, or the equivalent production value of a hotel, hospital, or school. This means that 1% gain in productivity (\$30/m^2/year) has a larger economic benefit than a 100% reduction (\$20/m^2/year) in energy usage. In addition, the productivity gains will increase the benefits such as repeat business in hotels, faster recovery times in hospitals, and attainment of better jobs due to a better education in schools. A small gain in worker productivity has major economic impacts and it makes sense to invest in improving the indoor environment to achieve productivity benefits. Dorgan (1994) states that productivity gains of 1.5% in generally healthy buildings, and 6% in sick buildings, can be easily achieved. As typical payback costs of improvement in the indoor air ranges from less than 9 months to 2 years, the benefits clearly offset the renewal cost resulting in a very favourable cost-to-benefit ratio. The 1.5% improvement is conservative. Some literature indicates that this may be as high as 5 to 10%. However, achieving such productivity gains may require using advanced active or passive environmental control as well as personal controls. Examples of productivity gains in the order of 1-3% are found in several studies. Informal (unpublished) and anecdotal reports on productivity gains have been performed in supermarkets, fast food outlets, retail department store, schools, and office buildings resulting in estimated gains in sales ranging from 4 to 15% in retail stores during summer months .

By focusing on the productivity benefits, projects which improve the indoor environment are moved away from an energy-saving viewpoint and more towards productivity-increase issues. Even if a proposed project improves the indoor environment but increases the energy cost by 5%, the project may still be economically feasible if the productivity increase is greater than 0.04%. Wyon states that the *leverage* of environmental improvements on productivity is such that a 50% increase in energy costs of improved ventilation would be paid for by a gain of only 0.25-0.5% in productivity, and capital investments of $\$50/m^2$ would be paid for by a gain of only 0.5% in productivity. The pay-back time for improved ventilation is estimated to be as low as 1.6 years on average, and to be well under 1 year for buildings with ventilation that is below currently recommended standards.

An increase in productivity can be achieved with either (i) no increase in energy usage or even a decrease (ii) with an increase in funding for the given level of technology. The use of energy recovery systems, and the increased use of such technologies as advanced filtration, dehumidification, thermal storage, natural energy and personal environmental control systems are all examples of energy improving technologies the cost of which can be offset by increase in productivity. The increased building services budget can allow for the introduction of the best system, not the cheapest. Any indoor environment productivity management program should be able to include reducing energy consumption as one of the design objectives. Improving indoor environment will provide a high return on investment through productivity gains, health saving and reduced energy use. The benefits of improved indoor environment are improved productivity, increased profits, greater employee-customer-visitors health and satisfaction, and reduced health costs. The potential productivity benefits of improved indoor environment are so large that this opportunity cannot be ignored. There are indirect long-term, and social benefits.

Hawkins (2001) states that productivity in the USA, in terms of GDP per worker, is currently 1.4 times greater than the UK. Massive investment in information and communications technologies is seen as the main driver in the surge in US productivity. Indeed, recent studies have shown that the UK is only

15th in an international league table of worker productivity. For 2000 UK construction was valued at £69.5 billion; of this the wage bill for construction project personnel amounted to £17 billion. Each 1% global improvement in workforce performance would therefore generate a saving of £170 million in labour costs and enable construction programme times to be reduced.

Fisk (2000) reports that in the US respiratory illnesses cause the loss of about 176 million workdays and the equivalent of 121 million days of substantially restricted activity. Fisk (1999) and Clements-Croome (2000) state that in office buildings, the salaries of workers exceed the building energy and maintenance costs and the annual construction rental costs by a factor of at least 25. This means that small increases in productivity, of 1% or less, are sufficient to justify additional capital expenditure to improve the quality of the building's services. Ultimately, this will result in healthier working environments as well as reduced energy and maintenance costs.

People spend about 90% of their lives in buildings, so the internal environment has to be designed to limit the possibilities of infectious disease; allergies and asthma; and building related health symptoms, referred to as sick building syndrome symptoms. Buildings should provide a multi-sensory experience, and therefore anything in the environment which blocks or disturbs the sensory systems in an unsatisfactory way will affect health and work performance. Thus, lighting, sound, air quality and thermal climate are all conditions around us that affect our overall perception of the environment. Air quality is a major issue because it only takes about four seconds for air to be inhaled and for its effect to be transmitted to the bloodstream and hence the brain. Clean, fresh air is vital for clear thinking, but it is not the only issue to be considered. Fisk (1999) discusses linkages between infectious disease transmission, respiratory illnesses, allergies and asthma, sick building syndrome symptoms, thermal environment, lighting and odours. He concludes that in the USA the total annual cost of respiratory infections is about $70bn, for allergies and asthma $15bn, and reckons that a 20-50% reduction in sick building syndrome symptoms corresponds to an annual productivity increase of $15-38bn. The linkage between odour and scents and work performance is less understood, but Fisk (1999) concludes that the literature provides substantial evidence that some odours can affect some aspects of cognitive performance. He refers to work by Rotton (1983), Dember *et al.* (1995), Knasko (1993), Baron (1990) and Ludvigson (1989). The application of scents has been used by the Kajima Corporation in their Tokyo office building, as reported by Takenoya in Clements-Croome (2000). Fisk (1999) goes on to consider the direct linkage between human performance and environmental conditions and writes that for US office workers there is a potential annual productivity gain of $20-200bn. His conclusions are that there is relatively strong evidence that characteristics of buildings and indoor environments significantly influence the occurrence of respiratory disease, allergy and asthma symptoms, sick building syndrome and worker performance. Langston and Ding (2001) briefly describe a number of case studies which demonstrate how the environment can improve worker productivity.

There are only crude estimates of the magnitude of productivity gains from improvements of indoor environments. Those for the US office workforce are shown in Table 1.2.

Productivity depends on four cardinal factors: *personal*, *social*, *organisational* and *environmental*. There are preferred environmental settings which decrease dissatisfaction and absenteeism, thus indirectly enhancing productivity. The assessment of problems at the workplace based on numbers of complaints is unreliable, because there is little mention of positive aspects and because complaints may be attributable to other, entirely different factors.

In the Summer 1997, the Journal of the British Council for Offices, entitled Office, reckoned that *advanced building intelligence* can increase the productivity of occupants by 10% annually and improve efficiency to satisfy owner-occupiers. In contrast, *standard building intelligence* can improve efficiency by 8% annually and improve efficiency to result in a payback within two to four years. The argument is that in an intelligent building there is less illness and absenteeism.

Table 1.2 Estimated potential productivity gains from improvements in indoor environments (Fisk, 1999)

Source of Productivity Gain	**Potential Annual Health Benefits**	**Potential U.S. Annual Savings or Productivity Gain (1996 $U.S.)**
Reduced respiratory disease	16 to 37 million avoided cases of common cold or influenza	$6 - $14 billion
Reduced allergies and asthma	10% to 30% decrease in symptoms within 53 million allergy sufferers and 16 million asthmatics	$2 - $4 billion
Reduced sick building syndrome symptoms	20% to 50% reduction in Sick building syndrome health symptoms experienced frequently at work by approximately 15 million workers	$15 - $38 billion
Improved worker performance from changes in thermal environment and lighting	Not applicable	$20 - $200 billion

Productivity depends on good concentration, technical competence, effective organisation and management, a responsive environment and a good sense of well-being. The economic assessment of environment, both in terms of health (medical treatment, hospitalisation) and of decreases in productivity has received very little attention by researchers as yet. However, this assessment is absolutely necessary in order to assess the effectiveness of improved design and management protocols (Barbatano, 1994). Until now there have not been any standard procedures to measure productivity. Thus it has been difficult to persuade clients to accept the concept of a relationship between economic productivity benefits and indoor environment. The challenge is to investigate productivity and develop a strong methodology to assess the link between indoor environment and productivity.

Several methods of performance measurement have been reported in the published literature. For example, Ilgen (1991) classified the methods of performance measurement into three categories: *physiological, objective* and *subjective.* The rational for using physiological methods is based on the reasoning that physiological measures of activation or arousal are associated with increased activity in the nervous system, which is equated with an increase in stress on the operator. However, physiological measures of workload have received wide criticism regarding their validity, the sensitivity of measures to contamination and the intrusive nature of the measures themselves.

Objective measures (O'Donnell and Eggemeier, 1986) are frequently used to infer the size of workloads, both mental and physical. A further class of workload measures comprises subjective measures (Cyfracki, 1990). Subjective measures of workload are applied to gain access to the subjects' perceptions of the level of load they face in task performance. Rating scales, questionnaires, and interviews are used to collect opinions about the workload. While these methods may not have the empirical or quantitative appeal of physiological or objective measures, it is often argued that subjective measures are more appropriate and realistic since individuals are likely to work in accordance with their feelings, regardless of what physiological or behavioural performance measures suggest. There needs however to be a distinction between *being busy* and being *work effective* as assessed by quality indicators. Working long hours for example does not guarantee high productivity.

1.6 CONCLUSIONS

We live through our senses and the environment we provide for them to interact with is important. A building and its environment can help people produce better work, because they are happier and more satisfied when their minds are concentrated on the job at hand; building design can help achieve this. At low and high arousal or alertness levels, the capacity for performing work is low; at the optimum level the individual can concentrate on work while being aware of peripheral stimuli from the physical environment. Different work requires different environmental settings to achieve an optimum level of arousal. It is necessary to assess if a sharper or leaner indoor environment is required for the occupants' good health and high productivity and to redefine comfort in terms of *well-being.* There are three current standards providing guidance for the assessment of occupant comfort: ASHRAE standard 55-92; ASHRAE standard 62-89; and ISO standard 7730 (ISO, 1984). All emphasise thermal comfort rather than overall sensory comfort.

Kline (1999) believes it is important to design *thinking environments.* The most important aspect is to have places for work *where people feel that they matter.*

When that becomes a guideline for architectural interior design she argues a very different place emerges, than when some abstract standard of opulence and furnishing for pure functionality is adopted as a guideline. Building regulations and codes to practice are only a basic foundation for providing health and safety in the workplace; they do not guarantee producing an environment which is conducive to well-being and this includes feelings and emotions.

Froggatt (2001) enunciates eight principles for workplace design:

- the *initiative* to explore remote and mobile work strategies
- *trust* employers to work out of sight of management
- encourage *joy* in the workplace (Cabanac, 2000)
- value *individuality*
- emphasise *equality* more than *hierarchy*
- engage in open honest *dialogue*
- epitomise *cognitivity* between all the stakeholders in the business
- provide access to a wide range of *workplace options.*

Froggatt (2001) states that:-

The physical infra-structure of workplaces and the technological infra-structure of cyberspace are both critical elements of the new world of virtual work. One will not cause the demise of the other; rather, they re-enforce the need for each other. Knowledge work will continue to be a combination of solo contribution and collaborative team effort. While these activities can happen anywhere, they do have to happen somewhere. People will still need places where they can gather for face-face interaction, places where they can share resources, and places for solo work.

Offices of the future will be thought of as organisms which are developing in response to changes in technology and ways of working. It is important that office spaces allow people to work in teams, but at the same time bond to individual needs for motivation to stimulate productivity. Some examples of futuristic offices are those of Cellular Operations Ltd., in Swindon; the Pittard Sullivan and the TWA Chiat Day Company buildings both in Los Angeles. These buildings have some common properties in that they are designed for people to enjoy working in them and have a happy experience. Common descriptors used for such buildings are: *views*; *flood of light*; *the sound and sight of water*; *perfumed air*; *use of colour and abstract forms*; and *fresh air.* Good environments can enrich the work experience. Stimulating environments can help people to think creatively and buildings have a role here because spaces have an emotional content (Farshchi, 2000). It is important that the built environment is designed to respect feelings of people as well as the functional aspects.

The Health and Safety Executive list the following causes of sick building syndrome (Turner, 2001):

- Poor building and office design
- Deep plan or open plan offices of more than ten workstations

- Large areas of soft furnishing, open shelving and filing
- New furniture, carpets and painted surfaces
- Poor building services and maintenance
- Poor air quality
- Lighting (particularly the type and positioning which causes high glare and flicker) and insufficient daylight
- Low level of user control over ventilation, heating and lighting
- Poor design and maintenance of building services
- Poor standards of general repair
- Insufficient or badly organised office cleaning
- High temperature or excessive variations in temperature during the day
- Very low (<40%) or high (>60%) humidity
- Chemical pollutants - tobacco smoke, ozone, volatile organic compounds from building materials and furnishings
- Dust particles and fibres in the atmosphere
- Job factors
- Routine clerical work
- Work with display screen equipment

Prevention is better than cure. Consideration of all these factors at the design stage can prevent these problems occurring later.

Working with display screen equipment deserves particular mention, it can give rise to body postural problems, repetitive strain injuries and eyestrain. There can also be effects from low frequency electromagnetic fields and this is the subject of this book.

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