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Impact of Indoor Air Pollution on Health, Comfort and Productivity of the Occupants

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Abstract

In this special report, Dr Jagjit Singh, building pathologist and environmental health scientist, director at Environmental Building Solutions Ltd (tel. 01525 261922) and consultant to Oscar Faber Consulting Engineers Ltd discusses the possible causes of indoor air pollution and its impact on the health, comfort and productivity of the building occupants. The causes and symptoms of sick building syndrome, allergy and environmental illnesses and building related illnesses are discussed in the context of building environments. The remediation and prevention measures examine the solution to the problems caused by indoor air pollution in buildings

Key words

Indoor air quality, sick building syndrome, building related illness, health, comfort and productivity in buildings, indoor air pollution.

INTRODUCTION

An average North American or European man spends 80 to 90 per cent of his time indoors and the air he breathes is mostly indoor air (Berglund et al 1988). The indoor air as well as the temperature, light and sound conditions in our dwellings, offices, schools and other premises is of decisive importance for the health, comfort, morale, productivity and well-being of the occupants (Curwell et al 1990). Health and comfort problems associated with indoor air have nevertheless come to constitute a major problem in recent years. The sick building problem seems to coincide with the introduction of energy conservation measures, following the oil crisis of the early 1970's. Among the influencing factors are chemical pollution (ozone, formaldehyde, volatile organic compounds etc) inert fibres, biological (fungi, viruses, bacteria, mites, algae and other allergens) radon and electromagnetic forces.

The allergic substances can be airborne and inhaled, such as pollen, fungus and dust or indigested such as food and drink or be contracted. Airborne allergies however cause more problems throughout the world than all other allergies combined (Singh, 1994). People complain about fatigue, headache, skin irritation, mucus membrane trouble and smell.

A number of environmental, design and construction and other and other factors determine the quality and quantity of allergic components, for example, geographical location, time of the year, time of day, altitude, weather conditions and flora and forna, shape and configuration, materials and structures, design of ventilation systems, thermal insulation, tightness, air change and energy (Singh 1993).

BUILDING ENVIRONMENTS

Buildings can be likened to living organisms. The useful life of a building depends on its internal and external environments, both in terms of longevity of materials and as an appropriate habitat for its occupants. Buildings work as spatial environmental ecostystems and provide ecological niches and pockets of microclimates in their built environment for the development

of building biology and must be understood as a whole. The ecological niches and microclimates of the built environment in which biological agents live and interact have many dimensions. It is of fundamental importance to measure as many relevant variables as possible and to characterize the role of biology in man-made spatial ecostystems, which are part of the larger ecostystem outside. Buildings separate their occupants from external environments and create a better internal environment for them. Therefore buildings can be likened to human skin (a second skin), or an extension of our bodies as the third skin, (considering the body as the first skin and clothes as the second skin), which forms a physical barrier to separate the inside from the outside.

The building shell needs to be adaptive, flexible and reactive in order to maintain a relatively constant built environment in circumstances of regular- or cyclical-changing external conditions and the varying activities of the occupants. Changing internal environments (both fully-controlled 'museum' environments and simpler and more intermittently-operated systems) and their effect on the fabric and contents of the building must be understood holistically. These changes can be permanent radical change, for example the installation of a new heating system; shifting equilibrium, a progressive change from one state to another; spatial variations, non-uniform environments which result from diverse occupancy, both in space and time; cyclic fluctuations, the control strategies of most heating and ventilation systems; seasonal variations; and violent changes. The building envelope must function in close correspondence with the processes and biorhythms of the body, for example regulation of moisture, breathing and heat balance. These issues have led us to understand the need for the use of ecologically sound materials to design a breathing fabric which balances the sources of moisture with its reservoirs and sinks in the built environment.

Scale of the problem

The WHO have estimated that as many as 30% of new buildings in the developed world may have problems leading to occupant complaints and illnesses which can lead to lowered morale, loss of productivity and even absence from work (Singh 1994). The combined effect on productivity, absence from work and staff turnover is likely to have a considerable economic impact (Singh, 1994).

INDOOR ENVIRONMENT

The quality of the indoor environment reflects on the health, comfort and productivity of individuals in buildings. The main reason for the lack of awareness of the problems is due to the fact that the effects of indoor air pollution are mostly chronic and long term and not directly and immediately life threatening. However, there is a growing concern about people's dissatisfaction with the air quality in their places of work (Berglund et al 1988). In addition, there is evidence that external environmental conditions (e.g. traffic pollution) which may be associated with indoor air quality such as asthma and allergies are increasing in the population (Gravesen, 1990). The indoor air quality and healthy and comfortable internal environment is the product of interaction of design, construction, use and maintenance of buildings (Fig. 1). At present there are no government guidelines or codes of practice with respect to biological

contamination in the indoor air quality. However, a number of Guidelines on the indoor air quality have been published by ASHRAE, ACGIH, EPA-NIOSH (USA), CSA (Canada), OSHA, Health and Welfare (Canada), BGERA.
People have become more aware of environmental pollution, acid rain, depletion of ozone, global warming, additives in food, CFC's, so their awareness of the impact of the places in which they live and work is increasing. The increasing incidence of chronic conditions such as asthma and allergies and the number of people who might be affected by sensitisation, allergies and environmentally-triggered asthma has led to new thinking in the building industry. For example, attitudes are changing towards creating environmentally friendly building design and construction, effective maintenance and ventilation rates, materials from sustainable sources etc.

The following categories broadly influence the indoor air quality and these categories operate cumulatively and it's their cocktail effect which is contributing as a risk factor to health in the indoor environment.

- **Design and construction** factors eg. office design and layout, poor lighting and ventilation scheme, ergonomics.

- **Environmental factors**, eg. odour, lighting, temperature, dust, noise, outdoor and indoor environment.

- **Perceptual and psychological** factors eg. hysteria and stress due to lack of privacy, control or claustrophobic effects due to sealed construction.

- **cultural and organisational factors** eg. cleaniness, maintenance and management and their relationships with occupants.

INDOOR POLLUTION

Pollutants in the indoor environment arise from many sources, such as external environment (radon and outdoor pollution oxides of sulphur, nitrogen and carbon) (HMSO 1991). The number of potential pollutants in the indoor environment is enormous, for example volatile organic compounds, environmental tobacco smoke, moulds, pollution from the activities of the occupants. Indoor pollution arises from all stages of a building's life and for this reason a multidisciplinary approach is necessary. A close dialogue between various disciplines, for example, material manufacturers, contractors, architects, surveyors, building services engineers, building pathologists and other professionals, financiers and developers, is necessary.

There are a very wide range of potential indoor air pollution sources, the effects of which may impinge on human health or the synergetic effect of these factors may be the cause of health related problems in buildings. The following list covers the broad areas of sources of indoor pollution.

- **materials** - formaldehyde, solvents, mineral fibres, radon gas, pesticides
and interior furnishings - volatile organic compounds

- **construction** - airtightness and energy conservation vs ventilation for occupants and fabric

- **services and controls** - thermal comfort, lighting, air conditioning, and control of indoor micro climate

- **workplace design** - building layouts, ceiling heights and volume of space per occupant

- **occupants** - occupant activities, moisture and introduction of pollutants, tobacco smoking, photocopying, cleaning and other activities - ozone, organic compounds, particulates

- **environmental factors** - humidity and mould growth, noise, radon, odour and irritation, emission of gases and outdoor pollution

- **maintenance and management factors** - poorly maintained building fabric, controls and cleaniness routine

MATERIALS

The selection of building materials affects the environment, both externally and within buildings. For example, chlorofluorocarbons (CFC's), asbestos, solvent and lead based paints, timber treatments and formaldehyde, has significant impact on the indoor environment and the health and comfort of the occupants (Curwell, et al 1990). The significance of building materials' impact should not be under estimated in creating a healthy environment.

Interiors and Finishes

- flooring and carpet adhesives
- carpet backing, carpets
- wall covering
- adhesives
- paints, stains
- panelling
- partitions
- furnishings

Building Materials

- shell and facade construction
- cleaning materials, sanitary and cosmetic facilities
- insulation/fabric/void foam fillers/CFCs
- asbestos, hardwood
- pipework insulation/location/protection
- paints and furnishings/carpets, volatile organic solvents

- furniture
- decoration and cleaning
- wood preservatives
- concrete sealants

Design & Construction

Poor building design and construction contribute to building related health problems. The following factors should be taken into consideration to improve the indoor air quality.

- orientation, shading, views
- location
- organisation of space
- special industrial processes
- building use and hours of occupation
- use and number of employees
- vertical transportation
- public transport, vehicle access and parking
- social facilities: disabled, rest rooms, creche, canteen, coffee machines, fitness facilities, toilets
- waste disposal
- commissioning and initial air change/water control

Services & Controls

The following criteria of water, heating, cooling, humidification and air quality should be taken into consideration for the improvement of health related problems in buildings.

Domestic Water

- type of system/store/showers/delivery temperature
- designed to CIBSE TM 13
- fuel/efficiency
- control strategy/system/monitoring
- operational strategy/disease control

Heating

- type of system
- fuel/efficiency
- control strategy
- greenhouse gas emission
- location of flue
- operational strategy/maintenance

Cooling

- type of system
- fuel/efficiency
- control strategy
- refrigerant type
- refrigerant leak detection/location
- pump-down equipment
- heat rejection (if wet CIBSE [Chartered Institute of Building Services Engineers] TM 13)
- operational strategy\maintenance, adequate access

Humidification

- type (spray, steam, none)/cleaning/condensation
- fuel/efficiency
- operational strategy/maintenance

Lighting

- type of system/switching
- efficiency
- lighting levels
- location of luminaires
- in relation to task/VDUs etc
- operational strategy/maintenance

Air Quality

- type of air handling system
- fuel/efficiency
- air volume/change/velocity
- relative humidity
- location of intakes/adjoining buildings
- control strategy
- adaptability of system
- filtration/quality/materials
- operation strategy/maintenance

Workplace design

The following categories cover the range of factors involved in contributing to the building related health problems.

- low floor-to-ceiling height

- large unstructured open plan areas
- absence of natural light
- inadequate supply of air to the workstation (occupied zone)

Occupants

A range of potential sources of contaminants can be introduced by occupants or emanate from the occupant activities in the indoor environment.

- water vapour
- Carbon dioxide and particulates
- tobacco smoking
- emission of a range of organic compounds

Environmental factors

- humidity and mould growth
- noise
- radon and radon daughters
- odour and irritation
- emission of gases
- outdoor pollution

Maintenance & Management factors

- poor maintenance and management
- poor cleaniness
- lack of communication
- cultural aspects

CAUSAL AGENTS OF ILLNESS AND STRESS

Many factors influence the indoor environment within buildings, including the choice of building materials, infestation by insect, pest and other forms of biological organisms and the efficiency of services equipment. Causal agents of illnesses and stress in buildings may be chemical, physical, biological, psychosomatic or the synergetic effects of one or all of these agents.

CHEMICAL

• Inorganic	• Gaseous	• $SO_2 NO_x CO_x O_3$ Chlorine, Ammonia
	• Liquid	• Aerosols (aerosols may be of gaseous, particulate, liquid or mixture of these)

	• Particulate	• Heavy metals, Mineral fibres
• Organic	• Very Volatile Organic Compounds (VVOC) Benzene, Toluene Boiling Point range <0°C to 50-100°C	• Formaldehyde
	• Volatile Organic Compounds (VOC) Boiling Point range 50-100°C to 240-260°C	• Solvents, Plasticisers, Wood Preservatives
	• Semi-Volatile Organic Compounds(SVOC) Boiling Point range 240-260°C to 380-400°C	• Pesticides, Fungicides
	• Particulate Organic Matter (POM) Boiling Point range >380°C	• Soot, Dust

The classification of volatile organic compounds based on Curwell et al, (1990).

BIOLOGICAL

Biological contamination of indoor environments has received increasing attention in recent years as a possible cause of indoor-air-related illness at home and at work.

The impact of building biology on the built environment is man's commonest problem and can be traced back to biblical times or earlier (Singh, 1994). Biological agents have not only a serious impact on the maintenance and repair of the national housing stock but also cause great concern about the health of occupants (Singh, 1994b). The main biological factors causing building-related sickness are fungi, bacteria, viruses, protozoa, pollens, house dust mites, insect pests, algae, pigeons and rodents (Singh 1994). Indoor environments in these sealed buildings allow the accumulation and proliferation of microorganisms and their metabolites (i.e. endotoxins and mycotoxins) as well as other volatile organic compounds, and their ciruclation within the indoor air.

• Microbes	• Viruses	• Influenza
	• Bacteria, Mycobacteria	• Endotoxins, *Legionella pneumophila*
	• Fungi, Mycoplasmas	• Spores, Toxins, Mycotoxins, Conidia, Hyphae

	• Thermophilics Actinomycetes	• Thermoactinomyces *vulgaris,* *Saccharopolyspora rectivirgula* (*Micropolysporum faeni*)
• Plants	• Seed plants	• Pollen
• Arthropods	• Mites	• House-dust mites Storage mites
	• Insects	• Cockroaches (disease carriers)
• Animals	• Rodents	• Rats (disease carriers)
	• Pets	• Excretions, Animal Dander,Skin, Scales, Fur, Feathers, Serum proteins
	• Birds	• Disease Transmission
	• Humans	• CO_2, Ammonia, disease carriers

PHYSICAL

• Sensible	• Temperature, Humidity	• (at extremes)
	• Light	• Glare, Flicker Circadian Dis-synchronisation
	• Noise	• Printers
	• Vibration	• Traffic, trains, aircraft
• Insensible	• Static electricity	• -ve/+ve ion imbalance

- Electromagnetic radiation:

Ionising	• Radon
Non-Ionising	• UV under/over exposure Bio-electromagnetic effects

- **PSYCHOSOMATIC & PSYCHOGENIC**

- depression

- anxiety

- overwork

- frustration

BUILDING HEALTH

Indoor environment may influence the health of occupants in buildings in the following three different ways:

-Allergy and environmental hypersensitivity

-Sick Building Syndrome

-Building related illnesses

Sick Building Syndrome (SBS)

The World Health Organisation (WHO) definition of health - a state of complete physical, mental and social well being, nor merely the absence of disease and infirmity. **SBS** is the name given to a condition in which the occupants of the buildings experience symptoms which disappear soon after the affected people leave the building. The other terms used are Tight Building Syndrome, Stuffy office Syndrome.

The WHO identify the following typical symptoms:

Stuffy NoseBlocked , runny or itchy nose
Dry ChestDry skin
Chest tightnessWatering or itchy eyes

LethargyHeadache
Loss of concentration

Building related illness, Building associated illness are the terms used to cover the range of ailments which commonly affect occupants in buildings. For example legionnaire's disease, radon, asbestos etc.

Allergies such as rhinitis and asthma can be caused by diverse allergens, for example house dust mite, pollen, cat dander and moulds.

COMFORT AND HEALTH

The quality of the built environment is associated with the health, comfort and productivity of building occupants (Curwell, et al, 1990). Perception of an odour is a comfort effect, whereas irritation is usually defined as an acute health effect. Comfort has been defined as that condition of mind which expresses satisfaction with the environment (Curwell, et al, 1990). Of the many days work lost through absenteeism a notable amount is caused by SBS and building-related illnesses which can also lead to low morale inability to concentrate, eye strain and poor productivity. Careful environmental assessment of building plans and monitoring the built environment can alert managers to problems before they arise. An independent investigation is required to recommend ways of improving standards, and suggest strategies for improving the quality of the work place and minimising the impact of buildings on the environment. Most comfort standards are based on acceptable level of dissatisfaction normally taken as 20% occupational exposure limits does not include the synergetic or cocktail effect of pollutants or effect on comprised individuals eg. some immuno compromised individuals may experience allergic reactions, which normally healthy may not react to. Sick building syndrome symptoms (or tight building syndrome) sometimes associated with inadequate ventilation and result in loss of productivity and absenteeism (Curwell, et all, 1990).

The Health and Comfort should be addressed as below:

- advise and guidance on environmental design, control and maintenance
- environmental assessment and monitoring
- air and water quality control
- building services design and review
- energy efficiency assessment
- simulation-based problem solving

Health and comfort in the built environment is a cross-disciplinary issue, e.g.

- engineers and scientist expert in health and comfort, air conditioning environmental control

Regulations and Standards

There is no separate body for environmental laws in England and Wales appliable to buildings.

However, The Environmental Protection Act (EPA) 1990 and the Water Resources Act 1991 consider environment and pollution. The indoor air quality and the health and comfort in the workplace environment depends upon a number of factors in the life cycle of the building. For example, legislation relating to the planning stage (development of plans, environmental assessment), contaminated land, construction (building regulation, noise, air pollution and statutory nuisances, interaction with health and safety legislation), occupied buildings, demolition and future developments.

The workplace and the environment are now regulated by several acts of Parliament, and control of substances hazardous to health and various building regulations, HSE (Health & Safety Executive), EPA and CIBSE (Chartered Institute of Building Services Engineers) guidelines. The recent HSE approved code of practice for legionella for example requires employers and others to

- identify and assess the sources of risk
- prepare a scheme for preventing or controlling the risk
- keep records of its implementation

Employers now have to show that they have exercised due diligence in the operation of their offices and buildings.

Risk Assessment

Investigation of environmental conditions

The investigation of external and internal environmental conditions should be made using appropriate instrumentation. This may include the use of monitoring systems including a full weather station. There are a variety of instruments which can be used to measure the environmental parameters in the built environment (Singh, 1994b). These instruments range from simple hand-heldcapacitance and moisture meters to computational fluid dynamics code flow vent using tracer gases and infra-red photoacoustic detectors. Temperature measurement can be carried out using thermometers, or thermocouples and a data logger. The detailed description of inspection and monitoring of environmental conditions within the building fabric is beyond the scope of this paper.

Data required from physical and biological factors in the building can be interpreted to identify the cause and effect of the problem. These measures, combined with observation of the occupants' activities, building design, materials, finish and maintenance, could lead to better understanding of the risk assessment. Environmental reactions and ill health associated with buildings are so variable that it is difficult to establish that symptoms are caused by a specific factor measured. High level of fungus spores in buildings, particularly of types which are known to cause serious health effects (for example *Aspergillus flavus*, *A.parasiticus* and *Stachybotrys* sp.) should be considered a potential risk for disease and a potential cause for non-specific building-related complaints.

The measurement of moisture, relative humidity, microventilation and salt content could lead to an assessment of fungal activity. The data required from these observations, combined with the level and extent of fungal activity, knowledge of the building's design and construction and the patient history, can be used to monitor the risk assessment for indoor health problems.

Remediation and Prevention Measures

There are health implications in the use of certain building materials, the type of building design and construction, and the maintenance and management schedules. Remedial and preventative measures should focus on the selection of materials with minimum indoor pollution impact. For example, the use of pesticides, fungicides, solvent based paints, timber treatment chemicals, asbestos, substances such as CFC's which contribute to ozone depletion, should be avoided.

Solutions for indoor air pollution should be addressed as follows:

- Buildings - Improve aspects of design, construction, surrounding of building and its services and furnishings which contribute to the sick building, allergy and illnesses.

- Materials - control at source (i.e. use of non toxic materials).

- Indoor environment - improve indoor environment and organize management of various indoor environmental pollution sources and factors.

- Local environment control (workstation control).

- Improve organisational function and culture to alleviate stress.

- Control of lumina intensity/or improved natural day lighting.

- Occupant response - identify individual behavioural factors and state of mental and psychological health.

- The use of aromatherapy, or use of plants.

- Design with end user needs, e.g. flexibility, robustness and controlability.

- Increase rate of fresh air.

- Disinfecting and cleaning of air distribution systems. (Ensure that disinfecting chemicals have no ill effects.)

- Negative air ionisation.

- Improved filtration.

- Increase building user awareness.

- Improve maintenance and management procedures

Building Health Questionnaire

In order to identify and assess the building related health problems it is necessary to employ the use of a questionnaire. The questionnaire should aim to cover the various aspects of building design and construction, services and controls, management and organisation cultural aspects, occupancy and use of the building and the building environment. The following set of questionnaires may be helpful in identifying some of the causes and symptoms and the information gained may be useful to prepare a scheme for preventing and controlling the risk.

Questionnaire 1

Mainly aimed at building services, ergonomics, acoustic and HVAC and their impact on occupants' health:

- noise levels
- lighting
- odour
- furniture
- room layout
- personal health

The questionnaire may consist of 20-30 questions, depending upon the type, size and location of the building.

Questionnaire 2

This questionnaire mainly aimed at management and organisational cultural aspects and also the role of individuals in the organisation, for example:

I work on Floor 1 2 3 ?
by window Yes No
by a doorYes No
near a machine Yes No

and flexibility, manageability and accessability of space, conditions around the workstation.

This questionnaire may consist of 30-40 questions, depending upon the size, function and complexity of the organisation.

Questionnaire 3

This questionnaire mainly related to finding out the cause and effect of the building related problems. It covers a range of symptoms experienced by the occupants, e.g. headache, eye irritation, noseirritation, throat irritation, dry mouth, backache, shortness of breath, chest pains, nausea, fever, flu-like symptoms, fatigue, malaise, lethargy, drowsiness, dizziness and faintness, difficulty in

concentrating, skin dryness, rash irritation etc. The next section of the questionnaire asks to describe symptom patterns, e.g. symptoms occur continuously, intermittently and for how long they last (several minutes, several hours, all day, all week etc). What months of the year symptoms experienced and time of the day - a.m. or p.m. and are the symptoms experienced away from work, for example at home or other locations.

Control Methods

Preventative methods are preferred to remedial chemical solutions. The concept of eradication of causal agents of illnesses and stress from buildings is practically impossible. The remedial approach often involves considerable reliance on the use of chemicals and extensive exposure of the building fabric. This could have a detrimental effect on the health of the building fabric and its occupants and is environmentally damaging. Environmental control strategies are preferred which are based on the sound understanding of the construction details and the detailed knowledge of the causal agents of illnesses and stress, including their environmental requirements.

- Source removal - include removal of breeding grounds for bioaerosols (that is control of relative humidity and water vapour) and e.g. banning of smoking

- Avoidance - use of less hazardous materials

- Isolation - isolation of a contaminant or a source from exposure to occupants e.g. by contaminant, encapsulation, shielding and sealing

- Design criteria - new design and construction should have an emphasis on the effectiveness of ventilation, thermal comfort,lighting and maintenance needs.

- Reservoirs - remove contaminant or pollutant reservoirs, institute good housekeeping and dust suppression practices

- Checks - check and repair furnaces, flues, heat exchangers for leaks of CO (carbon monoxide) and other gases

- Ventilation - ventilate under floor spaces and ensure the effectiveness of cross ventilation. Ventilate all cavities, voids, concealed spaces, roof voids, wall voids etc

- Damp and decay - check dampness in walls e.g. rising damp and condensation to avoid mould and decay organisms

Cleaning and Maintenance

Facilities management and the institution of effective cleaning and maintenance regimes is by far the best policy to reduce indoor air pollution. For example, regular cleaning and maintenance of the following components in the air conditioned building is of fundamental importance.

- Air handling unit
- Filters (filtration efficiency is important and also the seal on the filters should be varified)
- Cooling coils, condenser trays and water trays
- Ducting
- Wet cooling towers
- Air washers/humidifiers
- Mechanical operation

Remediation

If the problems still persist after the preventative maintenance and cleaning regimes and environmental control strategies, under these circumstances certain remedial actions are necessary.

- Filter the contaminants
- Dilution ventilation - increase ventilation to purge out pollutants
- Remove the source - eliminate smoking
- Treatment with liquid nitrogen - to kill house dust mites
- Vacuum cleaning with high efficiency filtering
- Steam cleaning - for example chairs and carpets
- Biocide treatment of cooling towers

Occupational exposure limits do not take into account the synergetic or cocktail effect of pullutants nor the fact that more sensitive individuals may experience allergic reactions, which normally healthy individuals may not.

Health and comfort in the built environment is a cross-disciplinary issue which may involve input from a variety of sources including engineers, scientists, other experts in air conditioning or environmental control. To ensure health and comfort in the workplace, employers should:

-seek advice and guidance on environmental design, control and maintenance;
-assess and monitor the environment;
-monitor air and water quality control;
-ensure that building services are adequately designed and reviewed;
-carry out energy efficiency assessments.

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