Desk based research into volatile organic compounds (VOCs) and indoor air quality

British Gypsum
SAINT-GOBAIN

Overview

There is a large body of information available on VOCs generally, specifically identifying which particular substances are included, their characteristics and relative prominence / importance as emissions within buildings, i.e. from specific building materials and contents.

The information and research in this area goes back many years (in to the 1990s and even 80s). Certainly, in academic and medical research circles, the harmful nature of VOCs and linkage between exposure to VOC emissions and human health problems is well established, acknowledged and accepted.

There is a long track record of studies examining this issue and linkage, either in 'laboratory' conditions or in the field tests (many of which are referenced below, as prominent examples but not an exclusive list). These appear to have moved on in character over the years, from initial identification and measurement of VOC emissions and VOC emitting products / materials; to linkage of VOCs to specific health issues; and formation of policies and guidance regarding VOC management and control.

However, there is much less specific reference to VOCs amongst the Architect / Building & Construction trade press; and what there is mainly relates to issues such as compliance / regulation limits, low-VOC products, etc. which would indicate a that VOCs are generally lower on the agenda.

Although the detrimental effects of prolonged exposure to VOCs in buildings are accepted pretty much as fact, some of the research studies appear to have struggled to prove this definitively – owing to the timescales involved in 'prolonged exposure'; the difficulty of isolating the impact of VOCs from other elements in a real-life environment; and the 'total exposure' nature of VOCs, i.e. exposure to many different VOCs in combination at different levels, rather than to specific VOC substances in isolation. In some ways this feels similar to the development of knowledge on the damage caused by tobacco smoking/secondary smoke, where the linkage to cancer and other health problems was widely acknowledged as true in advance of irrefutable proof being provided.

Specific Output

Below are a selection of specific organisations that have written, researched and/or published reports and papers, etc. regarding VOCs, Indoor Air Quality and related health issues; together with URL links to their websites and/or specific publications/downloads.

American Industrial Hygiene Association Journal

Concentrations of Volatile Organic Compounds at a Building with Health and Comfort Complaints (1990)

http://www.tandfonline.com/doi/abs/10.1080/15298669091369628#.UZX94JRwbIU

C.J. WESCHLERa, H.C. SHIELDS & D. RAINER

(Abstract): For four separate periods over a 1-yr span, the concentrations of volatile organic compounds (VOCs) have been measured at a facility with a history of occupant complaints. The reported symptoms were characteristic of “sick building syndrome.” This study was initiated to determine if VOC levels were higher than those measured in “complaint-free” buildings and, if so, to identify sources and other factors that might contribute to the elevated concentrations. VOCs were collected with passive samplers, using a sampling interval that lasted from 3 to 4 weeks. Following collection, the samplers were extracted, and the compounds in the extract were separated and identified using standard gas chromatographic-mass spectrometric procedures. Over 40 different organic compounds with concentrations in excess of 1µg/m^3 were identified; several species had values greater than 100µg/m^3. For each of the lint three sampling periods, the total concentration of VOCs detected using this methodology was in excess of 3mg/m^3. Sources of the identified compounds included cleaning products, floor wax, latex paints, and reentrained motor vehicle exhaust. However, the dominant source was the hydraulic system for the buildings' elevators. Compounds were volatilizing from the hydraulic fluid used in this system. Neither the elevator shafts nor the mechanical room housing the fluid reservoirs were vented to the outside. The problem was compounded by the relatively small amount of outside air used for ventilation at this facility (less than 6L/sec [12cfm]/occupant or about 1/4 air change/hr). At such low ventilation rates, compounds with strong sources can achieve high steady-state concentrations within the facility. Recommendations have been made to reduce the VOC levels at this site. Although implementing the recommendations will be costly, even a slight improvement in employee productivity will offset these costs.

Architects Journal

Home isn't where the health is - 11 June, 1998 | By PETER BURBERRY

http://www.architectsjournal.co.uk/home/home-isnt-where-the-health-is/779093.article

BRE

Assessment and evaluation of indoor air quality

http://www.bre.co.uk/page.jsp?id=720

Building Technology Programme at Massachusetts Institute of Technology (MIT)

http://bt.mit.edu/

http://bt.mit.edu/?page_id=14

Publications:

Various research studies carried out, e.g.

Modeling Volatile Organic Compounds (VOCs) Sorption on Building Materials
(Summary) Building materials are not only a source of volatile organic compounds (VOCs) but also affect the transport and removal of indoor VOCs by sorption (adsorption and desorption) on the interior surface. The re-emission of adsorbed VOCs from building materials can elevate VOC concentrations and indoor air quality in buildings during the entire service life of a building. This investigation is to determine accurately the sorption of VOCs by building materials and the impact of sorption on IAQ.

Building Material Emissions and Indoor Air Quality
(Summary) Since over 60% of indoor pollution comes from building materials, it is important to reduce material emissions for better indoor air quality. We have developed several computer models to calculate the emissions from building materials, and have validated the models by the experimental data obtained from both small and large test chambers. The models can replace traditional measurements of material emissions in a small chamber. The research is in collaboration with the National Research Council Canada.

Modeling Contaminant Exposure and Indoor Air Quality in a Single-family House

http://web.mit.edu/bt/www/bt/iaq_contaminantexposure.html

British Lung Foundation

Organisation supporting people with lung disease, including basic information about indoor air quality.

http://www.blf.org.uk/Home

http://www.blf.org.uk/Page/Indoor-Air-Pollution

Clean Air in London (CAL)

Pressure group in London. Simon Birkett (Founder & Director) was elected a founder member of the Executive Council of the European Chapter of the International Society for Environmental Epidemiology in February 2013

- Simon Birkett assisted Policy Exchange with its report 'Something in the Air: The forgotten crisis of Britain's poor air quality' published on 19 July 2012
- Simon Birkett has been a Science and Policy Adviser to ClientEarth since July 2009
- Simon Birkett has been a member of Environmental Protection UK's Air Quality Committee since [2009]

http://cleanairinlondon.org/

http://cleanairinlondon.org/about/

Clean Air in London's Mission is to achieve urgently and sustainably full compliance with WHO guidelines for air quality throughout London and elsewhere. It works closely with other campaign groups and a wider network of supporters and volunteers to identify and build understanding of the most important issues and encourage decisive action on them.

Clean Air in London's immediate priority is to see that air quality laws are enforced rigorously in London in 2013 (and thereafter). Clean Air in London believes that if we comply fully with relevant laws Britain can show the world how to tackle successfully air quality, climate change and sustainability issues.

Clean Air in London is a not-for-profit organisation funded by donations, sponsors and other supporters. It is not a charity in part because a registered charity is not allowed to have political objectives or take part in political lobbying (other than in a generally educational sense). Clean Air in London may wish to participate in such activities.

Indoor air quality (IAQ) can be worse than outdoor (or ambient) air quality (AAQ) due to the many sources of pollution within buildings and homes. Clean Air in London (CAL) is therefore campaigning to build public understanding of indoor air quality with support from Camfil Farr. CAL does Pollution Checks to investigate air quality. (NB: The Camfil Group is a world leader in the development and production of air filters and clean air solutions and is a sponsor of CAL)

http://www.keepthecityout.co.uk/2012/09/
This article originally featured on POLITICS HOME: 19 September 2012

http://www.keepthecityout.co.uk/category/iaq-and-health/
This article first appeared in the January 2013 issue of The Safety & Health Practitioner

http://www.keepthecityout.co.uk/2012/10/new-report-reveals-ignorance-over-indoor-air-quality-in-public-buildings/

Other articles…

http://cleanairinlondon.org/hot-topics/indoor-air-quality-can-be-worse-than-outdoor/

http://cleanairinlondon.org/indoor-air-quality/air-quality-in-hospitals-may-be-no-better-than-warehouses/

Committee on the Medical Effects of Air Pollutants (COMEAP)

(Dept of Health)

The Air Pollution Group provides the Secretariat for the Committee on the Medical Effects of Air Pollutants (COMEAP) on behalf of Department of Health. COMEAP provides expert assessment of the evidence on the effect of different air pollutants on health and recommends concentration-response functions to relate changes in levels of air pollutants to changes in effects on health.

COMEAP is an expert Committee that provides advice to government departments and agencies, via the Department of Health's Chief Medical Officer, on all matters concerning the effects of air pollutants on health.

The COMEAP website

http://comeap.org.uk/

Guidance on the effects on health of indoor air pollutants (December 2004)

http://comeap.org.uk/images/stories/Documents/Reports/Effects_on_Health_on_Indoor_Pollutants.pdf

Chartered Institute of Environmental Health

The Chartered Institute of Environmental Health is a professional, awarding and campaigning body at the forefront of environmental and public health and safety

http://www.cieh.org/policy/environmental_protection/air-pollution.html

Centers for Disease Control and Prevention (CDC) / National Institute for Occupational Safety and Health (NIOSH) / Environmental Protection Agency (EPA)

http://www.cdc.gov/niosh/

http://www.epa.gov/iaq/voc.html

US government bodies providing a range of specific studies and publications and advice related to VOCs and indoor air quality, e.g.

http://www.cdc.gov/niosh/topics/indoorenv/ChemicalsOdors.html

Commercial Air Filtration (London)

http://www.allergycosmos.co.uk/commercial-air-filtration/concern/voc-pollution

Commercial Air Filtration by Allergy Cosmos is a London based company specialising in providing businesses with expert advice on airborne contamination and infection control; to effectively manage a wide range of particulate, chemical and gaseous odour contamination.

Publications:

PFC Pollution in the Office Environment

http://www.allergycosmos.co.uk/blog/pfc-pollution-in-the-office-environment/

VOCs in Paints, Stains and Varnishes

http://www.allergycosmos.co.uk/blog/vocs-in-paints-stains-and-varnishes/

EurActiv Network

Based on independency and close mutual co-operation, the EurActiv Network delivers localised EU policy information in 15 languages, reaching readers across Europe and beyond.

The co-branded partner publications produce content in Brussels (Belgium), Bulgaria, the Czech Republic, France, Germany, Greece, Hungary, Italy, Lithuania, Poland, Romania, Serbia, Slovakia, Spain and Turkey – reaching over 80% of EU citizens in their mother tongue.

The Network partners complement the 'Brussels perspective' on EU affairs with national points of view and adapt the contents to the interests and needs of local readers.

Article:

http://www.euractiv.com/climate-environment/closed-doors-air-quality-buildin-linksdossier-505458

European Commission – Research & Innovation

The European Commission, in declaring 2013 as the Year of Air, is bringing forth new proposals on how to improve air quality across Europe

The Airmex study (Funded by the EU Joint Research Centre)

http://ec.europa.eu/research/infocentre/article_en.cfm?id=/research/headlines/news/article_10_02_26_en.html&item=&artid=15233

As one of several EU funded research projects, the European Indoor Air Monitoring and Exposure Assessment Project (AIRMEX) study monitored indoor, outdoor and individual exposure to selected chemical compounds (aromatics, carbonyls, terpenes and other volatile Organic Compounds (VOCs)) around Europe. A total of ca. 1000 samples were taken from public buildings, schools/kindergartens, individual volunteers and the homes of those volunteers.

http://ihcp.jrc.ec.europa.eu/our_databases/airmex

EnVIE - Co-ordination Action on Indoor Air Quality and Health Effects

http://www.envie-iaq.eu/

EnVIE is a European Co-ordination Action interfacing science and policy making in the field of indoor air quality. EnVIE is collecting and interpreting scientific knowledge from on-going research, in particular from EU funded projects and Joint Research Center activities, to elaborate policy relevant recommendations based on a better understanding of the health impacts of indoor air quality. This project is funded by the European Commission 6th Framework Programme of Research

Reports:

http://cordis.europa.eu/search/index.cfm?fuseaction=lib.document&DOC_LANG_ID=EN&DOC_ID=126459681&q=

WP1 Technical Report - Health Effects

http://paginas.fe.up.pt/~envie/documents/finalreports/Final%20Reports%20Publishable/EnVIE%20WP1%20Final%20Report.pdf

WP2 Technical Report - Indoor Air Pollution Exposure

http://paginas.fe.up.pt/~envie/documents/finalreports/Final%20Reports%20Publishable/EnVIE%20WP2%20Final%20Report.pdf

WP3 Technical Report - Characterisation of spaces and sources

http://paginas.fe.up.pt/~envie/documents/finalreports/Final%20Reports%20Publishable/EnVIE%20WP3%20Final%20Report.pdf

Final Report Summary - ENVIE (Co-ordination action on Indoor Air Quality and Health Effects)

http://cordis.europa.eu/search/index.cfm?fuseaction=result.document&RS_LANG=EN&RS_RCN=12645905&q=

(Abstract)
The aim of the ENVIE project was to increase the understanding of the Europe-wide public health impacts of indoor air quality by identifying the most widespread and significant indoor causes for these health impacts and evaluating the existing and optional building and housing related policies for controlling them. It addressed in particular how indoor air quality might contribute to the observed rise in asthma and respiratory allergy, together with other acute and chronic health impacts. The intention was not to conduct new experimental or field research, but rather to build on the broad scientific experience and the wealth of accumulated literature from the domestic and international indoor air research projects as well as the EU, WHO, ISIAQ and CIB committees and expert groups during the past 20 years.

Buildings play a multitude of roles in air pollution exposure:
(i) Depending on the national energy 'mix', climate zone, typology, quality and age of the building stock, circa 40 % of the primary energy is used to heat, light and ventilate buildings and to run a variety of electrical equipment in buildings from elevators to personal computers. Consequently, buildings are directly and indirectly responsible for a similar proportion of air pollution from heat and power generation by burning conventional fossil fuels.
(ii) The building structure and materials as well as other sources in buildings - from invisible dirty air ducts and water damaged mouldy insulation materials to unflued combustion appliances, candle burning and the use of organic solvents, hypochlorite and ammonia containing cleaning agents, for example - contaminate the air inside the buildings where people spend most of the time.
(iii) 20 to 100 % of the concentrations of outdoor air pollutants are transferred inside the buildings - depending strongly on the pollutant of concern and the ventilation or air conditioning system - and, consequently, most exposure to so-called outdoor air pollution occurs indoors. For traffic pollution, about half the total exposure, on average, occurs indoors and the other half while in transport or outdoors. In summary, buildings have a large impact on both outdoor and indoor air quality (IAQ) and, relative to outdoor air pollution; buildings may significantly increase or decrease people's air pollution exposures. Buildings are, therefore, the most important factor in air pollution exposure and associated health effects.

The complexity of indoor pollution sources, effects pathways and the multitude of parties responsible for generating and respectively controlling indoor air pollution make the coherent

development of risk reduction strategies a challenge. To be effective, policies directed at improving IAQ need to be part of a comprehensive, internally and externally consistent management strategy involving governments, institutions, professional bodies and individuals. Plans need to be directed at both new and existing buildings and involve action at both local and national levels. Important considerations include outdoor climate and air quality, building materials and styles, knowledge and behaviour patterns of the occupants, energy and sustainability policies, and building system technologies. Requirements for the establishment of a successful strategy include prior justification, goal setting, appraisal of management options, and political willingness.

Many previous indoor air quality and policy assessments have taken specific contaminants or indoor sources as the starting point. The logic behind this is the flow of molecules from sources via the environment to exposure, whole body dose, target organ dose, and the consequent health outcome. ENVIE follows an opposite logic, starting from consideration of the most pronounced indoor air related health outcomes (which may have also other sources and causes), then identifying the most widespread indoor air exposures that are likely to cause these health outcomes and the most common sources which dominate the indoor air exposures. The intention was to focus from the start on those indoor air quality issues that have the highest Europe-wide health relevance. Having defined a shortlist of such 'reverse' indoor health-exposure-source chains, the project evaluates the policy alternatives for minimising both unwanted health consequences, in terms of achievable public health benefits, and invasiveness, while taking into account political, legal, technological, economical and social feasibility. A further outcome is the identification of a set of highly advisable and feasible indoor air quality policy options for Europe. Europe-wide applicability brings the benefits of enhanced competition in a broader marketplace.

The selection of issues for and the structure of this report is based on the ENVIE concept, starting from (i) the selected shortlist of high priority indoor air quality related public health concerns, identifying (ii) the key indoor exposures that are believed by most experts to significantly contribute to these health outcomes, (iii) identifying the sources which are known to significantly contribute to these indoor exposures and finally, (iv) identifying and assessing the existing and missing policies to control these sources (and consequently the health outcomes) as well as the critical new research that would be needed to develop the missing policies. The first three issues were covered in the ENVIE WP1, WP2 and WP3 final reports. The WP4 (final) report concentrates on the last issue, that is, the indoor air policies.

European Commission Joint Research Centre (European Concerted Action (ECA) Indoor Air Quality (IAQ) Steering Committee)

Publications:

EUR 17334 EN (1997) Evaluation of VOC emissions from Building Products (incl. Ch 4 page 31 - Evaluation of the effects of VOC emissions on Human Health)

http://www.inive.org/medias/ECA/ECA_Report18.pdf

Health and Environment Alliance (HEAL), Brussells

The Health and Environment Alliance (HEAL) is a leading European not-for-profit organisation addressing how the environment affects health in the European Union. We demonstrate how policy changes can help protect health and enhance people's quality of life

http://www.env-health.org/about-us/

Articles:

How is indoor air quality in your school?

http://www.env-health.org/news/latest-news/article/how-is-indoor-air-quality-in-your

Indoor air quality: results from EU research projects

http://www.env-health.org/news/latest-news/article/indoor-air-quality-results-from-eu

Indoor Air Quality (IAQ) Scientific Findings Resource Bank (IAQ-SFRB)

http://www.iaqscience.lbl.gov/sfrb.html

A resource being developed by the Indoor Environment Group of the Lawrence Berkeley National Laboratory with funding support from the U.S. Environmental Protection Agency

Publications:

Overview of IAQ

http://www.iaqscience.lbl.gov/overview.html

Indoor Volatile Organic Compounds (VOCs) and Health

http://www.iaqscience.lbl.gov/voc-introduction.html

Impacts of Indoor Environments on Human Performance and Productivity

http://www.iaqscience.lbl.gov/performance-summary.html

Benefits of Improving Indoor Environmental Quality

http://www.iaqscience.lbl.gov/benefits-summary.html

Indoor Air Quality Assoc. UK

http://www.iaquk.org.uk/about.html

http://www.iaquk.org.uk/index.html

IAQ UK is an independent organisation with the aim of 'raising the agenda of indoor air quality within the home and work'…

- Provide a comprehensive reference source for the UK regarding indoor air quality.
- Establish UK indoor air quality accredited training certificate with national training body for practitioners and students.
- Influencing IAQ practitioner's competence standards.
- Influence Government and associated national bodies to take ownership of developing IAQ best practice.
- Consolidate knowledge and standards from silo disciplines

These objectives are achieved by working with the various agents and organisations in promoting indoor air quality and ensuring the information is accessible to enable individuals to make a choice about their environment.

IAQ Background & Rational

During the oil crisis in the 1970s more attention was given to the introduction of energy saving measures in buildings (Hammond and Stapleton, 1991) This resulted in energy efficient buildings, with mechanical systems controlling air flow and comfort factors (heat, humidity), initiating a reduction in the amount of outdoor air being supplied into buildings.

Outdoor air quality has remained a focus in the UK over the last 2 decades but during this period changing conditions within indoor environments have tended to reduce ventilation and increase the opportunity for accumulation of undesirable levels of indoor air pollutants. The first reports of an imprecise and unrecognised general sickness related to the occupancy of buildings were investigated 40 years ago in North America and Scandinavia. The UK has incurred a similar sick building effect and as the carbon footprint demands for buildings to become more efficient will ensure that the problem associated with poor indoor air quality will continue to become exasperated.

Most individuals spend about 90% of their time indoors and are therefore exposed to the indoor environment to a much greater extent than to the outdoors. Information obtained from laboratory and epidemiological studies suggests that indoor air pollutants are an important cause of avoidable morbidity and mortality in the UK expectancy (Department of Health, 2001), (Brunekreef and Holgate, 2002). Contaminants in the indoor environment are more than 1,000 times more likely to be inhaled than outdoor air (Levin, 2007) and can be up to 10 times more polluted than outside air (US EPA, 2001). The potential effects of indoor air pollution include unpleasant smells, sensitisation and asthmatic reactions, related to biological aerosols in the indoor air and the fatal consequences of exposure to pathogenic organisms or chemicals.

As standards for external air quality improves, it would therefore seem evident that equivalent standards of health for exposure to outdoor pollutants should be applied to indoor air quality whereby often concentrations of outdoor air are in greater quantities. There is considerable research to demonstrate that indoor air is more pollutant than outdoor air, thus the reason why we are seeing an increase in respiratory diseases, sensitivities, asthma (Department of Health, 1998) (Seppanen, Fisk, Mendell, 1999), and even cognitive conditions, including stress and migraines (Zvolensky, Eifert and Lejuez, 2001).

In 2004, a study showed that around 15% of people in England have asthma, and the UK has the highest prevalence of asthma symptoms in the whole world (Howieson, 2005). 'Many of these illnesses can be linked with poor indoor air quality' Howieson (2005). Despite such research directed to improving the quality of outdoor air, the UK only recognised the requirements for indoor air quality guidelines in 1991, by the House of Commons Select Committee, which, in its report on indoor pollution recommended that the Government develop guidelines and codes of practice for indoor air quality in buildings, which specifically identify exposure limits for an extended list of pollutants.

The Department of Health Committee on Medical Effects of Air Pollutants (COMEAP) released guidelines for manufacturers, architects and engineers involved with building design and services, to assist in the process of reducing poor air quality (Department of Health, 2004). However, there are currently no regulations on the quality of indoor air in the UK. Indoor air quality was excluded from the Department of the Environment, Food and Rural Affairs Defra Air Quality Strategy (2007). Building Regulations F (Department for Communities and Local Government, 2006) consolidate energy efficiency, requiring further ventilation designs to be incorporated within airtight buildings. This has been an encouraging step. They are also perceived as 'performance criteria' which contain some guidelines but these are not mandatory.

The Health, Safety and Welfare Regulations 1992 (HMSO, 1992) cover a basic requirement for sufficient ventilation and thermal comfort, governing a minimum working temperature of 16℃ or 13℃ if physical effort is required. There are no maximum working temperatures. The Health & Safety Executive have recently developed guidance for thermal comfort and heat stress in the workplace (HSE, 2008), but offer no further guidance for indoor air quality standards. The British Occupational Hygiene Society, the occupational hygiene standards group discusses health hazards associated with dust, chemicals and biological compounds with regards to Control of Substances Hazardous to Health Regulations 2002 (HMSO, 2002) occupational exposure limits.

There are numerous organisations which are in charge of different aspects of indoor air quality, of which the sources of information are disparate. There is a clear need to address indoor air quality more seriously and effectively, which should include a coordinated approach by the various organisations. A regulatory framework is also absent which could provide guidelines for a range of parameters using best practice standards from International and European research.

Managing indoor air quality is challenging because it crosses many disciplinary boundaries, from architecture, and building design to occupational health and human behaviour; and covers many types of variables relating to buildings, including their layout and technology, the organisations which occupy them, the management styles and the people themselves.

Despite health being an important issue to people's lives, studies have shown that people remain unaware and often apathetic of the health risks posed from indoor air (Harrison, 2002). This could be argued understandable when comparing priorities of high risk activities and hazards. However the effects of indoor air quality is indispensable in the economic impact in the workplace, which is the justification of IAQ UK.

Institute of Environment and Health (Cranfield University)

http://www.cranfield.ac.uk/health/researchareas/environmenthealth/ieh/page19562.html#

IEH works to promote a healthier environment through activities such as:

- Assessing and evaluating environmental pollution and health impacts
- Investigating and identifying disease conditions caused or influenced by environmental exposure
- Undertaking primary research in the areas of bio-monitoring and risk assessment
- Coordinating and managing research
- Facilitating information exchange within the research community
- Publishing reports and assessments on subjects of topical interest

Publications:

Indoor air: can it harm me?

www.cranfield.ac.uk/health/researchareas/environmenthealth/ieh/doc6.16finalgeneralpublic%5B1%5D.pdf

Health Effects of Indoor Air Pollution

www.cranfield.ac.uk/health/researchareas/environmenthealth/ieh/doc6.17finalhealtheffects%5B1%5D.pdf

Volatile organic compounds (including formaldehyde) in the home

www.cranfield.ac.uk/health/researchareas/environmenthealth/ieh/ieh%20publications/vocslflt.pdf

Indoor Air Quality in the Home

www.cranfield.ac.uk/health/researchareas/environmenthealth/ieh/ieh%20publications/iaq.pdf

Low Emitting Materials for Better Indoor Air Quality

www.cranfield.ac.uk/health/researchareas/environmenthealth/ieh/doc6.14finallowemittingmaterials%5B1%5D.pdf

Indoor Child Health and Learning & Indoor Air Quality in Schools ...

www.cranfield.ac.uk/health/researchareas/environmenthealth/ieh/doc6.18finalschools%5B1%5D.pdf

Indoor air quality in the home: Final report on DETR contract EPG 1/5/12

http://www.cranfield.ac.uk/health/researchareas/environmenthealth/ieh/ieh%20publications/w7.pdf

International Centre for Indoor Environment and Energy (ICIEE)

ICIEE is a research and dissemination organisation. The main activities of the Centre are to perform research projects within the areas specified under the vision and mission

The Centre is located at the Technical University of Denmark, north of Copenhagen

http://www.iciee.byg.dtu.dk/About-ICIEE/Mission--Vision

Vision: ICIEE will be the world leading research centre on indoor environment and energy. ICIEE will provide planners and producers of buildings and HVAC systems with criteria, methods and tools for achieving an optimal indoor environment by design and during operation of low energy buildings and energy efficient HVAC systems

Mission: The mission of the International Centre for Indoor Environment and Energy (ICIEE) is to serve to achieve healthy, comfortable and productive indoor environments with minimal energy consumption. The activities focus on three critical issues:

1. Impact of indoor environment on health, comfort and performance of people (including buildings and vehicles)

2. Development and study of advanced and energy efficient systems for heating, ventilation, and cooling of spaces

3. Dissemination of results through papers, conferences, education and standardisation

Indoor environments and human comfort, health and productivity

http://www.iciee.byg.dtu.dk/Research/health_productivity

An important research area is field and laboratory studies of the impact of indoor environment factors on human comfort, health and productivity, with particular emphasis on the mechanisms underlying these effects.

In the recent years, several studies have been completed that investigated the effect of such factors as pollution load and ventilation rate on human productivity. As a result, it was documented for the first time that the performance of office work is affected by the indoor air

quality. Studies of this nature continue with an extended scope that includes not only the performance of office employees, but also indoor environmental effects on the performance of school work by children. Indoor environment factors to be investigated include air cleaning, temperature control, ventilation rate, etc.

Productivity is affected by the air quality in offices

Poor indoor air quality decreases human productivity

Perceived air quality, sbs-symptoms and productivity in a low-polluting and a non low-polluting building

Negative impact of air pollution on productivity: Previous Danish findings repeated in new Swedish test room

Human requirements in future air-conditioned buildings

IAQ in the 21st Century

Effects of exposure to noise and indoor air pollution on human perception and symptoms

Impact of sorption phenomena on perceived indoor air quality

New studies on emissions from electronic equipment

Indoor environment and learning in schools

http://www.iciee.byg.dtu.dk/Research/Indoor-environment-and-learning-in-schools

Preliminary results of studies investigating the effects of IEQ on the performance of schoolwork by children…

(Abstract): Recent experiments have shown that poor indoor environmental quality (IEQ) in office buildings can reduce the performance of office work by adults. It is thus reasonable to suspect that poor IEQ can also negatively affect the performance of schoolwork by children. While it is well documented that IEQ in schools is both inadequate and frequently much worse than in office buildings, there is little direct evidence that classroom performance is being negatively affected. New studies carried out at the International Centre for Indoor Environment and Energy, Technical University of Denmark investigated whether IEQ can affect the performance of schoolwork by children. They were supported partially by American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) through contract 1257-RP “Indoor Environmental Effects on the Performance of Schoolwork by Children” and partially by the Danish Technical Research Council (STVF) as part of the research programme of the International Centre for Indoor Environment and Energy established at the Technical University of Denmark. The preliminary results of the these studies are reported in the following.

Three independent field intervention experiments investigated the effects of increased

outdoor air supply rates and reduced air temperatures in classrooms on the performance of schoolwork. They were carried out in an elementary school in Denmark in classrooms with about 100 10- to 12-year-old pupils. The experiment investigating the effect of reduced temperatures was carried out in late summer using two parallel classes of 10-year-old children. The air temperatures were reduced from 23.6ºC to 20ºC in a 2x2 crossover design balanced for order of presentation, each condition being maintained for a full week. The temperature was reduced using wall-mounted split air conditioning unit. The experiments investigating the effects of increased outdoor air supply rates were carried out in late summer and in winter in four identical classrooms of 10- and 12-year-old children. The outdoor air supply rate was increased from about 5 to 9.5 l/s per person in summer, and from about 4 to 8.5 l/s per person in winter, in each case in a cross-over design balanced for order of presentation. Each experiment was carried out in two parallel classrooms at a time and each condition lasted for a week. The outdoor air supply rate was increased using the existing mechanical ventilation system. In all three experiments the performance of schoolwork was measured using parallel versions of performance tasks representing up to eight different aspects of schoolwork, from reading to mathematics. The tasks were selected so that they could have been a natural part of an ordinary school day. The tasks were administered by the children's usual teachers. They included: addition of numbers; multiplication of numbers; subtraction of numbers; checking columns of numbers against each other; sentence comprehension; proof-reading of text in which deliberate errors had been inserted; acoustic proof-reading, i.e. listening to a recorded voice and checking a transcript in which deliberate errors had been inserted; and reading a text in which choice points had been inserted to determine whether the children understood the text (reading and comprehension). In addition the teachers carried out check-list observation of the children's behaviour. Parents and teachers recorded their observations of children's health and mood in logbooks, and the children themselves marked visual-analogue scales each week to indicate the intensity of various symptoms of ill health. During experiments, the teachers and pupils were allowed to open the windows as usual, and no changes to the lesson plan or normal school activities at school were made, so as to ensure that the teaching environment and daily routines remained as normal as possible. Both teachers and pupils were blind to interventions.

Reduced temperature significantly ($P<0.05$) increased the rate at which pupils subtracted numbers and performed a reading and comprehension task and the rate at which pupils categorized logical statements as true or false. It tended ($P<0.10$) to reduce errors when they proof-read what purported to be a transcript, in which discrepancies had been inserted, while listening to a recorded voice reading the original text aloud and to increase the rate at which numbers were compared. In no test (except for acoustic proof reading) was the proportion of errors affected. Increased outdoor air supply rate significantly ($P<0.05$) improved the performance of the following individual tasks by from 3% to 35%: addition, multiplication, number checking and subtraction in summer, and reading and comprehension, sentence comprehension, subtraction and multiplication in winter. In all the tasks mentioned, there was a statistically significant improvement in the work rate, while the error rate remained constant. For none of the tasks was a statistically significant reduction in performance associated with the increased outdoor air supply rate or the reduced temperature.

Using the performance of individual tasks that were affected by an increased outdoor air

supply rate, the average performance of schoolwork was computed and a regression equation against the outdoor air supply rates measured in the classrooms was derived (Fig. 1). The regression indicates that doubling the outdoor air supply rate would improve the average performance of schoolwork by about 15%. It may be seen that there is extremely good quantitative agreement between the results of the two independent experiments, which were performed at different times of year, in different classrooms and with children at two different ages.

In conclusion, the present results indicate that improving classroom conditions can considerably improve the performance of school work by children. Since the performance of schoolwork affects learning, they also imply that improving classroom conditions can have lifelong consequences both for pupils and for society.

Institute of Occupational Safety & Health (Wigston, Leicestershire)

http://www.iosh.co.uk/default.aspx

IOSH is the Chartered body for health and safety professionals

As the world's biggest professional health and safety membership organisation, we're the voice of the profession, campaigning on issues that affect millions of working people. We set standards and support, develop and connect our members with resources, guidance, events and training.

International Society of Indoor Air Quality and Climate (ISIAQ)

An international scientific organization whose purpose is to support the creation of healthy, productive, and comfortable indoor environments. ISIAQ does this by advancing the science and technology of the indoor environment, facilitating international communication and information exchange.

http://www.isiaq.org/

ISIAQ is an international, independent, multidisciplinary, scientific, non-profit organization whose purpose is to support the creation of healthy, comfortable and productive indoor environments, by advancing the science and technology of indoor air quality and climate as it relates to indoor environmental design, construction, operation and maintenance, air quality measurement and health sciences.

Members of the Society are:

- Scientists involved in all aspects of indoor air quality
- Government and regulatory professionals

- Medical practitioners
- Occupational health professionals
- Building owners and managers
- Building, construction and air-conditioning engineers
- Architects
- Environmental lawyers

Some of ISIAQ's most important activities include:

- Publication of a high profile journal Indoor Air which reports original research results in the broad area defined by the indoor environment of non-industrial buildings.
- Publication of a Newsletter which carries news and information.
- Developing guideline documents by a number of Task Forces focused on specific issues. Task Forces convene during ISIAQ conferences.
- Organising Indoor Air and Healthy Buildings series as primary Society conferences.

IAQ Information Centre

The IAQ Information Centre consists of a Physical Centre and a Cyber Centre, which is set up, operated and maintained by Hong Kong Productivity Council for Environmental Protection Department.

The function of the IAQ Information Centre is to allow public access to information on IAQ by visiting the Physical Centre or access to the Cyber Centre through the internet webpage.

Guidance notes on indoor air quality management.

http://www.iaq.gov.hk/guidance/doc/gn_eng.pdf

Indoor Air – the International Journal of Indoor Environment & Health

The quality of the environment within buildings is a topic of major importance for public health. *Indoor Air* provides a location for reporting original research results in the broad area defined by the indoor environment of non-industrial buildings. An international journal with multidisciplinary content, Indoor Air publishes papers reflecting the broad categories of interest in this field:

- health effects
- thermal comfort
- monitoring and modelling

- source characterization
- ventilation and other environmental control techniques.

The research results present the basic information to allow designers, building owners, and operators to provide a healthy and comfortable environment for building occupants, as well as giving medical practitioners information on how to deal with illnesses related to the indoor environment.

Article from 2004…

Chamber Assessment of Formaldehyde and VOC Emissions from Wood-Based Panels

http://onlinelibrary.wiley.com/doi/10.1111/j.1600-0668.1999.t01-1-00008.x/abstract

(Abstract) Volatile organic emissions from particleboard, medium density fibreboard (MDF) and office furniture have been measured in dynamic environmental chambers, both small and room-sized. Characterisation of product emission properties in small chambers was possible when inter- and intra-sheet variations were considered. Formaldehyde emission factors for all products were approximately double European low-emission specifications and did not decay to the latter for several months. Long-term emission behaviour could not be predicted from short-term measurements. Volatile organic compounds (VOC) emissions were low for the MDF product, higher for particleboard, and highest for laminated office furniture. The compounds emitted differed from those reported in other countries. VOC emissions from the sheet products decreased more quickly than formaldehyde, reaching low levels within two weeks, except for MDF which was found to become a low-level source of hexanal after several months.

Also in Indoor Air…

Wolkoff, Peder. (National Institute of Occupational Health, Copenhagen, Denmark) (1995), Volatile Organic Compounds Sources, Measurements, Emissions, and the Impact on Indoor Air Quality.

http://onlinelibrary.wiley.com/doi/10.1111/j.1600-0668.1995.tb00017.x/abstract

Also…

Organic compounds in indoor air - their relevance for perceived indoor air quality?

http://www.nchh.org/Portals/0/Contents/Article0579.pdf

Also several other original research studies, Peder Wolkoff…

A Study of Human Reactions to Emissions from Building Materials in Climate Chambers. Part I: Clinical Data, Performance and Comfort

A study of human reactions to emissions from building materials in climate chambers. Part II: VOC measurements, mouse bioassay, and decipol evaluation in the 1-2 mg/m3 TVOC range

Published in Indoor Air journal…1992

http://onlinelibrary.wiley.com/doi/10.1111/j.1600-0668.1991.00002.x/abstract

(Part 1 Abstract): The purpose of this study was to evaluate whether asthmatic reactions and changes in tear film quality could be provoked by exposing subjects to emissions from building materials in climate chambers. Twenty asthmatics and 5 healthy controls were exposed to (1) gypsum board hung with waterborne painted wallpaper; (2) rubber floor covering; (3) nylon carpet with rubber mat; (4) particle board coated with acid-curing paint; and (5) no test materials in climate chambers for 6 h. Participants recorded symptoms by filling in questionnaires, and clinical data were evaluated by lung function measurements at intervals of 30 min to 1h, and external eye examinations before and after exposure (appearance of foam at eyelid, semi-quantitative measurements of precorneal superficial lipid layer, break-up time and epithelial damage). There was agreement between a trained panel's evaluation of perceived air quality and the participants' opinion of indoor air quality. No correlation was found between lung function measurements and exposure to the materials. However, for all materials, statistically significant changes in tear film quality were observed to varying degrees. Lipophilic Volatile Organic Compounds (VOCs) may destabilize the lipid multilayer of the tear fluid, and this mechanism is suggested to be at least partly responsible for eye irritation.

http://onlinelibrary.wiley.com/doi/10.1111/j.1600-0668.1991.00003.x/abstract

(Part 2 Abstract): Monitoring of human reactions to the emission of formaldehyde and volatile organic compounds (VOC) from four commonly used building materials was carried out. The building materials were: a painted gypsum board, a rubber floor, a nylon carpet, and a particle board with an acid-curing paint. The exposures were performed in climate chambers. The air quality was quantified on the decipol scale by a trained panel, measurements of formaldehyde and VOC being performed simultaneously. The irritating potency of the materials was measured by a mouse bioassay. The VOC measurements showed several malodorants and irritants. Some abundant VOC identified in the head-space analyses were absent in the climate chamber air. The rubber floor and the nylon carpet exhibited a marked increase in decipols compatible with a number of odorous VOC identified in the air. A high formaldehyde concentration (minimum 743µg/m^3) was measured for the particle board coated with an acid-curing paint. This was not reflected by a corresponding relatively high decipol value but a long-lasting irritating potency was observed in the mouse bioassay. TVOC sampled on Tenax and expressed in mass per volume as well as in molar concentration, and decipol evaluation both have limitations and should be used with caution as indicators of (perceived) indoor air quality. Eye irritation expressed by means of the eye index reflecting the tear film quality index (comprised of break-up time, foam formation, thickness of the precorneal lipid layer of the tear film, and epithelial damage) was found to be insensitive to formaldehyde and a VOC mixture but sensitive to TVOC concentrations of 1–2 mg/m^3. Lipophilic VOC may be the cause of reduced tear film quality by destabilization of the lipid multilayer of the tear film.

Volatile Organic Compounds, Indoor Air Quality and Health

By Lars Mølhave

Published in Indoor Air journal…2004

http://onlinelibrary.wiley.com/doi/10.1111/j.1600-0668.1991.00001.x/abstract

(Abstract): This publication summarizes field investigations and controlled experiments on the relation between low levels of indoor air pollution with volatile organic compounds (VOC) and human health and comfort. The Henle-Kock criteria from epidemiology are revised for the dose-response relation between VOC's and health as comfort effects and existing evidence for each criterion are discussed. A biological model for human responses is suggested, based on three mechanisms: sensory perception of the environment, weak inflammatory reactions, and environmental stress reactions. Further, the TVOC-indicator concept for exposure is discussed. The conclusion is that no experimental or field data contradict the proposed causality. On the contrary, evidence supports the suggested causality. The biological model, however, is not yet based on acceptable measures of the variables for exposures, co-variables or health effects. A tentative guideline for VOC's in non-industrial indoor environments is suggested. The no-effect level seems to be about 0.2 mg/m^3. A multi-factorial exposure range may exist between 0.2 and 3 mg/m^3. Above 3 mg/m^3 discomfort is expected.

The Danish Twin Apartment Study; Part I: Formaldehyde and Long-Term VOC Measurements

1. P. Wolkoff[1],
2. P.A. Clausen[1],
3. P.A. Nielsen[2],
4. L. Mølhave[3]

http://onlinelibrary.wiley.com/doi/10.1111/j.1600-0668.1991.00012.x/abstract

(Abstract): Field measurements of 21 volatile organic compounds (VOC) using diffusive samplers, formaldehyde, temperature, and humidity were performed from the time of building completion throughout the following one-year period in two new semi-detached twin apartments. One of these was occupied after six weeks. Headspace analyses from all building materials and products showed 120 different VOC. Formaldehyde concentrations were strongly seasonally dependent in the vacant apartment and increased to above 400µg/m3 during the warm season. The formaldehyde concentration generally decreased in the occupied apartment but increased again during the fall season. VOC originating from building materials generally showed a decrease in emission, but strong seasonal variations were observed. It was shown that human activity introduces several VOC to the indoor environment. Storage of motorcycle parts in the crawl space of the occupied apartment resulted in migration and an infiltration of benzene and toluene into the apartment above and probably to a delayed peak concentration in the twin vacant apartment. Similarly, large VOC increases in one apartment were reflected by a later increase of the same VOC in the twin apartment. Hexanal increased during the warm season. TVOC, as the sum of 21 VOC, was generally approximately 50 % higher in the occupied apartment during the cold season. The

results indicate the difficulties in interpreting long-term measurements. The “flushing period” recommended for this type of building has been estimated to be about 130 days.

Concentrations of Volatile Organic Compounds in Indoor Air – A Review

1. S. K. Brown[1],
2. M. R. Sim[2],
3. M. J. Abramson[2],
4. C. N. Gray[3]

http://onlinelibrary.wiley.com/doi/10.1111/j.1600-0668.1994.t01-2-00007.x/abstract

Published 2004

(Abstract): A review is presented of investigations of volatile organic compound (VOC) concentrations in indoor air of buildings of different classifications (dwellings, offices, schools, hospitals) and categories (established, new and complaint buildings). Measured concentrations obtained from the published literature and from research in progress overseas were pooled so that VOC concentration profiles could be derived for each building classification/category. Mean concentrations of individual compounds in established buildings were found to be generally below 50 μg/m^3, with most below 5 μg/m^3. Concentrations in new buildings were much greater, often by an order of magnitude or more, and appeared to arise from construction materials and building contents. The nature of these sources and approaches to reduce indoor air concentrations by limiting source VOC emissions is discussed. Total VOC (TVOC) concentrations were substantially higher than concentrations of any individual VOCs in all situations, reflecting the large number of compounds present, but interpretation of such measurements was limited by the lack of a common definition for TVOC relevant to occupant exposure.

TVOC and Health in Non-industrial Indoor Environments - Report from a Nordic Scientific Consensus Meeting at Långholmen in Stockholm, 1996

1. K. Andersson[1],
2. J. V. Bakke[2],
3. O. Bjørseth[3],
4. C.-G. Bornehag[4],
5. G. Clausen[5],
6. J. K. Hongslo[6],
7. M. Kjellman[7],
8. S. Kjærgaard[8],
9. F. Levy[9],
10. L. Mølhave[10],
11. S. Skerfving[11],
12. J. Sundell[12]

http://onlinelibrary.wiley.com/doi/10.1111/j.1600-0668.1997.t01-2-00002.x/abstract

(Abstract): The presence of Volatile Organic Compounds (VOC) in indoor air has in past decades often been associated with adverse health effects such as sensory irritation, odour and the more complex set of symptoms called the Sick Building Syndrome (SBS). More recently, a possible link between the increase in the prevalence of allergies throughout the industrialized areas of the world and exposure to elevated concentrations of VOCs has been suggested. In many cases, the total VOC (TVOC) is used as a measure of the concentration of air pollution and, by extension, as a measure of the health risk in non-industrial buildings. However, the TVOC concept has been questioned for a number of reasons, including the facts that it is an ambiguous concept, that individual VOCs making up the whole can be expected to give rise to different effects in people and that researchers have been using different definitions and interpretations of TVOC. This means that simple addition of the quantities of individual VOCs may not be relevant from a health point of view.

Twelve researchers from the Nordic countries have reviewed the literature on VOC/TVOC and health. A search of the literature resulted in the identification of about 1100 articles, of which 120 were selected for further examination. A final review of the articles reduced their number to 67 that contained data on both exposure and health effects.

The group concluded that indoor air pollution including VOC is most likely a cause of health effects and comfort problems in indoor environments in non-industrial buildings. However, the scientific literature is inconclusive with respect to TVOC as a risk index for health and comfort effects in buildings. Consequently, there is at present an inadequate scientific basis on which to establish limit values/guidelines for TVOC, both for air concentrations, and for emissions from building materials. The group concluded that continued research is required to establish a risk index for health and comfort effects for VOC in non-industrial buildings

Medscape News

Volatile Organic Compounds in Buildings Linked to Allergic Rhinitis

http://www.medscape.com/viewarticle/713926

Jacquelyn K. Beals, PhD

December 16, 2009 (Buenos Aires, Argentina) — A Brazilian study comparing the prevalence of allergic rhinitis in people working in sealed artificially ventilated buildings and those working in buildings with natural ventilation.

National Research Council Canada

http://www.nrc-cnrc.gc.ca/eng/index.html

NRC-IRC (The National Research Council (NRC) is the Government of Canada's premier organization for research and development).

A list of other reports/studies from this organisation that may be relevant can be found via the link below:

http://www.nrc-cnrc.gc.ca/eng/publications/index.html

Including:

IRC conducts complex indoor air quality field research v4n1-12

http://www.nrc-cnrc.gc.ca/ci-ic/article/v4n1-12

NRC's indoor air strategies and solutions

http://www.nrc-cnrc.gc.ca/eng/reports/2013_2014/clean_air_regulatory_agenda.html

Office of the Deputy Prime Minister's report from 2005

Ventilation and Indoor Air Quality in Schools – Guidance Report 202825

http://webarchive.nationalarchives.gov.uk/20120919132719/http://www.communities.gov.uk/documents/planningandbuilding/pdf/144155.pdf

Patty's Industrial Hygiene & Toxicology

Indoor Air Quality in Nonindustrial Occupational Environments

1. Philip R. Morey Ph.D., CIH,
2. Gary N. Crawford CIH,
3. Robert B. Rottersman CIH

Published in Patty's Industrial Hygiene & Toxicology, Feb 2011

http://onlinelibrary.wiley.com/doi/10.1002/0471435139.hyg065.pub2/abstract

(Abstract): The study summarises about the indoor air quality of the buildings. Historically, the concept of indoor air quality (IAQ) has included viewpoints that outdoor ventilation air is required both to prevent adverse health effects and to provide for comfort of occupants. It has been observed that airborne contagious diseases and malodor are more prominent in the crowded places with deficient ventilation. The different approaches that can be used during IAQ evaluations reflect the varied kinds of problems that can occur in buildings. Higher morbidity and mortality in developing countries have multifactorial causes, with contaminated food, water, and air as major risk factors. An ASHRAE ventilation standard recommends the provision of outdoor air rate per person to lower the risk of diseases. The article focuses IAQ evaluation protocols and guidelines, Canadian and EPA guides, etc.

Primary Care Respiratory Journal

Article:

Volatile organic compounds and risk of asthma and allergy: a systematic review and meta-analysis of observational and interventional studies

http://www.thepcrj.org/journ/view_article.php?article_id=1013

Royal Borough of Kensington & Chelsea (Council)

http://www.rbkc.gov.uk/environmentandtransport/airquality/indoorairquality.aspx

Providing general information on indoor air pollutants and health effects.

Scientific American

VOCs and Allergies; article in Scientific American Oct 2010

Volatile Organic Compounds May Worsen Allergies and Asthma

http://www.scientificamerican.com/article.cfm?id=volatile-organic-compounds

SINPHONIE project, the Schools Indoor Pollution and Health: Observatory Network in Europe

http://www.sinphonie.eu/about

The SINPHONIE project, the Schools Indoor Pollution and Health: Observatory Network in Europe, is a complex research project covering the areas of health, environment, transport and climate change and aimed at improving air quality in schools and kindergartens. The project is implemented under a European Commission service contract of the DG Sanco. Thirty-six environment and health institutions from 25 countries are participating in the SINPHONIE research project in order to implement Regional Priority Goal III (RPG3) of the Children's Environment and Health Action Plan for Europe (CEHAPE), which is to prevent and reduce respiratory disease due to outdoor and indoor air pollution.

http://www.sinphonie.eu/sites/default/files/publications/school_staff/SINPHONIE_school%20staff%20brochure_ENG_Final.pdf

UK Green Building Council

The UK Green Building Council is campaigning for a sustainable built environment. As a charity and membership organisation, it facilitates dialogue between industry and Government to promote greener approaches in the construction sector

http://www.ukgbc.org/

The website has various case studies of low VOC emitting materials in use in buildings.

University of Cambridge (Estates Management)

http://www.admin.cam.ac.uk/offices/em/sustainability/environment/guidance/emissions.html

Volatile organic compounds (VOCs): Volatile organic compounds are compounds that have a high vapour pressure and low water solubility. Many VOCs are man-made chemicals that are used and produced in the manufacture of paints, pharmaceuticals, and refrigerants. VOCs typically are industrial solvents, such as trichloroethylene; fuel oxygenates, such as methyl tert-butyl ether (MTBE) or by-products produced by chlorination in water treatment, such as chloroform. VOCs are often components of petroleum fuels, hydraulic fluids, paint thinners, and dry cleaning agents. Therefore, during the course of many industrial processes, VOCs are released to the atmosphere. Once released, they undergo a series of complex reactions resulting in the formation of ground-level ozone, which is harmful to human health and the environment. Some VOCs are quite harmful, including benzene, polycyclic aromatic hydrocarbons (PAHs) and 1,3-butadiene. Benzene may increase susceptibility to leukaemia, if exposure is maintained over a period of time, and PAHs may be carcinogenic.

Wikipedia

Entry giving description of VOCs and related links

http://en.wikipedia.org/wiki/Volatile_organic_compound

World Health Organisation (WHO)

Guidelines for indoor air quality

http://www.erg.kcl.ac.uk/News.aspx?NewsId=WHOIndoorAQ

Indoor Air Pollution - Children's Health and the Environment (2008)

http://www.who.int/ceh/capacity/Indoor_Air_Pollution.pdf

Indoor Air Pollution and Health

http://www.who.int/mediacentre/factsheets/fs292/en/index.html

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EMS 543324 *FM 550533*

Technical enquiries
British Gypsum
Technical Advice Centre
East Leake
Loughborough
Leicestershire
LE12 6HX

Telephone: 0844 800 1991
Fax: 0844 561 8816
Email: bgtechnical.enquiries@bpb.com

Training enquiries: 0844 561 8810

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