INTERNATIONAL ENERGY AGENCY
energy conservation in buildings and community systems programme

An Annotated Bibliography
Impact of Urban Air Pollution on the Indoor Environment

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Impact of Urban Pollution on the Indoor Environment An Annotated Bibliography

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Preface

International Energy Agency

The International Energy Agency (IEA) was established in 1974 within the framework of the Organisation for Economic Co-operation and Development (OECD) to implement an International Energy Programme. A basic aim of the IEA is to foster co-operation among the twenty-four IEA Participating Countries to increase energy security through energy conservation, development of alternative energy sources and energy research development and demonstration (RD&D).

Energy Conservation in Buildings and Community Systems

The IEA sponsors research and development in a number of areas related to energy. In one of these areas, energy conservation in buildings, the IEA is sponsoring various exercises to predict more accurately the energy use of buildings, including comparison of existing computer programs, building monitoring, comparison of calculation methods, as well as air quality and studies of occupancy.

The Executive Committee

Overall control of the programme is maintained by an Executive Committee, which not only monitors existing projects but identifies new areas where collaborative effort may be beneficial.

To date the following have been initiated by the Executive Committee (completed projects are identified by *):

I	Load Energy Determination of Buildings*
II	Ekistics and Advanced Community Energy Systems*
III	Energy Conservation in Residential Buildings*
IV	Glasgow Commercial Building Monitoring*
V	Air Infiltration and Ventilation Centre
VI	Energy Systems and Design of Communities*
VII	Local Government Energy Planning*
VIII	Inhabitant Behaviour with Regard to Ventilation*
IX	Minimum Ventilation Rates*
X	Building HVAC Systems Simulation*
XI	Energy Auditing*
XII	Windows and Fenestration*
XIII	Energy Management in Hospitals*
XIV	Condensation*
XV	Energy Efficiency in Schools*
XVI	BEMS - 1: Energy Management Procedures*
XVII	BEMS - 2: Evaluation and Emulation Techniques*
XVIII	Demand Controlled Ventilating Systems*
XIX	Low Slope Roof Systems*

XX	Air Flow Patterns within Buildings*
XXI	Thermal Modelling*
XXII	Energy Efficient Communities*
XXIII	Multizone Air Flow Modelling (COMIS)*
XXIV	Heat Air and Moisture Transfer in Envelopes*
XXV	Real Time HEVAC Simulation*
XXVI	Energy Efficient Ventilation of Large Enclosures*
XXVII	Evaluation and Demonstration of Domestic Ventilation Systems
XXVIII	Low Energy Cooling Systems
XXIX	Daylight in Buildings
XXX	Bringing Simulation to Application
XXXI	Energy Related Environmental Impact of Buildings
XXXII	Integral Building Envelope Performance Assessment
XXXIII	Advanced Local Energy Planning
XXXIV	Computer-Aided Evaluation of HVAC System Performance
XXXV	Control Strategies for Hybrid Ventilation in New and Retrofitted Office Buildings (HYBVENT)
XXXVI	Retrofitting in Educational Buildings - Energy Concept Adviser for Technical Retrofit Measures.
XXXVII	Low Exergy Systems for Heating and Cooling of Buildings.

Annex V Air Infiltration and Ventilation Centre

The Air Infiltration and Ventilation Centre was established by the Executive Committee following unanimous agreement that more needed to be understood about the impact of air change on energy use and indoor air quality. The purpose of the Centre is to promote an understanding of the complex behaviour of air flow in buildings and to advance the effective application of associated energy saving measures in both the design of new buildings and the improvement of the existing building stock.

The Participants in this task are Belgium, Denmark, Finland, France, Germany, Greece, Netherlands, New Zealand, Norway, Sweden, United Kingdom and the United States of America.

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(6). Ventilation in Schools
(7). Ventilation and Acoustics
(8). Passive Cooling Technology for Office Buildings

Scope

This bibliography is aimed at researchers, designers and engineers who are seeking an introduction into the impact of urban air pollution on the indoor environment. Given the extremely wide scope and nature of this subject, covering many specialist areas of research, the aim of this bibliography is to simply identify and introduce the most significant areas of concern. References quoted in this document are taken from the AIVC's bibliographic database, AIRBASE and, subject to copyright restrictions are available to organisations in AIVC participating countries through the Centre's library service. The reference section also contains a list of other papers of interest, which are not covered in the text. Many of these are also available from the AIVC Library upon request.

1.0 Introduction

Urban areas are prone to significant levels of air pollution. Typical sources include:

- Pollutants from industrial sources (processes, power stations etc);
- Pollutants from vehicles;
- Pollution from adjacent buildings;
- Smogs.

These all combine to result in a regional 'background' pollutant concentration on which local sources of pollutant (e.g. nearby traffic) are superimposed. The actual concentration at any particular location is dependent on many factors including:

- Regional concentration;
- Proximity of polluting sources;
- Weather conditions;
- Local Terrain.

As an approximate guide, urban pollution in developed countries is strongly influenced by traffic densities, whereas in developing areas, it is likely to be influenced by industrial emissions and the use of coal burning appliances.

Whatever the cause, however, clean outdoor air is essential for achieving good indoor air quality as well as for providing for the good health of the population in general. Such is the importance of outdoor air quality, regulations on emissions are imposed in many countries. In the United States, for example, emissions are governed by the 'Clean Air Act', whereas, in Europe, it is covered by the 'Air Framework Directive'. Both impose restrictions on pollutant discharges and incorporate requirements to clean exhaust air. Emission requirements for vehicles are also becoming steadily more stringent.

Despite these moves, the growing population density of urban areas and resultant emissions is causing concern about the build up of pollutants and their impact on building occupants. The purpose of this bibliography is to highlight recent literature that has focused on the impact of urban pollution on the indoor environment. The main areas are:

- Typical pollutants and sources;
- Measurements in buildings;

- Specific case studies;
- Remedial measures;

2.0 Typical Urban Pollutants, Sources and Characteristics

The importance of the quality of outdoor air has significant impacts both in terms of health and wellbeing of the occupants and in terms of energy. Tyler (#11583, 1993) has examined the effects of rapid urbanisation and the resultant impacts on economies and environment. With urbanisation the major emissions are not only building related, but are also related to vehicle emissions which contribute a significant share of particulate, smoke, carcinogenic hydrocarbons and toxic heavy metals. Over the past two decades the environmental impacts of these actions have been made clearer. Consequently measures are now in place to restrict pollution emissions, via taxation and global collaboration (Montreal Protocol and Kyoto Conference). Despite such good intention, though, the shear number of additional devices and vehicles currently counteracts attempts to improve efficiency and reduce pollution.

Several authors have examined the general question of urban air pollution, for example Oke (1983) considers the effects of an urban heat island as well as associated air pollution in the boundary layer. While other authors more specifically deal with the connections and interactions between the outdoors and indoors. Shair and Heitner (#469, 1974) present a dynamic model for relating indoor pollutant concentrations to pollutants outdoors. This model shows that at certain times outdoor concentrations change very slowly, compared to the time required either to remove the air within the structure or to remove the pollutant by internal means. More recently Hall et al (#10697, 1996) examined the types of pollutants, their sources and the effects on the indoor environment. In essence Hall explains that pollutants can be categorised in terms of 'primary' and 'secondary'. Primary pollutants are those that are emitted directly into the atmosphere and concentrations respond linearly with emission rates. Restrictions in emissions would therefore lead to a proportionate decrease in atmospheric concentrations. Secondary pollutants are not emitted directly but are formed as a result of chemical reactions between pollutants within the atmosphere, such as the formation of nitrogen dioxide from nitric oxide and the development of low altitude ozone formed by the chemical reactions of nitrogen oxides and hydrocarbons.

Hall (#10701, 1997) further examined the relationships between local and background levels of pollutants; their contribution to the total local pollution levels and the vertical and lateral gradient of pollution. His paper outlines the way in which pollutant sources, especially from varying distances, contribute to different features of the total concentration at a point. Both spatial and temporal variations of pollutant concentrations can be large and generally increase with reducing averaging time and spatial scale. Ajiboye et al (#11358, 1997) considered the significance of urban pollution and its dilution effect with height. This involved an initial examination of air quality data from 1992-1995, to determine the most significant pollutants, and corresponding peak concentration times, both of the year and days of the week. Identified pollutants included nitrogen dioxide (NO_2), sulphur dioxide (SO_2), ozone (O_3) and particulate matter (PM_{10}). The main pollutants, NO_2 and PM_{10}, were measured at different heights outside a ten storey naturally ventilated office building located adjacent to a busy London road. Air quality measurements were made at varying heights from between 5m (fixed) and 11.10m to 32.45m. The authors derived an overall picture of concentration verses height effects by calculating percent change in concentration between points. Results indicated that PM_{10} concentrations are diluted with height in all cases, although not in a linear way. NO_2 concentration was found to behave differently. Initially the concentration increased with height (up to about half the building height) beyond which it fell by between 10-16%.

Harrison (#11585, 1994) presents an historical background of air pollution in the UK from the 1950's when the deaths of 4000 people where attributed to the combination of cold stagnant weather and high levels of smoke and SO_2. The Clean Air Acts' of 1956 and 1968 followed, together with the switch to natural gas for domestic heating. These actions have lead to a large reduction in SO_2 concentrations in most UK towns and cities. However, during the past twenty years there has been a significant growth in road traffic, and total emissions from motor vehicles have now begun to dominate the urban air pollution figures. Renewed interest in urban air pollution has lead to an increase in the number of pollutants monitored as well as an increase in national monitoring sites such as the Enhanced Urban Nctwork (EUN) and Toxic Organic Micro-pollutants Network (TOMPS). In addition, emissions from traffic queues, tunnel entrances, underground car parks and multi-storey car parks are finding their way into buildings. Reports from the Quality of Urban Air Group (QUARG #11590, #11591, 1993, (#11798, 1996) report on both a steady increase in traffic growth and, despite pollutant control measures, increased pollution. In comparing the polluting performance of diesel and petrol driven cars they argue that, in general, diesel cars perform better than petrol cars equipped with modern three-way-catalytic converters in terms of carbon monoxide and carbon dioxide. On the other hand, in terms of NO_x and, especially in relation to particulate matter, they are inferior. Therefore, if an upward trend in market share of diesel engines continues, emissions of VOC's and carbon monoxide will continue to fall but emissions of particulate matter and oxides of nitrogen will rise. Future advances to reduce pollution include particulate traps and the development of NO_x reduction catalyst for diesels.

Contributions to man made hydrocarbon emissions in Western Europe are given by Perry and Gee (#7088, 1993), with solvents being the single largest at 4Mt/yr (40%), and total vehicle related emissions are approximately 4.2Mt/yr, representing a significant source of polluting hydrocarbons (approximately 40% of the annual released amount). Within the EEC the authors note that there is proposed legislation to control vehicle related emissions, including distribution and refuelling, as well as exhaust and evaporative emissions, although this is only beginning to currently take effect. The authors' note that the capability of the refinery is crucial in order to optimise blends, with greater flexibility leading to improved blends and ultimately air quality.

Growth in pollutant concentrations may not simply result from an increase in emissions, but rather from the interactions of several chemicals present in the atmosphere at the same time. Moore (#11778, 1989) focuses of atmospheric ozone and examines efforts to prevent its build up at ground levels where it contributes to urban smog whilst at the same time preventing its destruction in the stratosphere where it protects us from ultra violet rays. Ozone is not directly emitted from any source, yet Moore notes that over 60 major US urban areas are now above federal air quality limits for ozone of 120 ppb. Moore gives a detailed review of the whole problem of ozone generation and depletion and suggests that scientific insights should be used to inform the policy and regulatory governing bodies. Physick (#11776, 1996) considers the formation of photochemical smogs in Sydney and Melbourne, over the past 20 years, in Perth over the past 5 years and several other smaller studies in Brisbane and Adelaide. Motor vehicles are believed to be the main pollutant source in these areas, but the author emphases the importance of a detailed understanding of the meteorology associated with elevated smog levels. Modelling has shown that recirculation of the same day and previous days' emissions back over the source areas have been shown to occur in each of the studied cities and this makes a significant contribution to the high levels of pollution in these areas.

Infectious pollutants are also a source of concern. Many authors note the potential existence of legionnaires disease in the location and operation of wet cooling towers and humidification equipment, such authors include McGlone (#7819, 1992); Anon (#8963, 1995); Burton (#10865, 1995) and Godish (#9460, 1995; #4271, 1990). Guidance to reduce the risk of legionnaires disease is given by both ASHRAE (HVAC Applications Handbook 1995 (7.2 and 44.12) and Systems Handbook 1996 (19.8 and 36.11)) and CIBSE (1988) (Chapter B14-13). As will as most standard institutions, for example in the UK Health and Safety Executive Guidance Note HS (G) 70. Such guidance includes the fitting of drift eliminators, minimising human exposure to the aerosol and adequate and correct maintenance and operation. One of the most common places that the legionella bacteria has been found and reported is inside hospital environments. These buildings often have wet cooling towers or humidification equipment and an operating ventilation system. They also contain people who are more prone to infection and are often weak or recovering from illness. Streifel and Marshall (#11025, 1998) discuss the control of the Legionella pneumophila inside a hospital environments. They do not discuss the re entrainment or spread of the bacteria throughout the hospital via ventilation equipment, but concentrate on the ventilation and logistics of isolating this disease and controlling its further spread. The authors note that such isolation units should be designed into these buildings and should be adequately pressure tested to ensure they meet all standards. The European Collaborative Action on Indoor air quality and its impact on man, report 12 also draws attention Legionellae in its discussion on biological particles in indoor environments (Anon #7518, 1993). In this report the authors outline the background to the infection, and briefly discuss its occurrence within the indoor environment.

Exhaust emissions from stacks can find their way into buildings and cause indoor air quality and health problems. This topic area is vast and is necessarily restricted in this bibliography, but has been covered in a previous bibliography by Limb (#9107, 1995). Information is also regularly updated in the ASHRAE Fundamentals. A number of analytical and wind tunnel models have been developed to predict such contaminant dispersal. A jet plume model for short stacks is described by Halitsky (#8762, 1989) which contains a realistic initial jet region merged with a subsequent gaussian plume region. According to the author, the model brings together three experimentally verified elements; the initial jet region, the subsequent simple plume region and a curved plume centreline. He concludes, the jet plume model can be expected to produce meaningful predictions only if the assumed and actual wind fields are in general agreement. Large roof cavity regions on buildings in normal orientation and edge vortex regions on buildings in diagonal orientation are excluded. Wilson (#2914, 1982) presents an equation to predict the minimum exhaust to intake dilution factors and includes the capability of being able to account for the intake dilution due to exhaust jet momentum, turbulent entrainment of ambient air. Three factors are suggested that should be considered to minimise intake air contamination, i.e: exhausts should be designed to;

- Maintain a minimum distance from intakes in order to take advantage of distance dilution;
- Have uncapped exhausts that produce a strong exhaust jet perpendicular to the building surface. (It is suggested avoiding louvres and rain caps and maintaining the exhaust velocity at least as high as the local average airport windspeed);
- Exhausts should be located on the upper two thirds of the building, and always above the level of intakes to take advantage of exhaust buoyancy and to avoid being trapped in flow recirculation regions near the ground. If these points are considered by the designer it should be possible to avoid having more than 1% of exhaust gas contamination in intake air, when averaged over an exposure time of several hours.

Developments in Computational Fluid Dynamics (CFD) have meant plume and dispersion type modelling can now be undertaken numerically for exhaust stacks and pollution sources. An example of such a study is Ong (#8447, 1991), in which the wind flow over a factory roof was analysed.

High energy use can result in a 'heat Island' effect, which can exacerbate urban pollution problems, especially in relation to trapping pollutants and developing smog. Tarumi and Fuji (#11594, 1990), examine the impact of exhaust heat released as a consequence of providing energy to a large city, as well as associated changes in land use. For the Tokyo Metropolitan area, the authors quote mean energy consumption as 740 kcal/m^2 per day, representing an equivalent to 25% of the insolation from the whole sky. Tarumi and Fujjii suggest that there are several ways in which a good thermal environment can be maintained. The authors model the effectiveness of various approaches. They attempt to show the applicability of their model by using it to study soot and smoke emitting facilities in the Tokyo Metropolitan Area. Results show that the coefficient of exhaust heat management decreases as the temperature limit of the exhaust heat used for power generation decreases, and also as the temperature level of the exhaust heat taken up for processing increases. When the temperature levels of exhaust heat used for processing and power generation are equalised, the coefficient of exhaust heat management reaches approximately zero. Therefore by maximising the use of exhaust heat for power generation is effective in terms of conversion from exhaust heat to latent heat. Figures show that about 72% of exhaust heat can be converted to latent heat.

Sound that disturbs or irritates is described as noise. Sources and control measures of internal sound and noise generation have been identified and reviewed by Limb (#10716, 1997). The importance of outdoor noise is more significant in buildings equipped with natural ventilation since these buildings rely on their interaction with the outdoors for their source of clean ventilation air. As such noise from traffic, industrial processes, people, music and other outdoor processes, such as road works and other buildings can prove extremely problematic and disturbing. Op't Veld (#9250, 1996,) examined eight countries and found that the maximum acceptable noise level generated by outdoor noise sources inside rooms was between 30 to 35 dB(A). Op't Veld (#9250, 1996,) also notes that facades containing windows, unweatherstripped, and with regular glazing (single sheet 4 or 6 mm or double sheet 4/6/6/ mm or 4/12/6 mm achieve a noise reduction of approximately 20 dB(A). With windows open for ventilation a noise reduction of approximately 15 dB(A) can be achieved. Special acoustic measures will be required if outdoor noise levels at the facade exceed 50 to 55 dB(A). Noise can enter the building via joints and cracks around windows and doors, through ventilation openings in facades and through air ducts in facades and the roof with or without grilles. If noise reduction beyond about 20 dB(A) is required any joints and cracks will have to be properly sealed. Alternatively special acoustically treated ventilation openings are available. Op't Veld outlines typical noise reduction values of a closed facade openings with and without soundproofing and well as for a variety of facade types, such as weatherstripped, standard glass with minor weatherstripping and standard glass good single. Izard (#10647, 1997) notes that the recent French regulations specify that the internal level do not exceed 30 dB(A) during the night in the habitable rooms. To reduce noise, he explores the use of acoustic shutters, room location and other techniques.

Popav and Power (#11776, 1996) consider the impact of landfill emissions of gases to the atmosphere. The main gases of concern include carbon dioxide (CO_2) and methane (CH_4). The authors suggest that landfills are estimated to be a major source of CH_4 emissions and account for 38% of total anthropogenic sources. The UK Building Research Establishment gives guidance to constructing new buildings on gas contaminated land (#6865, 1991). The guidance notes that the two main pollutants are methane (flammable) and carbon monoxide (toxic), both of which are associated with coal strata, river silt, sewage and peat. It points to the relevant section in the UK Building regulations and offers guidance in terms of best practice. It discusses the principles of gas contaminated sites and outlines the construction principles (including concrete slab with granular venting layer and a ventilated subfloor void) needed to build on land contaminated by methane and carbon dioxide.

Poor atmospheric conditions can lead to the airflow around a building becoming stagnant, or altered. The problems of unfavourable atmospheric conditions were highlighted by Ferahian (#3569, 1989,). Such conditions were believed to be responsible for indoor air quality complaints at the McGill Medical Building in Canada. The author notes that this building occasionally suffers from air inversions, principally caused because of its location next to the mountain near Montreal, and downward wind around the building can bring exhausted air back through the air intakes. Solutions including inlet location design, based on wind tunnel studies are described.

3.0 Measurements of Outdoor Contaminants In Buildings

A significant number of measurements have been made in buildings to evaluate the impact of urban pollution on indoor air quality. However, because of characteristics such as individual building structures, activities and regional climates, the results of these measurements reveal little about the mechanisms of pollutant transport.

3.1 United States and Canadian Studies

Ott and Flachsbart (#11586, 1982) outline monitoring using small personal exposure meters to monitor carbon monoxide (CO). A total of 220 indoor commercial sites (including department stores, hotels, office buildings and parking garages) and 368 outdoor commercial sites (including street intersections, sidewalks, parks, arcades and parking spaces) in four cities in the US were investigated. The authors found that of the 210 indoor commercial settings, excluding garages, the average CO concentration was less than 9ppm. Of 368 outdoor settings 355 (96.7%) had an average CO concentration of less than 9ppm. CO concentrations were found to be very different in garages and sometimes quite high. The results indicated CO emissions from traffic in downtown areas tend to seep into buildings and stores. However, although indoor levels correlate with outdoor values, they do not get very high, except in buildings associated with parking garages or in garages themselves.

In a further study Ott et al (#11775, 1986) outline the US Environmental Protection Agency's research program on total human exposure. This research does not focus primarily on the sources of pollution or their transport and movement through the environment, but more on the people as receptors. In this context this paper provides useful and valuable information about the methods and equipment used to measure and detect pollutants such as carbon monoxide (CO) volatile Organic compounds (VOC's), pesticides, nitrogen dioxide (NO_2) formaldehyde and radon. This paper therefore provides valuable information that may not be contained to adequate detail elsewhere. When analysing an individual's exposure to pollutants, Silvermann et al (#11589, 1982) indicates that there can be substantial differences between air pollution levels measured at a site and measurements carried out a short distance away. An individuals personal exposure should also be considered in any assessment of health effects of air pollution since personal air pollution exposure depends upon mobility, activity, occupation and life style patterns. Personal samplers are more likely to be representative of the environments encountered by the subjects than global air quality monitoring. Further, when analysing exposure, Irving (#11773, 1998) proposes a generalised method of predicting the indoor air quality of a room, by combining varying external air quality with a knowledge of the internal sources and ventilation strategy.

Colome et al (#11603, 1982) examined the outdoor environment in two US regions (Steubenville, OH, an industrial city and Portage, WI, a rural farming community), and compares the resulting indoor pollutant concentration of houses within these areas. Ten homes were selected in total; five from the city and five from the rural community. The authors expected because of the complex topography and localised pollutant sources found in Steubenville that concentration gradients across ground level sites would be visible. At Portage a 524MW coal fired power station has produced measurable but minor effects on the air quality on the rural farming community in this area. A significant difference can be seen between the indoor and outdoor constituents at each site. Measured were sulphur dioxide (SO_2), nitrogen dioxide (NO_2), mass respirable particles (MRP), water soluble sulphate (SO_4), aluminium (Al), bromine (Br), chlorine (Cl), manganese (Mn), sodium (Na) and vanadium (V). The authors found that outdoor concentrations of most constituents in Steubenville are relatively high, with corresponding indoor levels being lower for all measured pollutants, except chlorine. The high level of chlorine at this location is believed to be caused mainly by indoor cleaning agents. The measured outdoor levels of pollutants in Portage were very low, and as a result elevated levels show greater differences. Typical outdoor pollutants such as SO_2, SO_4, Mn and V tend to show lower levels compared with those measured outside, while concentrations of NO_2, MRP, Al, Br, Cl and Na where all higher than outdoors. For example NO_2 is associated with gas-fired stoves and MRP associated with tobacco smoking. However the elevated levels of Al, Br Cl and Na the authors could not explain properly and suggested that possibly a multiplicity of indoor sources were responsible. In conclusion the authors note that there is a great variation in air quality when a single home is considered.

Pope et al (#11955; 1991) evaluated changes in respiratory health associated with daily changes in fine particulates (PM_{10}) in students and older patients with asthma in the Utah valley, USA. This region experiences high PM_{10} episodes during winter months, and previous studies have indicated that 30 to 40% of respiratory cancer and non-malignant respiratory disease in Utah county may be attributable to air pollution. The main cause of PM_{10} pollution is an integrated steel mill built during World War II. When in operation the mill emits 50 to 70% of the total Utah valley PM_{10} emissions. The author found that elevated levels of PM_{10} (150 $\mu g/m^3$) were associated with 3 to 6% decline in lung function as measured by peak expiratory flow. Elevated PM_{10} levels were also associated with increases in reported symptoms of respiratory disease and use of asthma medication. Associations between compromised respiratory health and elevated PM_{10} pollution were observed even when PM_{10} levels were well below the 24-h national ambient air quality standard of 150 $\mu g/m^3$.

Samet, et al (1995) report on the findings of the US Health Effects Institute, who in the light of a many studies that questioned the current NAAQS standard of particulate matter. They undertook a thorough and impartial evaluation of key elements of the epidemiologic data to assess the validity of the earlier results and re-examine their findings. The four specific aims included reconstructing the database for Philadelphia, developing an overall analytic strategy, applying this strategy to selected data bases and undertaking a sensitivity analysis for one city. The analyses yielded findings comparable to the original investigations. Conducted sensitivity analyses showed that TSP had little effect on mortality until it reached 100$\mu g/m^3$. Sulphur dioxide (SO_2) had an increasing effect on mortality in its lower range, and more of an effect on mortality in the middle and higher ranges. However, the findings do not clearly indicate that the increased mortality associated with increasing indexes of air pollution can be assigned to either TSP or SO_2 alone. The study found effects of both variables in the additive model. The effect of TSP was more dominant in the summer while SO_2 was more dominant in the winter. In conclusion for all six data sets considered, daily mortality from all causes combined, and from cardiovascular and respiratory causes in particular, increased as levels of particulate air pollution indexes increased. However, the detailed analyses of the Philadelphia data set supports a call for caution is assuming that this association represents an independent effect of particles alone.

In a similar study Kinney P L et al (#11956, 1995) evaluates a sensitivity analysis of mortality PM_{10} associations in Los Angeles county, between 1985-1990. Collected data includes total daily deaths (including accidents and suicides), 24-h average PM_{10}, daily 1-h maximum O_3 and carbon monoxide, maximum daily temperature, and mean daily relative humidity. PM_{10} concentrations occurred every six days, and therefore the analysis was limited to a subset of these days. The data was examined in terms of cyclic data variations, weather influences, other air pollutants, and the distribution of residuals. The authors also undertook several alternative methods of dealing with the data, to determine whether this had an impact of the results obtained. Kinney found that the estimated proportional increase in daily mortality associated with a 100 $\mu g/m^3$ increase in PM_{10} concentrations (or relative risk) fell generally between 1.03 and 1.05, regardless of the method used, indicating that sensitivity to methods was low in this data set. No definitive conclusion could be drawn regarding the role of ozone, except that O_3 appeared to be associated with mortality in univariate regressions (with weather and cyclic controls), however the association disappeared when PM_{10} was added to the model. Implying the preserved relationship between O_3 and mortality is weaker than with PM_{10}. Also that the univariate O_3 effect may have been due to O_3 acting as a PM_{10} surrogate. Regarding carbon monoxide (CO), this study indicated that CO had an independent association with mortality similar to that of PM_{10}. Although the authors note that more analysis on larger data sets is needed before any firm conclusions can be drawn about the relative roles of PM_{10} and CO as predictors of daily mortality.

The acute effects of summer air pollution on respiratory illnesses reported by children was undertaken by Schwartz et al (#11964, 1994). Data was collected from parents of 1,844 school children in six US cities. Three hundred elementary school children in each six communities kept a daily dairy of the respiratory symptoms for one year. Daily measurements of ambient sulphur dioxide, nitrogen dioxide, ozone, inhalable particles (PM_{10}), respirable particles ($PM_{2.5}$), light scattering, and sulphate particles were made, along with integrated 24-h measures of aerosol strong acidity. Associations were found between the occurrence of PM_{10}'s and the incidence of coughing, lower and upper respiratory symptoms. Associations were also found between sulphur dioxide or ozone and the incidence of cough, and between sulphur dioxide and incidence of lower respiratory symptoms. The relationship between ozone and incidence of cough was independent on other pollutants, however the relationship between sulphur dioxide and incidence of lower respiratory symptoms appeared to derive only from a few influential observations, and could be confounded by PM_{10}. Aerosol acidity was not associated with the incidence of any respiratory symptoms. The highest daily PM_{10} concentration was 117 $\mu g/m^3$ during the study, indicating that these relationships occurred at concentrations bellow the ambient air quality standard.

Weschler et al (#11978, 1983) reports on a study where the effects of fan operation on indoor-outdoor dust relationships were monitored at 2 typical telephone offices. Automatic dichotomous samplers were used to collect fine and coarse aerosol particles inside, and at both sites, outdoor roof samples were also taken at the same time. Fans normally operate when necessary to bring the temperature back to allowable limits and not continuously. Fans were operated intermittently as well as continuously during the experimental period. When the fans were off, dust levels rose, indicating this was due to loss of constant filtration, rather than due to loss of building pressurisation. The authors have derived and presented an expression to describe the relative dust increase when the building fans were off. Stating that among other factors, the relative increase is directly proportional to the efficiency of the building filters and to the rate at which air is re-circulated through them. The relative increase does not depend on the outdoor dust concentration, and therefore these findings can be extended to other buildings.

In previous similar studies the authors undertook measurements over a simulated time period, and the day to day operating conditions were not monitored. Thus prediction of indoor surface accumulation rates from outdoor concentrations was limited to predicting likely average values for typical operation of HVAC system. This current study by Sinclair et al (#11977, 1989) includes a system for continuous remote monitoring and control of the HVAC operating parameters. They report on the extensive data on the airborne concentrations of ionic substances, their surface accumulation rates and operating parameters for the air handling system. The authors state that the deposition velocities derived from the measurements of ionic substances and the HVAC parameters provide the necessary inputs for a mass balance model to calculate the steady state indoor concentrations. These can be directly compared to the measured concentrations for each sampling interval. Results have helped the investigators understand the effects of the HVAC operating parameters on the surface accumulation rates of water-soluble pollutants. They have found that the indoor surface accumulation rates of ions in fine particles, vary in a predictable way with the air handling systems parameters. Comparing quantitative data with measured data in this way the authors believe is sufficient to make accurate predictions of surface accumulation rates. Predictions can also be made, although less accurately, without sufficient quantitative data, such predictions would be based on typical indoor outdoor ratios of water soluble inorganic ions that have been measured at other locations by the authors, such as outlined by Weschler et al (#11963, 1983).

Armstrong et al (#4036, 1989) describe an epidemiological and environmental investigation into the air quality of a high rise office building with reported SBS symptoms, consistent with an irritative rather than infectious or allergic process. This was further backed-up by elevated Total Suspended Particle (TSP) concentrations on many of the study floors. These high levels of TSP were traced back to soot from vehicular traffic on the adjacent road being drawn into the ventilation system. Recommendations where made, including the improvement of the filtration system to reduce indoor TSP concentrations.

Gebefuegi and Korte (#7439, 1990) also studied vehicular pollutants entering an office building through fresh air intakes. The building being studied contained Environmental Tobacco Smoke (ETS) and a variety of Volatile Organic Compounds (VOC's). It was found that the ventilation system effectively removed the ETS from the 1200 to 1500 cigarettes consumed per day in the office. However, evidence of aromatic hydrocarbons and some natural compounds still remained. Further investigation showed that odours where being drawn in through the "fresh air" intake located near the parking entrance at street level. The study also found that peak levels were experienced at car arrival and departure times. The Sources of other VOC's were found to be from chemicals used to clean the office. The materials used to clean the offices were changed and the fresh air intakes were modified, resulting in an 80% reduction in limonene and a 30% reduction of toluene concentrations of VOC's.

Mandell (#7563, 1994) reports on the build up of volatile organic compounds (VOC's) in a 10 storey office building adjacent to an 8 year old printing facility and outdoor multi level parking garage. Apart from a failed HVAC system, investigation revealed that the building was in negative pressure relative to the outside and that vehicle exhaust fumes were entering the occupied zone from the loading/shipping dock. In addition to re-commissioning the ventilation system, a VOC sensing controller was used to control an large capacity extract fan in the loading area.

Shield et al (#9660, 1996) measured indoor/outdoor VOC concentrations at 50 sparsely occupied offices, 9 variably occupied data centres and 11 densely occupied administration offices over a six week sampling period. The aim of this research was to establish a data base on the concentration distributions of VOC's identified in these three different types of buildings. At all locations even the sparesly populated offices VOC concentrations were significantly greater than outdoor levels. Ventilation rates were found to have a profound effect on indoor VOC concentrations, for example the admin offices are better ventilated and this is reflected in the concentrations of aromatic compounds, despite the occasional influence of smoking. Eight of the data centres were minimally ventilated, while one is very well ventilated. This is reflected in the geo maen of the I/O ratios for the summated VOC's with the poorly ventilated offices having a mean of 10.9, while the very well ventilated offices' mean was 1.7. Sources were also found to have a major effect, with comparable ventilated admin offices having more sources than telecom (sparsely populated) offices. Results further suggest that the source of most VOC's are those commonly associated with sources found in most buildings, and not dependant upon occupancy. Examples include wall and floor coverings, cleaning products etc. Although some VOC's are occupant dependant, such as antiperspirants and deodorants. In conclusion the authors note that this study provides a database which helps identify atypical VOC concentrations in each of the three types of sampled buildings. To avoid unacceptable VOC concentrations the main mechanisms remain source control and ventilation, although in special situations charcoal filtration or other similar techniques could also be used.

Weschler et al (#5200, 1989) investigated the significance of indoor ozone levels compared with and outdoor concentrations in three offices with different ventilation rates. Experiments took place between late May to October, a complete ozone season (150 days) in New Jersey. The authors then used a mass balance model to estimate indoor/outdoor ozone ratios. Results indicate that indoor ozone exposures are frequently greater than outdoor exposures, in the region of between 20 to 80 percent of outdoor levels. The mass balance model was then used to estimate similar ratios for other buildings. The results from these and other studies indicate similar findings. Therefore from observations and the length of time people spend indoors (approximately 90%). indicate that indoor ozone exposure is greater than outdoor exposure for many people. Ozone reduction strategies do exist and include the provision of appropriate filters (activated carbon, for example (See paper Section 4, #11959)) with mechanical systems, Noble metal catalysts could also be used to reduce indoor ozone concentrations. In naturally ventilated buildings occupants could be encouraged to open windows during the cooler part of the day, such as late evening or early morning and to close their windows during the warmest part of the day. The effect will be to reduce ventilation rates, which the authors stress should be undertaken with caution, since poor ventilation can itself lead to a build up of pollutants such as VOC's. Such ozone reducing strategies are especially recommended for hospitals, nursing homes and schools.

In another study Weschler et al (#11976, 1994) undertook a year long real time continuous measurement study in a communications office in Burbank California. Measured were ozone (O_3), nitrogen oxide (NO) and nitrogen dioxide (NO_2). Air exchange rates, indoor/outdoor temperatures and relative humidities were also investigated. The aim of the study was to better understand the measured parameters, their exchange with the outside and their transport around the office, as well as their interactions and reactions with each other. The study revealed that while the building offered protection from wind, rain and temperature extremes, it offered little in terms of protection from gaseous pollutants such as were O_3, NO and NO_2. The authors found that the indoor concentration of all three pollutants can be associated with outdoor levels, although indoor O_3 concentrations vary from 30 - 70% of outdoor levels and can reach more than 100 ppb. Indoor NO levels are close to those outdoors, and can reach 500ppb, while levels of NO_2 and consistently high throughout the year with mean levels reaching approximately 40 ppb (with at times nitrous acid, nitric acid and peroxyacetyl nitrate (PAN) contributing to this value).

Chemical interactions between these indoor compounds, for example during late morning and early evening when indoor concentrations of O_3 and NO cross. Evidence of faster decay and slower growth of the respective reactants coupled with a larger peak in the indoor concentration of NO_2. Other reactions such as O_3 with NO_2 producing HNO_3 and NO_2 with indoor surfaces, producing gas phase HONO are also described in the paper. While many studies attempt to understand the impact of a given pollutant, its interactions with other pollutants should not be overlooked.

Stock and Morandi (#11600, 1990) examine the indoor outdoor microenvironmental concentrations of aeroallergens such as pollen and mold spores and relates them to personal exposures of susceptible individuals with asthma, allergic rhinitis and other allergic conditions. The authors conducted parallel indoor/outdoor air quality measurements around residential buildings in Houston, Texas. At two centrally located fixed sites consecutive 12-hour samples of aeroallergens were collected throughout the study. With parallel measurements also being taken inside and outside twelve study subject homes for one week each time. Total Pollen and spores species were also examined. Results should that during September and October high pollen counts are typically dominated by ragweed pollen, elevated mould spores were also detected. Due to increased rainfall relative to the preceding dry summer. Aeroallergen data also should strong pollen concentrations. The outdoor spatial heterogeneity of airborne pollen and spores over community scale distances were also investigated. Results show indoor concentrations of both pollen and spores are much lower than outdoors. Residential pollen and spores measurements are consistent with previous reported large filtering effect of buildings on outdoor aeroallergens as observed indoors. In conclusion the results of this study suggest that the main determinants of personal exposure to pollens and spores for the residents of these homes are the seasonal and diurnal influences on outdoor aeroallergen concentrations and personal indoor/outdoor activity patterns. Results also indicated that outdoor concentrations over community scale distances from fixed site measurements are more reliable for pollen than for spores.

Wallace et al (#11604, 1986) undertook a comprehensive investigation in which 355 residents of two New Jersey towns were studied using personal samplers. A total of 20 carcinogenic or mutagenic organic compounds were measured. The personal samplers were carried for a 24 hour period and at the end of the study period, each person gave a sample of exhaled breath. A detailed questionnaire was also administered and results collated. Results should that 20 chemicals were prevalent in the air and 3 in water samples. Air was considered the most important pathway of exposure for 10 compounds and drinking water important for 3 trihalomethanes. Median personal exposures were 2–5 times larger than median outdoor concentrations; maximum personal exposures were as much as 100 times corresponding maximum outdoor concentrations. The authors concluded that in the areas studied, living near major point sources had no effect on exposure, but more common activities such as filling a gas tank, visiting a dry cleaner and smoking had significant effects on exposures.

Goldstein et al (#11605, 1986) discusses a large epidemiologic study of inner city asthma. Nitrogen dioxide (NO_2) concentrations were measured in three rooms as well as outside 44 inner city apartment buildings with gas cooking stoves. These buildings are located in high outdoor pollutant areas, as well as having gas stoves and fires. Both contribute to elevated NO_2 with residences. The 48 hour average was found to exceed the US EPA outdoor mean annual mean NO_2 standard of $100\mu g/m^3$ and were observed in some homes to reach as high as $300\mu g/m^3$. Short peaks of NO_2 were also observed has high has $2000\mu g/m^3$ at 2.3m from ground level and $1700\mu g/m^3$ at 1.7m from ground level. The questionnaire completed by the residents revealed that many spent a large amount of time indoors, many of these were asthma suffers. Therefore the authors concluded that the length of time spent indoors coupled with high NO_2 levels in inner city apartments, indicate that individuals in this population are likely to have elevated personal exposure of this combustion by-product. Such elevated levels will undoubtedly affect the health of occupants, which might include stages of asthma or other respiratory illnesses prevalent in this community.

Colome et al (#11599, 1990) conducted a study in which 120 homes were approached in order to measure NO_2 levels using, with 102 residences agreeing to participate. In each home one NO_2 diffusion tube was placed outside on the north side of the house and another placed outside on a pole 6ft above ground level, away from building structures and vegetation and covered with an opaque cup. The authors found that correlation between two tubes placed in different locations at the same site were not high. There is also evidence that such tubes will yield more accurate results when placed away from structures and potential interference such as vegetation. Such potential problems could provide inaccurate results.

Shepard (#11973, 1988) examines the possible health effects relating to sulphur dioxide (SO_2) air pollution, produced by combustion and processing of sulphur containing fossil fuels. It is also used by industry from smelters and paper pulp mills to wineries and food processing plants, with an estimated 500,000 workers in the US regularly exposed. Research on animals found that SO_2 did not cause morphologic evidence of lower respiratory injury unless it was inhaled at high concentrations (>25ppm). While studies on humans, have found that inhalation concentrations greater than 5ppm was demonstrated to cause small but significant decrements in airway function. Some sensitive individuals were found to react similarly to concentrations as low as 1ppm. However, Shepard suggests' that because measured effects were small, and required inhalation of concentrations of SO_2 in excess of those found in the outside air, many results were interpreted to imply that SO_2 itself was not likely to be responsible for the adverse health effects of air pollution. Several studies have demonstrated that concentration of SO_2 such as outlined above can have symptomatic bronchoconstriction in subjects with asthma. Thus exercising subjects with even mild asthma routinely develop bronchoconstriction when they inhale concentration of SO_2 >0.4ppm during moderate or heavy exercise. It can occur after a exposure as little as 2 minutes and is associated with symptoms typical of an acute exacerbation of asthma. Such concentrations required to bring on such attacks, occur around point sources of SO_2 emissions and in indoor air of homes heated with kerosene space heaters, with higher concentrations occurring in some work places. Shepard also cites further work to suggest that SO_2, while inducing bronchoconstriction could also increase the likelihood of bronchoconstrictor responses to allergens. Making those of come into contact with SO_2 concentrations more susceptible to it in the future.

3.2 European Studies

Several studies have been undertaken as part of a European study "Air Pollution on Health : European Approach" (APHEA). Examples include Katsouyanni et al (#11957, 1995); Ballester et al (#11962, 1996); Katsouyanni et al (#11958, 1997); Toloumi et al (#11959, 1997); Anderson et al (#11960, 1997); Sunyer et al (#11961, 1997); and Spix et al (#11963, 1998). This project attempts to provide quantitative estimates of the short term health effects of air pollution, using an extensive data base from 10 different European countries, representing various social, environmental and air pollution situations. Within the framework of the project, the methodology of analysing epidemiological time series data, as well as that of performing meta-analysis, are further developed and standardised. Katsouyanni et al (#11957, 1995) outlines the project approach. Data have been collected from 15 European cities, exposure data consists of daily measurements of black smoke, sulphur dioxide (SO_2), suspended particles (TSP), nitrogen dioxide (NO_2) and ozone (O_3) (available data from most cities). The mean (24h) levels of SO_2 range 27-327 $\mu g/m^3$ in the winter season, and those of black smoke range 15-292$\mu g/m^3$. The mean (1h) levels of ozone in the summer season range 32-166$\mu g/m^3$. As can be seen from the data there is substantial variability in air pollution mixtures and air pollutant levels in participating cities. The outcome data are daily counts of total and cause specific deaths and hospital emergency admissions. Climatic conditions also vary greatly, with mean winter temperatures ranging from -4 to 10°C (minimum -1 to -37°C) and the mean summer temperature 16 to 26°C (maximum 26 to 35°C). Spix et al (#11963, 1998) outlines some of the results of this study to date, from five west European cities; London, Amsterdam, Rotterdam, Paris and Milano. Age groups studied were 15-64y (adults) and 65+ (elderly). Air pollutants studied included sulphur dioxide, particles (black smoke or total suspended particulates TSP), ozone and nitrogen dioxide. Poisson and standardised confounder models were then used to examine relationships between daily hospital admissions and air pollution, followed by more in depth statistical analysis. The most consistent and strong finding according to the authors was a significant increase of daily admissions for respiratory diseases (adults and elderly) with elevated levels of ozone. The elderly had a corresponding stronger and immediate effect (same or next day), and was homogeneous over cities, especially noted in the warm season. The sulphur dioxide daily mean was available in all cities and was not associated consistently with an adverse effect. The effects of Black Smoke was significantly stronger with high nitrogen dioxide levels on the same day, but nitrogen dioxide itself was not associated with admissions. The Ozone results showed good agreement with the results of similar US studies. The author concludes that the results found strengthen the argument that pollution episodes do in fact impact significantly on the health of nearby residents.

A number of other similar European studies have investigated the effects of air pollution on mortality levels. These studies include Touloumi et al (#11971, 1994) who studied these effects in Athens, Wietlisbach et al (#11968, 1996) focused on three Swiss urban areas, Sunyer et al (#11969, 1996) concentrated on Barcelona, Spix et al (#11967, 1993) studied East Germany and Verhoeff et al (#11972, 1996) examined Amsterdam. Touloumi et al (#11971, 1994) who studied these effects in Athens, monitored SO_2, smoke and CO. Results showed that SO_2 and smoke were independent indicators of daily mortality, though to a lesser extent than temperature and relative humidity. Carbon monoxide CO had only limited effects on daily mortality levels, where a 10% reduction in smoke is estimated to decrease daily mortality by only 0.75%. They concluded that current air pollution levels in Athens may be responsible for substantial numbers of premature deaths, and hence remain an important public health issue.

Wietlisbach et al (#11968, 1996) focused on three Swiss urban areas (Zurich, Basle and Geneva). The authors took data from monitoring stations and compared the results against mortality. Results indicate that TSP, SO_2 and NO_2 all have an impact on mortality levels. Smaller observations were associated with CO, and even smaller with ozone. The authors conclude that they have seen a statistical association between daily mortality counts and ambient air pollution levels. Mortality was strongly associated with 3-day lagged moving averages of particulate air pollution, although similar results were observed with SO_2 and NO_2. A trend that the authors note has been seen in other similar studies. Sunyer et al (#11969, 1996) concentrated on Barcelona, studied black smoke and sulphur dioxide (SO_2) and related them to total mortality, elderly mortality, cardiovascular mortality and respiratory mortality. Results should that the association between SO2 and respiratory mortality was stronger in summer than winter. Oxidant pollutants (nitrogen dioxide and ozone) were positively related to elderly mortality and cardiovascular mortality during the summer, but not during the winter. The authors conclude that current air pollutant levels were related to mortality in Barcelona. These results were consistent with similar studies conducted on emergency room admissions in Barcelona.

Spix et al (#11967, 1993) studied an area of East Germany, Erfut with unfavourable geography and very high (approximately 4000 $\mu g/m^3$ SO_2 in 1980-89) ambient pollution from coal burning activities. The health effects of this exposure was studied by examining total mortality levels of the same period. Results indicated that daily mortality increased by 10% for an increase in SO_2 from 23 to 929 $\mu g/m^3$. The effect for particulates was stronger. Log daily mean increasing from 15 $\mu g/m^3$ to 331 $\mu g/m^3$ was associated with an increase of 22% in mortality. The authors found that the effect of air pollution was smaller than the effects of influenza epidemics and are of the same size as meteorologic effects. The authors also conclude that undertaking the modelling procedure with the effects of meteorology made little difference in the pollution levels. Therefore although meteorology may be an important covariate, it is not an important confounder. Verhoeff et al (#11972, 1996) examined air pollution and daily mortality levels in Amsterdam. Daily mortality counts and the concentrations of black smoke, inhalable particles (PM_{10}), sulphur dioxide (SO_2), carbon monoxide (CO) and ozone (O_3). Poisson regression was used to control for seasonal and other long term temporal patterns. Results indicate that black smoke and PM_{10} were positively associated with increased risk of mortality. No consistent association was found between the levels of SO_2 or CO and daily mortality, but ozone lagged 2 days was positively associated with daily mortality. The effect of particulates was found to be independent of these pollutants. Again the findings of this study were similar to other studies conducted in the US and Europe.

Seaton et al (#11966, 1995) proposes that acidic ultra fine particles found in urban air pollution, provoke alveolar inflammation which causes both acute changes in blood coagulability and release of mediators able to provoke attacks of acute respiratory illness in susceptible individuals. Seaton then examines the effect of particulate air pollution on the health of individuals in the UK in order to substantiate he hypothesis. He looks at studies since the Clean Air Act of the 1950's and the change in the nature of particulate pollution to motor vehicles in place of pollution from coal fires etc. This change in pollutant source has lead to increased health effects and pollution episodes, although not a severe as in the 1940's and 50's, but still noteworthy. The author notes that the chemical composition of urban particulate clouds varies greatly, but the fine fraction, below 2.5μm diameter to which PM_{10} approximates, is about half carbon and half salts (mainly ammonium sulphate and ammonium nitrate). In urban areas particles are derived mainly from combustion of diesel engines and the carbon has chemicals absorbed onto its surface. Results show that fine particles can easily penetrate into most buildings. Average PM_{10} values in the UK are approximately 15-35 $\mu g/m^3$ with daily maxima of around 70 $\mu g/m^3$. The author notes that similar US studies suggest that rises of 10 $\mu g/m^3$ are accompanied by an increase in relative risk or mortality of about 1% in the exposed population, including elevated risks from both respiratory (around 3.4%) and cardiac (around 1.4%) causes. Other studies have shown higher instances of asthma and respiratory associated problems when PM_{10} levels rise.

In a similar study Holgate (1995) chaired a UK government sub group set up to investigate asthma and outdoor air pollution. The report notes that there has been a 50% increase in the prevalence of childhood asthma over the last 30 years. Over the same period emissions of coal smoke and sulphur dioxide have fallen markedly while those of oxides of nitrogen and volatile organic compounds from motor vehicles have increased. During this time emissions of particles from coal smoke have fallen, whiles those from diesel vehicles have increased. The committee examined available epidemiological evidence from a wide variety of sources and concluded most of the available evidence does not support a causative role for outdoor air pollution, excluding the effects of biological pollutants such as pollen, fungal spores and urban smog episodes (black smoke and SO_2). They also state that most asthmatic symptoms should be unaffected by exposure to such levels of non biological air pollutants common in the UK. A small number of patients may experience clinically significant effects which may require an increase in medication or attention by a doctor. Factors other than air pollution are influential with regards to the initiation and provocation of asthma and are much more important than air pollution in both respects. These include exposure to indoor chemical air pollutants and allergens, maternal smoking and exposure to infection and composition of diet. Finally they conclude that asthma has increased in the UK over the past 30 years but this is unlikely to be a result of changes in air pollution.

Moseler et al (#11965, 1994), investigated the effect on lung function of outdoor NO_2 air pollution levels at low and moderate concentrations in winter. Also the type of heating system was examined as a possible source of indoor air pollution was considered as a risk factor. A total of 467 children of school age in the urban area of Freiburg were studied. Information from standardised interviews, lung function measurements, skin prick tests with inhalant allergens, and NO_2 measurements from October to April near the children's homes. The results were subjected to statistical analysis and indicted that for those children who had no asthmatic symptoms, neither NO_2 nor individual room heating had any obvious significant effects. While those children with asthmatic symptoms did show a reduction in lung function with both outdoor NO_2 (or NO_2 associated pollutants) and individual room heaters at outdoor NO_2 levels above 40 $\mu g/m^3$. The authors suggest that for to prevent susceptible groups of children having increased asthmatic symptoms air pollution levels should be reduced as far as possible.

Ponka (#11970, 1991) undertook a similar study in which the effects of relatively low levels of air pollution and prevailing weather conditions were studied on patients admitted to hospital with asthma attacks over a 3 year period. They found that the number of admissions of working age people but not children increased during cold weather. After standardising for temperature, all admissions including emergency's were significantly correlated with ambient concentrations of nitrogen dioxide (NO_2), nitric oxide (NO), sulphur dioxide (SO_2), carbon monoxide (CO), ozone (O_3) and total suspended particulates (TSP). Statistical analysis indicated that NO and N_3 were more strongly associated with asthma problems. Generally the combined effects of air pollutants and cold weather maximised the ill health effects of pollution episodes. The only exception was with ozone which displayed a more pronounced effects after 1 day lag time. Among children only O_3 and NO were significantly correlated with admissions. Measured pollutant levels were considered low with the long term means being for SO_2 19.2$\mu g/m^3$, for NO_2 38.6$\mu g/m^3$, for O_3 being 22.0$\mu g/m^3$ and for CO 1.3$\mu g/m^3$. In contrast the mean concentration of TSP was high (76.3$\mu g/m^3$) and the mean temperature was low (+4.7°C). The authors conclude by suggesting that these results indicate that concentration of pollutants lower those given as guidelines in many countries may increase the incidence of asthma attacks.

Kruger (#8344, 1994) studied the location of air inlets of buildings in relation to streets with heavy traffic flow. Results, based on the measurements of carbon monoxide (CO) inside and outside the building over a week, found that several parameters were of vital importance when considering traffic related pollutants. These included the distance between the traffic and the building, the traffic intensity (both during the day and during peak hours), wind direction and velocity, street geometry and building construction. Five different multifamily houses in urban areas were studied, although Kruger points out that the measurements are equally applicable to other types of buildings. The study found that in the buildings with heavy traffic close by on one side, the locations of air intakes were significant. Similarly located buildings should not use ventilation systems where the supply air intakes are situated on the street side. If streets with heavy traffic are some distance away, then both mechanical exhaust systems and balanced systems could be used to supply the building with outdoor air. Thus the outdoor environment should always be studied before choosing ventilation systems. The author also notes that the investigation has shown that measuring periods of at least a week are needed to get a sufficient basis to be able to correctly analyse the measurements of traffic related pollutants.

Green et al (#11245, 1998) focused on vehicle produced carbon dioxide (CO) and its interaction with the indoor environment. The significance of CO has been well documented as a health hazard. The established recommended safe threshold exposure level of an average 10 ppm over an 8 hour period, has been adopted by both the World Health Organisation (WHO) and Expert Panel on Air Quality Standards (EPAQS). The paper focuses on levels of CO recorded at a building facade, inside a building and those recorded at the roadside (Nottingham, UK). Total daily flows were estimated around 25000 vehicles in either direction during the week, and noticeably smaller flows over the weekends. The window of the room kept mainly closed, due to the time of year, although was opened and shut for occupant satisfaction as and when necessary. Results showed that:

- CO levels fluctuated with peak traffic flow periods;
- There is slight benefit in locating vents at higher locations on the building façade;
- Varying ventilation rates may yield gains;
- The monitored buildings were ventilated mainly by the stack effect, therefore efforts to control pollution intake would have to be aimed at reducing the air entry through some of the low level openings.

Kukadia et al (#11671, 1998; #11774, 1998) has undertaken a detailed review of the ingress of pollution into naturally ventilated buildings. This covers ventilation strategies, existing measurements of internal/external pollutant levels, urban air quality and long term air quality strategies, building ventilation and the dispersion of pollutants around buildings as they affect the ingress of pollutants. In a further paper (Kukadia and Pike #10804, 1997) discuss the indoor air quality of two naturally ventilated office buildings, sited adjacent to major roads. The first building is located in Birmingham adjacent to an 8 lane major road on one side and a courtyard on the other. The second building is located in London, UK and comprises of a two storey day care facility completed in 1994. This second building is located on a busy road but the air intakes are located in a rear courtyard. The authors found that, for the first building, traffic was the major source of carbon monoxide (CO) and oxides of nitrogen (NO_x) pollution. However, internal measurements of sulphur dioxide (SO_2) could not be clearly correlated to vehicle pollution. In all instances internal pollutant concentrations were much reduced from the outside value. The building also 'smoothed out' the high external pollutant levels over approximately one hour. Similarly, in London, the main cause of indoor CO was associated with traffic, although its concentration was, again, much attenuated.

Kukadia et al (#10305, 1996) and Kukadia and Palmer (#9833,1996) also describe an analysis in two buildings situated in the same urban locality. Both buildings are offices, one is air conditioned while the other was naturally ventilated. For the air-conditioned building, air is drawn from high level on the tenth floor, and via the roof top plant room. It is filtered and conditioned before distribution to the ceiling voids for terminal re heat and cooling. The offices in both buildings were in normal use with variable occupancy. Measurements were taken over a seven day period. Results show that indoor pollutant levels were lower than corresponding outdoor levels, and that neither building reacted to the rapid and sudden fluctuation experienced outside. As with the previous study, traffic was identified as the major source of CO and NO_X In general similar pollutant concentrations were measured in each building, although much higher levels of CO_2, SO_2, NO and NO_2 were measured over short periods on two days (Saturday and Monday) in the air-conditioned building. These higher levels were associated either with cross contamination from the ventilation exhaust or high level discharges from the boiler plant being drawn into the ventilation intake. Indoor CO concentration tracked the outdoor value although, in the mechanically ventilated building was lower than in the naturally ventilated building, possibly as a consequence of the height of the air intake. Indoor NO and NO_2 concentrations followed the same trend as external levels. However, in the mechanically ventilated building NO concentrations were lower during the day than at night and in the naturally ventilated building NO_2 levels were higher than in the mechanical ventilated building. The authors suggest that possible sources of NO in the mechanically ventilated building could be the ventilation plant itself, which was in operation all day and took air from high level. The lower night-time air change rate in the naturally ventilated building may have allowed the NO in the building to slowly oxidise to form NO_2 resulting in elevated levels.

Coviaux et al (#11587, 1990) investigated the effect of working conditions in tunnels on the health of maintenance staff. A 860m one way road tunnel in Paris, with an estimated traffic flow is up to 4000 vehicles per hour was monitored. The authors found that despite the ventilation system their were high levels of carbon monoxide (CO) (max in tunnel 41 $cm^3.m^{-3}$), oxides of nitrogen (NOx) (max in tunnel 1.29 $cm^3.m^{-3}$), particles, (max in tunnel 410 $\mu g/m^3$) lead (Pb) (max in tunnel 11.20 $\mu g/m^3$, iron (Fe) (max in tunnel 11.4$\mu g/m^3$), Copper (Cu) (max in tunnel 0.89$\mu g/m^3$), Coronene (max in tunnel 40.00 $ng.m^{-3}$) and Benzo(ghi)Perylene (max in tunnel 83$ng.m^{-3}$). Further analysis of data given by the author. The study also showed that pollution concentrations for working premises located near a road tunnel were influenced by the pollution in the tunnel, although the indoor concentrations were generally lower. The ChHb of workers in the technical rooms adjacent to the tunnel increased significantly and is directly correlated to CO concentrations.

Kajtar and Banhidi (#10046, 1996) have measured mass concentration of settling dust and suspended dust at green belt sites, streets of heavy traffic, streets of moderate traffic and in nearby industrial areas in Budapest. They note that the level of dust contamination of external air will influence the air quality of rooms with natural ventilation, and in buildings equipped with air conditioning the filters and air cleaning sections will be the most affected. The authors focus their discussion to two areas of Budapest, one of moderate vehicle traffic and the other in walking areas, free from motor vehicles. Measurements were taken from 9am to 6pm on the 30th April and 30th May 1995. The sampling period took 30 minutes with 6 samples being taken per day. At the time this paper was written Hungary had no indoor air quality standards for dust, therefore concentrations of standards specified for external air quality were applied to the indoor space. Specified maximum values of suspended dust mass concentration are 200 g/m for 30 minutes, 100 g/m^3 averaged over 24 hours and 50 g/m^3annual average. The results showed that, in the working area, measured values exceeded the specified 30-minute maximum value of dust pollution. In the traffic free zone, the dust threshold was not exceeded. It is recommended that windows on the roadside should not be used for ventilation purposes during the daytime.

Lagoudi and Loizidou (#9442, 1995) undertook statistical analysis of total volatile organic compounds (TVOC) inside and outside six office buildings in Greece. Offices were located in both urban and rural sites. The sources of most TVOC were internally generated, however correlation matrics were used to examine the interactions between indoor and outdoor concentrations. The outdoor air of 3 buildings had a lot of similarities, with a correlation coefficient of 0.75. These buildings showed higher TVOC concentrations in the outdoor air since they were situated near busy roads. One building, located in a suburban area had a coefficient of 0.5-0.6, where there was less traffic, while the final two buildings, located in rural areas displayed weak correlation's (0.25-0.55) between indoor and outdoor TVOC concentrations. The authors therefore conclude that this indicates that there is a relationship between outdoor and indoor pollutant levels, and that the outdoor air influences significantly the concentration pattern of the indoor air.

The influence of external and internal air quality and its effects on the internal Hospital environment (Italy) is investigated by Basilico et al (#9566, 1995). Data on carbon monoxide was found to reflect that of outdoor air concentrations (mean indoor values 1 and 5 mg/m^3 with daily peak maxima approaching 10 mg/m^3). Comparing this data with CO concentrations taken outside the reference buildings, which show much lower levels, it reflects well the outdoor concentrations of CO generated by traffic in urban areas, due to the combined effect of production rate by direct sources and vertical/horizontal environment transport by air convection/diffusion. The authors conclude that the air quality inside hospital departments is affected by the quality of air outside of the building, requiring the adoption of either filtration or chemical purification of the outside air. Demand controlled ventilation could be used to deal with build-ups of CO_2, which were found to rise to up to 3500mg/m^3. The authors suggest that the most immediate and inexpensive countermeasure would be to ban or restrict the use of automotive circulation in the immediate neighbourhoods of or within the hospital. Care should be taken when designing HVAC systems in such environments and the location of fresh air inlets is vital.

Coward and Raw (#11592, 1995) examined the occurrence on nitrogen dioxide in homes in the UK. Nitrogen dioxide (NO_2) is produced by the combustion of fossil fuels for power generation and vehicles combustion and is a common pollutant in the outside air. In homes NO_2 ingress's from outdoors as well as being produced by combustion heating, cooking fuels and tobacco smoking. NO_2 has series of possible effects on the respiratory health of children, and may further aggravate people with bronchitis or asthma, and raise individual susceptibility of other harmful environmental factors. Many standards exist, but the authors quote the World Health Organisations (WHO) recommendations that NO_2 concentrations should be exceed 150 $\mu g/m^3$ (80 ppb) over 24 hour, based on the lowest concentration known to affect asthmatics. The authors studied homes in Bristol, UK. They took measurements inside and outside and compared the results. They found that in all rooms and for all seasons, higher mean outdoor NO_2 concentrations were associated with higher mean concentrations indoors. This relationship was significant in almost all cases. In conclusion the authors note that high outdoor levels and gas cooking appear to be important factors determining indoor levels of NO_2.

3.3 Studies from Other Regions of the World

Gil et al (#11584, 1997) have undertaken a study to investigate the atmospheric air pollution (CO, nicotine, PM_5 and total and carcinogenic polycyclic aromatic hydrocarbons (PAH's)) on the indoor air quality of downtown Santiago, Chile. Buildings studied included offices and restaurants. Measurements showed that indoor CO levels fluctuated in line with rush hour traffic levels, and at times of peak flow masked the effects of other pollutants. Indoor CO concentrations ranged from 1.0 to 73ppm, whilst outdoor CO concentrations ranged from 0.5 to 93ppm. In conclusion the authors suggest that it is the high number of diesel engine buses that are present in this region for the high level of pollution, and suggest that the government restrict such vehicles to improve the indoor air quality of nearby buildings. Also the introduction of outdoor air filtration systems would also be advantageous. The cost of such an exercise should be considered against the economic loss in productivity resulting in discomfort and absenteeism as a consequence of poor occupant health.

Xiaoming et al (#11595, 1993report on a urban air quality project carried out to compare the coal burning districts with those centrally heated in Chengde City, China, where the winter urban pollution is very bad. The project compared two types of house, those burning coal for cooking and heating and those with central heating in which liquefied gas is used for cooking and central heating. A health investigation was conducted on the school children of age between 11 and 13, within these regions. The measured pollutants were SO_2, NO_2, CO, and Total Suspended Particles (TSP). The location of the city, in a river valley basin, combined with temperature inversions causes pollutants to accumulate over the city. Coal consumption is 1.4 Mtons each year. Ash content of the burned coal is 24.5% to 45.25% and sulphur content is 0.5-2.5%. Investigations revealed that, in 1986, coal burning was spread over the whole region, by 1990 half the households had central heating. Measurements taken in 1986, showed that SO_2 levels were 3.86mg/m^3 and TSP was 3.09 mg/m^3 (comparable to those recorded in London in 1952). Results of this study reveal that all winter outdoor air pollution levels are extremely high, with SO_2 levels being 11 times higher that in summer. The areas using coal burning appliances showed the highest concentrations. Indoor air pollution levels, too were more severe in winter than summer with concentrations exceeding 0.15mg/m^3 on over 80% of occasions. Personal exposure to SO_2 by school children was 0.47 in the coal burning areas, 2.76 times as high as the regions with central heating (0.17). Exposure to TSP was 0.79 and 4.16 times as high (0.19). These higher exposure levels show themselves in higher prevalence rates of asthma chronic bronchtits pharyngitis and tonsillities in areas were coal burning in more common. The authors estimate that by transferring from coal to central heating, the economic loss of 53,400 labour days and 700,000 yuan (1993 figures), could be avoided each year.

Basmadjiveva and Tabacova (#11598, 1990) studied the health effects on residents of a Bulgarian City, polluted by emissions of chlorine compounds. The authors undertook a epidemiological study on the total population, including vulnerable groups such as children and people prone to chronic pulmonary diseases. The concentrations of chlorine as well as other irritative gases such as sulphur dioxide and nitrogen dioxide were continually monitored. Occurrence of acute health problems were monitored during high pollution episodes and compared to periods of lower pollution. Five year and national average data was also examined to provide more detailed information. Results indicated that chlorine was the main pollutant, during high pollutant episodes. Short term concentrations reached as high has 1.6 mg/m^3 (16 times the national standard) and mean annual levels ranging from 0.14 to 0.36 mg/m^3. Corresponding levels of SO_2 (National Standard 0.05mg/m^3) H_2S (National Standard 0.08mg/m^3) and NO_2 (National Standard 0.04mg/m^3) were lower than their respective national standards. Results indicate that the high chlorine pollution was responsible for the high occurrence of respiratory diseases and eye inflammations, and especially so for asthma followed by acute bronchitis. The reporting of acute health problems continued up to 3 days after an high concentration episode. Examination of the five year data, showed that prior to the pollutant emitter being installed, no differences could be seen between the national average and this region, however, following the installation of the chlorine emitter, results showed an increase as outlined above. The authors conclude that they have shown and identified that exposure of urban pollution to chlorine at levels exceeding 0.100mg/m^3 leads to acute respiratory effects and long term increase of respiratory and non respiratory morbidity.

Nel et al (#11597, 1993) examine the extent of exposure and health effects of household coal burning in urban residential areas of South Africa. In this country 40% of the total population use coal for cooking and heating, making it one of the major polluting sources if TSP in African urban and peri urban residential areas. This paper outlines an air pollution study, known as theVaal Triangle Air Pollution Study (VAPS), in which a information on exposure and health effects of coal burning in urban areas were investigated. Interviews and a health questionnaire were conducted on occupants in two residential areas of central South Africa. Mothers of 8-12 year old children were asked about household fuel use, socio economic status and respiratory health of their child. Three air pollution exposure areas were chosen, electrified areas, partially electrified and coal burning. Over 540 households took part. Measurements of the TSP show that 99% of the 72, 12hour monitoring sessions were above 24h TSP health standard. Added to these findings were the data for tobacco smoke. More that 40% of the population reported that there are people that smoke on a daily basis were the child lives, with 47% of the population considering that tobacco smoke constitutes a major source of environmental air pollution. It was found that children in the coal burning region had a 120% higher risk of developing upper respiratory infections than children living in either the electrified or partially electrified areas.

4.0 Mitigation or Methods of Control

Methods to mitigate or control the ingress of outdoor pollution include:

- Reducing Emissions
- Closing off the supply air during periods of temporary high outdoor pollutant concentration;
- Siting air inlets away from local pollutant sources;
- Using filtration.

Reducing urban emissions requires a strategic approach. Lyons et al (#11777, 1995) examine the complex interaction existing between the level of urban air pollution and the local area. Such interactions include the nature of land use (urban, rural, city etc); infrastructure (fast motorways or slow single lane carriageways etc); and the level of public transportation. As part of a book on urban air pollution, Lyons attempts to define similar regions within a city based on these factors, thereby allowing a direct comparison of urban vehicle pollution within similar regions. The authors define similar regions in terms of:

- Social/economic factors (Population, total vehicles on register, houschold income);
- Land use intensity factors (Total area, urbanised area, number of dwellings);
- Road availability factors (Total length arterial roads);
- Congestion factors (Vehicle Kms on arterial roads);
- Public transport availability factors (Length of routes, Service Km);
- Modal split factors (Journey to work by public, private transport, walking, cycling etc).

This approach illustrates they ways in which vehicle emissions are linked to the urban morphology and contribute to localised pollutant loads. The authors suggest that by increasing the intensity of urban activity, a reduction in vehicle dependence can be achieved leading not necessily to a reduction in congestion but a reduction in overall emissions.

Kraenzmer (#9843, 1996) examines the effect of controlling a building's airflow rate at peak times of peak traffic flow in order to reduce the pollutant entry into the building. As the concentration of CO present in the outdoor air rises next to the air intake, an evaluation is made to determine acceptable indoor concentrations and, in response, the air flow rate is reduced. Using measured data the author modelled a building in Stockholm, Sweden, using two techniques, either single monitoring (outside air only) or double monitoring (outside and inside air). For single monitoring the air change rate is reduced from $0.5h^{-1}$ or $1.0h^{-1}$ to $0.1h^{-1}$ when the outdoor concentration exceeds a specified limit. Alternatively both the inside and outside CO concentrations are measured and compared and the airflow reduced accordingly. This latter type of control allows the indoor concentration to be reduced faster after a peak in the outdoor concentration. In conclusion, the author notes that the project has shown that a potential exists for such control procedures however, the effects on the indoor air quality and occupant health and comfort sets limits on the level of air flow rate reduction.

In a similar study Sohn et al (#9583, 1995) examines the impact of varying the air supply rate as a method of controlling the indoor air quality at times of peak pollution emissions in four commercial buildings located near Seoul, Korea and Tokyo Japan. The concentration levels of the indoor air pollutants were monitored at different outdoor air intake rates and the odour and discomfort ratings were made by occupants via a questionnaire. Internally generated pollutants were found to increase during periods of reduced outdoor air supply

Weschler et al (#11975, 1996) outline a study in which optical particle counters continuously measured the concentrations of submicron particles in a telecommunications facility in Southern California. Four locations were sampled, the outdoor air intake, immediately upstream of the HVAC filters, as well as immediately downstream of the filters and inside the offices themselves. The authors used a one compartment mass balance model. Indoor concentrations of particles ranged from 0.5 to 1.0 μm are were found to have originated outdoors. Therefore reducing indoor concentrations of submicron particles was seen as a possible objective, by reducing the amount of outdoor air during periods when the outdoor concentrations of submicron particles is higher. By feeding information about indoor concentrations back to the HVAC system a control systems was established. This did result in a reduction of average indoor concentration of submicron particles in the facility. The author noted that for particle counters to become wider employed in this manner, they must become cheaper, more reliable and less frequently calibrated before such an approach becomes more cost effective.

Bearg (#8883, 1995) investigates the application of a CO_2 demand controlled ventilation system to monitor inlet exhaust and control the air supply rate. This is aimed at detecting re-entrainment of exhaust and vehicle emissions. A multi point CO_2 monitoring system is used to monitor air just outside a building's air intake and establish whether the level of CO_2 has risen. Its operation is based on the assumption that the CO_2 concentration in a vehicle's exhaust is 150,000ppm (15%) compared with clean air 380ppm. From this it is calculated that outdoor air at 570ppm contains less than 0.13% vehicle exhaust. The DCV system continuously monitors CO_2 at the air intake and identifies times that the outdoor air damper should be closed to prevent vehicle exhaust contaminants being drawn into the HVAC system

The location of air intakes and outlets is an important ventilation and building design consideration since it is at this point that outside air is drawn into a building for ventilation. Problems occur because pollutants can become entrained in incoming air stream because of the airflow characteristics around the building or intake, or indeed may simply be drawn in through the choice of intake location. Short-circuiting, badly chosen fresh air intake locations and poor HVAC maintenance have been cited as the most common causes of ventilation air contamination (Ferahian, #3569, 1989,). Similar problems have been highlighted throughout a wide variety of buildings by a number of other authors, including Walkinshaw (#7291, 1993), Gorman (#8441, 1984) and Solberg et al (#3777, 1990).

An analytical design procedure for estimating air intake contamination from nearby exhaust vents is described by Wilson (#8438, 1983). A simple design procedure is given for determining the necessary height of an exhaust stack to produce a specified level of dilution at a nearby air intake. The effects of internal system dilution, wind dilution and that from stack height are considered separately. The three effects are then combined to determine the available dilution at a critical wind speed which produces minimum dilution. The concept of "available dilution" is used to give a ventilation designer better information on the amount of contamination expected at an air intake for a given exhaust intake configuration. This method has been adopted by ASHRAE. Wilson has gone on to examine intake pollution. A more in depth bibliography has been complied by Limb (1995, # 9107) on the location of air inlets to avoid contamination of ventilation air.

Strindehag et al (#11601,1993) examined the properties of particle filters and gas adsorption filters to determine their effectiveness in cleaning outdoor supply air to buildings in urban environments. The main pollutants are CO, NO_2, SO_2 as well as a number of hydrocarbons, including polycyclic aromatic hydrocarbons (PAH) and particulates. six class F85 (EU7) high grade filters in urban industrial locations were studied, to determine their overall effectiveness and life span. The authors also conducted separate studies of particulate filters to collect particulate PAH. These filters are of different classes and operate at different dust load levels than adsorption filters using activated carbon. Such filters are installed into buildings close to busy roads and are used mainly for cleaning outdoor air. The authors studied four different filter media for efficiency, pressure drop and scope for regeneration. Tests on the F85 fine filters were conducted in accordance with ASHRAE Standard 52-76. Results show that all of these filters have a collecting efficiency of 85-90% for particles larger than 1.0 micrometre and that over the operating period, the collecting efficiency remains fairly constant. The PAH filters, had a collecting efficiency of 75% and could substantially reduce the concentration of particulate PAH. The authors thought that it should be possible to use gas adsorption filters of these types for the efficient collection of PAH in gaseous form. Such filters are specially impregnated to collect SO_2 and NO_2. The authors noted that, although such filters will remove pollutants, they recommend that advantage should be taken to reduce outdoor airflow rate during periods of peak outdoor pollutant concentrations.

Weschler et al (#11974, 1994) evaluates the efficiency of commercial charcoal filters to remove ozone. The author examined three applications, a test plenum, an air handler providing outside air to a Class 100 clean room and a plenum downstream of an air handler providing outside air to another Class 100 clean room. Results indicate that after 37 months, the charcoal in the test plenum decreased in removal efficiency from 95% to 90%. Over the same time period the filter serving the first clean room decreased in efficiency from 85% to 60%. After 24 months the charcoal servicing the second clean room was still removing 95% of the ozone in the airstream. The authors conclude that properly sized filters can efficiently remove 0_3 from the outdoor air in mechanically ventilated buildings. In each of the case studies the removal efficiencies are independent of O_3 concentrations, which ranged from 20 to 140 ppb. The effective services life is expected to depend upon the rate at which air flows through the filter and the rate at which airborne contaminants, such as submicron particles accumulate on the adsorption media. Finally the authors note that the results of this study show that in severe photochemical pollution areas, charcoal filtration offers an effective means of controlling indoor O_3, especially in facilities with high air exchange rates.

Costa (#11593, 1995) examines the use of vegetation as a filter in the built environment, firstly in an acoustic sense, and then as an aid to sick building syndrome other building related illnesses. Costa then cites the use of trees to filter airborne industrial contaminants around an Indian town. This study concluded that leaf shape and surface area have a bearing on the filtration effectiveness of trees. Costa states that trees will function as either short or long term sinks for pollutants. Leave morphology and local meteorological conditions, govern how long pollutants stay on the leaves. Leaves with hairy surfaces will be more efficient in retaining atmospheric heavy metals. The leaf and stem surfaces act as temporary sinks, transporting pollutants to the soil. Trees also act as long term sinks for pollutants, heavy metals can be retained in the longer lived tissues of the tree, mainly wood and bark. With a correlation being drawn between the roughness of the tree back and the amount of trace heavy metal deposit. Costa reports on a reduction in airborne chloric dust, after 17,000 chlorine resistant trees and shrubs around a chemical works in South China. Costa also reports on studies where trees helped to reduce the overland movement of particulate pollutants in rural and urban locations. Throughout the study deciduous trees were thought to be responsible for a reduction of 30% of overall dust levels, and confers, in the order of 40%. Interception of total suspended particles was approximately 12% for both urban and rural sites. In conclusion the author also notes that in parks 85% of particles can be filtered out, and up to 70% by trees in avenues at optimal arrangement. When leafless, trees can retain 60% of their filtering efficiency.

An extensive overview of filtration techniques has been produced by Liddament (#9535, 1996), who reviews the nature of outdoor pollutants and the variety of methods available for filtering them from the outdoor air.

5.0 Conclusions.

This bibliography has touched upon many of the important issues surrounding the impact of urban air pollution on the internal environment. Many examples exist of how important pollutant sources are and how they affect the type of control measures used. However actual concentrations for any particular location are dependent upon many other factors such as regional concentration, proximity of polluting sources, weather conditions and local terrain. In industrialised countries traffic pollution has now overtaken industrial and domestic coal burning pollution. Legislation in these countries is working to steadily improve fuel types, engine performance and filtration systems to reduce emissions. In developing countries industrial and domestic fossil fuel pollution still presents a problem, although the poor infrastructure and motor vehicle conditions exacerbate the urban pollution problems.

Other pollution sources can result due to poor design or maintenance, for example bacteriological contamination such as Legionellae, Pontiac and humidifier fever. Atmospheric chemical reactions lead to high levels of outdoor ozone. While urban heat islands are formed in densely urbanised areas to add to air quality and comfort problems, by trapping pollutants and developing smog. Noise too is an important consideration, especially for naturally ventilated buildings since these buildings rely on their interaction with the outdoors for their source of clean ventilation air.

To understand in more detail the nature of urban air pollution and its effect of our indoor environment many experimental and theoretical studies have been undertaken. Studies conducted along the side of roads, were vehicular traffic is an important pollutant source, have identified particulates (PM_{10} $PM_{2.5}$ and TSP), nitrogen dioxide (NO_2) and carbon monoxide (CO) as the main pollutants. Industrial pollutants sources emit mainly black smoke and (SO_2). While general outdoor air pollution includes all mentioned pollutants as well as VOC's, radon, pesticides and ozone (O_3). Studies associated with emissions from land fill sites have cited carbon dioxide (CO_2) and methane (CH_4) as the main pollutants.

Indoors while the ingress of outdoor pollutants is an important issue, especially if poor ventilation leads to a build up of otherwise irritant pollutants to potentially harmful levels, other issues include the interaction of these pollutants and the production of by products, such as ozone (0_3).

The increase in asthma prevalence has been studied as a consequence of rising urban pollutant concentrations. Authors are divided as to the significance of urban air pollution on asthma.

Authors have cited among others pollutants NO_2, SO_2 and outdoor O_3 has having an effect on asthma and mortality. However, a UK study conducted an in-depth investigation into the effects of asthma and air pollution, concluding that most evidence does not support a causative role for outdoor air pollution, excluding the effects of biological pollutants and urban smog (black smog and SO_2). They also suggest that other factors have a larger part to play in the cause and provocation of asthma, including exposure to infection and composition of diet. A difference of opinion is therefore evident, but work is continuing to help find the cause of rising world wide asthma levels. Other studies have indicated that subjects that would be susceptible to asthma, are affected by increases in atmospheric pollution levels, while those who are not susceptible remain unaffected.

Methods to control such pollution include reducing emissions, modulating air supply during periods of high pollutant concentrations, siting air inlets away from local pollutant sources and adequate filtration. There exists a complex interaction between the nature of land use, infrastructure, the level of public transport and the number and location of pollutant sources. This review has considered a wide range of urban air polluting sources which are both building related (i.e. pollution emissions from buildings themselves) and non-building related sources (i.e. motor vehicles, outside noise etc.) Case studies are considered on a regional basis to reflect climate and type of urbanisation.

Given the complex nature and wide scope of this subject, covering many specialist areas of research, the aim of this bibliography is to identify and introduce the most significant areas of concern, in order to provide an introduction into the impact of urban air pollution on the indoor environment.

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