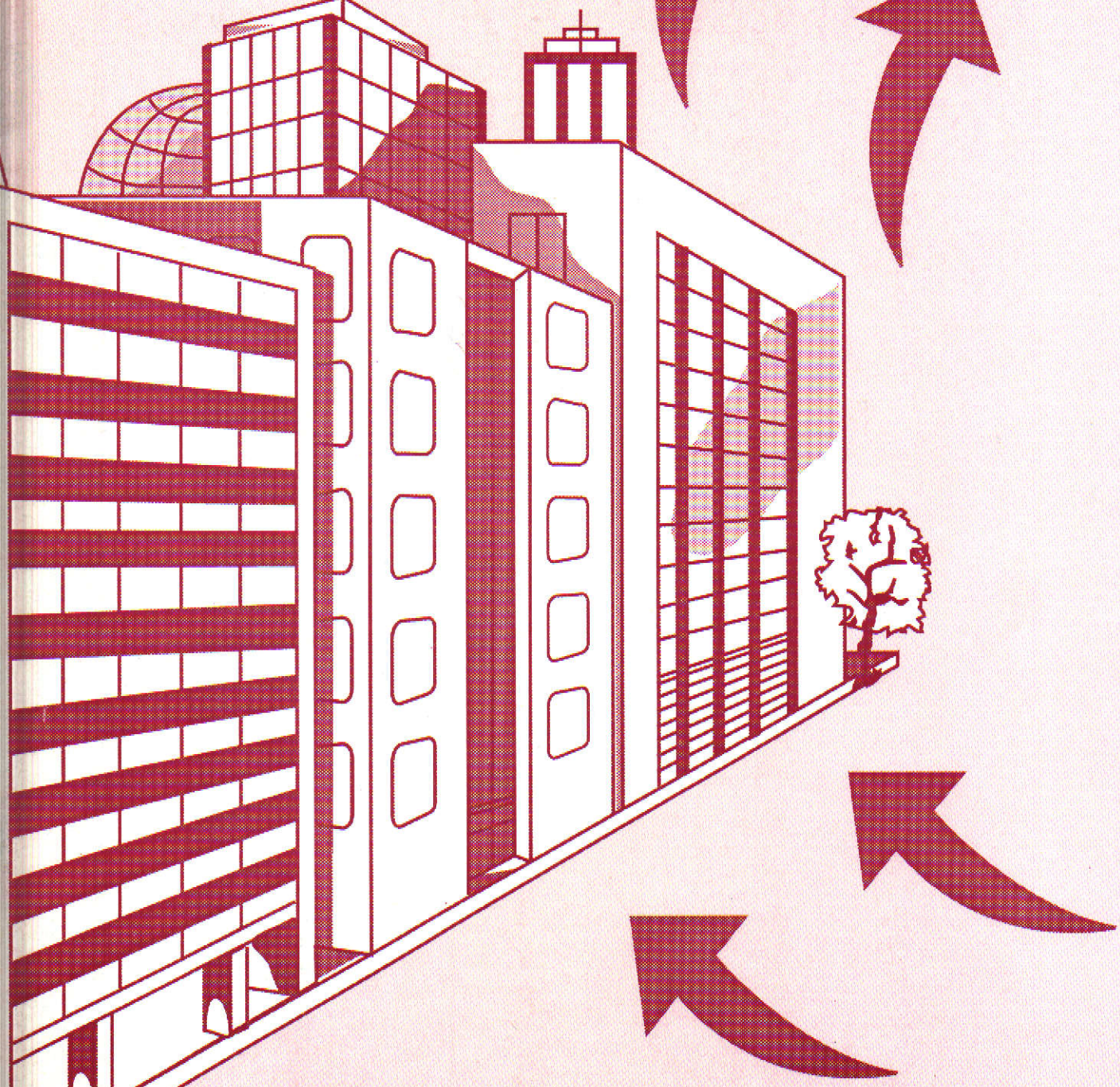
INTERNATIONAL ENERGY AGENCY
energy conservation in buildings and community systems programme

An Annotated Bibliography
Garage Ventilation



Air Infiltration and Ventilation Centre,
University of Warwick Science Park,
Sovereign Court,
Sir William Lyons Road,
Coventry. CV4 7EZ

AIVC

Garage Ventilation
An Annotated Bibliography

Mark J Limb

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 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 projects 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 Ventilation 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 & Demonstration of Domestic Vent.Systems
XXVIII Low Energy Cooling Systems

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, Canada, Denmark, Germany, Finland, France, Netherlands, New Zealand, Norway, Sweden, Switzerland, United Kingdom and the United States of America.

CONTENTS. **Page**

This report is part of the work of the IEA Energy Conservation in Buildings & Community Systems Programme.

Publication prepared by
Annex V Air Infiltration and Ventilation Centre

Document AIC-BIBLIOG-1-1994
ISBN 0 946075 78 6

Participating countries:

Annex V
Belgium, Canada, Denmark, Germany, Finland, France, Netherlands, New Zealand, Norway, Sweden, Switzerland, United Kingdom, and United States of America

Distribution: Annex V only

Additional copies of this report may be obtained from:

The Air Infiltration and Ventilation Centre
University of Warwick Science Park
Sovereign Court
Sir William Lyons Road
Coventry CV4 7EZ
Great Britain

GARAGE VENTILATION - An Annotated Bibliography

By Mark J. Limb
Air Infiltration & Ventilation Centre
United Kingdom

July, 1994.

SCOPE.

This bibliography summarises research into the health, energy and design aspects of the various systems used in garage ventilation. It is aimed at researchers, designers and engineers who would benefit from an introductory overview of research into this area. References quoted in the report are available, to all participating countries, from the AIVC's Bibliographic Database, "AIRBASE".

1.0 INTRODUCTION.

Garages, while providing convenient places to store motor vehicles, also represent potential pollutant traps for combustion gases. In such places, vehicle occupants may only be subjected to high pollutant concentrations for a short time, but for those who work in these environments, and for those who are continually trapped in lengthy exit queues, long term exposures can cause prolonged illness, possibly leading to death. Good design and ventilation are two essential elements in the construction of parking garages. This review outlines research in parking garages where design and ventilation options have resulted in both good and poor garage environments.

Garages can be underground, above ground or a combination. The Association for Petroleum and Explosives Administration outline the Recommended code of practice for all car parks, multi story, ground floor and underground (#7696). Essentially, an underground car park means any car park which has a significant part of its floor more than 1.2 m below the level of the surrounding ground. Underground car parks must be mechanically ventilated, whereas above ground car parks can be naturally or mechanically ventilated. Open-sided car parks are classified as any car park which has natural ventilation openings at each level direct to the open air equivalent to 2 1/2% of the floor area in each of its two longest and opposite sides. Above ground car parks should also have no part of its floor more than 30m from an open side, to prevent heat build up within the structure in the event of fire. Multi-story car parks are those in which cars stand on more than one floor.

1.1 Pollutants.

Good ventilation is essential in garages to regulate the build up of pollutants, particularly carbon monoxide, as well as preventing high heat accumulation from motor vehicles. Carbon monoxide is the main combustion pollutant generated from vehicle exhausts and therefore has been the focus of legislation. Such legislation has been addressed by many standard organisations, and authorities, both regionally and nationally. For example Koskela H K et al (#5138, 1991) state the Finnish hygienic limit for CO is 30ppm for an eight hour average and 75ppm for a 15 minute average.

Leene J A and Knoll B (#984, 1981) state the Dutch regulations NPR2443 allows a maximum mean concentration of CO in the air of 200ppm during half an hour or 50 ppm during 24 hours. It is proposed that personal exposure should not exceed half an hour.

The United Kingdom Health and Safety Executive (EH33, 1982) gives the threshold limit value (TLV) for carbon monoxide in car parks as 50ppm, as an 8 hour weighted average (TWA). A further guidance note EH40 (1994) outlines occupational exposure limits, and gives the short term exposure limit for CO over a 15-minute reference period of 300ppm. EH33 also points out that, as well as carbon monoxide, a number of other pollutant compounds have been identified in vehicle exhausts. These include oxides of nitrogen, unburnt fuel and products of partial combustion of fuel. These products cause an unpleasant smell and can be irritating and noxious in very small quantities.

ASHRAE (1991) state that in the United States it is recommended that the ventilation rate be designed to maintain a CO level of 57 mg/m3 (50ppm), with peak levels not to exceed 143 mg/m3 (125ppm). The American Conference of Governmental Industrial Hygienists recommends a threshold limit of 57 mg/m3 (50 ppm) for an 8 hour exposure and the EPA has determined that, at or near sea level, a CO concentration of 143 mg/m3 (125ppm) for exposure up to 1 hour would be safe. For installations above 1000m far more stringent limits would be required.

In an overview by Sterling and Kobayashi (#470, 1977) it was noted that available literature about pollutant in enclosed spaces was sparse but sufficient to indicate the magnitude of possible exposure to inhabitants. This study included a number of enclosed environments, including garage spaces, and maintained that garages displayed similar pollutant concentrating abilities as tunnels. They cite Ramsey, who in 1967 found garage air contained 7 ppm to 240 ppm of CO, with a mean concentration of 58.9 ppm. He found that employees carbonmonoxyhaemoglobin (COHb) levels tended to increase from morning to evening. Several other cases are noted reporting similar findings. Goldsmith in 1970 is also cited as reporting that traffic jams in parking garages during mass exits, could raise levels of pollutants to extreme concentrations. It was also believed that high levels of other pollutants such as benzo(a)pyrene, soiling particles, or lead were present, based on the findings of the CO measurements. However no measurements where undertaken on these pollutants.

1.2 Ventilation Rates.

Legislation controlling the rate of ventilation to prevent the build up of combustion pollutants in garages has also been addressed. For example Ancker K (#6344, 1992) notes that the Swedish construction code requires ventilation of at least 0.9 l/s per m2 in large detached garages (such as those described by Ancker), despite the fact that they are only used sporadically. This results in high costs for ventilation and heating, since they are not in continual use.

In Finland, Koskela H K et al (#5138, 1991) report that the minimum supply airflow rate given in the Finnish building code for garages of office buildings is 2.7 l/s per m2.

In the United Kingdom the Chartered Institute of Building Services Engineers (CIBSE) encourage natural ventilation in above ground car parks. For natural ventilation, openings in outside walls should have a total area equal to at least 5% of the floor area at each level, at least half of that area should be on opposite sides. CIBSE also recommend that where mechanical ventilation is used ventilation rates allowing between 6 and 10 ach are necessary, depending upon building type. Extract points should aim to eliminate pockets of stale air where dangerous fumes could collect, and should be from both high and low level, with special attention given to low points and drains. An automatic CO detection system should be used to initiate increased ventilation and raise an alarm when the CO concentration rises above 100ppm. Additional standby fans connected to a secure power supply should also be fitted.

At entrances and exits where vehicle engines are likely to be running, the ventilation rate

should be related to the rate of pollution generation in the exhaust gases. Carbon monoxide is the most critical pollutant although other exhaust gas constituents, such as oxides of nitrogen and hydrocarbons, may need to be taken into account.

Similar requirements are given by the American Society of Heating Refrigeration and Air Conditioning Engineers (ASHRAE) in the United States. To determine the amount of ventilation needed in garages, the number of cars in operation and the emission quantities must be known. This determination is often simplified by requiring four to six air changes per hour, or 4 l/s per square metre for fully enclosed parking garages. For partially open parking garages, 2.5 to 5% of the floor area is required as a free opening to permit natural ventilation. When natural ventilation is used the free area opening should be as large as possible at floor level. In parking levels with large interior floor areas a central emergency smoke exhaust system should be considered. The ventilation system whether mechanical, natural, or both, should be designed to meet applicable codes and maintain an acceptable contaminant level. To conserve energy, fan systems should be controlled by carbon monoxide meters.

Stankunas et al (#7434, 1989) reviews the effectiveness of current ASHRAE guidelines for maintaining acceptable air pollutant levels in garages and discusses ways of including economic utilisation of energy in future guidelines. ASHRAE's existing guidelines provide adequate air quality with respect to the allowable OSHA carbon monoxide concentrations. All of the garages studied had better air quality (CO) concentration than required by current US Occupational Safety and Health Association (OSHA) standards, the authors point out that pollutants, such as smoke and soot, fuel vapours, and odour causing compounds, should also be considered prior to the finalisation of further guidelines. A recommendation is that garage ventilation systems should schedule fan operation in line with occupancy patterns, which can be overridden at times of excess pollution. Such a philosophy could lead to significant energy savings. The relative position of air supply and exhaust ducts to each other, to building design and to traffic flow patterns, has a major impact on the ventilation system efficiency. Factors such as short circuiting, thermal stratification and emission hot spots, together with inadequate ventilation, can adversely affect air quality. Design guidelines should consider emission variability as well as the average emission rate when recommending ventilation requirements and safety margins.

Sufficient ventilation is not only essential to control pollution levels it is also necessary as a fire precaution. According to The National Fire Protection Agency (NFPA) of the USA, whenever mechanical ventilation systems are employed in parking structures, they should be installed in accordance with NFPA 90A Standard for the installation of air conditioning and ventilation systems. When blower and exhaust systems are installed for vapour removal, the systems should be installed with NFPA 91 Standard, for the installation of Blower and Exhaust systems for dust, stock and vapour removal. All enclosed basement and underground parking structures should all be capable of providing a minimum of 6 ach.

ASHRAE (1991), also give guidelines governing the ventilation of large hanger type facilities, used to house buses or military vehicles. These state that waiting rooms and consumer spaces should be pressurised against intrusion of the busway environment. When natural ventilation is selected the bus levels should be open on all sides, or contoured to permit free air circulation. The components of diesel exhaust gases that affect the ventilation system design are oxides of nitrogen, hydrocarbons, formaldehyde, odour constituents, aldehydes, smoke particulates and a relatively small amount of carbon monoxide. According to ASHRAE the Federal Occupational Health and Environmental Control Regulation, Subpart G, sets out the contamination levels for an 8 hour exposure as, CO 50ppm (57 mg/m3) and nitric oxide 25 ppm (31 mg/m3) with the ceiling (Max) limit for nitrogen dioxide at 5ppm (9.4 mg/m3).

Oxides of nitrogen occur in two basic forms; nitrogen dioxide (NO_2) and nitric oxide (NO). NO_2 is the major contaminant to be considered in the design of a ventilation system. Exposure to

concentrations of 19 mg/m3 and higher will cause adverse health conditions. NO2 also affects light transmission , causing visibility reduction. Odour perception is immediate at 0.79mg/m3 of NO2 and can be perceived by some at levels as low as 0.23 mg/m3.

To estimate the ventilation rate the total amount of engine exhaust gases is determined. The discharged contaminant quantities should be diluted by natural and or forced ventilation to acceptable, legally prescribed levels. To maintain visibility and odour control the exhaust gas contaminants should be diluted in the proportion of 75 to 1 with outside air.

The European Concerted Action, Report 3, "Indoor air quality and its Impact on Man", (#7517) outlines current standards and guidelines for NO2 contamination by household appliances in dwellings. Although no mention is made of vehicle emissions and occupant exposure these guidelines give further evidence of the exposure limits considered acceptable.

Morgan and Gardner (1990) outline design principles for smoke ventilation in enclosed shopping centres. They note that little guidance currently exits and describe the approach used by the Fire Research Station in the UK to cover smoke ventilation systems for an enclosed car park under such a complex. From experimental data, they represent a single burning car with a fire size of 2.5MW, 12m perimeter. They also note the concern in recent years due to the increasing use of plastics in car bodies, and of plastic petrol tanks and the implication these would have on the design fire size. Using the fire size on 2.5MW ventilation flow rates are given ranging from 9 Kg/s mass flow, with a temperature of smoke above ambient of 278 degree C a ventilation extract rate of 15 m3/s is required. The higher end of the range at a mass flow of 70Kg/s with a temperature of smoke above ambient of 36 degree C, requires an extract ventilation rate of 66 m3/s. An equation is also given to determine the aerodynamic free area if natural ventilation is to be used.

2.0 THE MAIN PROBLEMS ASSOCIATED WITH CAR PARKS.

Car park ventilation problems occur primarily on two scales, those related to large garage facilities or small scale garages connected to dwellings.

2.1 Problems in Large Scale Garages.

Large scale garage complexes include those beneath or above office or shopping complexes; those housed in their own building designed solely for the purpose of car storage and those which double as storage and workshop facilities, such as bus or military hangers or sheds. In all of these structures sufficient ventilation is essential, although despite a host of regulations and standards problems are still encountered often associated with inadequate ventilation.

2.1.1 Contamination build-up within car parks.

The most important and commonly occurring of these problems is the build up of contaminants within these structures caused at certain times by traffic congestion. A number of studies have been conducted in order to ascertain the specific nature and level of these pollutants, and the main cause of congestion.

Fox (#7435, 1987) investigated eight carparks all displaying a variety of common pollution problems. Typical problems were found in one carpark situated on top of a redeveloped shopping centre and comprising two floors. The lower floor has a complicated and obstructed configuration, while the upper floor is completely open. Two areas of high pollution were noted, the first occurred at an internal traffic junction with several conflicting traffic flows. Levels of

carbon monoxide were recorded up to 120ppm at this point. The second point of high pollution was found on the exit ramp which takes the form of an intertwined double helix of entrance and exit ramps, enclosed in a totally glazed rotunda. Peak values of CO were measured between 210 ppm and 280 ppm with transient values going up to 450ppm. Carbon monoxide levels in the cash kiosks were found to be between 50 and 80 ppm, levels in excess of the recommended TLV values.

In a separate car park Fox (#7435, 1987) found carbon monoxide levels in cash kiosks were as high as 250-300 ppm. Continuous monitoring during the week showed the atmospheric lead content of 2.08cmg/m3, however measurements during Saturday showed a peak value of 16.63μg/m3, this increase was directly proportional with the number of cars passing through. Fox deduces that carpark attendants, therefore, appear to be at the most risk from continual exposure to high levels of carbon monoxide and lead often present in car parks. Vehicle occupants are also at risk especially if trapped in congested traffic on a regularly basis. Car park design is therefore of great importance in that it does not inhibit traffic flow, and ensures that pollutants are removed by ventilation quickly and thoroughly.

Tully (#7427; 1979) recognises that there is a wide variety in staff attendance levels, and the location of ticket kiosks, in each garage. Some kiosks are located on a gradient, which will have considerable effect on the carbon monoxide emission of passing vehicles, as up to 50% more CO is emitted on up-gradients than on down gradients, where the CO is reduced by 40%. This represents a further problem that should be considered in underground car parks. Tully advocates the use of natural ventilation when ever possible, but when mechanical ventilation is necessitated its proper design is vital. Combustion products should be removed at source. It is important to have a fresh air supply to the ticket kiosks, 6 ach is suggested as desirable, and there should be a face velocity over the ticket window of not less than 0.5 m/s. This fresh air must not be derived from a contaminated source. Filters to remove CO can be installed in the fresh air inlet, but do represent extra costs. Where there is likely to be a build up of traffic at the exit a higher proportion of internal air should be extracted. The distribution of ventilation air is also essential, and Tully gives a number of guidelines similar to Anon (Recommended code of practice for all car parks, multi story, ground floor and underground). Additional precautions include CO monitoring equipment connected to supplementary ventilation plant, and effective sealing of ductwork, especially after settling has occurred.

Fox (#7433, 1987) attributes pollution problems in multistory car parks to traffic congestion and poor natural ventilation air flow caused by stagnant weather conditions. Fox studied a number of different car park structures and found that a particular feature of air pollution is the sudden and acute nature of the incident. He discovered that the highest carbon monoxide concentrations, between 40-60 ppm, on busy days were near the exit ramps and internal junctions. Traffic congestion on the outside street often hindered vehicle exit from within the enclosed exit ramps. This resulted in CO concentrations of between 130-210 ppm for periods of over an hour, with peak values of 450ppm. These levels are inhaled by people sitting in vehicles relatively immobilised for periods up to 30-40 minutes. In the continuous ramp type of car park, either single or double ramps are intertwined with separate entrances. Such structures are usually massive, tall buildings which stand alone and have good natural ventilation. The only areas of vehicle pollution found in this type of car park were the payment kiosks areas, again in a tunnel like configuration, or close to ground level. Measured levels of CO ranged from 50 to 120 ppm, on busy days as vehicles queued to leave the car parks. However the exit to this form of car park is unhindered.

In underground car parks, Fox found that the lowest l3 levels of car parking were positively ventilated through ducting, and at peak times the flow of vehicles within the car park was positively organised through management, so as to maximise traffic flow. Additional pay kiosks were available at peak traffic flow times. The lower levels exited to a quiet street away from the main city centre traffic, whereas vehicles leaving the other sunken levels were required to

circulate through the higher levels, to pay kiosks at the end of a steeply inclined ramp. Final exit from the car park is to a main city centre street. Due to the complex configuration of this car park, ventilation is poor and at peak times a queue of vehicles fills the ramps all the way down to the lowest level. Steady carbon monoxide levels of 400-450ppm were recorded in this car park, with exit times of 25-30 minutes. Concentrations of between 100-170 ppm CO were observed over several hours on the exit ramp with values of 200-270 ppm for the same period at the pay kiosks. The management were not present at this end of the car park. Three factors were identified in the conclusion of this report as to the cause of pollution incidents in car parks; inadequate natural or forced ventilation; hindered vehicle dispersal from the car park; poor management response to the sudden occurrence of air pollution incidents.

2.1.2 Contamination build-up within adjoining buildings and offices.

A common problem has been the detection of carbon monoxide and other pollutants in offices situated above underground garages. A number of studies have reported on such cases.

Hodgson et al (#3722; 1989) for example, investigated a newly constructed office building in Portland, Oregon, USA. Although the study focused on the source of VOC's (mainly attributable to photocopiers and plotters), other hydrocarbons were found within the office space, originating from the basement loading dock and parking garage levels. Both had their own air handling plant, but during the winter and autumn months the domination of the stack effect via stairwells and lift shafts, resulted in high hydrocarbon concentrations within high level offices. In response to these findings the garage exhaust fans were modified so that they ran continuously during occupancy. This reduced, but did not eliminate the transport of CO to the upper building.

Grot et al (#3609;1988) undertook a similar IAQ study in a seven story office building with a one story basement and a two and one half story underground garage. Among the measured variables were air infiltration and ventilation rates, internal temperatures and humidity, exterior temperature, wind speed and direction, the indoor and outdoor levels of CO and CO2 and indoor levels of respirable particles. As with the study by Hodgson et al (#3722; 1989) during the winter and autumn incidents of high CO concentration in upper floor offices were experienced. It was found that despite the automated sensors in the garage functioning as designed (to activate the garage's exhaust fans when the level in the garage exceeds 50 ppm), the transport of CO up the elevator shafts and stairwells in extreme weather conditions still occurred. Once the garage exhaust fans (at least two of the four) were operated continuously during the occupied hours, the CO level in the office space never exceeded 5 ppm.

Fellenbaum (#7432;1968) studied a large parking garage for 1000 cars in Buffalo, USA, occupying the subbasement, and one street level of the shopping centre. In accordance with the maximum allowable concentrations of CO the garage ventilation system was designed for long term maximum permissible CO concentration of 100ppm; long term average permissible CO concentration of 50 ppm; and peak CO concentration for one hour of 200 ppm. With the design average set at 50ppm, there would be a safety factor of two to safeguard against stratification, pocketing and local concentrations due to normal packing. For jams at exit ramps for periods not exceeding one hour, an agreed peak concentration of 200ppm could be accepted. Assuming the CO emission per car set a 30 cfh (900 l/s) the volume of air required on this minimal basis is 10,000 cfm (300,000 l/s) for 400 sq ft, an impossibly high ventilation rate. In an attempt to reduce this rate, comparisons with other garage spaces were made, including vehicular tunnels. Ventilation rates of between 600 to 900 cfm (300 to 450 l/s) resulted in air that while acrid, constituted no obvious health hazard. Ventilation rates as low as 240 cfm (120 l/s) per parking stall where also found with few reported complaints. Measurements confirmed that peak CO concentrations corresponded to peak hours of parking

activity. The calculations were undertaken to find the total air flow required to maintain CO concentrations at 50 ppm based on the 24,000 cfm (12,000 l/s) per car requirement and 1000 cars, the result was 840 cfm (420 l/s) per car. For design purposes therefore the median between average and peak conditions were used, scaled from 450 cfm (225 l/s) per car on the first level where operating time is short to 550 cfm (275 l/s) per car on the subbasement level where operating time is necessarily longer.

Boelter and Monaco (#4025; 1987) investigated the ventilation provisions of an internal parking garage inside a 100 story building, built and designed during the 1960's. The ventilation study focused on a seven story garage located in the lower part of the building. The garage occupies floors 6 through to 12, and represents a potential source of indoor pollution. The garage was designed with a ventilation system to meet local codes of 1 cfm (0.5 l/s) per square foot, producing a total of 280,000 cfm (140,000 l/s) when all fans are in operation. A double vestibule, one for entry and one for exit, was installed on the sixth floor which permits the garage doors to open and close with minimum air infiltration. The vestibules also served to isolate the passenger and freight elevators, a migration path for the stack effect. These vestibules were serviced by an independent ventilation system. Each floor of the garage was sealed at the perimeter and sensors were connected to fans and ensured that if the CO concentration is less than 35ppm and the temperature is above 40 degrees C, no fans are operating. When the CO concentration reaches 35 ppm, one exhaust fan starts, if the concentration rises to 50ppm the second exhaust fan is started. If heat is required according to the temperature probe, the resistance heater starts. As a complement to the automatic fan activity initiated by the CO sensors, one exhaust and one supply fan operate on alternating floors during such hours. In conclusion, the authors state that buildings designed during the period of low energy costs generally require some updating. These modifications have the potential to cause problems such as indoor pollution if not handled properly. Through a combined effort of contaminant control and other efforts, such as infiltration reduction, cost savings can be realised which will easily justify the expense.

A slightly different problem is described in the Indoor Air Quality Update (Anon, (#6756; 1993), where employees in an American two story warehouse/office block complained of respiratory problems and headaches, offensive odours and excessive dust particles on the second floor. The building has sealed windows, a basement garage and an asphalt plant situated across the street, which was thought to be the main cause of complaints. Upon investigation it was found that the existing HVAC systems had many deviations from the mechanical design drawings. For example, problems included insufficient outdoor air supply to the sealed offices, insufficient air being exhausted from the garage space and improper location of the thermostat that served the training and work room, which had the potential to create adverse thermal conditions. The IAQ assessment revealed carbon monoxide concentrations throughout the building were governed by the emissions from within the garage space which was found to have a positive pressure. Levels of between 9-10 ppm CO were recorded and were believed to be the cause of occupants headaches. It was concluded that the lack of outside air and the build up of CO levels from the basement garage could account for some of the symptoms reported by the building occupants. The asphalt plant could under certain climatic conditions have been responsible for the VOC's and tar like odours, although this was unsubstantiated.

A similar problem is outlined by Sterling et al (#7426, 1987) who investigated a Canadian Public Library where occupants have reported complaints of persistent problems of odours, identified as traffic fumes and restaurant odours. Results revealed that indoor CO concentrations appeared to be strongly influenced by the outdoor CO concentrations measured in the vicinity of the outside air intake. There did not appear to be a relationship between CO concentrations measured in the library and in the parking garage. Inspection of the outside air intake for the northwest zone confirmed its location at street level on a busy downtown street. The installation of an activated carbon filter had no effect on the CO concentrations in the northwest zone. This study concluded that the infiltration of CO into the

library from the parking garage was not a problem. However, CO concentrations in the parking garages were elevated. Upon further investigation it was found that modifications to the fan configurations had been implemented since construction of the garage. This modified configuration was intended to promote a transverse airflow from the supply vents on the south wall to the north and east wall exhausts. It was also found that this pattern was not effective due to the spiraled design of the vehicle pathways, resulting in elevated CO concentrations toward the north side of the garage. The amount of outside air supplied to the garage did not meet the ASHRAE 62 -198 requirement of 1.5 cfm/ft2 (0.75 l/s per square feet). Recommendations were made that the fan arrangement be altered to enhance the stack effect, resulting in airflow patterns up the helical roadways. Fresh air would be delivered to all fans on level 3 and 6 fans on level 2, whereas the remaining ones on levels 2 and 1 would be exhaust fans. This change would allow airflow patterns to utilise the roadway design of the garage rather than the roadway acting as a barrier to airflow. This alteration would also increase the fresh air level to comply with the ASHRAE standard.

Ferahian (#3569; 1989), studied the pollutant transportation paths in an underground garage. The author notes a number of problems and failings with current systems including careless construction and inadequate inspections which can lead to indoor air problems, including death. Occupants in offices above the garage had been subjected to very high levels of CO. It was found that an unblocked opening in the concrete structure had provided direct access of the CO from the garage ramp to the offices. Other problems, unrelated to the operation of the HVAC system, such as faulty design and or poor maintenance, can be the cause of serious indoor air pollution. For example, on the Saturday the emergency generator was tested, its fumes infiltrated the underground garage area and ventilation system, accumulating in the above offices. Upon closer examination, it was found that poor maintenance and design lead to garage ventilation fans not being connected to the emergency generator. The author also discusses changes in American and Canadian legislation and notes that such changes, while attempting to save energy, has at times, endangered the occupants of the building, due to poor indoor air quality.

Koskela et al (#5138; 1991), compared the performance of forced displacement and mixing ventilation in an underground garage of an office building by measuring CO concentrations and ventilation efficiency. The critical measure of ventilation in garages is the carbon monoxide concentration, which can be strongly affected by the supply air distribution, traffic patterns, variation in the traffic rate, and co production of the cars. Measurements were taken in an underground garage of an office building, composed of five parking caves excavated in rock. Four of these caves have forced displacement ventilation, and one has ordinary mixing ventilation. The supply and exhaust system operates at a constant airflow, working at full capacity during rush hours. All of the caves have an equal air flow (2.7 l/s.m2), which disregards that traffic intensity is not the same. In conclusion, the forced-displacement ventilation appears more efficient than conventional mixing ventilation. The supply air flow required for forced displacement was about half that for the mixing system, when exposure at the same load is used as the criterion. The best efficiency is achieved when the hall is suitable for piston flow (long and narrow) and the car and pedestrian traffic flow takes place at opposite ends of the hall. The CO load of the garage showed large variations, being at its highest during the afternoon rush hour, when CO production per car was about 3 times higher than in the morning.

Hayashi and Sakurai (#7428; 1975), propose a simple designing formula applicable to underground garages of any size and shape, based on a review of available literature. They conclude that even when incoming and outgoing cars per unit area are the same, the difference in the driving speed due to the difference of scale of the parking places results in different exhaust gas volumes. Furthermore even when the scales of the parking places are the same the difference in the shape of the parking places or in the route of incoming or

outgoing cars results in different exhausts gas volumes. The degree of pollution is different between winter and other seasons. In areas where open air conditions are bad, the concentration of the open air must be taken into consideration. The presence of a vortex or stagnant air makes the concentration of polluted air higher locally. The authors also advocate piston type ventilation with laminar flow to be the most effective method of ventilation.

High pollutant concentrations were reported in a UK case study (#7425; 1981), in a car park within a large pedestrianised shopping complex in a UK city centre. The resulting investigation revealed a number of interesting points. The car park for 453 cars, is built on two levels, with the upper level open to the air. The lower level is approached via a curved ramp providing access to the partially enclosed portion at the first floor. The car park is open to the air along the length of the north west wall and 19 pairs of air extraction grilles are located on the opposite wall. The north wall is totally enclosed and the south west wall is open for the majority if its length. Mechanical extract ventilation is combined with natural ventilation to provide the six ach with a split of one third high and two thirds low level extraction. Seven ach were achieved when the system was in operation. Investigations indicated that CO levels were reaching at least twice the TLV-TWA. Concentrations seemed highest along the rear wall containing the air extraction grilles. The air extraction fans were tested, eliminating the possibility of a breakdown or imbalance of mechanical ventilation. Upon closer examination higher pollution levels arose when the car park was full and cars slowly circulated looking for vacant parking places. It became obvious that the CARPARK FULL sign was either not being seen or ignored. The solution included an improved system of ventilation to the offices and traffic lights controlled by the traffic counting mechanism. These alterations dramatically improved the situation.

Flaschbart and Ott (#7436; 1986), outline a simple survey methodology applied to diagnose indoor air quality problems in high rise buildings. Seven high rise buildings located in the United States, were investigated, five of which exhibited elevated CO concentrations, attributed to underground parking facilities. The stairwells were found to be the main path of diffusion. They highlight the unawareness of occupants to their indoor CO problems, who may attribute their symptoms, headaches and dizzines to other causes. To conduct the survey the investigator enters the main lobby of the high rise building and takes three readings of CO with a personal exposure monitor (PEM). Readings can be instantaneous, recorded at 1 minute intervals or can be exact CO averages over a 1 minute period. The latter approach is proffered but requires an integrator or a digital averaging system. The investigator enters the elevator and proceeds to the next desired floor, taking three more 1 minute readings in the same manner. The survey can be made more efficient if every three or four floors are sampled, since CO concentrations can remain stable for about 2 hours. Once all floors have been surveyed the investigator can quickly scan the results to determine if the building has high CO concentrations. For comparative purposes the investigator should take CO readings outside the building immediately before and after the building has been surveyed. Potential sources can then be identified, and solutions proposed.

Lorenz (#7429; 1982), models the ventilation requirements of an office building's parking garage, where all the cars enter and leave at nearly the same time. The volume of this type of garage is usually considerable and therefore the system has a large time constant, implying a dynamic evaluation is needed, rather than a static approach. The author stresses that this work tries to determine the usefulness of a simple dynamic calculation, and not to simulate the response of the structure to general pollution emission problems and ventilation system designs. In conclusion, the authors found that by using the dynamic model described in this paper, for the case study, three different modes of operation were identified. In the third zone they concluded that a two level ventilation system should be applied. A new parameter appears in the determination of these two levels, representing energy consumption or running cost considerations. They also found a limit value to this new parameter above which the flow rates reduce to the classical static sizing on one hand, and zero on the other hand. Although

the calculations seem sophisticated, the authors computed the equations on a programmable handheld calculator in approximately 1 minute. Therefore the method proved to be of great help in an accurate sizing of ventilation systems.

Overgaard (1983), describes the energy retrofit of a major office building in San Francisco, USA, including the underground garage. The system incorporated two garage exhaust fans operated 24hr per day, despite little or no vehicle activity over much of the time. The system was sized to handle carbon monoxide generated during periods of peak vehicle activity. Garage air samples taken under various conditions indicated that the ventilation could be reduced for long periods of each day. One garage exhaust fan motor was replaced with a two speed fan motor, and a carbon monoxide detector was installed to cycle the exhaust fans. If low amounts of CO are detected, one fan exhausts the garage at low speed. If CO levels increase, the first fan will be switched to high speed, followed by the second fan, to provide the garage with full ventilation should levels continue rising. This new control system allows the garage to be exhausted by a single fan operating at low speed, while CO content of the air is continuously monitored and kept well below the allowed maximum.

The mechanical ventilation services of a 15000 m2, two story underground garage designed to serve a 1970's conference centre are described by Moran (#7700, 1979). The car park has space for approximately 500 vehicles. A mechanical extraction system removes two thirds of the extract air from low level and one third from high level, with all the supply air introduced at the high level. The car park is comprises of three zones each with its own ventilation plant, designed to give 3 ach under normal conditions. At times of maximum co-emission, when vehicles are queuing to enter or leave the building, 6 ach can be selected. The system has a total capacity of 53m3/sec of fresh air introduced, diffused and finally extracted. In addition, the carparks have an automatic sprinkler system and entry and exit ramps with electric underfloor heating, which is automatically switched on and off by means of the data collected from the surface temperature sensor, a surface moisture detector and a surface snow detector.

3.0 RESEARCH INTO NATURALLY VENTILATED GARAGES.

Natural ventilation of above ground level car parks has also been the subject of many investigations. Such studies investigate new designs to enhance and utilize the natural pollution removal capacities of the wind, and study potential and real IAQ problems in naturally ventilated garages.

Kornaat and Lemaire (1994; AIR vol15 No. 2 March 1994 + #7437), outline a study in which they attempt to model whether natural ventilation can be used to adequately remove pollutant emissions from garages. Natural ventilation systems are simpler, cheaper and have fewer breakdowns than mechanical systems. They require less maintenance and use no energy (for air transfer). A multi cell ventilation model and a CFD code are used to check whether enough natural ventilation can be maintained. The garage itself is relatively small with spaces for 49 cars, in a housing and shopping complex. No ventilation provisions can be installed in the walls of the parking garage because the walls are under ground level or border shops in adjacent areas. The ventilation needs to be sufficient to keep CO concentrations around the Maximum Accepted Concentration (MAC value). This is given in the Dutch regulations NPR2443, as CO in the air of 200ppm during half an hour or 50 ppm during 24 hours. Calculations based on these levels of CO exposure show that ventilation for a situation with peak load must be approximately 1 m3/s. Using the multi cell model, ventilation openings in the roof of the garage were selected. In the model, the entrance/exit is also modelled as a ventilation opening, because this cannot be closed and therefore is always fully open. This configuration meets all initial criteria. The net opening of the provisions are 8 and 2 m2 respectively. For the net opening of the entrance/exit 10 m2 is assumed. This configuration provides higher ventilation levels than required. The airflows were modelled using a CFD code

and have shown that during the most unfavourable of weather conditions, pollution concentration levels could be higher than those recommended. An additional mixing fan could, therefore be installed to help the dispersion of high pollution concentration in certain areas. A number of considerations were not dealt with in this modelling exercise, including the potential mixing due to the movement of cars, the possible heat emission by the engines, and the fact that the exhaust fumes are warmer then the air. By not taking these factors into account the authors believe that a saftey margin exists, especially if the design meets current standards.

Leene and Knoll (#984; 1981) describe a similar study on a naturally ventilated garage. A wind tunnel investigation and a mathematical simulation technique were used on models of a two story parking garage situated beneath a large block of buildings and containing houses, shopping centre and offices. Garage air change rates were computed for several opening configurations of garage walls and roof, from wind pressures measured on a 1:300 model. Concentrations of exhaust gases released in the garage were measured mainly at a height corresponding to 2m full scale in front of the buildings. Air pollution within a garage depends upon the number of cars with running engines, the type of engines (type of fuel, cylinder volume etc), the condition of the engine (tuning up of fuel and ignition), the number of revolutions of the engines, whether the engine is hot or cold, and the speed of the vehicle. It is therefore difficult to establish the extent of the pollution at different times of the day. According to the Dutch regulation, the required airflow for ventilation in a garage such as this would be 2.2 ach (for a volume of approx. 48000m3). By examining the weather data, in most cases ventilation provisions can be based on a wind velocity of 2 m/s and if necessary on a frequently occurring temperature difference. In conclusion, the authors found that from wind pressure measurements on the walls and roof of a large parking garage beneath a block of buildings, the overall ventilation of the garage can be calculated. With the position and area of openings, as outlined in the report natural ventilation will provide sufficient ventilation under all practical circumstances of weather and garage use.

4.0 RESEARCH INTO LARGE SCALE BUS AND HANGER TYPE GARAGES.

Large hanger type facilities, used to house buses or military vehicles, present a variety of different problems. These have large volumes and often correspondingly complex and varying pollutant and heat loads. A number of studies outlined below identify these problems and describe ways in which they can be overcome.

Cockram and Bearman (#7435; 1982) noted that during the 1970's an increasing awareness of health and safety encouraged a new garage modernisation program, with a view to increasing the health and safety of staff. Mechanical ventilation was thus installed as a standard provision of parking areas. Initial investigations revealed that, neither the physical size nor the capacity of the garage had much bearing on the pollution potential, since the run-out (i.e. the time all buses leave the garage in the morning) could be more intense in a small garage than a larger one. The experimental procedure includes a detailed study of the path of the exhaust fumes created by the buses and the effectiveness of the natural roof ventilators. Results indicated that buoyancy played a significant role in the dispersion of exhaust fumes, while the natural vents where largely ineffective. From the results of this work it was decided that the basic design of parking area ventilation should be by roof extraction to boost the buoyancy effect and the volume related to the dilution rate required by the bus "turn-out" intensity. There should be air inlets, carefully placed to avoid short circuiting and to get air movement into any dead areas.

Shaw (#7431; 1990) described a similar study of the renovation of a bus garage in Glasgow, Scotland formally an old depot for tramcars. The existing garage was heated by an oil fired vertical boiler system supplying steam to unit heaters in the garage area and to conventional radiator and pipes in the offices and other accommodation. The inspection pits in the workshop

area had a warm-air system which was completely ineffective. The need for continuous entry and exit of buses during early morning and evening meant that the large doors were continually open. The need to shut, re-fuel and re-position buses overnight created a similar situation. Initially, the heating system was changed to a low pressure hot water gas fired system in a new location. Under the Scottish Building Regulations, an enclosed workshop should have a minimum of 4ach, which represents a volume of 15.6 m3/sec. It was therefore decided to form a closed workshop within the existing space, heated and ventilated independently. The remaining area remains unheated but mechanically ventilated. The provision of a ducted supply and extract system to the workshop permitted integration of a diesel exhaust system from the pit areas. Small heat reclamation is available from the diesel exhaust. The supply air is discharged at high level in the workshop through suitable air terminals. The exhaust air is extracted in the proportion of two thirds at low level and one third at high level, in order to give effective removal of diesel fumes, which tend to settle in a blanket fashion about 1 metre above the floor level.

A UK case study (#7702, 1986), describes the retrofit of a bus station in Doncaster. The ventilation for the new 25 workstation bus maintenance workshop comprises eight air handling (input/output) units at 4.06 m3/s. Extract air is taken from the perimeter at high and low level, with re-heat batteries on the supply side and heat recuperators installed in the air handling units. The air handling units are automatically operated in sequence as the NO2 level rises. Mechanical ventilation is required to ensure that the legally permissible concentration of nitrogen dioxide from vehicle exhausts is not exceeded (in this case 5ppm). The air handling plant has been designed with a turn down ration of 8:1, controlled by a nitrogen analyser, to ensure that only sufficient plant is operating to prevent excessive concentrations of toxicants. Calculations indicated that the air handling plant would achieve 9.5 ach, sufficient for this purpose. The system does not recirculate air and can therefore be used to clear the workshop of smoke in the event of fire. In practice however, the extract system is not always powerful enough to cope with such demands. Floor extract systems enable buses to be tested in the work bays, ensuring that CO gases are removed. A common problem is the revving up of buses outside the bays where the extract systems will not reach. Another problem is the building energy management system. Despite having a manual override, each of the workshop fume detectors are monitored for 30 seconds by the Building Energy Management System (BEMS), which means the fumes from a standing bus can build up considerably before the ventilation system begins to operate.

March (1987), describes how cost effective ventilation was provided at a major bus maintenance and repair facility of the Chicago Transit Authority. Before the retrofit the building was subject to infiltration due to a negative pressure balance, and engine gases lingered in the service and repair areas. Once all the vehicles were driven out of the building, the ventilation rates were determined. Results indicated that the exhaust volume was more than adequate, but the supply was insufficient. In response, additional supply fans and new exhaust fans were installed. To handle the increased outdoor air heating load, a second boiler was added. To reduce the increased ventilation air heating costs, coil run around cycles were included in the ventilation system. Exhaust air heat reclaim coils were installed in exhaust ducts to capture heat that was transferred to similar coils in four new air supply units via a piping loop and an ethylene glycol solution. The existing ducts were cleaned to remove internal dirt to reduce static pressure. The air distribution was improved by the additional of four supply ducts. The supply systems at the exit were retained. Nine exhaust duct systems were fitted with new fans and heat recovery coils. These systems would represent a considerable imbalance between the supply and exhaust air volumes, if other areas of the building were not maintained at a positive pressure relative to the service and repair areas. This confines the engine exhaust fumes to where they can be quickly removed. The flow of air from these spaces also minimises infiltration and outdoor air into the service/repair location. To achieve the required ventilation, packaged air supply units were selected which would ensure that the plant could be built by the manufacturer to high quality standards and be installed as complete units on the roof. This

report written two years after commissioning, indicates that employees are pleased with the improved conditions within their workplace. The new exhaust and supply systems have performed well. The equipment is being well maintained, aided by good access to the roof top units.

Anker K (#6344, 1992), studied a number of different ways to ventilate large military garages. These buildings are detached garages, used for parking, maintenance and for educational purposes. Tracer gas measurements were made using CO and CO2 as tracers. The experiments commenced when vehicles were parked in the garages. Their engines were started and allowed to idle for 1-2 minutes before being reversed out. They were taken out in shifts, there being about three vehicles for each driver. Six tanks each powered by a diesel engine with a cylinder volume of 5.2 litres, were used. Different ways of moving the vehicles and various ventilation methods were investigated. Both passive and active ventilation systems were also studied. The authors conclude that exhaust fumes in large garages (625 m2) can be effectively removed by allowing the doors to remain open for, at most 10 minutes after the last vehicle has been driven out or the last engine has been switched off. For a mechanical system to accomplish this, an air flow through the fans of around 20,000 m3/hour would be required. The experiments suggested it was twice as effective to ventilate the garages with doors open. It was considered important to be able to reheat the garages quickly after airing, to ensure continued occupant comfort. The investigation revealed that the use of infra red oil heating has reduced costs and energy consumption by 50% compared with conventional forms of heating. The installation would also have a 4 year pay back period, although it should be noted that the outdoor temperature was high during the trial period. The tested gas oil infra red heating system is both effective and cheap and highly suitable for light buildings that are only in occasional use.

Chan et al (#5583; 1991) describe a study to investigate the ventilation requirements of a six story container freight station cum port warehouse facility in Singapore. The building consists of a mixture of warehouse units and loading bays. The ventilation system design for the multistoried warehouse may be considered as three separate systems, a mechanical ventilation system for the warehouse units, a dilution air system for the access driveway and a pollution control system for the truck parking bay.

Scale model tests were compared with computer simulation to provide valuable design information. Preliminary work on a pollution control system for the truck parking bay has indicated that the flow pattern around the truck exhaust system is enhanced by having a suction located near the exhaust of the trucks.

Curnew (#4034, 1988), outlines a study to improve the indoor air quality of a 43,360 square foot airplane hanger used for parking diesel powered and gasoline powered vehicles. Ventilation is essential to provide an acceptable working environment. The majority of complaints came from drivers awaiting their assignments and from various other areas throughout the building, where vehicles were being maintained or warmed up. The problem was to design a cost effective ventilation system for an open building 43,360 square feet, that would reduce the exposure of workers to air contaminated with gasoline and diesel combustion products. Due to the large open area, an attempt was made to remove the pollutants by zoning the ventilation systems to dilute the contaminated air at the point of generation without loss of total building heat. The system is composed of 5 individual functions, each with a monitoring and control system, a fresh air make up system and a contaminated air exhaust system. When all controls set to automatic operation, the veiling thermostat reaches its set point, opens the return air dampers and starts the make up fan, recirculating tempered air down to the work area. If the CO level reaches 50ppm, or the CO2 level reaches 1400ppm, the system control overrides the thermostat, starts the exhaust fan, closes the recirculating dampers, opens the outside fresh air dampers and starts the make up air fan. If the concentration of CO or CO2 continues to rise, the system control causes the

neighbouring ventilation unit to start. If the concentration is not reduced after 30 minutes, operation of two ventilation units will go to the running position and visual and audible alarms located at the control center will sound. An advantages of this system is that it does not produce hot or cold blasts of air but provides a gentle and uniform air distribution. The system also reclaims warm stratified air trapped in upper regions of the building, combines CO and CO2 detection, and saves operating costs by running only when required.

5.0 SMALL SCALE CAR PARK PROBLEMS AND SOLUTIONS.

This section describes pollutant generation and migration problems from small garages, such as those connected to residential buildings.

Gammage, et al (#1649, 1984) and Hawthorne, et al (1985) both describe the same project, i.e. the concerns that VOC's have the potential for producing hepatitoxic, nephrotoxic, neurotoxic, cardiac and respiratory effects. The authors try to identify some of the VOC's of concern in residential buildings, the specific source and the levels generated by the source. Measurements of VOC's were made in 40 homes in east Tennessee, USA, using a portable gas chromatograph. Measured levels of NOx in dwellings were generally below 25 ppb during the summer. Outdoor levels were also below this value except near a busy road where the outdoor NOx levels ranged between 10 and 65 ppb. The main indoor level in the two houses near the road were 30 ppb of NO and 60 ppb NOx. These high levels were associated with the operation of a car in a basement garage. The NOx concentrations in the bedroom above the garage increased from 5 to 70 ppb after the engine was operated for a period of 3 minutes. The central circulation fan of the HVAC was operating during this period and seemed to rapidly spread the exhaust pollutants through the house. Carbon Monoxide levels measured during the summer phase were generally near the detection limit of about 1 ppm, except for the two houses located near the busy road. Again, elevated CO indoor levels were also associated with a basement garage. The CO concentration in the bedroom above the garage increased from <1 to 17 ppm after the engine was operated for a period of 3 minutes. Traces of gasoline vapour were evident in the indoor air of the 40 homes. This is attributed to the operation of automobiles and the storage of petroleum based products in garages, usually attached directly to the house. There appeared to be a tendency for some of the HVAC systems to pull garage air into the living spaces. Air samples outside the house also frequently contained trace levels of gasoline vapours. The authors note that the findings of this study have important implications for homeowners, designers and builders of homes.

Alevantis and Girman (1989) studied the effects of window opening behaviour on residential ventilation rates. Using tracer gas methods the ventilation rates of three houses with attached garages were studied. Experiments were conducted with the garage doors at different opening stages. In conclusion, the authors report that opening the garage door can cause the ventilation rates to increase to 4 times the garages' natural infiltration rate with the door closed. In one garage a portable fan was also used (when the garage door was closed), and the effect of this was to increase the garage ventilation rate by 40%.

6.0 CONCLUSIONS.

Essentially many carparks do not pose health hazards to their users, however some carparks by virtue of their design, site configuration, position and poor quality of management do pose such a hazard. The main pollutants in garages are carbon monoxide and oxides of nitrogen and the recommended exposures are governed by a variety of guidelines, recommendations and standards. Such documents give general design guidance including recommended ventilation rates and system configuration. However, high pollution concentrations in neighbouring and attached buildings problems are still encountered, as well as in the garages

themselves. Such problems have been attributed to poorly designed exit and entrance points, insufficient ventilation rates, and stack driven flows. Generally it can be concluded that vehicle occupants are at minimal risk from high pollution levels if they enter and leave the car park straight away. However, if heavy congestion results in a long delay, then they may suffer mild or even severe health problems. What is generally recognised is that employees are often at most risk. Their working location and prolonged exposure mean that sufficient ventilation is therefore vital to ensure occupant health and safety in these environments.

7.0 REFERENCES

#NO 470 Exposure to pollutants in enclosed "living spaces".
AUTHOR
Sterling T.D. Kobayashi D.M.
BIBINF
Env. Res. vol13 p1-35 18 tabs. 89 refs. #DATE 01:01:1977 inEnglish
ABSTRACT
A review of literature reporting investigations of pollution in enclosed spaces. Discusses pollution in sealed environments such as submarines, the relation of indoor to outdoor pollution, sources of indoor pollution, and tobacco-induced pollution.Outlines problem of pollution in transportation-related enclosures such as tunnels, subways and garages. Suggests that indoor pollution in public office buildings is of greater potential harm than outdoor pollution. Gives 18 tables summarising measurements of various indoor pollutants made by different studies.
KEYWORDS
air quality, pollution,

#NO 984 Natural ventilation of parking garages.
AUTHOR
Leene J.A.
BIBINF
"Designing with the Wind" CSTB Seminar Nantes 15-19 June 198115pp. 8 figs. 9 refs. #DATE 15:06:1981 in English
ABSTRACT
A combination of a wind-tunnel investigation and a mathematical simulation technique conducted on models of two-storey parking garage situated beneath a large block of buildings (consisting of houses, shopping centre and offices) shows that wind penetrating the partly open garage facades can provide sufficient ventilation. Studies the effects on ventilation of varying the open area of the facades and of fitting openings in the garage roofs. Measures the effect of such ventilation meanson air quality close to buildings.
KEYWORDS
natural ventilation, garage, wind tunnel, mathematical modelling,

#NO 1649 Parameters affecting air leakage in East Tennessee homes.
AUTHOR
Gammage R B. et al.
BIBINF
Indoor Air. Vol 5. Buildings, Ventilation and Thermal Climate. Edited by B
Berglund, T Lindvall, J Sundell. Swedish Council for Building Research, 1984.
429-434, 2 tabs, 6 refs. #DATE 00:00:1984 in English AIVC bk,
ABSTRACT
A major pathway for loss of conditioned air in East Tennessee homes with externally located heating, ventilation, and air-conditioning (HVAC) systems is leakage in the ductwork. The average infiltration rate, as measured by Freon-12 tracer gas dilution, nearly doubles if the central duct fan is operating: duct fan on and duct fan off measurements of the rate of air exchange gave mean values of 0.78 and 0.44 h to the -1, respectively, in a total of 31 homes. Specific leakage areas measured by the blower-door, pressurization-depressurization technique are affected to a lesser extent by inclusion of the ductwork volume within the total volume of the house that is being pressurized: the average increment in the specific leakage area for a subset of 7 of the study homes is about 15%. For homes that have central HVAC systems, weatherization and energy conservation programs should be cognizant of the seriousness of air and energy losses that can be caused by leaking ductwork.
KEYWORDS
component leakage, air infiltration, tracer gas, freon, pressurization

#NO 3569 Building design and maintenance and indoor air pollution.
AUTHOR
Ferahian R H
BIBINF
In:UK, AIVC, 10th AIVC Conference, held at Espoo, Finland, 25-28September 1989, Volume 1, February 1990, pp429-442, 21 refs.#DATE 00:02:1990 in English
ABSTRACT
This paper examines some designs which lead to indoor air pollution and exhorts mandatory maintenance of all building services which determine the health and safety of the building occupants as an integral part of our city bylaws. Effect of poor maintenance of some of these systems on the indoor air quality is examined together with the effect of the interruption of the ventilation fans for energy conservation purposes, not always done legally. Among the examples considered are the effect of underground parking and its ventilation system, proximity of the fresh air

intakes to exhausts of the building and/or adjacent buildings and the drains of the plumbing system. The author's denied appeals to ASHRAE committees regarding adoption of ASHRAE Standard 62-1981R, done to ensure that the ventilation fans are not turned off when such buildings are occupied are discussed together with the City of Westmount's maintenance bylaw for apartment buildings adopted June 1989 which incorporates such a requirement. Our laws must ensure good air quality in our habitat as an environmental human right with the citizens' right of access to the information necessary to determine the quality of their indoor air environment for their health and safety.Examples from present Quebec legislation are presented.

KEYWORDS

maintenance, design, indoor climate, pollution

#NO 3609 Ventilation and indoor air quality in a modern office building.

AUTHOR

Grot R A, Persily A, Hodgson A T, Daisey J M

BIBINF

In: UK, 9th Conference AIVC, "Effective Ventilation" Gent ,Belgium, 12-15 September 1988, Vol.2, pp303-326, 25 figs, 1 tab,4 refs. #DATE 00:09:1988 In English

ABSTRACT

The new office building study is being investigated in order to establish a long-term record of a modern office building's thermal and environmental performance and to document what parameters in the design, construction and operation of a new office building will effect this performance. Other than initial problems associated with "debugging" the HVAC system and controls, the building has adequate ventilation under most operating conditions. The envelope of the building is not tight for a new office building and infiltration is a significant source of building air exchange. The levels of CO2, HCHO, radon and respirable particles are well within the established guidelines. An area of concern is the airflow from the garage into the occupied space. This airflow can cause high levels of CO2 in the vicinity of elevator shafts and stairwells on the upper levels and near the loading dock. The garage exhaust fans are adequate to reverse this flow, but in the automatic mode they currently do not operate for a sufficient amount of time to do so. A change in their controls, or an attempt to isolate the vertical shafts (stairs and elevators) from the garage, would alleviate these problems. There is no evidence of any significant outgassing of pollutants from the building materials and furnishings. There is however a total of at least 37 volatile organic compounds in the building air which seem to be related to the activities occurring in the building. The levels of all these compounds are of at least two orders of magnitude below established limits (1/10th of the TLV's). However, the vast amount of VOCs found in the building are compounds for which no extensive amount of research has been done to establish irritant levels and therefore these compounds could be a source of complaints from the building's occupants at low ventilation rates.

KEYWORDS

office building, indoor air quality, thermal performance,organic compound, pollutant

#NO 3722 Source strengths and sources of volatile organic compounds in a new office building.

AUTHOR

Hodgson A T, Daisey J M, Grot R A

BIBINF

USA, NIST, May 1989, 13pp, 5 figs, 11 tabs, 6 refs. #DATE 00:05:1989 InEnglish

ABSTRACT

This study was conducted at a newly constructed office building in Portland, OR. The primary objectives were to identify the major sources of volatile organic compounds (VOC) in the building and to measure both long-term (one year) and short-term(several day) variations in source strengths. Samples for VOC were collected on four occasions over a period of 14 months starting with the first month of occupancy. During the final sampling period, samples were collected over four days(Friday-Monday). The primary source of VOC in the building was liquid-process photocopiers and plotters which emitted a characteristic mixture of C10-C11 branched alkanes. Motor vehicles in the below-ground parking garage probably were also a major source of hydrocarbons. The source strength of total organic carbon, which was dominated by the office-machine emissions, remained relatively constant over the course of the study. Short-term variations in the source strengths of many compounds were related to occupant activities.

KEYWORDS

organic compound, office building

#NO 4025 Ventilation modification in a parking structure.

AUTHOR

Boelter F W, Monaco E A

BIBINF

In: Practical Control of Indoor Air Problems, proceedings of IAQ87, ASHRAE 1987, pp41-44. #DATE 00:00:1987 In English

ABSTRACT

The operation of very tall multi-use facilities presents challenges to both the designer and engineer. An investigation was conducted to determine the indoor air quality in a very tall building as it related to the operation of an internal parking garage. The original design for the garage called for continuous ventilation at the rate of 1 cfm/ft2. Based on the degree days in the Chicago area, the costs for operating the garage ventilation amounted to more than $290,000 per year. In an effort to reduce the operating costs, the ventilation system was operated manually as needed rather than be allowed to operate continuously. This resulted in the buildup of automobile emissions under certain conditions. Additionally, efforts to reduce natural infiltration of outside air into the garage during cold weather was complicated by the stack effect of the building and the need for regularly opening the garage doors. A sophisticated system was designed for solving this problem. The solution consisted of four interrelated components including perimeter enclosure, continuous carbon monoxide sensors,computerized fan operation, and a garage door airlock. The perimeter enclosure sealed one contributing opening to the stack effect problem by eliminating the leak along the skin of the building. The computer received the CO information and would automatically start exhaust fans at a concentration of 35 ppm.Enough exhaust fans are started to prevent the CO concentration from reaching 50 ppm. Supply fans would ultimately be started,as would be the heat, to assure the effective operation of the exhaust fans and prevent the freezing of the garage sprinkler system. The airlock limits the surge of incoming air to thus control heat loss and infiltration. The system has been fully functional for more than one year. The results have proven that indoor air problems can be solved with a cost saving.

KEYWORDS

garage, multi-storey building, ventilation system

#NO 4034 A solution for detecting and removing polluted air from large vehicle storage buildings.

AUTHOR

Curnow A

BIBINF

In: Engineering solutions to indoor air problems, proceedings IAQ 88, ASHRAE 1988, pp360-373, 8 figs, 2 refs. #DATE 00:00:1988In English

ABSTRACT

The control of indoor air quality quite often poses a very challenging problem to designers. This paper presents one solution that was adopted at Canadian Forces Base Montreal, St.Hubert, to improve indoor air quality in an industrial environment situation. The requirement was to ventilate a 43,360square foot airplane hangar used for parking diesel-powered and gasoline-powered vehicles. The need for ventilation was generated by the belief that symptoms of annoyance experienced by the employees, such as headaches and eye irritations, were related to the odours and a high concentration of polluted air emitted by the vehicles. In line with energy conservation, a practical system was designed to solve the problem. The solution consisted of five individual systems, each containing four interrelated components including a special polyethylene tubing type make-up air supply unit, continuous carbon monoxide and diesel fume sensors, exhaust fans, and heating thermostat. Each system is area orientated and starts automatically when a signal is received from the sensor. The signal starts the exhaust fan, closes the return air dampers, and opens the motorized shutters supplying outside air to the contaminated area. The outside air introduced together with the air exhausted results in the reduction of the level of pollutants. The other four systemsoperate when and if necessary. The building's heating system starts automatically to ensure that the heating level is maintained. The system also serves a second purpose, as it can reclaim and recirculate stratified air, providing tempered airthroughout the building. This sytem has been in operation for the past four years and has provided good ventilation, while complaints of annoyance have not been registered during its operation. Based on these satisfactory results, eight other large buildings have been upgraded with similar systems.

KEYWORDS

garage, pollutant, hangar, ventilation system

#NO 5138 Comparison between forced-displacement and mixing ventilation in a garage.

AUTHOR

Koskela H K, Rolin I E, Norell L O

BIBINF

USA, Ashrae Transactions, Vol 97, Pt 2, 1991.#DATE 00:00:1991 In English

ABSTRACT

The purpose of this study was to compare the performance offorced-displacement and mixing ventilation in the underground garage of an office

building by measuring carbon monoxide concentrations and ventilation efficiency. The garage consisted of five long halls, three of which were selected for measurements. Two of the halls in which measurements were carried out used forced-displacement ventilation and one used conventional mixing ventilation. Carbon monoxide concentrations were measured at four locations in each hall using a multipoint sampling system. Concentrations were registered during one day of normal parking traffic. Additional experiments were carried out with a concentration decay procedure using carbon monoxideas the tracer gas.
KEYWORDS
displacement ventilation, mixing ventilation, garage

#NO 5583 Design of a ventilation system for a multistoried warehouse.
AUTHOR
Chan W K, Wong Y W, Liu C Y
BIBINF
USA, Ashrae, Far East Conference on Environmental Quality, held Hong Kong, 5-8 November 1991, pp 61-65, 13 figs, refs. #DATE 05:11:1991 in English
ABSTRACT
This paper presents experimental and numerical studies in the design of a ventilation system for a multistoried container warehouse and distribution center. A system based on uniform air change rate for the warehouse unit was ruled out due to the amount of fan energy involved in circulating air in a largespace. The approach used was to ventilate the space at variable rates-6 air changes per hour (ACH) from floor level to a 3-m height, and at 1 ACH above that level. The studies show that a stratified system at 6-1 ACH as compared to a 6-0 ACH for asingle warehouse unit provides a good mixing of supply air as well as a minimum of dead spots. Investigation of the locations of the inlets also indicated that the optimal position for the 6-1 ACH is at a height of 3 and 5 m, respectively. Results on half- and full-wall analysis also show a greater mixing between adjacent units for the half-wall units. Effects of scaling have shown that model testing provides a good representation of flow pattern in the prototype. Preliminary work on a pollution control system for the truck parking bay has indicated that the flow pattern around the truck exhaust system is enhanced by having the suction located near the exhaust of the trucks.
KEYWORDS
ventilation system, large building, pollutant

#NO 6344 Ventilation of large military garages and heating with IR radiators. Examples and economic aspects.
AUTHOR
Ancker K
BIBINF
Roomvent '92, Third International Conference, Aalborg, Denmark,September 2-4 1992, Publisher: DANVAK, Lyngby, Denmark, Volume 3,pp 447-462. #DATE 02:09:1992 in English
ABSTRACT
Different ways of ventilating large military garages were studied. The study was prompted by complaints from soldiers and officers concerning exhaust gases from vehicles driven out of orinto the garages. This type of military garage is only used once or twice a day, and sometimes not at all for several days. Nevertheless, the Swedish Construction Code prescribes an exhaust air flow rate of at least 0.9 l/s per m2 floor spacewhen premises are ventilated by fans. In this case, this seems both unnecessary and expensive. We found that these highly specialized garages could be effectively ventilated just by leaving the doors wide open - for at least 7 minutes after vehicles had been driven in, and for 10 minutes after they have been driven out of the premises. IR radiators are used only when people are present in the garages, and they provide an effective means for providing good climatic conditions. The indoor climate was perceived as pleasant and comfortable when IR radiation was used after the garage doors were closed. The IR radiators neededto be on for about 20 minutes to provide a steady-state temperature. Moreover, the total energy cost for heating the garages was only half that of conventional water-heated systems.
KEYWORDS
large building, garage, ventilation strategy

#NO 6756 Poor garage exhaust leads to elevated CO levels in offices.
AUTHOR
Anon
BIBINF
USA, Indoor Air Quality Update, March 1993, pp 11-14.
ABSTRACT
This case involves a building, located in an industrial park near an asphalt/cement plant, and housing a garage facility inits basement for the firm's service vans. Employees in the offices above the garage complained of respiratory problems and headaches, as well as offensive odours. They also

complained of excessive dust particles on the second floor. Investigators found inadequate ventilation and filtering, as well as a lack of proper exhaust from the garage facility.
KEYWORDS
garage, carbon monoxide, office building

#NO 7425 Carbon monoxide levels in a car park - a case study.
AUTHOR
Anon.
BIBINF
UK, Health and Safety at Work, October 1981, pp 94-95.#DATE 00:10:1981 in English
ABSTRACT
A complaint was received by the environmental health department of a city council from the National Union of Public Employees that fumes from vehicle exhausts were too concentrated in one of the car parks where their members were employed by the council as attendants. Theinvestigation and actions which followed illustrate thelack of information generally available about the design of ventilating systems for car parks. The investigation also showed the success of a joint approach between the employing authority, the enforcing authority and the employees to quantify the position, assess the risk and provide remedies, and demonstrated the pertinence andinteraction of section 2,3 and 7 of they Health and Safety at Work Act.
KEYWORDS
carbon monoxide, garage, health.

#NO 7426 Case studies of ventilation retrofits designed to resolve air quality problems in public buildings.
AUTHOR
Sterling E M, Collett C W, Meuller B, Meredith J,Blomfield T.
BIBINF
USA, Ashrae, proceedings of IAQ 87, "Practical Control ofindoor Air Problems", pp 308-318, 5 figs, 1 tab, refs.#DATE 00:00:1987 in English
ABSTRACT
Ventilation air distribution problems involving system design, installation, operation and maintenance are often suspected of causing air quality problems that plague many modern sealed office buildings. Such air quality problems have resulted in occupants suffering symptoms of discomfort and ill health . Three case studies are described in which tests of ventilation performance appear to relate poor air quality to air distribution and ventilation. In all cases, ventilation system retrofits were designed to improve indoor environmental conditions.
KEYWORDS
public building, garage, library, indoor air quality.

#NO 7427 Car park ventilation.
AUTHOR
Tully R.
BIBINF
UK, Building Services, September 1979, pp 52-53, 1 tab.#DATE 00:09:1979 in English
ABSTRACT
The article gives practical advice on ventilation requirements for underground car parks, emphasising theneed to remove fumes quickly from exit ramps, where vehicles emit up to half as much carbon monoxide again ason the level.
KEYWORDS
garage, pollutant, carbon monoxide.

#NO 7428 Researches on ventilation of underground parking places.
AUTHOR
Hayashi T, Sakurai H.
BIBINF
Japan, Transactions SHASE, Vol 13, 1975, pp 69-76, 11figs, 7 refs. #DATE 00:00:1975 in English
ABSTRACT
When an underground parking place is not ventilated frequently enough, it is natural that the concentration of contaminated air cannot be lowered to less than the safety limit. Further, when the supply or exhaust air is not of laminar flow, the contaminated air concentration will increase locally due to stagnation of contaminated air ordue to vorticies generated in that place, even with a sufficient number of times of ventilation per unit time.In this connection, comparatively few reports about ventilation of underground parking places are found; and if any, most of them are directed to large-scale parking places. Therefore, the authors are going to offer a new simple designing formula applicable to underground parking places of any size and shape.
KEYWORDS
garage, ventilation system.

#NO 7429 Calculation of ventilation requirements in thecase of intermittent pollution : application to enclosed parking garages.
AUTHOR

Lorenz F.
BIBINF
USA, Environment International, Vol 8, 1982, pp 515-524, 8figs, 3 tabs, refs. #DATE 00:00:1982 In English
ABSTRACT
The ventilation requirements for decontamination arenormally determined with a static calculation method. Insome cases, the pollutant emission is intermittent, for example in the car park of an office building, where all the cars enter and leave the place nearly at the sametime. Generally, in such a case, the volume of the garage is large, consequently the time constant of the system has a high value. So a static approach would no longer stay accurate and a dynamic evaluation is needed. With the help of some assumptions, calculation remain rather simple and results can be plotted on nomographs or computed on a programmable handheld calculator. The amount of energy saved may appear very large in some cases. A sizing optimization will be required but also remains easy to compute. The paper presents the method of calculation for a single ventilation level and the optimization of a two-level ventilation.
KEYWORDS
ventilation requirements, garage.

#NO 7431 Ventilation Systems Incorporating Heat Recovery: Industrial application.
AUTHOR
Shaw K A.
BIBINF
IEE "Effective use of electricity in building " conference publication 186, 1980, pp 129-134, 7 figs. #DATE00:00:1980 In English
ABSTRACT
Describes the extensive programme of refurbishment carried out on the Possil park bus garage, which included the consideration of the heating and ventilation systems to provide for the requirement of the Building Standard within economic boundaries; the proposals incorporated included changing the heating system to a gas fired low pressure hot water system and incorporating a thermal wheel in the air handling equipment for the workshop, and providing an air extract system for the unheated garage area. Also included was the complete enclosure of the Pit/Workshop area including a hung insulated ceiling so that the volume of air change could be reduced and controlled, and the installation of a diesel fumes extract system for direct connection to bus exhaust pipes.
KEYWORDS
heat recovery, garage.

#NO 7432 Ventilation design for 1000 car parking garage.
AUTHOR
Fellenbaum B.
BIBINF
UK, Heating, Piping and Air Conditioning, November 1968,pp 113-116, 2 figs, 4 tabs. #DATE 00:11:1968 In English
ABSTRACT
This article deals with the ventilation of a 400,000 sq ft parking garage, which occupies the subbasement, basement,and one street level of the shopping centre. The design criteria for garage ventilation were carefully analysed in light of modern views on air pollution. High ventilation rates are necessary if the quantities of carbon monoxide emitted by typical passenger vehicles are considered.
KEYWORDS
garage, large building, design, ventilation system.

#NO 7433 Controlling air quality in car parks.
AUTHOR
Fox M F.
BIBINF
UK, National Society for Clean Air (NSCA), 1987 Workshop Proceedings "Indoor Air Quality : Acceptable Standard andBuilding Design", pp 1-10, 2 figs. #DATE 00:00:1987 InEnglish
ABSTRACT
Survey results are presented and discussed in the context of the design and construction of car parks. Proposals are made to reduce the incidence of air pollution in car parks and other enclosed spaces such as car ferries and customs posts. A method for calculating an index of the pre-disposition of a given car park for sudden, acute, air pollution incidents is described which takes into account the flow capacity at peak times into the surrounding roads, the natural draught ventilation rate and the capacity of the management to respond to sudden peak flow rates of vehicles leaving the car park.
KEYWORDS
garage, indoor air quality.

#NO 7434 Contaminant level control in parking garages.
AUTHOR
Stankunas A, Bartlett P T, Tower K C.
BIBINF

USA, Ashrae Transactions. #DATE 00:00:1989 In English
ABSTRACT
This paper presents the results of a research program that was conducted for ASHRAE by TRC-Environmental Consultants,Inc. The purpose of the study was to provide information on the effectiveness of existing ASHRAE ventilation guidelines for maintaining acceptable air pollutant levels and to develop a methodology for including economic utilization of energy in the consideration of future guidelines. Ventilation requirements for enclosed parking garages are currently expressed in terms of flow rate per unit of floor area or in air volume changes per unit time. Such guidelines are based on assumptions about ventilation system flow rates, motor vehicle emissions, traffic patterns and resulting carbon monoxide (CO) concentrations. This program was based on measurement of all these parameters at several underground parking garages. Data analysis included a review of pertinent literature and development of simple mathematical models for ventilation assessment. This study has focused on Carbon monoxide (CO). Other pollutants such as sulfates, oxides of nitrogen and odorous compounds also affect air quality, but CO is universally associated with garage operation and is generally seen as the major health factor.
KEYWORDS
garage, pollutant, ventilation requirements.

#NO 7435 Public transport garage (parking area) ventilation.
AUTHOR
Cockram I J, Bearman J F.
BIBINF
UK, BHRA Fluid Engineering, 1982, International Conferenceon Fan Design & Applications, Guildford, UK, September7-9, 1982, pp 147-160, 10 figs. #DATE 00:09:1982 InEnglish
ABSTRACT
After numerous tests and experiments on the best way toovercome the problems associated with Bus Garage Ventilation, a simple solution was arrived at - being themost effective economic.
KEYWORDS
garage, ventilation system.

#NO 7436 A rapid method for surveying CO concentrations in high-rise buildings.
AUTHOR
Flachsbart P G, Ott W R.
BIBINF
USA, Environment International, Vol 12, 1986, pp 255-264,2 figs, 5 tabs. #DATE 00:00:1986 In English
ABSTRACT
A rapid method for employing personal exposure monitors(PEMs) to measure carbon monoxide (CO) concentrations in high-rise buildings is described. The purpose is to determine whether or not a CO problem exists in abuilding, and, if so, what corrective actions should be taken. The methodology was applied to a 15-story buildingin PaLO aLTO, ca, where elevated CO concentrations were discovered on the first 11 floors. The source appeared to be an underground parking garage. A follow-up survey four years later revealed that mitigative measures designed to reduce these concentrations had been successful. The survey methodology is inexpensive and can be applied to a number of buildings in a city.
KEYWORDS
carbon monoxide, high rise building, garage.

#NO 7437 Natural ventilation of parking garages : dimensioning of ventilation units with the assistance of air flow models.
AUTHOR
Kornaat W, Lemaire A D.BIBINF UK,Air Infiltration Review, Vol 15, No2, 1994, (preprint), 9pp, 6 figs, 8 refs. #DATE 00:00:1994 In English
ABSTRACT
Parking garages require ventilation because the exhaust fumes produced by the vehicles have to be discharged. This can be achieved with a mechanical or a natural ventilation system. A natural ventilation system has several important advantages compared with a mechanical system. As a rule natural ventilation systems are simpler, cheaper and have fewer breakdowns, furthermore a natural system requiresless maintenance and uses no energy (for air transfer). For the dimensioning of the necessary ventilation units in a parking garage, the calculating regulations (for TheNetherlands) are given in NPR 2443 "parkergarages" [1].Recently the department of Indoor environment, building physics and systems of TNO Building and Construction Research has carried out further investigations regarding naturally ventilated parking garages. Using a multi cell ventilation model [2] research has been carried out to check if enough natural ventilation can be maintained,while the regulations according to NPR 2443 are not precisely taken into account. In this article one of these investigations [3] will be discussed. This concerns an investigation by which also the airflow (concentration distribution) is investigated with a so called CFD-Model[4], which

stands for Computational Fluid Dynamics.
KEYWORDS
natural ventilation, garage, air flow, modelling.

#NO 7617 Indoor pollution by NO2 in European countries.
AUTHOR
The Community-COST Concertation Committee.
BIBINF
Luxembourg, Office for Official Publications of the European
Communities, EUR 12219 - European concerted action. Indoor air
quality and its impact on man, COST Project 613, 1989,
25pp.#DATE 00:00:1989 in English
ABSTRACT
The report summarizes information on indoor pollution by nitrogen dioxide (NO2) in European countries participating in the concerted action "Indoor Air Quality and its Impact on Man" (COST project 613). Major scope of the report is to give concise information to people involved in research planning, policy making and regulatory activities and to help to identify a European view of the issue.The summary includes a short review of health effects of NO2, and of existing air quality guidelines and standards. For those countries for which information has been made available the more important sources, occurring indoor concentrations and national policies have been collated. Preventative measures are briefly discussed and research needs are identified.
KEYWORDS
Nitrogen dioxide, indoor air quality, health, standard.

#7694 EH40/94 (1994), Occupational Exposure Limits 1994.Health and Saftey Executive. UK, Broad Lane Sheffield, S3 7HQ.

#7695 NFPA 88A (1985), Standard for Parking Structures. National Fire Protection Association. Batterymarch Park Quincy MA 02269.

#7696 Code of practice for ground floor, multi-storey and underground
car parks
AUTHOR
Association for Petroleum and Explosives Administration
BIBINF
APEA June 1991, 8pp, p625.712.63
ABSTRACT
States the Code offers guidance for architects, designers and engineers on the requirements needed to to obtain a petroleum licence under the Petroleum (Consolidation) Act 1928. It covers a number of important areas, including lobby separation, sprinklers, ventilation, drainage, means of escape and fire-fighting equipment. It also lays down standards for mechanical ventilation for combined systems for petrol vapour and smoke extraction.
KEYWORDS
Lb, codes of practice, car parks, underground, underground spaces, drainage, multistorey buildings, ventilation, smoke ventilation, sprinklers, petrol, fire fighting installations, mechanical ventilation, ventilation,

#7697 Health and Safety Executive,The (EH33, 1982) Atmospheric Pollution in car parks.

#7698 Hawthorne, et al (1985), An indoor air quality study of 40 east Tennessee homes. Environment International Vol 12, pp221-239, 1986.

#7699 Overgaard (1983), Energy conservation retrofit. Heating/Piping/Air conditioning. January 1983. p65-75.

#7700 Moran E (1979), Comfort for the multitude. Consulting Engineer. August 1979 p45-49

#7701 March H (1987), Custom built heating and ventilation units improve garage climate. Heating/Piping/Air conditioning. July 1987. p75-79.

#7702 Anon (1986), Low Energy Workshop. Pub IN Building Services p19-22. March

#7703 Alevantis and Girman (1989), Occupant Controlled residential ventilation. IAQ 89 P 189-191

#7704 Morgan and Gardner (1990), Design principles foir smoke ventilation in enclosed shopping centres. BRE report 1990. Fire Research Station, BRE, Borehamwood, Herts, WD6 2BL. CI/SfB 34 (K23).

7.1 Reference Books used in this Review.

ASHRAE (1991), HVAC Applications, ch. 13.11. American Society Heating Refrigeration and Air Conditioning.

CIBSE (1988), Guide B2-6. Chartered Institute of

Building Services Engineers (CIBSE), UK

7.2 Bibliography of none English Articles Relevant to Garage Ventilation.

#NO 259 Does a grill help ?
Helpt een rooster ?
AUTHOR
Ferwerda G.G.J.
BIBINF
Klimatbeheersing vol.8 no.6 296 - 297, 6 figs. #DATE 01:06:1979 in Dutch
ABSTRACT
Treats odour penetration from garages etc. into connected room, caused by wind pressure on windward side openings. Discusses measures to prevent overpressure e.g. by a leeward side grill or an exhausting ventilator. Explains with mollier diagrams.
KEYWORDS
wind pressure, odour

#NO 1009 Ventilation of underground car-parks.
La ventilation des garages souterrains.
AUTHOR
Dozias A. Cluzel D. Sarrat P.
BIBINF
Chauffage, Ventilation, Conditionnement 1982 vol.58 no.1/2 p. 13-22 16 figs. 3 tabs. 5 refs. #DATE 01:01:1982 in French
ABSTRACT
Discusses a method of calculating the amount and type of ventilation required in an underground car-park, based on likely usage.
KEYWORDS
garage, ventilation needs,

#NO 5428 Chemical analysis of air quality in an office building equipped with a garage.
Kemisk analys av luftkvalitet i kontorshus med garage.
AUTHOR
Guhl A, Nicander-Bredberg H
BIBINF
Sweden, Swedish Council for Building Research, unpublished
report [1991]. #DATE 00:00:1991 in Swedish
ABSTRACT
Chemical analyses comprising volatile organic compounds, CO, and CO2 were performed in an office building in Stockholm. The composition of volatile organic compounds was almost the same as in another office building investigated earlier. The concentration of CO sometimes was very high, up to 5.0 ppm. The gas emanated from a garage in the ground floor, and the concentration increased when the ventilation air flow was decreased in the evening. The concentration of CO2 never exceeded 610 ppm. A project of ventilation by demand with 800 ppm of CO2 as a control factor would result in recirculation of ventilation air more than 80%. For this reason the building was considered as unsuitable for CO2-control of the outdoor air-flow.
KEYWORDS
indoor air quality, office building, garage, carbon monoxide, carbon dioxide, organic compound

#NO 5668 Air flow simulation. Modelling supply and exhaust
ventilation of a public underground motor-garage.

Experimentelle Stroemungsuntersuchung. Zur Be- und Entlueftung
einer oeffentlichen Tiefgarage anhand eines Modells.
AUTHOR
Kaufer H, Liepsch D, Fahr R
BIBINF
Germany, TAB Technik am Bau, September 1990, pp 687-694, 14
figs, 6 refs. #DATE 00:09:1990 in German
ABSTRACT
The simulation of the air flow proportions of an underground motor-garage required a model scaled 1:100. The geometrical similarities were guaranteed through the proportional reduction of the originals' actual dimensions. The dimensionless coefficients which distinguish the air flow had to show the same values both for the experimental field and for the original fluid, that is the Reynolds numbers or the Froude numbers of model and building had to be the same. The results show that the simulations produced the same air flows as those which occurred in the garage. Moreover, it became apparent that this way of construction - no pipe-liners were necessary - helps save both during the construction and the design of the plant. The final product was a daylight, user-friendly underground garage - as builder and architect had desired.
KEYWORDS
extraction, air volume, smoke experiment, air change, exhaust ventilation, sound mufflers, fan

#NO 7440 Ventilation of garages. Lueftung von garagen.
AUTHOR
Gottfried E.
BIBINF
Germany, KI Klima-Kaelte-Heizing, No 10, 1985, pp 395-399,
2 refs. #DATE 00:00:1985 in German
ABSTRACT
In the submitted paper an attempt is made to analyse the hitherto existing building bylaw and technical development. Thereafter the physical and technological principles of planning, the erection and the operation of ventilation plants in garages is shown as well as forecasts made with regard to the future development. Substantially the author refers to the model garage regulations and he works on the text of the Bavarian garage regulations. Noy excluded, however, are insignificant deviations from the regulation text of other Federal Countries. The essential point of the statements always remain the physical and technical principals.
KEYWORDS
garage, ventilation system.

#NO 7441 Monitoring of carbon monoxide concentrations in
large garages.
AUTHOR
Schumm H P.
BIBINF
Germany, HLH, No 4, April 1975, pp 143-144, 2 figs.
#DATE
00:04:1975 in German
ABSTRACT
Reports current CO monitoring procedures in large garages whose ventilation meets standard regulations. Discusses installation and location of measuring points and describes measuring process. Treats measurement results for the case of single or double measuring points.
KEYWORDS
carbon monoxide, garage, large building.

#NO 7506 Free air flows for the removal of pollutants from car parks.
AUTHOR
Krug H
BIBINF
Germany, HLH, Vol 45, No 3, 1994, pp 111-114, 8 figs, 7 refs. in German.#DATE 00:00:1994 in German
ABSTRACT
In car parks of considerable length, the removal of exhaust emissions, in particular their CO gas component, is carried out by air-conditioning systems mainly through transverse ventilation over short routes. The required air-conditioning ducts frequently produce a reduction in the available parking space simply due to their presence, resulting in restrictive effects on the level of acceptance by the users.In such cases, remedial action can be taken by creating ductless longitudinal ventilation. Depending on the required room air quality in the zones with the highest level of pollution, the volumetric flows for longitudinal disposal are no greater than those for conventional transverse ventilation. In conjunction with architecturally clear and positive lighting designs, clearly laid out car parks with a friendly atmosphere can be created which the user will be pleased to accept. This article deals with the differing mode of operation of both systems: Where the time of longitudinal removal is critical, the particular local air-conditioning features for transverse ventilation must be taken into account. With regard to their removal effect, both systems are equal. When changing to tunnel parking systems, longitudinal ventilation could however reach its limits beyond the presently installed systems, due to flow velocities of the room air that are no longer acceptable for the user. Compared with transverse ventilation, with single storey parking facilities, this has the advantage of usually being able to manage with one exhaust air system without duct systems.
KEYWORDS
Air flow, pollutant, garage, carbon monoxide.

#7705 Fire protection for air conditioning and ventilation plant
Der Brandschutz an Luftungs - und Klimaanlagen
AUTHOR
Gottfried
BIBINF
DT (Klima Kalte Heiz.) July/August 1985, vol.13, no. 7/8, 273-275. in German
(00/07/85)
ABSTRACT
Notes that W.German fire safety regulations for buildings have compelled air conditioning and ventilation engineers to concern themselves with fire protection measures, which ten years ago were mostly considered to be part of the building sector. Treats testing of fire dampers and fire safety equipment in W.Germany. Describes difficulties with fire protection equipment as a result of faulty planning and design. Cites examples of faulty installation of this equipment as a consequence of design errors. Describes how fire dampers

frequently have defective sealing where they penetrate walls and fire breaks, which either allows fumes and flames to penetrate, or is applied so clumsily that the damper cannot operate. Notes the need for regular and careful checking and maintenance by the building user. Notes areas requiring special fire safety equipment - garage ventilation, ventilation of kitchens. Concludes that although
fire protection of ventilation and air conditioning installations is well regulated, different interpretations can be placed on the texts. Despite this ventilation fire safety has greatly improved in W.Germany over the last ten years.
KEYWORDS
Air conditioning, ventilation, fire protection, Germany, buildings, regulations, standards, safety, designing, fire dampers, kitchens, garages, walls, flames, smoke, safety

#7706 Ventilation systems for underground car-parks SWKI 68-1
AUTHOR
Switzerland:SWKI (1968),
BIBINF
Switzerland:SWKI 1968. sp625.748.2:697.9(083.7)
ABSTRACT
KEYWORDS
ventilation, underground, car parks, Switzerland, standards

7707 100% outside air ventilation installations-possibilities and problems. Luftungsanlagen mit 100% Aussenluft - Moglichkeiten und Probleme
AUTHOR
Pielke:R. (1978),
BIBINF
DT (Kalte.) June 1978, vol. 31, no. 6, 266-274, 12 figs. 725.381:697.92 In German
ABSTRACT
Contrasts characteristics and operation of 100% outside air ventilation installations with systems using recirculated air. Cites a case from practice where a planned recirculation air garage ventilation system was converted to
100% outside air with no loss of comfort and considerable savings of capital and operating costs. Questions some commonly accepted assumptions concerning ventilation. Treats use of heat pipes for heat recovery with 100% outside air plant. Describes correct design and siting of room air outlets and application of filtration techniques to demonstrate feasibility of 100% outside air ventilation in summer and winter.
KEYWORDS
Outdoor air, ventilation, air, recirculating, garages, costs,
heat pipes, pipes, heat recovery, designing, rooms, vents, filters, feasibility, operations

7708 Covered car parks
Parcs de stationnement couverts
AUTHOR
Anon
BIBINF
DT (Chauff.Vent.Condit.) 1984, May, June/July and July/August, vol.60,
nos.5, 6/7 and 8/9, 41-44, 33-36 and 33-36, 2 figs. In French
ABSTRACT
Provides the text of an official circular treating the construction, operation and ventilation of covered car parks.
KEYWORDS
Car parks, ventilation, France

#7709 Simulation of multizone pollution problems
Simulazione di problemi d'inquinamento plurizonale
AUTHOR
Lorenz:F.
BIBINF
Condiz.dell'Aria. September 1982, vol.26, no.9, 788-792, 4 figs, 4
tabs. (In Italian)
ABSTRACT
In some cases, a pollution problem can be a multizone problem. A typical example is the case of a multilevel garage. A solution to the pollution problems of the ramps is to create a disequilibrium between inlet and removal of air at each level to produce a scavenging of the ramps. Assuming this hypothesis, this problem can be treated with the help of the state approach. The system may be considered as linear and time invariant if the ventilation level is constant. If it is controlled by a clock, the problem remains linear but time variant and if the ventilation level is controlled by measurement of the pollutant concentration, the system becomes non-linear. A simple solution to compute these last two cases is to consider that the system remains linear and time invariant between time steps.
KEYWORDS
Air pollution, garages, calculating, ventilation, zones

#7710 Proposals for solving the *ventilation* problem in underground garages.
AUTHOR
Schneider:J.
BIBINF
DT (Chem. Rundschau.) 21st July 1966, vol. 19, no. 15, 469-471
697.9:625.748.26:661.993 (In German)
ABSTRACT
Calculates CO emission by vehicles in litres/min and per ton of vehicle weight, and then shows how the emission per unit time may be calculated for a known number of vehicle movements. Data may be used to compute exhaust ventilation requirements. Describes a method of automatically controlling the forced fresh air supply and exhaust ventilation by a switching system - contact strip or photoelectric cell - triggered by vehicles entering or leaving the garage.
KEYWORDS
Ventilation, underground, garages, calculating, carbon monoxide,
exhaust air ventilation, switches, automatic, controls, vehicles

#7711 Ventilation plant for garages and tunnels. Part 1. Garages. (In German)
AUTHOR
Germany VDI Standards
BIBIBF
VDI September 1989 #RS (VDI 2053:Part1:1989), 19 pp, 4 figs, 5 tabs, Sp
ABSTRACT
Presents guidelines which apply in conjunction with German Standard #RS (DIN 1946) Parts 1 and 2, and supply in addition recommendations for the design, selection and operation of *ventilation* installations for garages and areas for the repair and maintenance of vehicles. Defines garages for the purpose of the Guideline as areas in which principally motor vehicles with internal combustion engines are both driven and parked. Unlike DIN 1946, the Guideline can also be applied to garage ventilation plant which do not heat the supply air, where the areas which require warm air have it supplied by other means.
KEYWORDS
Garages, Germany, guidelines, ventilation, supply_air,

#7712 The District Savings Bank in Osnabruck. (in German)
AUTHOR
Anon
BIBINF
DT (Technik am bau,) December 1987, no. 12, 945-958, 31 figs, 1 tab.
ABSTRACT
Illustrates the new headquarters building, which includes offices, a car park, dwellings and a restaurant. Provides a detailed description of the building services - heating, ventilation, air conditioning, plumbing, electrical installations, centralised building controls. Summarises the building services controls. Summarises the building services installations and their costs in a table.
KEYWORDS
offices, car parks, dwellings, restaurants, heating, ventilation, air conditioning, plumbing, electrical installations, building services, centralised services, controls, costs,

Garage Ventilation Bibliography
Update
March 1998

#NO 7828 Measurement of cross-contamination between vehicles using scalemodels
AUTHOR Riffat S B, Clarke R
BIBINF UK, University of Nottingham, Building Technology Group 1994, 21 pp, 10 figs, 6 refs#DATE 00:00:1994 in English
ABSTRACT This paper deals with the problem of exhaust cross-contamination between vehicles in a slow-moving traffic queue, as would be found in a busy modern city. This study has been undertaken using a open-jet wind tunnel, to determine the level of exhaust contamination around a 1:10 scale model car under various prevailing wind conditions. Tracer gas technique have been combined with static pressure measurements, to model the flow of pollutants around a vehicle body. Analysis of experimental data has shown that high concentrations of pollutants are present around the front, and in the lee of a vehicle in slow moving traffic.
KEYWORDS pollutant, modelling, outdoor air

#NO 7900 Natural ventilation of parking garages: dimensioning of ventilation units with the assistance of air flow models.
AUTHOR Kornaat W, Lemaire A D
BIBINF UK, Air Infiltration Review, Vol 15, No 2, March 1994, pp 9-12, 6 figs, 9 refs. #DATE 00:03:1994 in English
ABSTRACT Garages require ventilation because the exhaust fumes produced by the vehicles have to be discharged. This can be achieved with a mechanical or a natural ventilation system. A natural ventilation system has several important advantages compared with a mechancial system. As a rulenatural ventilation systems are simpler, cheaper and have fewer breakdowns. Furthermore a natural system requires less maintenance and uses no energy (for air transfer). For the dimensioning of the necessary ventilation units in a parking garage, the calculating regulations for the Netherlands are given in NPR 2443. Recently TNO has carried out further investigations regarding naturally ventilated parking garages. Using a multi cell ventilation model, research has been carried out to check if enough natural ventilation can be maintained, while the regulations are not precisely taken into account. In thisarticle one of these investigations will be discussed.This concerns and investigation by which also the airflow (concentration distribution) is investigated with a computational fluid dynamics model.
KEYWORDS garage, pollutant, natural ventilation, building regulations

#NO 8048 Free air flows in parking garages. Freie Luftstroemungen entsorgen Parkraeume. Part 2.
AUTHOR Krug H
BIBINF Germany, HLH, VOL 45, No 4, April 1994, pp 176-180.In German
ABSTRACT Describes free air flows in parking garages.
KEYWORDS (garage, air flow)

#NO 8083 Air quality.
AUTHOR Godish T
BIBINF USA, Lewis, 1991, 422 pp.
ABSTRACT General textbook on air quality. Chapters include: the atmosphere; atmospheric pollutants; dispersion; atmospheric effects; health effects; welfare effects- vegetation, livestock, materials and odour; air quality surveillance; regulation and public policy; motor vehicle emissions control; stationary source control; indoor air pollution; noise pollution.
KEYWORDS (pollutant, health, indoor air quality)

#NO 8310Integral simulation of air conditioning in passenger buses
AUTHOR Andre J C S, Conceicao E Z, Silva M C, Viegas D X.
BIBINF Poland, Silesian Technical University, 1994, proceedings of Roomvent '94: Air Distribution in Rooms, Fourth International Conference, held Krakow, Poland, June 15-17, 1994, Volume 1, pp 273-292.
ABSTRACT A computational model, developed with the objective of simulating the behaviour of the air conditioning system used in the passenger compartment of buses, is presented. The model is based on the space integral energy balance equations for the air inside and for the main vehicle bodies and surfaces. It can solve two kinds of problems. In the first one, calculates the heat stress that the air conditioning system must equilibrate, in order to satisfy predefined permanent regimen project specifications. In the second one, once imposed a particular air conditioning system

and given the ambient conditions, it computes the different temperatures and heat fluxes either in transient or steady regimens. Particular care was put on the solar radiation modelling. Some simple experimental tests in a real bus, done with the objective of illustrating the model's application in a typical situation, were performed with encouraging results.
KEYWORDS simulation, air conditioning

#NO 8434 Automobile passenger compartment ventilation.
AUTHOR Heinsohn R J, O'Donnel W R, Tao J
BIBINF Ashrae Trans, 1993, Vol 99 part 1, paper no. 3669, pp 476-487, 12 figs, 4 tabs, refs.
ABSTRACT A sequential box model (SBM) is proposed that predicts the instantaneous contaminant concentration at arbitrary points in a three-dimensional enclosure when the contaminant generation rate varies with time and location. The method can also accommodate time-varying ventilation flow rates and contaminant concentrations in the makeup air supply. The method is used to predict the passenger breathing zone concentrations of (a) cigarette smoke, when passengers smoke following some describable schedule, and (b) carbon monoxide, when the exhaust from a vehicle is drawn into the air intake of the vehicle behind it. The critical parameter affecting the accuracy of the method is the selection of exchange coefficients that describe the transport of air and contaminants from one box to another.
KEYWORDS modelling, pollutant, air flow

#NO 8609 Ventilation for bus drivers
AUTHOR Wang X-L, Petersen F.
BIBINF Sweden, Proceedings of the 4th International Symposium on Ventilation for Contaminant Control, Ventilation '94, held in Stockholm, September 5-9, 1994, Arbetsmiljoinstitutet, 1994:18, Part 1, pp 517-522.
ABSTRACT The micro-climate for bus drivers has been the subject of several studies in Sweden (1,2,3). The "indoor climate" in a bus is affected by various design aspects of the bus, such as its large window area and small volume and heat capacity (compared to those of a building.). One way of providing bus drivers a comfortable micro-climate is to use a suitable ventilation system. Experiments were carried out on a bus with three heating and ventilation systems: conventional, displacement ventilation, and an air curtain. The objective of this was to study the effects of the ventilation systems and to find the most suitable type. A thermal manikin was used because of the long measuring sessions involved. The thermal manikin consists of seven segments: head, trunk, arms, hands, thighs, legs, and feet. Surface temperatures could be regulated by altering the input powers for the seven segments (4). A ventilation system affects bus drivers by controlling the air temperature, velocity and direction of air flow. These may cause heat losses from the driver, especially convective losses, and cause sensations of draught. The convective heat losses were analysed to determine which ventilation system is best. The results show that the air curtain is the best of the three systems for bus drivers.
KEYWORDS displacement ventilation, air curtain, air flow, draught, motor vehicle, air conditioning

#NO 8682 Computer simulations of airflow and radon transport in four large buildings.
AUTHOR Fang J B, Persily A K.
BIBINF USA, National Institute of Standards and Technology, NISTIR 5611, April 1995, 43 pp.
ABSTRACT Computer simulations of airflow and radon transport in four large buildings were performed using the multi-zone airflow and pollutant transport model CONTAM88. These buildings include a twelve-storey multi-family residential building, a five-storey mechanically-ventilated office building with an atrium, a seven-storey mechanically-ventilated office building with an underground parking garage, and a one-storey mechanically-ventilated school building. Interzone airflow rates and radon concentrations are predicted in these buildings as a function of wind speed and direction, indoor-outdoor temperature difference, and ventilation system operation. Ventilation system factors that are studied include the operation of exhaust fans in the apartment building and variations in the percent outdoor air intake in the office buildings. Simulations in the office buildings are also made with the ventilation systems off and with variations in the balance of the supply and return airflow rates.
KEYWORDS air flow, pollutant, mechanical ventilation, radon.

#NO 8737 Local aspects of vehicular pollution
AUTHOR Clifford M J, Clarke R, Riffat S B.
BIBINF UK, University of Nottingham, Building Technology Group, 1995, 15 pp, figs, 17 refs.
ABSTRACT We consider the local aspects of vehicular pollution by wind tunnel testing used in conjunction with a tracer-gas technique. These initial results show that the level of pollution received by a commuter in slow-

moving heavy traffic may be as much a function of the pollution produced from the car in front as other environmental aspects.
KEYWORDS motor vehicle, pollutant, wind tunnel, tracer gas.

#NO 8760 Natural ventilation of car parking buildings. Natuurlijke ventilatie van parkeergarages
AUTHOR Kornaat W.
BIBINF Netherlands, TVVL Magazine, No 4, 1995, pp 28-31, 3 figs, in Dutch.
ABSTRACT Car park buildings have to be properly ventilated to remove exhaust gases. Unjustly natural ventilation often is regarded to be insufficient. This article deals with the advantages of natural ventilation. With air movement modules the effect of a natural ventilation system can be made understandable and the design can be ameliorated. The ventilation and the flow rate of a car park building can be determined, advancing the applicability of natural ventilation.
KEYWORDS garage, motor vehicle, natural ventilation, pollutant

#NO 8831 Air-conditioning and mechanical ventilation design for queuing enclosures in a bus terminal
AUTHOR Yik F W H, Yiu J, Burnett J.
BIBINF UK, Building Serv. Eng. Res. Technol, Vol 16. No 1, 1995, pp 9-16, 4 figs, 7 tabs, 10 refs.
ABSTRACT Passengers have complained about poor air quality inside several semi-enclosed but termini in Hong Kong, but analysis of measured contaminant concentrations revealed that the levels were rather low. This implies that poor air quality may not be the only cause of such complaints - the thermal stress experienced by the passengers is likely to be a major factor. For sheltering passengers from the contaminated environment inside a bus terminus, and to provide an acceptable thermal environment, a fundamental solution is to provide air-conditioned queuing enclosures. The method for establishing appropriate indoor environmental design criteria and the ventilation and cooling requirements for queuing enclosures in a bus terminus are discussed. Energy expenditure for ventilating and air-conditioning the queuing enclosure is also discussed.
KEYWORDS air-conditioning, mechanical ventilation, motor vehicle

#NO 8883 Evaluation of DVC system using multi-point sampling strategy
AUTHOR Bearg D.
BIBINF Canada, proceedings Indoor Air Quality, Ventilation and Energy Conservation in Buildings , Second International Conference, held May 9-12, 1995, Montreal, edited by Fariborz Haghighat, Volume 2, pp673-679.
ABSTRACT A ventilation monitoring and management system was installed in a building to continuously measure carbon dioxide (C02) concentrations at 24 locations throughout the HVAC system and occupied spaces. The intent of this installation was to be able to utilize the concept of Demand-Controlled Ventilation (DVC), where the amount of ventilation air delivered to the occupants would be based on the actual number of occupants present. The DVC approach therefore offers advantages for both energy conservation and indoor air quality (IAQ). In terms of energy use, the quantity of outdoor air being drawn in and thermally conditioned is no more than required and therefore is not wasteful of energy. In terms of IAQ, since the control of the ventilation quantity is based on the actual occupancy, the system will track variations in the number of people in the building and will call for additional quantities of ventilation when the population requires it. In addition to being able to provide DVC, this multi-point CO2 monitoring system also was determined to provide significant advantages in being able to evaluate the performance of the ventilation system. These advantages include: the ability to evaluate the relationship between the distribution of the supply air and the distribution of the people in the building, the ability to evaluate the adequacy of the duration of operation of the HVAC system, the ability to easily determine the percentage of outdoor air in the supply air, the ability to evaluate the frequency and magnitude of elevated levels of motor vehicle generated contaminants being drawn into the building air intakes, and the ability to document the performance of ventilation systems with a permanent historical record.
KEYWORDS demand controlled ventilation, sampling, carbon dioxide, outdoor air

#NO 8891 Ventilation design for large enclosed car parks in buildings
AUTHOR Uiu J.
BIBINF Canada, proceedings Indoor Air Quality, Ventilation and Energy Conservation in Buildings , Second International Conference, held May 9-12, 1995, Montreal, edited by Fariborz Haghighat, Volume 2, pp845-853.
ABSTRACT In a highly populated city like Hong Kong, the majority of buildings are invariably highrise. With a big demand for off-street parking, large multi-storey car parks and underground car parks are common solutions for the Government and developers. Enclosed

car parks are invariably provided with mechanical ventilation. As society becomes more educated and more affluent there is more concern and awareness about health and environment. The air quality inside car parks has been the subjects of complaints leading to the enactment of legislation for IAQ, and guidelines for ventilation system design. This paper reviews criteria for IAQ in car parks and the approaches to car park ventilation system design as applied in Hong Kong, including a new approach proposed by the Government s Environmental Protection Department (EPD)[1}. The various methods are examined and their suitability for local applications are trial tested in five existing car parks. A range of car park configurations and designs are compared. Some improvement to EPD s model and further work are suggested.
KEYWORDS building design, motor vehicle, mechanical ventilation

#NO 8901 Tunnel temperature control by ventilation.
AUTHOR Dai G, Vardy A
BIBINF Aerodynamics and ventilation of vehicle tunnels, Conference proceedings, Liverpool, July 1994, Cockram I Ed., MEP, 175-198, 13 figs, 1 tab, refs.
ABSTRACT States that the primary purposes of ventilation systems in underground railway systems are 1) the supply of fresh air during routine and non-routine operation and 2) air temperature control. Reports the early stages of an investigation into potential conflict between (short term) air temperature control and (long term) ground temperature control. Includes an assessment of when external temperature is of greater importance than train-generated heat. Deals only with one-way traffic in a single tunnel with and without a mid-tunnel fan shaft. Investigates the performance of this system separately for typical days in summer, winter, and spring/autumn. Draws provisional conclusions about year-round operation.
KEYWORDS temperature, motor vehicle

#NO 8902 Longitudinal ventilation by injection.
AUTHOR Costeris N P
BIBINF Aerodynamics and ventilation of vehicle tunnels. Conference proceedings, Liverpool, July 1994, Cockram I Ed., MEP, 695-715, 4 figs, 13 refs.
ABSTRACT Draws attention to the alternative injection system of longitudinal ventilation. Presents a brief overview of the system and its operation and advantages. Presents the basic theory supported by the results of tests on a model tunnel system. Also discusses the resulting flow patterns and their possible application. Concludes that in certain applications, the injection system has much to offer and there are possible savings to be made.
KEYWORDS ventilation system, motor vehicle

#NO 8903 Tunnel ventilation system modelling.
AUTHOR Casale E, Charvier J M, Lemaire G
BIBINF Aerodynamics and ventilation of vehicle tunnels. Conference proceedings, Liverpool, July 1994, Cockram I, Ed., MEP, 69-81, 7 figs, refs.
ABSTRACT Develops a numerical simulation tool to help understand how the various parameters in a tunnel ventilation system interact. Performs a partial validation. Compares measurements in the A40 (France) motorway tunnels and the model calculations. Finds that, for longitudinal ventilation, simulations and measurements are in general agreement. States this shows the importance of convection in pollution transport and justifies investigation into specific aspects of tunnel transient aerodynamics.
KEYWORDS ventilation system, modelling

#NO 8904 Review of tunnel fire and smoke simulations.
AUTHOR Rhodes N
BIBINF Aerodynamics and ventilation of vehicle tunnels. Conference proceedings, Liverpool, July 1994, Cockram I.Ed., MEP, 471-486, 9 figs, 13 refs.
ABSTRACT Describes a mathematical model based on computational fluid dynamics used for prediction of smoke movement. The model provides the numerical solution of the basic equations governing two and three-dimensional transient flow with prescribed boundary conditions and includes the effects of turbulence, combustion and radiation. The model has been used to investigate the effects of the major parameters associated with tunnel ventilation design. Describes the effects of fire size, development time and ventilation arrangement on smoke behaviour for several tunnel and underground railway geometries.
KEYWORDS smoke ventilation, motor vehicle

#NO 8905 Ventilation and cooling studies for the Gotthard Base Tunnel.
AUTHOR Berner M A, Day J R, Bagnoud G
BIBINF Aerodynamics and ventilation of vehicle tunnels. Conference proceedings, Liverpool, July 1994, Cockram I. Ed., MEP, 523-531, 7 figs, 1 tab, 4 refs.
ABSTRACT Presents the current basis for the design of the main ventilation and cooling

systems for the Gotthard Base Tunnel and describes their use during normal operation and in an emergency. Note the project is still in the preliminary design phase. Provides an overview of the aerodynamic and thermodynamic studies made on the way to the current design.
KEYWORDS cooling, ventilation system

#NO 8906 Aerodynamics, ventilation and cooling of the CrossRail Tunnel system.
AUTHOR Pope C W, West A, Gray W G
BIBINF Aerodynamics and ventilation of vehicle tunnels. Conference proceedings, Liverpool, July 1994, Cockram I. Ed., MEP, 577-604, 22 figs, 6 tabs, 2 figs.
ABSTRACT Reports on a detailed study which has been carried out into the ventilation of the CrossRail tunnel system across London. Shows that the acceptable transient pressures and station air velocities can be achieved during normal train services. Notes that an under-platform exhaust system is required to produce a satisfactory thermal environment in summer. A forced ventilation system using fans installed in shafts located at various positions along the tunnel is proposed for the cooling of stationary trains in congested running tunnels and the control of smoke in the event of fire.
KEYWORDS ventilation system, cooling

#NO 8907 On the standards for the design of tunnel ventilation systems.
AUTHOR Fudger G
BIBINF Aerodynamics and ventilation of vehicle tunnels. Conference proceedings, Liverpool, July 1994, Cockram I. Ed., MEP, 655-664, refs.
ABSTRACT Presents a review of the problems which need to be considered when attempting to set a standard for the design of a tunnel ventilation system.
KEYWORDS standard, ventilation system

#NO 8920 Ventilation design: use of computational fluid dynamics as a study tool.
AUTHOR Chow W K
BIBINF UK, Building Serv Eng Res Technol, Vol 16, No 2, 1995, pp 63-76, 20 figs, 18 refs.
ABSTRACT The technique of computational fluid dynamics (CFD) is applied to simulate indoor air flow induced by air distribution devices and thermal sources in large enclosures. The CFD package FLOVENT is used as the simulation tool. Examples taken to illustrate the capability of the technique are the air movement on four large waiting halls and the associated air conditioning design. The air flow in a large car park is also adopted as an example for a critical review of the performance of the mechanical ventilation system. To validate the package, numerical; simulations are performed with experimental data for air-conditioned spaces reported by Sakamoto and Matsuo, Murakami and Kato and Chow and Wong. Further, the use of the model to calculate the mixing factor for a displacement ventilation system is illustrated.
KEYWORDS ventilation system, building design, computational fluid dynamics

#NO 9021 Tunnel ventilation control system.
AUTHOR Anon
BIBINF Netherlands, CADDET, DEMO 34, March 1995, 2pp, 1 fig.
ABSTRACT A new tunnel ventilation system is in operation in two road tunnels on the Kyushu Expressway. It is a flexible, real-time expert system, implemented by employing a combination of knowledge engineering and fuzzy control techniques. Since it went into operation in March 1988, it has proved effective in controlling tunnel ventilation and has reduced energy costs by 27%.
KEYWORDS ventilation system, motor vehicle, energy consumption

#NO 9022 Effect of vehicle emissions in tunnels on above ground air quality.
AUTHOR Wan P K, Burzinski M J
BIBINF Aerodynamics and ventilation of vehicle tunnels, conference proceedings, Liverpool, July 1994, Cockram I, Ed., MEP, pp 623-632, 1 fig, 4 tabs, 4 refs.
ABSTRACT Presents a case study of the as-built condition of the Boston Central Artery/Tunnel Project to assess the potential effect that the in-tunnel vehicle emissions, exhaust through above ground ventilation buildings, have on above ground air quality. Focuses on carbon monoxide, nitrogen oxides and respirable particulate matter. The dispersion of these pollutants was analysed by both analytical and physical modelling. Presents the results. Concludes that no adverse effects for public;health or environment are expected to occur.
KEYWORDS motor vehicle, air quality, pollutant

#NO 9079 Evaluation and demonstration of domestic ventilation: state of the art.
AUTHOR Mansson L-G
BIBINF UK, Air Infiltration and Ventilation Centre, 16th AIVC Conference Implementing the results of ventilation research , held Palm Springs, USA, 18 - 22 September, 1995, Proceedings Volume 2, pp 435-446.
ABSTRACT The IEA Annex 27, Evaluation and Demonstration of Domestic Ventilation Systems is aiming at developing tools by using the most developed computer models and

equations available including model development. Before starting up all the simulations an in depth review of the variables influencing the evaluation of a ventilation system has been done and a report is to be published. All parameters are needed to be mapped so that realistic assumptions can be made for the simulation phase. Also included in the review are the models that can be used for simulations of indoor air quality, thermal comfort, water vapour content, giving the possibilities to calculate the life cycle cost. In the review report is given facts about housing statistics, population densities, moving pattern. The residents behaviour is given for time spent in the dwellings, airing pattern, etc. The loads that have to be dealt with are given by reviewing the present results on particle, NOx, VOC s. The AIVC TNs have been used for the chapters concerning standards and leakages in dwellings. Also emissions from radon, landfill spillage, garage, and combustion can be influenced by the ventilation system and that has also been dealt with.
KEYWORDS residential building, modelling, ventilation system

#NO 9221 Survey on the indoor environment of enclosed car parks in Hong Kong.
AUTHOR Chow W K, Fung W Y
BIBINF Tunelling Underground Space Technol., April 1995, Vol 10, No 2, pp 247-255, 7 tabs.
ABSTRACT Results of an indoor environment survey of 19 underground car parks in Hong Kong are reported. The indoor air temperature, relative humidity and air speed were measured. Subjective feelings of the occupants and their views on the indoor environment were surveyed by questionnaire. The design and operation of the installed ventilation systems and the number of occupants staying at the car parks were also investigated. Finds that studies of this kind are very important in providing design data. Goes on to propose a four-point assessment system to quantify the indoor thermal environment of the car parks.
KEYWORDS garage, indoor air quality, temperature, questionnaire, motor vehicle

#NO 9236 IAQ in large enclosed car-parks in Hong Kong.
AUTHOR Yiu J, Burnett J, Chan M Y
BIBINF Indoor Environ., No 4, 1995, pp 227-236, 2 figs, 3 tabs, 18 refs.
ABSTRACT With the increasing number of vehicles on Hong Kong s roads there is a heavy demand for car parking spaces, especially in commercial areas. Given the shortage of land for development in the territory, multi-storey and underground car parks seem to offer the best solution for Government and developers alike. However, provision of adequate mechanical ventilation is essential to maintain an acceptable air quality in enclosed and underground car parks. The overall purpose of a study undertaken by the authors was to develop improved methods for designing car park ventilation systems. This paper considers current concerns in Hong Kong on the environments, as determined by carbon monoxide concentrations, and on existing ventilation design methodologies used in Hong Kong are reviewed and their suitability for local application is examined. Typical design and operating problems found in car parks are discussed. Case studies of typical underground car parks in the territory are included.
KEYWORDS indoor air quality, motor vehicle, large building

#NO 9370 Volatile organic compounds in the environment.
AUTHOR Knight JJ, Perry R (eds.)
BIBINF UK, Indoor Air International, 1995, proceedings of the second international conference, held in London, 7-9 November 1995, 324pp.
ABSTRACT The environmental and health implications of volatile organic compound emissions on indoor and outdoor air is an increasingly important environmental issue. Through the development of analytical methodologies, it is now possible to detect a wider range of these compounds, at lower concentrations, and is a greater variety of media. Continued research efforts are being made to identify and quantify sources of VOCs, and to elucidate the influence of, for example, changing fuel formulations on air quality. At the same time, medical studies improve our understanding of the health implications of human exposure to these compounds. The proceedings of this conference cover air quality management and legislation, vehicle emissions and fuel composition, evaluation technologies, health effects and air quality studies.
KEYWORDS organic compound

#NO 9371 Environmental and in-car measurements of aromatic compounds including benzene.
AUTHOR Harrison R M, Leung P-L
BIBINF UK, Indoor Air International, 1995, proceedings of the Second International Conference on Volatile Organic Compounds in the Environment, held London, 7-9 November 1995, edited by J J Knight and R Perry, pp 89-95.

ABSTRACT Concentrations of benzene, toluene and the xylenes have been measured inside passenger cars travelling on the road, as well as immediately outside the vehicle and at fixed points close to the roadside. Data are presented for benzene and toluene which show concentrations inside cars travelling on urban roads to be reflective of those immediately outside the vehicle, and higher than at the roadside. The source of aromatic compounds appears to be emissions from other vehicles using the road; only one of several cars tested appeared to be polluted by its own exhaust fumes.
KEYWORDS organic compound, motor vehicle, pollutant

#NO 9375 Volatile organic compounds in indoor environments of urban Brazil.
AUTHOR Santos C Y, Aquino Neto F R, Cardoso J N
BIBINF UK, Indoor Air International, 1995, proceedings of the Second International Conference on Volatile Organic Compounds in the Environment, held London, 7-9 November 1995, edited by J J Knight and R Perry, pp 223-234.
ABSTRACT Volatile organic compounds (VOCs) were sampled in six restaurants and six offices from the cities of Rio de Janeiro, Sao Paulo and Campinas, South eastern Brazil. Sites were selected to include different ventilation conditions (sealed/unsealed offices) and cooking fuels (LPG/electricity, charcoal/wood restaurants). Sample collection was performed on activated charcoal cartridges and recovery by solvent extraction (diethyl ether). Analyses were performed by high-resolution gas chromatography (HRGC) using three columns with different stationary phases and computerised HRGC-mass spectrometry. Around 30 compounds were identified (and quantified) by comparison with authentic standards (alcohols, aldehydes, ketones, esters, ethers, saturated and aromatic hydrocarbons, halogenated hydrocarbons, sesquiterpenes and amines). Indoor/outdoor ratios greater than one for almost all components in the various sites, clearly demonstrate the importance of indoor sources for air quality as typified by components from deodorizing/cleaning materials (beta-pinene, tetrachloroethene). A newly refurbished office showed high levels of formaldehyde indoors, as expected. In view of the widespread use of ehtanol as a vehicular fuel, the presence of higher concentrations of acetaldehyde indoors than outdoors is curious and could indicate unsuspected indoor sources or better preservations of such a structure in closed environments. A site near an electronic industry showed the presence of 1,1,1-trichloroethane, even though use for electronic board cleaning had allegedly been discontinued. Other components found are less specific and can be originate from multiple sources, such as dichloromethane, butanol, pentanes, hexanes etc.
KEYWORDS organic compound, public building, office building, formaldehyde, outdoor air

#NO 9434 Effects of modified residential construction on indoor air quality.
AUTHOR Lindstrom A B, Proffitt D, Fortune C R
BIBINF Indoor Air, No 5, 1995, pp 258-269, 11 tabs, refs.
ABSTRACT Indoor air quality (IAQ) was assessed in homes in an experimental community of single-family dwellings that had been built with materials chosen for low pollutant emission and other modified design features to provide enhanced residential indoor air quality. The IAQ was measured in six of these experimental homes and also in three conventionally built homes of similar size and price range. The IAQ was assessed shortly after construction before the houses were occupied and again after each of the houses had been occupied for five months. Before occupancy, there were higher levels of airborne particles and of some volatile organic compounds in the conventional homes than in the experimental homes. During occupancy, benzene, ethylbenzene, m- and p-xylene, and o-xylene were all higher in the conventional homes, but dichloromethane, Freon 11, and trichlorethylene were higher in the experimental homes. In the conventional homes, mean levels of benzene and chloroform increased, whereas methylchloroform and toluene levels decreased from preoccupancy to occupancy. In the experimental homes, dichloromethane increased, and m-and p-xylene and o-xylene decreased from preoccupancy to occupancy. The results suggest that attached garages, geographical siting, and occupants activities substantially influenced the IAQ in these homes. The enhanced indoor air quality homes tested in this study were judged to be a least partially effective, with the most obvious sustained IAQ benefits being related to the lack of an attached garage.
KEYWORDS indoor air qualiyt, residential building, organic compound, pollutant

#NO 9436 On ventilation design for underground car parks.
AUTHOR Chow W K

BIBINF Tunnelling Underground Space Technol., April 1995, Vol 10, No 2, pp 225-245, 15 figs, 3 tabs, refs.
ABSTRACT Ventilation design for underground car parks is studied, first through a brief review of the ventilation requirement. Carbon monoxide concentration is believed to be the most important chemical species to be considered. Some results on field measurement of underground car parks reported in the literature are reviewed. The well-mixed model, which is a basic design model for studying the transient variation of carbon monoxide concentration, is described. The model is then revised to describe multiple sources of emission for several cars staying in a carpark with their internal combustion engines operating. Two mixing models proposed by Sandbert 1981)-Model 1, based on a displacement ventilation system and Model 3, based on a ventilation system with a short-circuiting air flow path-are applied to study the ventilation design in car parks. The technique of computational fluid dynamics is used to verify those existing models and then to compute the mixing factors concerned. Key system performance parameters are calculated, and a set of graphs relating those system performance parameters with the input design data is presented. These graphs can be used for designing the required ventilation rate for the system under different carbon monoxide loads. Eight local car parks are surveyed to illustrate the application of the model. Field measurement data on underground car parks, as described above, are reviewed and applied to justify the mixing models.
KEYWORDS garage, motor vehicle, pollutant

#NO 9441 Indoor/outdoor measurements of VOCs in developing countries.
AUTHOR Gee I L, Perry R
BIBINF UK, Indoor Air International, 1995, proceedings of the Second International Conference on Volatile Organic Compounds in the Environment, held London, 7-9 November 1995, edited by J J Knight and R Perry, pp 247-252.
ABSTRACT The problems of developing countries are often very different to those of the industrialised regions of the world. The impact of VOC pollution in large cities in developing countries has not been adequately considered. Many of these cities have rapidly growing numbers of motor vehicles in climates that promote the formation of photochemical smog. The health implications of this, together with the cancer risks associated with several VOCs have not yet been properly evaluated. The levels of a variety of volatile organic compounds (VOC) were measured in several cities in Asia;Bangkok, Manila and Beijing, and in South America, Sao Paulo, Santiago and Caracas. Preliminary results of studies in these countries have indicated that VOC levels are higher than normally encountered in European counties and that indoor levels are not significantly different to those outdoors. It is likely that the majority of VOCs measured indoors and outdoors are attributable to motor vehicles, although the results of samples currently being analysed will enable a more detailed analysis to be given.
KEYWORDS organic compound, carbon monoxide

#NO 9443 Investigation of ventilation in underground car parks for the control of air pollution. DoE research project 11B.
AUTHOR Booker J, Tait L, Schwar M
BIBINF UK, TBV Science, February 1996, DoE Research Report 11B, [200pp].
ABSTRACT Describes the results of an investigation of the ventilation of underground car parks. Its purpose was to more fully understand pollution levels within underground car parks, as this is an important pre-requisite for discussion on central measures applicable to Building Regulation and Local Authorities. Sections include a literature review, study design, results and a discussion.
KEYWORDS garage, motor vehicle, ventilation system

#NO 9566 Air quality monitoring in hospital departments: influence of outside pollutants and inside human activities on global hospital air quality.
AUTHOR Basilico S, Rubino F M, Bernazzani G, Bocchi G, Colombi A, Ronchin M, Occhipinti E
BIBINF Healthy Buildings 95, edited by M Maroni, proceedings of a conference held Milan, Italy, 10-14 September 1995, pp 1055-1060, 3 figs, 4 refs.
ABSTRACT In order to investigate the factors influencing air quality inside hospitals, the concentration of atmospheric gases and of pollutant vapours was monitored in air-conditioned and naturally ventilated hospital buildings located in urban areas with different vehicular traffic density. The quality of inside air is strongly dictated by outside pollution, the latter mainly depending on hospital position with reference to automotive sources, as far as showed by measured CO and CO2 time profiles. CO2 indoor pollution is mainly dependent from human presence and its effect is particularly relevant in conditions of crowding and insufficient ventilation of environments, where CO2 build-up higher than 3500 mg/m3 can

cause subjective discomfort. Indoor pollution from volatile organics can be traced to peculiar sources and is characteristic of hospital activities, with respect to other collective buildings, mainly due to the extensive use of cleaning products and sanitary auxiliaries.
KEYWORDS hospital, pollutant, indoor air quality, carbon dioxide

#NO 9782 Numerical computation of airflow in air conditioning automobile compartment.
AUTHOR Xuejun S, Zhijiu C, Zongcai Q
BIBINF Japan, proceedings of the 5th International Conference on Air Distribution in Rooms, Roomvent '96, held Yokohama, Japan, 17-19 July, 1996, Volume 2, pp 249-254.
ABSTRACT This paper describes two-dimensional numerical simulation of steady air flow in air-conditioning automobile compartment with SIMPLEST method, body-fitted coordinate is used to set up computational grid, while solid-gas coupling heat transfer in the compartment is solved with whole-field-solving method, the effect of natural convection on airflow is taken into account. It is concluded that the location of inlet vent and outlet vent and inlet vent angle have great effect on air flow velocity and temperature distribution in the passenger compartment. The results of this paper lay a foundation for the study of ventilation optimization design in the chamber and comfort control of air-conditioning automobile system.
KEYWORDS numerical modelling, air flow, air conditioning, motor vehicle

#NO 9804 The design of ventilation systems of large enclosures with unconfined pollutant sources.
AUTHOR Fontaine J R, Rapp R
BIBINF Japan, proceedings of the 5th International Conference on Air Distribution in Rooms, Roomvent '96, held Yokohama, Japan, 17-19 July, 1996, Volume 3, pp 95-102.
ABSTRACT Indoor air quality of large enclosures containing unconfined pollutant sources is a really challenging problem. Local capture ventilation systems cannot be used because the contaminant source is either too large or even moving; available design principles for general ventilation systems are not very often applicable either, because they generally would lead to enormous air flowrates. It is the purpose of this paper to tackle this problem by using computational fluid dynamics methods. Two practical examples chosen in the domain of occupational health are presented. The first case concerns the ventilation of underground building sites of car parks. Here pollution produced by the earth movers is made of dust and diesel engines exhaust gases. In the second example a ventilated tunnel is used to protect the occupied zone of a large workshop from styrene vapours produced by the manufacturing of large fiber glass reinforced plastic pipes. For every example several ventilation strategies are tested, by performing numerical simulations of the resulting air and pollutants flow fields. In the second application a parametric study is carried out to optimise the design of the tunnel. Both cases have already been successfully implemented and tested on sites. All computer simulations are performed with the EOL-3D software developed at INRS. This paper shows that CFD is a real design tool for ventilation systems in complex industrial situations.
KEYWORDS large building, ventilation system, pollutant

#NO 9835 Particulate pollution interactions with indoor surfaces: measurement and modelling for risk assessment and contaminant control.
AUTHOR Byrne M A, Goddard A J H, Lockwood F C, Nasrullah M
BIBINF UK, Air Infiltration and Ventilation Centre (AIVC), 1996, proceedings of 17th AIVC Conference, "Optimum Ventilation and Air Flow Control in Buildings", Volume 1, held 17-20 September 1996, Gothenburg, Sweden, pp 65-73.
ABSTRACT In the urban environment, there is strong evidence that fine particulates associated with vehicular emissions are linked with respiratory problems and an increase in mortality. The population sector most at risk is the elderly who spend much of their time indoors; consequently, the infiltration of these particles and their subsequent behaviour indoors is of primary concern. The deposition of aerosol particles in the respiratory system and on indoor surfaces is a process governed by particle size; in addition to providing risk assessment data, an understanding of the interaction of particles with indoor surfaces can be applied to the design of systems for enhancing indoor aerosol deposition and thus inhibiting inhalation exposure. This paper describes experiments using tracer-labelled aerosols, in a range of monodisperse size distributions representative of real particulate pollutants, to study aerosol deposition on surfaces with representative roughness. Some preliminary data, exhibiting electrostactically-enhanced aerosol deposition are also presented. In order to make these data widely accessible, the experimental results are used to aid in the development of a CFD code by providing validation data. Simulations are described for a room-sized enclosure with representative indoor surfaces, to illustrate the

influence of internal building surface characteristics on indoor aerosol concentration modification.
KEYWORDS particulate, pollutant, motor vehicle, respiratory illness, aerosol

#NO 9839 Design guidelines for ventilation system for pollution control in large, semi-enclosed bus terminus.
AUTHOR Yiu J, Yik F, Burnett J
BIBINF UK, Air Infiltration and Ventilation Centre (AIVC), 1996, proceedings of 17th AIVC Conference, "Optimum Ventilation and Air Flow Control in Buildings", Volume 1, held 17-20 September 1996, Gothenburg, Sweden, pp 103-111.
ABSTRACT In response to complaints about poor air quality in bus termini, the Hong Kong Government is considering imposing legislative control over ventilation system design and operation of bus termini in Hong Kong. However, there are, as yet, no relevant air quality criteria and ventilation system design guidelines for Hong Kong. In this paper, measured air quality data for 5 semi-enclosed bus termini are reviewed. This provides a picture of the prevalent air quality in bus termini. To establish a design guide for ventilation systems for Hong Kong, a number of overseas design guides are examined and a ventilation system design method is proposed. The significance of design parameters, such as bus engine emission rates, utilization of the terminus, ventilation effectiveness, etc, are discussed.
motor vehicle, pollutant, ventilation system, building design

#NO 9840 Cooling and ventilation of a high-speed ground transportation system.
AUTHOR Rosemann P, Moser A
BIBINF UK, Air Infiltration and Ventilation Centre (AIVC), 1996, proceedings of 17th AIVC Conference, "Optimum Ventilation and Air Flow Control in Buildings", Volume 1, held 17-20 September 1996, Gothenburg, Sweden, pp 113-119.
ABSTRACT This paper presents the special needs and difficulties concerning cooling and ventilation of the SwissMetro high-speed ground transportation system. SwissMetro is based on four complementary technologies: a complete underground infrastructure, a partly evacuated tunnel system to reduce the aerodynamic drag of the vehicle with a maximum speed between 400 and 500km/h, linear electric motors and a magnetic levitation and guiding system. Due to high internal and external heat loads permanent cooling and air-conditioning of the vehicle is required. Additional thermal problems may occur in the case of an emergency. The pressure level inside the tunnel has to be raised within a short period of time to guarantee the safety of the passengers and to avoid any health risks. This repressurisation of long tunnel sections may cause shock waves and high temperatures inside the tunnel. The aim of the project is to analyse the spatial and temporal temperature evolution in the SwissMetro tunnels under different conditions and in emergency situations.
KEYWORDS cooling, motor vehicle, tunnel ventilation

#NO 9922 Dispersion of automotive alternative fuel vapours within a residence and its attached garage.
AUTHOR Lansari A, Streicher J J, Huber A G, et al
BIBINF Indoor Air, No 6, 1996, pp 118-126, 7 figs, refs.
ABSTRACT study was undertaken to investigate the use of mass balance modelling techniques to predict air pollution concentrations in residential settings where the source is evaporative emissions of alternative fuels emitted in the attached garage. Known quantities of methanol were allowed to evaporate in the garage, then measured and simulated using a multizonal mass balance model (CONTAM88). The study found that evaporative emissions in an attached garage have a tendency to infiltrate the house, with rooms adjacent to the garage showing the highest levels of methanol concentrations. Thus automotive evaporative emissions may represent a source of indoor pollution and human exposure in a residential attached garage and also in other critical locations of the residence.
KEYWORDS organic compound, pollutant, garage, motor vehicle, modelling

#NO 9932 Concentrations of volatile organic compounds in the passenger compartments of automobiles.
AUTHOR Lawryk N J, Weisel C P
BIBINF Environ Sci Technol, No 30, 1996, pp 810-816, 8 figs, 5 tabs, 10 refs.
ABSTRACT In-vehicle concentrations of selected gosaline-derived volatile organic compounds (VOCs) and formaldehyde were examined on 113 commuters through suburban New Jersey and 33 New Jersey/New York commutes. Overall median concentrations were lowest in a typical suburban commute, slightly higher on the New Jersey Turnpike, and the highest in transit through the Lincoln Tunnel. Median in-vehicle concentrations of benzene, ethylbenzene, m&p-xylene, and 0-xylene were

14, 6.8, 36, and 15ug/ m cube, respectively. One vehicle, with a carburetor engine, developed malfunctions that caused gasoline emissions within the engine compartment during driving, resulting in the gasoline-derived VOC concentrations in this vehicle being much higher than in the properly maintained fuel-injected vehicle, particularly for the low ventilation extreme. The highest in-vehicle benzene concentration measured during these malfunctions was 45.2ug/m cube. The air concentration in the vehicle driven in tandem was a factor of 25 less (1.8ug/m cube).
KEYWORDS organic compound, motor vehicle

#NO 10036 Air exchange rate of stationary automobiles.
AUTHOR Park J, Spengler J D, Yoon D, et al
BIBINF Indoor Air '96, proceedings of the 7th International Conference on Indoor Air Quality and Climate, held July 21-26, 1996, Nagoya, Japan, Volume 1, pp 1097-1102.
AUTHOR The air exchange rate (or air changes per hour:ACH) was measured under 4 different conditions in 3 stationary cars. The ACH ranged between 1.0 and 3.0-h1 with windows closed and no mechanical ventilation, between 1.8 and 3.7-h1 with windows closed and fan set on recirculation, between 13.3 and 26.1-h1 with windows open and no mechanical ventilation, and between 36.2 and 47.5-h1 with windows closed with the fan set on fresh air. ACH with windows closed and no ventilation was higher for the older car than for the newer cars. With the windows closed and the fan turned off, ACH was not influenced by wind speed. ACH in parked cars is relevant to understanding exposures to pollutants from internal sources was estimated using the EPA model for simulated "stop-and-go" urban driving cycles, and it was found that the pollutants build up rapidly and are diluted slowly inside parked cars.
KEYWORDS air change rate, motor vehicle, pollutant

#NO 10042 Construction of a new bullet train car providing satisfactory air to both smokers and non-smokers.
AUTHOR Ishii I, Sakurai T, et al
BIBINF Indoor Air '96, proceedings of the 7th International Conference on Indoor Air Quality and Climate, held July 21-26, 1996, Nagoya, Japan, Volume 2, pp 151-156.
ABSTRACT A new bullet train car with an effective ventilation system has been constructed as a result of co-operation between Japan Tobacco In. and East Japan Railway Company. The purpose of this system is to provide satisfactory and good quality air both to smokers and non-smokers on board. The principal aim of the system is to control the air stream in the carriage so as to prevent the tobacco smoke in the smoking section from moving into the non-smoking section. Moreover, an electrostatic precipitator and a deodorant filter were installed. The efficiency of this system was examined using this new train car.
KEYWORDS motor vehicle, tobacco smoke

#NO 10049 Assessment of the fire protection and ventilation systems in an enclosed car park.
AUTHOR Chow W K
BIBINF Indoor Air '96, proceedings of the 7th International Conference on Indoor Air Quality and Climate, held July 21-26, 1996, Nagoya, Japan, Volume 2, pp 253-258.
ABSTRACT The probable fire environment in an enclosed car park to be constructed was studied by using a fire zone model. Results are applied to assess the performance of the installed fir protection system. Alternate designs for smoke control and the thermal sensitivity of the sprinkler heads were evaluated. Performance of the ventilation system in this car park was assessed by studying the thermal environment at the occupied zone using Computational Fluid Dynamics. The air speed predicted were used to calculate the mean age of the air and the percentage of dissatisfied. From the investigation, designs on the fire protection and ventilation systems are recommended for providing a healthy and safe environment in this car park.
smoke control, motor vehicle

#NO 10181 Interzonal airflow from garages to occupied zones as one reason for building related illness: three case studies using tracer gas measurements.
AUTHOR Tappler P, Damberger B
BIBINF Indoor Air '96, proceedings of the 7th International Conference on Indoor Air Quality and Climate, held July 21-26, 1996, Nagoya, Japan, Volume 4, pp 119-124.
ABSTRACT Tracer distribution measurements were performed to assess pollutant transport from basement garages situated in a commercial building and in two residential buildings, in which the occupants had reported typical garage odors and complained about bad indoor air and typical SBS symptoms. A tracer gas technique (tracer gas SF6. infrared detection) was used in all three buildings to study the contaminant distribution in the buildings. In the commercial building, a leaky HVAC system distributed contaminated air from the garage to other zones of the building. A second reason was a large

opening in the encasing wall of the exhaust shaft of the garage. In the residential buildings exhaust fans as well as tightly sealed windows and doors led to interzonal airflow from the garage. The results indicate that faulty construction and insufficient sealing between the garage and the occupied floors can most certainly be a reason for building-related illness. The tracer gas technique applied has proved a good tool for detecting leaks and faulty construction in buildings.
KEYWORDS garage, sick building syndrome, tracer gas

#NO 10376 Wind and ventilation symposium. Wind en ventilate.
Stuutgroep windtechnogie
AUTHOR Netherlands, TUE Eindhoven,
BIBINF Stuurgroep Windtechnologie, proceedings of a symposium held 14th November 1996, University Eindhoven.
ABSTRACT Collection of papers on energy efficient ventilation; performance of naturally ventilated buildings; natural ventilation in parking garages;ventilation of parking garages with wind tunnel simulations; standards in natural ventilation; the Cp generator: a wind pressure database.
KEYWORDS wind effects, ventilation system

#NO 10378 Natural ventilation of garages. Natuurlijke ventilatie vanparkeergarages.
AUTHOR Kornaat W
BIBINF Netherlands, TUE Eindhoven, Stuurgroep Windtechnologie, proceedings of a symposium held 14th November 1996, University Eindhoven.
ABSTRACT Little research has been carried out into the natural ventilation of parking garages. Wind driven systems can have many advantages over mechanical systems with fans.
KEYWORDS natural ventilation, garage, fan

#NO 10379 Ventilation of garages: wind tunnel simulations. Ventilatie van parkeergarages: windtunnel simulaties.
AUTHOR Alders A W
BIBINF Netherlands, TUE Eindhoven, Stuurgroep Windtechnologie, proceedings of a symposium held 14th November 1996, University Eindhoven.
ABSTRACT A new air conditioning system has been developed and tested in an office building. Zones and wind are positively changed for the creation of a comfortable indoor climate through the automatic operation of conditioning, lighting, radiators and room openings. The emphasis of this article is on cooling dmv natural ventilation. The possibilities and limitations of regulating rooms for cooling and ventilation are also discussed.
KEYWORDS wind tunnel, garage ventilation, air conditioning

#NO 10574 The significance of traffic related pollution levels and its dilution associated with altitude.
AUTHOR Ajiboye P, Hesketh M, Willan P
BIBINF UK, Air Infiltration and Ventilation Centre, proceedings of "Ventilation and Cooling", 18th Annual Conference, held Athens, Greece, 23-26 September 1997, Volume 1, pp257-266.
ABSTRACT This paper identifies the significance of pollution at five sites amongst the worst on the British mainland hence indicative of other polluted areas within Europe. Three sites are located in London and one each in Birmingham and Cardiff. The pollutants examined are NO2, SO2, O3 and PM10. Newly proposed DOE figures defining poor air quality have been used to re-examine the frequency of excess pollution episodes between 1992-1995. The results identify the most appropriate periods for natural ventilation of offices in urban areas in terms of the hour in a day and time of year. Preliminary in-situ experiments also demonstrate that both PM10 and NO2 concentrations decrease with increasing height from a busy road, and that this could be a useful strategy for reducing the impact of contaminants derived from vehicle emissions.
KEYWORDS outdoor air, pollutant, particulate

#NO 10808 Patterns of urban air pollutants: an overlooked factor when operating ventilation systems.
AUTHOR Kjaerboe P, Burt T
BIBINF Indoor Air: An Integrated Approach, edited by L Morawski, N D Bofinger, M Maroni, Elsevier Science Ltd, 1995, pp 347-350, 5 figs, refs.
ABSTRACT In most cities, vehicles are the main source of pollutants. The concentration of pollutants is then known to vary with traffic intensity. Ventilation flows should be adjusted accordingly which would give improved air quality, especially in dwellings.
KEYWORDS urban, air pollutant, diurnal concentration, ventilation air flow

#NO 10858 Application of scale modelling in the design of a ventilation system for an underground car park.
AUTHOR Wong Y W, Liu C Y, Chan W K
BIBINF Australian Institute of Refrigeration and Heating (AIRAH) Annual Conference, Melbourne, 22-24 April 1991, 13pp.

ABSTRACT Modelling techniques were used to verify the success of a "minimal duct" ventilation system proposed for an underground car park in a prestigious project in Singapore. The procedure to determine the various model scaling parameters, to select the appropriate fans to model the supply and exhaust fans, as well as the "dilution fans", and to simulate the movement of air through the vehicle access ramps are presented. Measurements from the model were found to be reasonable when compared with results from numerical simulation. However, certain modifications were needed to improve the system.
KEYWORDS ventilation system, motor vehicle

#NO 10870 Low energy strategies in urban areas.
AUTHOR Twinn C
BIBINF in: Ventilation and air pollution: buildings located in urban and city centres. Proceedings. edited by V Kukadia, UK, Building Research Establishment, June 1997, Seminar, CR 133/97.
ABSTRACT In urban areas where traffic fumes contaminate the outdoor air, there seems less incentive to install natural ventilation systems. However the new generation of naturally ventilated buildings prove that good indoor air quality can indeed be supplied. The priority must be to design the building fabric as the primary internal climate modifier, and introducing building engineering systems to assist the building fabric to recycle ambient energy. The New Parliamentary Building being constructed in Westminster, London addresses these points. Starting with the prerequisite of a sealed facade, the design fully uses the passive abilities of the building's materials and form to maintain the indoor climate. Subsequently building services systems were chosen to enhance these abilities and introduce energy saving measures.
KEYWORDS outdoor air, motor vehicle, pollutant, natural ventilation, energy conservation

#NO 10941 Experimental study on airflow in underground space of Metro system with a constant tracer gas injection technique.
AUTHOR Li X, Li X, Zhu Y
BIBINF Belgium, Proceedings of Clima 2000 Conference, held Brussels, August 30th to September 2nd 1997, paper 278, 6 figs, 1 tab, 5 refs.
ABSTRACT A concept of mixing ratio of piston air is developed to evaluate the portion of the injecting air fro m tunnel mixed with the air in platform space of metro system. And a 3-dimensional turbulent model is used to simulate the airflow in metro platform resulted by the ventilation system and moving trains. Field measurement has been conducted to verify the 3-dimensional model. This experiment is performed during the normal operation time of a metro station with constant tracer-gas injection method. The results agree well with the numerical solution. The reason of the differences between experiment and simulation is discussed. It is concluded that the model is accurate enough for HVAC system design of metro line.
KEYWORDS air flow, motor vehicle, tunnel

AIVC Air Infiltration and Ventilation Centre

The Air Infiltration and Ventilation Centre provides technical support in air infiltration and ventilation research and application. The aim 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.