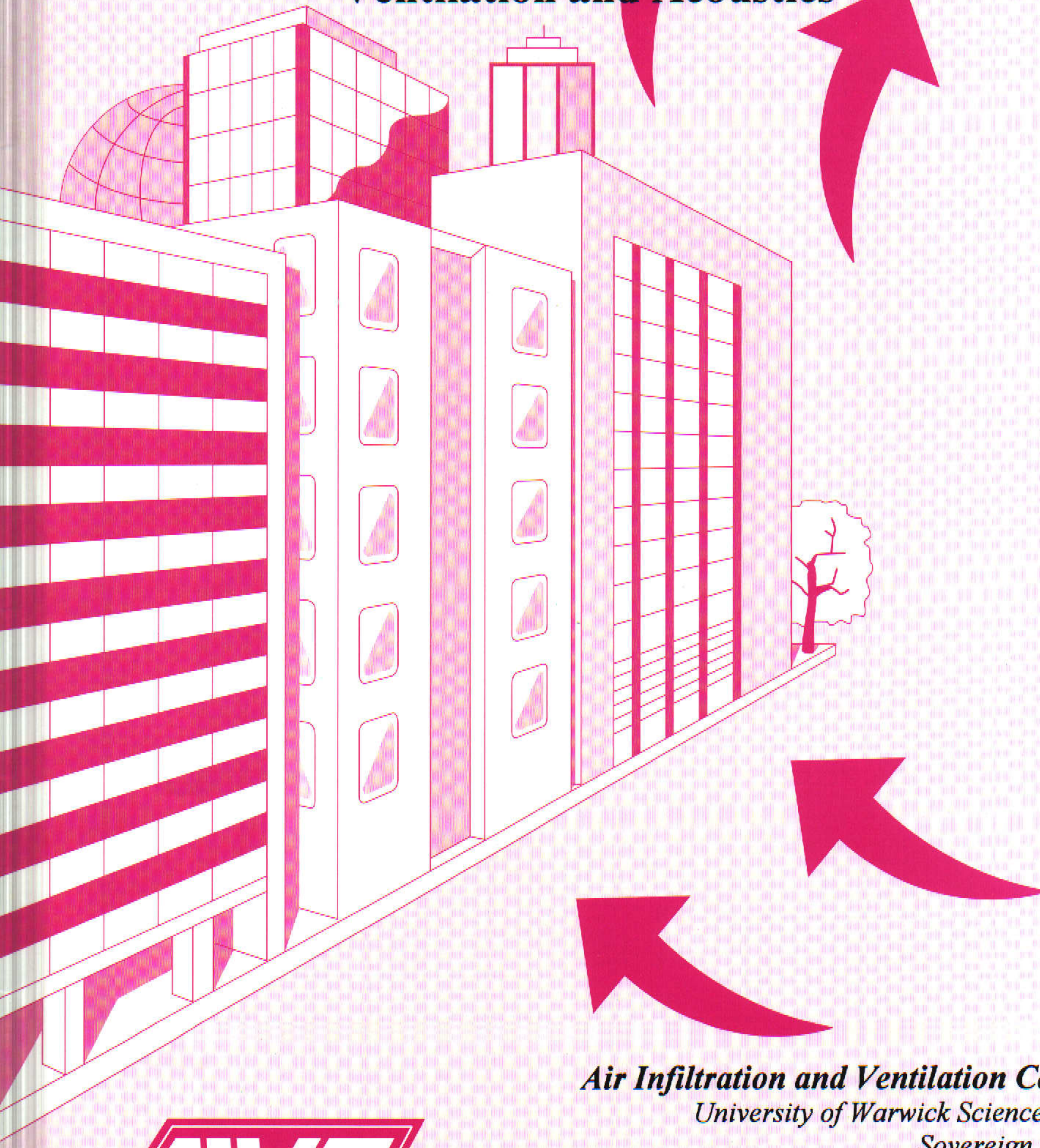
INTERNATIONAL ENERGY AGENCY
energy conservation in buildings and community systems programme

An Annotated Bibliography
Ventilation and Acoustics



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Ventilation and Acoustics
An Annotated Bibliography

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PREFACE

International Energy Agency

The International Energy Agency (IEA) was established in 1974 within the framework of the Organisation for Economic Co-operation and Development (OECD) to implement an International Energy Programme. A basic aim of the IEA is to foster co-operation among the twenty one IEA Participating Countries to increase energy security through energy conservation, development of alternative energy sources and energy research development and demonstration (RD&D). This is achieved in part through a Programme of collaborative RD&D consisting of forty-two Implementing Agreements, containing a total of over eighty separate energy RD&D projects. This publication forms one element of this Programme.

Energy Conservation in Buildings and Community Systems

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

The Executive Committee

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

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

Annex 1 Load Energy Determination of Buildings*
Annex 2 Ekistics and Advanced Community Energy Systems*
Annex 3 Energy Conservation in Residential Buildings*
Annex 4 Glasgow Commercial Building Monitoring*
Annex 5 Air Infiltration and Ventilation Centre
Annex 6 Energy Systems and Design of Communities*
Annex 7 Local Government Energy Planning*
Annex 8 Inhabitant Behaviour with Regard to Ventilation*
Annex 9 Minimum Ventilation Rates*
Annex 10 Building HVAC Systems Simulation*
Annex 11 Energy Auditing*
Annex 12 Windows and Fenestration*
Annex 13 Energy Management in Hospitals*
Annex 14 Condensation*
Annex 15 Energy Efficiency in Schools*
Annex 16 BEMS - 1: Energy Management Procedures*
Annex 17 BEMS - 2: Evaluation and Emulation Techniques
Annex 18 Demand Controlled Ventilating Systems*
Annex 19 Low Slope Roof Systems
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Annex 28 Low Energy Cooling Systems
Annex 29 Energy Efficiency in Educational Buildings
Annex 30 Bringing Simulation to Application
Annex 31 Energy Related Environmental Impacts of Buildings
Annex 32 Integral Building Envelope Performance Assessment.
Annex 33 Advanced Local Energy Planning
Annex 34 Computer-aided Evaluation of HVAC System Performance

Annex V Air Infiltration and Ventilation Centre

The Air Infiltration and Ventilation Centre was established by the Executive Committee following unanimous agreement that more needed to be understood about the impact of air change on energy use and indoor air quality. The aim 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, United Kingdom and the United States of America.

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Other Bibliographies in this series:

(1). Ventilation and Infiltration Characteristics of Liftshafts and Stairwells;
(2). Garage Ventilation,
(3). Natural Ventilation;
(4). Air Intake Positioning to Avoid Contamination of Ventilation Air;
(5). Heat Pumps for Ventilation Exhaust Air Heat Recovery;
(6). Ventilation in Schools.

VENTILATION AND ACOUSTICS - An Annotated Bibliography

SCOPE.

This bibliography is aimed at researchers, designers and engineers who are seeking an overview of current developments into acoustic control within buildings and their impact on current ventilation practices. References quoted in this document are taken from the AIVC's bibliographic database, AIRBASE and, subject to copyright restrictions are available to organisations in AIVC participating countries from the Centre's library service.

1. INTRODUCTION.

Noise, its determination and control has become an important issue. To be able to provide an acceptable indoor environment, not only in terms of indoor air quality, but also acoustically, is now an important element of the overall design process. There is wide and far reaching legislation to restrict and control the noise output from individual components, as well as from whole Heating Ventilation and Air Conditioning (HVAC) systems, noise transmission between rooms and to and from the building to outdoors. There is an altogether improved appreciation of the effects of noise and its generation. This review outlines current research and development with regard to acoustic control within buildings. It includes an examination of current design guidance and advances in acoustic measurement and calculation. Also, included are, research into noise generation and control in buildings, with the emphasis on both noise transfer by the building itself (structural elements, design or occupants), as well as HVAC generated noise (including noise transfer from the plant room, ducts, terminal devices etc.). The report concludes with an examination of the interaction of noise related problems with sick building syndrome and its impact on the quality of the indoor environment.

2. DESIGN GUIDANCE.

2.1 Domestic Ventilation Systems.

Part of International Energy Agency (IEA) Annex 27 "Evaluation and Demonstration of Domestic Ventilation Systems", Op't Veld (#9250, 1996; #9850. 1996) considers the problem of noise generated by, and within domestic buildings, in some detail. The two main aspects related to ventilation systems, identified by Op't Veld, are direct and indirect noise. Direct noise is generated by the system itself, where the system is both the source and means of transport of the noise. For example, fan noise, and noise generated by control valves and devices (aerodynamic noise). Indirect noise includes all of the noise outside of the system, such as, traffic noise and domestic noise (internal noise sources), where the system merely transfers the sound throughout the building. For natural ventilation systems, outdoor noise is important and sound transmission throughout the building is of minor importance. But, for extract systems it is the reverse, with outdoor noise and sound transmission being of little importance, since the outdoors can be sealed from the indoor environment. However for dwelling balanced ventilation systems, system noise and sound transmission are both important. The author notes that the allowable sound level in rooms, according to ISO recommendation 1996 (1971) "Assessments of noise with respect to community response", is 35 dB(A), and in some countries it is only 30 dB(A) (Sweden and Finland). In dwellings with facades containing windows unweather-stripped, and with regular glazing, a noise reduction of approximately 20dB(A) is achieved. With windows ajar (in the ventilation position) the noise reduction is approximately 15 dB(A).

If outdoor noise levels at the facade exceed 50 to 55 dB(A), natural ventilation systems will require some acoustic measures. Noise can be transferred across a facade by glass, ventilation openings, joints and cracks and by the closed facade areas (brickwork and panels). Such noise reduction measures include sealing all cracks and joints, soundproofing openings in supply windows, etc., or alternatively, introduce ventilation air through most noise free facade. The author has illustrated this point with a mathematical comparison between different facade types, in a test room with a volume of $40m^3$, and a total facade area of $10m^2$. Results show that the noise reduction can be as much as 40dB(A), provided there is proper soundproofing of the closed facade elements. Op't Veld notes that elaborate acoustic provisions to windows and ventilation openings can only be cost effective if other facade elements have good soundproofing properties. Outside noise can also be transferred throughout a building via the ventilation ductwork connecting the outside to the internal space. However, this will generally be lower than that generated by the system fans. The introduction of silencers, or soundproofed air ducts are possible answers.

Op't Veld continues by reporting that the main culprit for noise generation is more likely to be the ventilation system itself as ducts transmit fan and aerodynamic noise generated by bends, control valves and devices. The maximum indoor noise level criteria in most countries with respect to noise generated by ventilation system in rooms is 30 dB(A). With no special soundproofing measures internal noise levels of 30 to 45 dB(A) in rooms can be expected. Soundproofing materials in the supply system should ideally be placed immediately after the fan unit, but always before the first breaching of the duct. With a combined heating and ventilation system, soundproofing should be placed in the return duct just before the mixing box. In domestic systems this usually consists of flexible tubes, or double walled steel ducts insulated with mineral wool and with a perforated inner duct. Terminal devices must also be selected on the basis of the nominal sound power levels to meet the required noise levels. Manufacturer's data handbooks usually provide such data, which must be measured in accordance with the appropriate standard (for example ISO/DP5135). The author notes that some manufacturers prefer to give sound pressure levels instead of sound power levels. In general, the maximum allowable sound power level of terminal devices will be approximately 35dB(A) in bedrooms and in living rooms (with one terminal device approximately 35 dB(A), two devices 32dB(A), and 3 devices approximately 30dB(A).

In order to prevent aerodynamic noise in ducts, Op't Veld makes several recommendations, such as, the preferable use of round ducting; setting the maximum allowable air velocity in main ducts to 4 m/s and inside branch ducts, to the supply terminal devices, to 2 m/s; avoiding the use of sharp bends and making any changes of cross sectional area smooth; ensure that the air velocity inside silencers is such that the aerodynamic noise generated is 10 dB lower than the ventilation noise immediately after the silencer and make sure the airflow velocity after the silencer is correspondingly lower. In general the maximum allowable air velocity inside the silencer is 4 to 5 m/s. With regard to fan location, he notes that they should be placed in a vibration-insulated position on floors with a mass of less than 200 kg/m^2 in the case of single family dwellings and on floors with a mass of less than 400 kg/m^2 in multi family dwellings. Rubber blocks, at least 30mm thick, placed at the four corners of the unit provide additional vibration insulation. The total surface area of the blocks must be that the load is 4 to 5 kg/cm^2. An alternative form of insulation is elastic rigid mineral wool plates, with a thickness of at least 50mm.

Op't Veld also focuses on sound transmission in or between dwellings. A common problem is that of cross-talk which is defined as the effect that system components have on the integrity of sound reduction between two rooms. This phenomenon is a particular problem in balanced ventilation systems and in collective ducts between dwellings. However, both natural and mechanical duct work systems usually require sound proofing provisions, such as silencers fitted to each terminal device or a soundproofed exhaust terminal device. In dwellings, cross-talk occurs mainly in the supply duct of a balanced system when rooms are directly linked to one another. Another important point is that duct transitions must be properly constructed, since failure of these elements will lead to acoustic leaks as well as air leaks.

In Canada the Canadian, Mortgage and Housing Corporation (CMHC) has produced a publication "Noise Control" (#4298, 1988) which firstly explains how noise is measured and then goes on to give simple guidelines for effective noise control. The main body of the report is structured so that the noise problem, its cause and the effective solution are easily identified.

The report contains over 26 noise related problems, outlined below:

- *Too much noise from neighbouring apartments*
- *Kitchen, bathroom and entertainment noises clearly audible in neighbouring apartments.*
- *Not enough noise reduction, even though the wood stud wall contains sound absorbing material.*
- *Inadequate noise protection from the system with a drywall mounted on resilient metal furring.*
- *Sound leaking close to the floor-wall junction.*
- *Sound leaking through electrical outlets.*
- *Inadequate noise reduction provided by poured concrete wall.*
- *Poor noise reduction from lightweight floor system.*

- *In an existing building, a floor with acoustical ceiling not providing enough noise reduction.*
- *Floor not providing enough impact sound insulation.*
- *Floating floor not providing expected noise reduction.*
- *Good wall design but poor noise reduction.*
- *Excessive noise transmission through the floor, especially footsteps and impact sounds.*
- *Sound being transmitted through hollow core precast concrete slabs.*
- *Bathroom cabinets mounted back to back on a common wall.*
- *Footsteps on the stairs clearly audible in neighbouring apartments.*
- *Plumbing noises heard all over the apartment and in neighbouring apartments.*
- *Bath, shower and toilet noises heard in neighbouring apartments.*
- *Loud banging when dishwasher and clothes washing machine valves operate.*
- *Outdoor noise penetration into homes.*
- *Too much noise in outdoor space (balcony, patio).*
- *Neighbours annoyed or noise bylaw violation.*
- *Noise from furnace (forced air heating system)*
- *Ducts creak or bang when furnace cycles go on and off.*
- *Noisy appliances (dishwasher, washing machine, laundry dryer).*
- *Noisy ventilation equipment.*

For a specific problem, say where insufficient noise reduction is achieved despite the presence of a wood stud wall containing sound absorbing material, the report points out that the dry wall is directly attached to the wood studs on both sides. In this case, it is recommended that the drywall is removed on one side and resilient metal furring is attached to the studs. The dry wall is then reattached to the furring and acoustical sealing is then applied to the bottom of the drywall. Under each heading, the possible causes and various solutions are included.

2.2 Commercial Ventilation Systems.

In the United States Reynolds and Bledsoe (1991), and Schaffer (#10227, 1993) both outline the results of ASHRAE sponsored research (TC 2.6 "Sound and Vibration Control") into HVAC acoustics. Reynolds and Bledsoe review their work in providing and developing technical data and associated design procedures aimed at helping the HVAC designer, by providing a set of reliable and useful algorithms and related computer programs. The time required to make the many repetitive calculations necessary to examine the sound properties of a specific system represents a major area of difficulty and so a series of algorithms, under several headings, are presented by the authors to aid this process. These include

- Some basics, *(covers terminology, the addition of sound levels and the determination of Noise Criterion Curves (NC) and Room Criterion (RC) levels).*
- Equipment Sound Power, *(includes Fans and Chillers)*
- Duct Element Regenerated Sound Power *(includes dampers, elbows fitted with turning vans, junctions and turns, and diffuses)*

- Duct Element Sound Attenuation *(covers sound plenums, unlined and acoustically lined rectangular ducts, unlined and acoustically lined circular ducts, elbows, acoustically lined circular radioused elbows, duct silencers, duct branch power division, duct end reflection loss and terminal volume regulation units).*
- Duct Breakout and Breakin *(includes breakout and breakin of rectangular ducts, circular ducts, flat-oval ducts, and externally lagged rectangular ducts).*
- Sound Transmission in Indoor and Outdoor Spaces *(includes sound attenuation through ceiling systems, receiver room sound corrections, sound transmission through mechanical equipment room walls, floor and ceiling, and sound transmission in outdoor spaces).*

Schaffer (#10227, 1993) reviews "A Practical Guide to Noise and Vibration Control for HVAC Systems" which is the final book published by ASHRAE technical committee 2.6. The Committee found that, despite the growing amount of information that engineers and designers had at their finger tips, the number of noise and vibration complaints had increased. Most complaints usually had three underlying causes; acoustical aspects of HVAC design were never considered during initial design; system components, although selected correctly, possibly had not been integrated properly, and post design cost cutting had resulted in a system, although less expensive, generated more noise or vibration. The author states that the guidelines in the book were developed from reviews of hundreds of publications, as well as project files of mechanical engineers, contractors and acoustical professionals. Wide ranging guidelines give specific design and selection procedures to follow, and in other cases a comparison of alternative choices is given. This comprehensive book contains sketches, photographs and checklists for selection and application of basic HVAC system components, as well as noise and vibration control products. Schaffer concludes by stating that, if building professionals follow the guidelines laid out in this book, they can minimise the number and severity of HVAC system noise and vibration problems.

A wide range of standards governing acoustic control of a host of activities and HVAC elements within buildings exist within each country. For example, there are British Standards for sound insulation and noise reduction in buildings (British Standard 8233), fan coil units, unit heaters and coolers (BS 4856-4), industrial fans (BS 848-2), terminal reheat units (BS 4857-2) and acoustic absorption (BSEN 20354). A thorough international review of appropriate standards has not been undertaken here, but authors from different countries do refer to their applicable country standard where appropriate. Seppanen (#9547, 1995) and Roulet et al (#9577, 1995) both outline the European Pre-standard "Ventilation in Buildings - Design Criteria for indoor Environment".

Although essentially a ventilation design guide, including details about the selection of ventilation strategy, ventilation rates, etc., it also includes a small section on noise control. The guidelines note that, to be acceptable, the ventilation system should not generate or transfer disturbing noise. The standard gives maximum noise levels for noise generated by ventilation equipment and in offices these are 30, 35 and 40 dB(A) in category A B and C respectively. The standard is based on air quality as perceived by persons coming from fresh clean air and entering the room. Category A corresponds to 15% of occupants dissatisfied, while categories B and C correspond to 20% and 30% respectively. Where it is possible for the user to control the ventilation equipment, the noise level may be 5 dB(A) higher for higher volumes or velocities than for the nominal values. The ventilation system should neither transfer the noise from outdoor to indoors, nor between adjacent spaces. The paper outlines all of the other components of the pre-standard of which noise is only a part.

Other authoritative documents giving design guidance for acoustical problems, include: Reid(1991) *Understanding Buildings*, Lord and Templeton(1996) *Detailing Acoustics*, Bies and Hansen (1996) *Engineering Noise Control*, The Chartered Institute of Building Services Engineers (CIBSE) *Section B12 Sound Control* (1983) and The American Society of Heating Ventilation and Air Conditioning Engineers (ASHRAE) *Section A43 Sound and Vibration Control* (1995). All give design guidance and summarise the terminology, the main sources of noise emittence and sound attenuation devices, as well as a detailed review of fundamental measurement and calculation methods, including equations, correction factors and sound absorption properties of materials.

3. NOISE TRANSMISSION THROUGHOUT A BUILDING.

All structural building components can act as sound barriers or attenuators to both internal and external noise. Ideally noise should not be transmitted throughout a building, unless designed to do so. Therefore, the relative damping effectiveness depends not only upon the quality of the product and whether it was in fact designed to act as a sound barrier, but also on its fit with adjacent elements, as in much the same way as air leakage. Added insulation to inside walls or doors to improve their thermal capacity, and can also improve the acoustic insulating properties, in some cases. In much the same way as an extra pane of glass in double glazing helps restricts the entry and exit of sound to and from a building. The following references also discuss similar examples:

3.1 Sound Transmitted Directly Through The Building Structure.

Moorhouse (#10222, 1995), discusses the difficulty of characterising structure borne sound sources. Machines emit sound energy to the air and directly to the structure. Sound energy which is emitted to the air by the creation of pressure fluctuations can be simply described by a series of equations, and does not significantly vary from one building to the next. However, with structure borne sound the energy delivered to the receiving medium, for example the supporting floor, will vary from building to building and will depend not only on the source but also on the supporting structure. This makes the specification of independent structure borne sources and strengths for a machine very difficult. Moorhouse explains that by drawing a voltage analogy to describe the structure borne sound sources the source can be characterised independently by examining the properties of open circuit voltage (free velocity) and internal resistance (mechanical mobility). The reality is more complicated with the source being mounted at several points, and each point of contact with the supporting structure acting like separate voltage sources all interconnected by coupling impedance's. A further complication is that structure borne sound power is delivered, not just by normal forces at the interface, but also by bending movements which again act as separate voltage sources. In most cases however, the large amount of data required makes such characterisation impractical. Moorhouse briefly describes the Reception plate and Mobility methods which represent two approaches that are currently being studied. With the reception plate methods, the test machine is bolted to a standardised test plate and the average velocity of the plate is obtained by measurement with the machine running normally. This provides a single figure rating representative of the "activity" within the machine, and is increasingly being used to compare machines. The mobility methods represent a more scientific approach and use free velocity and mechanical mobility to characterise the source. In conclusion, Moorhouse notes that the characterisation of structure borne sound is a complex issue and research is still in its infancy.

Kang (#10219, 1995) focuses on sound attenuation in long enclosures, such as tunnels, corridors and underground stations. The author outlines a number of formulae established to explain sound attenuation in such enclosures in this paper. However, in his conclusions he notes that only the geometrical reflection model seems practical, although its range of applicability is limited to acoustically hard and smooth boundaries. The other formulae, especially those considering diffusion, are of theoretical importance but seem of a less practical nature. Using these equations, together with the assumption that the room has geometrical reflection and that diffusion and the angle dependent absorption coefficient are ignored, results indicate that, with a larger cross sectional size, the relative attenuation from a given section is less but the absolute attenuation with reference to sound power level is greater. With the same cross sectional area, when the width/height ratio is 1:4, the sound attenuation is close to, or slightly higher than, that of a square room. The author suggests that the combination of computer and scale modelling is sufficient to predict the sound attenuation in long enclosures.

3.2 The Influence of Structural Components.

The various methods of insulating masonry walls are discussed by Bradfield and Szoke (#6927, 1992). The acoustical properties of single masonry walls insulated internally, will be improved by the furring, insulation and finish. Typically the sound transmission class (STC) and sound absorption will increase. The authors cite an example, suggesting that the addition of ½ inch (12.7 mm) of gypsum board to one side of a concrete masonry wall increases the STC about 2 points. Also, mounting the gypsum board on resilient channels (furring or studs) will increase the STC by as much as 10 points. The durability and performance of the exterior of the wall will remain unchanged. Insulation can also be added to single wythe masonry walls, either as integral elements within cavities inside the concrete blocks, or externally in the form of rigid board attached to the exterior of the concrete wall, protected from the weather by an additional plywood or cementitious board. The acoustical performance of these walls depends largely upon the wall weight, and as neither of these methods represent any additional wall weight they do not, therefore, significantly alter the acoustical performance of walls to which they are attached. The acoustical performance of insulation placed with a multi wythe wall is much greater. The insulation provides an effective discontinuity of construction, which is then surrounded by heavy brick/concrete wall elements.

Tinsdeall (#10214, 1994) performs a number of experiments on the properties of windows that affect sound insulation. For example frame type, size of window and the spacing of multiple pane systems. The author notes that the common method used for improving sound insulation is to add a secondary pane of glass with a spacing of more than 50mm, or to add thermal glazing with a pane spacing which is usually less than 25mm. In an experiment, a single 4mm pane of glass with an opening pane, was replaced with two types of thermal glazing. Results found that where the two panes of glass are close together the mass-spring-mass -resonance reduces the sound insulation ability. With an increased air gap of 150mm the frequency of resonance was reduced to below 80Hz (for 4mm glass). Sound insulation can be further increased by the addition of sealants, such as those used to seal draughts. Poor sealant can usually be seen by an apparent flattening of the sound insulation curve above 600 Hz, often with a dip around 1600 Hz, caused by the gap behaving as a resonator. The type of frame also plays an important role in insulating against intrusive sound. The authors found that in experiments with standard wood frame with added sealant its performance was upgraded to that of PVC-U windows. However, the durability of the seals should be considered when selecting a frame construction. Finally, the authors concluded that sealing was probably the most important aspect for windows, more important than the material from which the frame is made. Multiple frames improve insulation as several small panes give slightly better insulation at lower frequencies than a single pane of similar area.

Bonvehi et al (#9706, 1994) and Traver et al (#6302, 1991) both briefly describe the Solar Acoustical Ventilated Window (SAV). This system is simply composed of a venetian blind, between two panes of glass through which air circulates. The window allows the amount of light entering the room to be varied, allows the air circulating between the glass to be warmed by solar radiation before it enters the room, and has an acoustic damping index of 46 dB(A).

Rousseau (#8262, 1993) outlines the soundproofing qualities of a variety of access doors installed in medium-cost, multiple-unit buildings in Canada. Tests were conducted on doors in two states, operable and closed, where doors are sealed into the frame. The most economical door to meet Canadian building code requirements is a solid core wood door of 4.5cm (1 ¾") thick, with particle board cores and high density masonite laminated surfaces. These doors come premounted with perimeter sound gaskets and bottom seals. Tests, however, showed that these doors were one of the least effective at blocking noise. The sound insulation was only improved slightly by using a thicker (5.7cm) (2 ¼") solid core wood door. The sound transmission class (STC) and the transmission loss results for the 4.5 cm (1 ¾") filled metal door were comparable to those of the wooden doors. When comparing the sound isolation characteristics of a hollow core (4.5cm) door with a similar metal door with mineral fibre added to the cavity, the filled door performed slightly better. The author also tested a sound and fire rated door of 4.5cm thickness. The door tested had an STC rating of 36, when operable it achieved an STC of 32, and when sealed its STC was 37, which was comparable to that of the filled metal door. This suggested that the double perimeter gaskets and bottom seal installed on the sound rated door significantly improved its performance. The use of gaskets around doors can, on the whole, improve the sound transmission of the door and with double perimeter and bottom seals, almost all of the doors tested could achieve STC ratings of 30 or more.

3.3 Buffer Rooms and Atria.

Mahdavi (#10218, 1993) studied the effect of "buffer rooms" with regard to their hygrothermal and acoustical performance. From an acoustical point of view, buffer rooms can be examined in terms of their acoustical environment. For example, sound distribution, reverberant field and ambient noise levels within the space, and their sound insulating effect on adjacent indoor rooms. This paper focuses on the latter case, with discussion of the results of an empirical study of the sound transmission through a sunroom. The author stresses that the acoustical buffer effects of sunrooms should not be seen as a general solution to the problem of traffic noise annoyance, with noise control strategies being source orientated. Measurements were taken in four sunrooms, consisting of double glazed timber framed window units. Using an externally located speaker source windows were opened and closed to various degrees, and the standardised sound level difference was calculated. Measurements show that the buffer room can provide a variety of ventilation configurations while achieving an effective sound insulation that is higher than the sound insulation of its individual components, even in the closed position. The study further examines the thermal behaviour within the buffer rooms and concludes that, under summer conditions, the risk of overheating is high if no shading is provided and the air change is low. However, thermally acceptable occupational conditions can be maintained in sunrooms providing shading and cross ventilation are available.

Kainlauri and Vilmain (#6528, 1993) undertook a similar study in which they examined various design considerations associated with atria within buildings. Acoustic control is part of these design elements, which according to the authors is often ignored as a design criterion. Reverberation is a big problem, although the shape of the space and the use of appropriate building materials can reduce this. However, the source of noise at various sound frequencies is a little harder to control, since the location of sound generation and its frequency are constantly changing, so much so that sounds of spoken words may be muffled by background noise, or be absorbed too much into the building materials. For those atria that are multi use, sound generated on a higher level may interfere with a different activity occurring on a lower level some distance away. The answer is to isolate the sources of particular sound frequencies and noise levels to certain preplanned areas. The authors stress that the properties of sound generation are important considerations, for example, that sound travels in a spherical fashion from its point of generation. Also, the separation of adjacent spaces by appropriate sound transmission coefficient materials is also important. To prevent resonance, double windows with two differing glass thickness are advisable.

3.4 Theory into Practice: Opera House and Auditoria Case Studies.

Several case studies are outlined below where the acoustic quality of the design and building is of fundamental importance. Brezski et al 1994 (#To be assigned June 1997) and Brister 1994 (#To be assigned June 1997) both discusses the new Glyndebourne Opera House. The acoustic aspects of the design are briefly discussed by the authors who also consider many other design aspects. The main auditoria was initially designed for $8m^3$ per seat, to achieve the preferred Reverberation Time (RT); for clarity a maximum 17-18 m between balconies was set to ensure strong early side reflections, whilst for acoustic and visual intimacy, the furthest seat was to be a maximum of 30m from the stage riser. The authors noted that the quality of any acoustic is immeasurably enhanced by a quiet background, and in this instance was achieved by a double skin wall and roof construction of sufficient mass with the appropriate cavity was specified, together with an air conditioning strategy that would ensure a background noise level of PNC15 - approximately the threshold of hearing. Carpets and curtains were not to be included whilst a minimum of absorbent secondary fixings were also used. However, the volume per seat did decrease a little to just below $7m^3$ per seat, indicting a mid frequency reverberation time of 1.4 seconds. This was considered to be slightly too much for an opera house, and therefore several modifications were modelled and subsequently made. Measurements in the model predicted a mid frequency RT of 1.4 seconds, with 1.7 seconds at 125 Hz. A test concert with full audience was held on 28th March 1994, where measurements gave an average mid frequency reverberation time of 1.25 seconds at 125 Hz. The clarity index was high throughout the auditorium and the impulse traces were of "text book" shape.

Another case study is described by Bullock and Philip (#9689,1996) who discuss the ventilation system operation behind the scenes of the Sistine Chapel. The authors note that such systems have to control much more that just air temperature and humidity, the contents of such buildings require strict environmental conditions. The paper focuses of the six main factors essential for environmental comfort, these include air temperature, air humidity, light, air circulation, airborne pollutants and sound level. Regarding sound levels, these should be low, lower than in most office or residential buildings, to ensure quiet comfort for visitors and staff. This is often a challenge because many exhibit spaces have little sound absorbing surfaces and are acoustically reverberant. An experienced system designer can achieve the required sound level, with the use of widely available materials and devices. The system designed for the Sistine chapel was designed for a noise level of RC25. A challenge according to the authors since the Sistine Chapel contains no carpets, furnishing etc, in fact no sound absorbing materials. All surfaces are hard. The RC 25 level was achieved through the use of a large sound attenuation unit at the air handling unit outlet, a minimum number of turns and area changes in the supply ducts, low air velocities in the supply ducts and outlet diffusers (below 5 m/s) and acoustic insulation in the outlet diffusers.

The authors noted the helpfulness of the ASHRAE acoustic computer programs. The system was started on July 1992, and has been in operation automatically since then, with no major equipment problems.

4. HVAC SYSTEM NOISE.

4.1 Ventilation System Noise.

The potential noise and vibration problems from HVAC systems are discussed by Schaffer (#10227, 1993) who reviews "A Practical Guide to Noise and Vibration Control for HVAC Systems"

After a thorough investigation of these problems, he outlines the frequency ranges of the most likely sources of common acoustical complaints, as follows:

- 8 to 32 Hz - **Throb** *(Turbulent airflow & fan instability)*
- 15 to 125 Hz **Rumble** *(Turbulent airflow and poor vibration isolation)*
- 63 to 250 Hz **Roar** *(Fans & Turbulent airflow VAV fans)*
- 125 to 500 Hz **Hum & Buzz** *(Poor vibration isolation Fan powered VAV units)*
- 250 to 1,000Hz **Whine** *(Pumps and Chillers)*
- 1,000 to 8,000 Hz **Hiss and Whistle***(Grilles & water valves)*

Schaffer also catalogues a series of common HVAC design errors. For example, in the case of fans and air handling units, such errors include, improper selection at an inefficient operating point; improper duct fitting; or, a sound trap located too close to a fan outlet or inlet. Common errors for ductwork include undersizing; excessive airflow velocity, high pressure drop (high turbulence) fittings and the use of rectangular ductwork to control low frequency noise. While common errors in the design of VAV and fan powered VAV units include undersizing leading to excessive inlet velocity; oversizing can lead to excessive airflow delivery and units located over noise sensitive areas.

Broner (#10213, 1994) discusses the assessment of low frequency background sound (<250Hz) produced by operating HVAC systems, especially VAV air distribution systems and floor by floor, or rooftop packaged air handling equipment, which produce low frequency rumble. This paper describes initial research sponsored by ASHRAE in the United States which attempts to define an appropriate assessment method for low frequency noise annoyance. From a review of existing methods of noise assessment, the author notes that the Noise Criteria (NC), Preferred Noise Criteria (PNC), Noise Rating (NR) and (Low Frequency Noise Rating) LFNR curves are basically single stage determinations because the spectra are plotted on the criteria curves and the exceedance is judged. The (Room Criterion) RC and (Balanced Noise Criterion) NCB ratings require a two stage process to determine the existence of rumble from an octave band analysis and therefore are more complex in use, especially NCB. Only the LFNR requires one third octave band analysis. From the review of available assessment methods mentioned at the beginning of this research, in terms of improving the current sound quality assessment methods, it is appropriate to consider incorporating the philosophy behind the LFNR curves (a one third octave band analytical approach), a low frequency noise penalty below 80 Hz, and a rumble penalty. Also, the speech intelligibility approach of the RC could be utilised to give a family of easy to use sound quality curves.

The project collected more than 75 HVAC noise samples, mainly from offices and meeting rooms of differing sizes, as well as from corridors and lobbies, using a sound level meter and professional DAT recorder. From the results obtained, it was decided to incorporate the philosophy behind the LFNR curves to improve the current sound quality assessment methods. Therefore, such new methods should include, a one third octave band analytical approach, the spectra for the "neutral" "neutral/marginal" and "rumble" sites showing a flattening below 31.5 Hz and the effect of the temporal character of the noise should be considered possible in the form of a "rumble penalty". The author concludes by proposing a set of modified RC curves, known as low-frequency room criterion (LFRC) curves, which take into account the factors mentioned above as well as a modified low frequency sensitivity.

4.2 Sound Attenuation in Ventilation Ductwork.

Most authors however, restrict their investigations to a specialised area, like Laine and Fry who both discuss sound attenuation in ductwork. Laine (#3597, 1989) looks at the design of demand controlled air ductwork. He considers that in future systems airflow's and thermal power will hinge to peoples needs. Therefore, calculations and working experiments are required from air flow and acoustical simulations of air duct systems, as well as equipment performances defined. He notes that there are several problems with dimensioning air ducts, as they are traditionally based on pressure loss calculations, which often result in excessive velocities and pressure loss in air ducts. These are difficult to adjust and balance, and thus can cause acoustical problems. Laine suggests that the more airtight the ductwork, the more able the designer is to control both the pressure loss and acoustic noise transmission. If the pressures within the system are controlled, this will in turn enable the airflow's and noise levels to be better regulated. By considering the transmission of sound from the duct into the room through terminal devices, especially the duct wall, the highest permissible duct velocities can be found, and thereby the greatest permissible sound power levels of the duct on the basis of acceptable room noise. Working from the room, one can then decide the maximum allowable noise to be generated by the system, and select appropriate components based on this premise. Silencers should be installed to further control duct noise transmission.

The author concludes by stating some operational pressure losses that could be expected, he notes that without silencers the present good duct air flow controllers and terminal devices can operate with pressure losses of at most 100-150 Pa, with corresponding pressure losses of the ducts at the most 50-75 Pa. The pressure losses of the flow controllers, attenuated with secondary silencers on the side of the terminal device, could be expected to be between 150-250 Pa, with corresponding duct pressure losses between 75-125 Pa. When use is made solely of effective primary attenuation of the fan, the total pressure loss of the air ductwork should be a maximum of around 200Pa. Using flow controllers attenuated with secondary silencers of the side of the terminal devices, the total pressure loss of the air ductwork should be at most some 300Pa.

Fry (#10222, 1995) also discusses the noise generated by air flow within ductwork, which is broad based or characterless in nature and provided it is not too loud, can be considered reasonably acceptable as background sound. To control air flow quietly, however, requires the use of guided divisions, such as turning vanes, rather than objects of obstruction which tend to deflect the airflow into a revised distribution. A common compromise is often partial but controlled deflection. The occurrence of obstacles across ductwork much as wire, results in a disturbed airflow pattern. Small whirls or vortices are formed, which themselves emit a broad band sound causing radiated noise. The rhythmic pattern of these vortices can cause a resonance in the obstacle which then radiates a purer tone. The author quotes "sing wires" in windy weather as an everyday example. Within ducting the 13mm support stays in a 600mm duct with air flow at 25m s^{-1}, tones can peak at 500Hz octave band. Dampers obstruct the airflow path, and therefore result in noise. Attempts have been made to predict the frequency dependent noise levels as a function of the damper size, flow rate and pressure loss. As the damper blades are throttled, a disturbed and less rhythmic pattern of turbulence is developed. The turbulence creates a peak in the broad band flow noise spectrum. The author notes that in general: the larger the object or opening, the lower is the frequency of this peak. The faster the flow rate, the higher is the frequency of this peak. Therefore according to the author, a large single blade butterfly damper will generate more low frequencies than a multi blade unit. Within the ductwork itself an NC sound power level of 40dB per square metre of duct cross section may be taken for a flow of 10 m-s. For doubling of air flow rate 18dB is added, and 1.5 dB for each doubling of cross sectional area. The paper gives similar guidance for transitions, bends, terminal devices and silencers. In conclusion, the author notes that flow generated noise is best minimised by smooth control of the air flow and minimal step changes in velocity. Where the realities of system design do not allow for this, guidance data for the generalised flow noise is available.

Strindelhag (#4371, 1990) discusses how ventilation system components can be improved to give complete system performance. With regard to reducing the acoustic infrasound levels within the building, the author states that circular ventilation ducts provide much better isolation than rectangular ducts. However, the isolation provided by rectangular ducts can be improved substantially by suitable staying. In most cases, infrasound levels in a ventilated room can be restricted to levels far below the relevant limit values.

4.3 Sound Attenuation of Vents and Grilles.

Jorro (#5521, 1991; #7854, 1990) discusses the acoustic performance of two types of passive ventilator; the trickle type, mounted in window frames, and the passive stack ventilator, a vertical pipe venting a room from the ceiling to the roof top by the stack effect. Such openings are likely to allow the ingress of outdoor noise into a building, therefore this paper outlines experiments that investigate this problem more fully. Stack ventilators were studied directly in a test house, in which different sizes and configurations of stack were installed between kitchen and roof top. The site was near a local airfield where light aircraft frequently flew overhead. The different stacks were made out of various materials, such as, smooth rigid plastic, flexible plastic, wire composite (having spiral ribbing of wire covered by plastic wire), and each type of tubing came in nominal six and four inch diameter. Two stack configurations were tested, with the vertical pipe passing either directly through the roof, or being diverted in the attic to the central line ridge and then to the outside through a ridge tile. Trickle vents were mounted in a wall between two semi-reverberant rooms. A block of wood, sealed into a slot which was cut through the blockwork in the recess, was used to mount each ventilator. Following the experiments, the smooth and rigid plastic tubing which went straight up to the roof without bends provided the least attenuation. The most effective was the ribbed and flexible plastic tubing which went up to the ridge of the roof by bending across the attic space. The larger diameter stack also let in less sound than its smaller counterpart. With regard to trickle vents, due to the transmission through the wall the attenuation of most ventilators can only be assessed from around 250 Hz. Results show that the larger the physical dimensions of the vents the more sound is transmitted. When closed the vents attenuated by at least 5dB more than when open. The ventilators that control the opening by a screw that moves the cover in and out can be closed tightly by clamping against the window frame. However, when it is open sound has an easier passage through the ventilator compared to the other design that has a boxed in tilting flap shutter operated by a slider.

Therefore in conclusion measurements of the acoustic insulation of passive ventilators showed that they could increase indoor noise levels at the higher frequencies, due mainly to the decrease in impedance of openings with frequency. However they provide a quieter indoor environment and a better way of controlling background ventilation than by window opening. It was found that trickle vents showed resonance effects due to standing waves through the depth of the opening, and generally they provided lower sound attention than stack ventilators, although stack ventilators are less vulnerable to the incidence of traffic noise.

Holmes (#6499, 1992) discusses the different types of air terminal devices, among which he includes special devices such as balcony slots used in the Birmingham Convention Centre, UK. Because these are being used to distribute air directly into the concert hall, they were designed to meet very low noise level requirements, (specified by the acoustical consultant). However, the air distribution required was at supply velocities of 3 m/s which no conventional devices could meet. Holmes notes that, although the jets themselves are silent, it is the components of the vents, the vanes and other devices within the terminal that make the noise. The jet theory of the balcony slot diffuser, follows a number of simple rules. For example, a jet is a constant momentum device, and at some short distance from it, all velocity profiles are similar. This distance is about 5 - 10 effective slot widths or grille diameters (the slot width of a conventional slot diffuser is about 7-10mm), although for most practical purposes this distance can be taken as zero. The author outlines two equations drawn from the above assumptions, that apply to isothermal jets. One is for two dimensional jets (slots, linear grilles) and the other for three dimensional jets (grilles, circular ceiling diffusers). Furthermore, the author notes that these equations can be used to exploit and confirm manufacturers test data. Concluding that if it is a linear device then it requires the throw to be increased by a factor of four to reduce the terminal velocity by 50%, while a factor of only two is required if a three dimensional or radial device is used. If the manufactures test data does not approximate to these rules, then look to find the basis of the information presented.

Jarman (#10225, 1992) suggests that, instead of designing to achieve the noise criterion at 100% volume which may only be necessary for a few hours each year, by designing to achieve the noise criterion of 80% volume, it can result in better supply conditions when operating on low volumes, yet only occasionally compromising the noise criteria by 3-4 dB. Unlike other components acoustic lagging cannot be fitted to noisy grilles and diffusers, so the use of the correct type of grill is an important consideration at the design stage. Jarman notes that, although there are a number of equations for the prediction of diffuser noise, most have some margin of error. Manufacturer's data should, therefore, be used in preference, if available, and if any doubts surround this data, then a quick comparison between the data supplied and empirical equations should be undertaken. The author also notes that supplied data, usually includes predicted NC/NR values in a room, which are based upon a room absorption of 8 dB. This means that room noise level is taken as 8 dB less than the sound power level radiated to the room from a single grille, but these are often usually optimistic. It should be remembered that different projects have different grille and diffuser layouts and different architectural finishes, and these, therefore, affect the noise. Additionally, these diffusers may not be the only noise source in the room, as VAV units, fan coil units or the main plant itself may be contributors too. Interpretation errors can also creep in, for example, sound power levels quoted are for a unit length of diffuser, if diffusers are twice the length then the noise levels radiated will be about 3dB higher. In conclusion, the author states that flexible ductwork connections to diffusers should be avoided, and the suppliers recommended sizes for ductwork and plenum connections should always be used.

4.4 Sound Attenuation of Ventilation Fans.

Clampton (#10228 1992) discusses fan and noise in ventilation ducts in submarines. The combined contribution of fan noise in submarines can represent a significant problem. This noise can be transmitted via air supply and exhaust ventilation ducts from noisy fan plenums to quiet compartments elsewhere in the boat. These plenums can often be situated adjacent to quite compartments due to the source restrictions of such vessels, and therefore airborne noise transmitted via common structural boundaries becomes significant. Computer models can help predict the occurrence and possible transmission of such noise at the design stage. These models also allow new ideas and innovative solutions to be tried out and incorporated at the design stage. All acoustical models must have noise sources, receiver points and acoustic transmission paths linking sources to each receiver point. The author describes in more detail the requirements of each of these components and their applicability to the submarine application. He three case studies to exemplify these points. In each case, computer models were used to reduce airborne noise levels due to fans and their associated ventilation ducts in submarines.

Michel and Guarracio (#8878, 1995) outline a study that not only examines fan performances in terms of ventilation criteria, but by integrating quality of life and comfort standards, also takes into account energy consumption and acoustic parameters. The objective is to optimise operating costs while reducing any nuisance factors, without interfering with the technical operation of the fan. Information was collected from French manufacturers for over 430 different appliances. A detailed statistical analysis was conducted and a synthesis of the comparisons presented in the paper. Acoustical preferences were of special interest and the author notes that, as a result of the variance analysis, "single" fans are clearly more efficient, acoustically, than Multi ones, whereas helicoid and centriual appliances are close to each other in the ratio of sound pressure levels. The author concludes by noting that the different indicators used in this paper appear as a first step in the definition of the global performance of a fan, taking into account basic elements of the global comfort of inhabitants in buildings, energy consumption, ventilation efficiency and noise pollution. The choice of an indicator depends upon design needs and standards etc.

CMHC (#6703, 1992), examined four homes located in Saskatoon equipped with central forced warm air heating systems and central ventilation systems. The study measured sound levels along with ventilation rates, room air flows, duct leakage, fan energy consumption rates and house depressurisation levels caused by the ventilation systems operation. Although all of the results are important, only the ones relating to acoustics will be discussed here. Two of the four houses could meet the ASHRAE Recommended Noise Criterion of NC-30 or less. The study found that noise problems from fans were sometimes considered a problem, particularly rigid mounting techniques along with inflexible connections to rigid ductwork are likely to cause noise problems, especially at low frequencies. A similar study was reported by Canadian Energy Mines and Resources (#3385,1989) who undertook sound level measurements in five unoccupied unfurnished Winnipeg houses, as part of the Flair Homes Energy Demonstration Project. Four of the houses were built to R-2000 standards, while the fifth house was built to conventional standards. Sound pressure levels created by the heating and ventilation systems were measured and compared to recommended indoor design goals for ventilation system sound control. The authors also made measurements of the attenuation of outdoor noise, generated with a gas powered lawnmower, by the different building envelope types in the houses. Results indicated that sound power levels generated by mechanical systems varied from house to house, but on average they exceeded the acoustical design goal for the worst case room, located directly above the mechanical system. This suggested that occupants would turn the system off to control noise, thereby loosing any benefits offered by the ventilation system. Acoustic weak spots were found to be windows and ductwork that passed through external walls. Windows represented a major pathway for noise transmission across a building envelope, suggesting that it was independent of wall type if it contained windows. The study concluded by stating that selected windows should be as airtight as possible, thereby minimising pathways that could be exploited by sound waves and also should be located away from major sources of outdoor noise. Exterior penetrations for duct work, represented another acoustic weak spot, the study advised builders to minimise such entry and exit points that were opposite noise sources.

5. ACOUSTICS AND INDOOR AIR QUALITY.

Several early studies (for example Loftness and Hartkoff #3724, 1989, and Davidge #4018, 1986). identify noise as a contributing factor in sick building syndrome and poor indoor air quality. However, its overall importance has increased in recent years, with the studies outlined below placing greater emphasis on noise as a major contributor to SBS and poor indoor environments.

5.1 Duct Silencers and Their Impact on the Indoor Air Quality.

Lizardos E (#10224, 1993) emphasises the importance of HVAC designers addressing both the energy efficiency aspects of design as well as ensuring good indoor air quality. Among other aspects of design, Lizardos also discusses the use of duct silencers. He notes that the use of internal acoustic duct lining to reduce equipment noise can significantly contribute to indoor air quality problems. Silencers of this type are typically placed in ductwork close to the air conditioning units, VAV units, return fans and in transfer ducts to help prevent transmission noise. However, unless regularly inspected, this lining can eventually degrade and break down, which can ultimately lead to the introduction of small particles into the air stream, from the degrading lining. Should this lining then become damp, from cool damp air passing over it, for example, it can then be a source of microbial growth, which can possibly release such microbes into the ventilation air. The author recommends sound traps or duct silencers as an alternative to duct linings. There are basically two types, packed and packless. In packed silencers, perforated metal baffles are filled with acoustic material which absorbs the sound as well as attenuation. Packless silencers do not contain fill material, the non perforated baffles work on the tuning principle only to attenuate sound. These, according to the author, maintain the highest indoor air quality, since they do not contain any fibre fill material, and therefore any possible contamination.

A similar study is outlined by Tolvanen et al (#10221, 1993) who examined the health risk posed by particles emitted from sound absorbent materials used in ventilation ducting. Such Man Made Mineral Fibres (MMMF) can enter the ventilation air resulting in a significant risk to the health and comfort of building users. Experiments were conducted in a test chamber with an air stream of up to 10 m/s. The concentration (number per cubic centimetre) of small particles in the testing chamber during the study was measured with a condensation nucleus counter. Particles emitted from the material were collected on polycarbonate filters and analysed with scanning electron microscopy (SEM) and on filters of mixed cellulose esters for optical microscopy. Three different kinds of glass wool material and five rock material were tested. The authors found that glass wool covered with a surface material emitted more fibres and small particles than material without the covering. The rock wool material covered with the same surface emitted fewer fibres and small particles than the material without the covering. Covering the surface with a steel screen, the authors found that they usually emitted more fibres. However, in the case of glass wool, fewer small particles were emitted. The materials that were wetted and then dried, did not emit an exceptional number of fibres, but the sizes of those emitted were different. In conclusion, the authors found that the fibre levels of sound absorbent materials tested were very low in comparison with hygiene limits.

5.2 Health Risks to Workers from Noisy Ventilation Equipment.

Burt (#10217, 1996) discusses a study which aimed to investigate the acoustic environment a building exhibiting SBS symptoms to ascertain whether noise may play a role in the buildings' problems. It is noted that the normal range of human hearing is usually given as 20-20,000Hz. Low frequency sounds, below 20 Hz, are known as infra sound, which although inaudible has a variety of effects on the human body. For example, it may cause disorientation, seasickness, digestive disorders troubled sight and general dizziness. Vibration at 7Hz can reduce concentration and can cause tiredness, headache and nausea, although the most dangerous frequency according to the author is 8 Hz, which has a natural resonance frequency of the human circulation system, and can cause cardiac arrest or vascular overload, resulting in a heart attack or stroke. Different parts of the body are sensitive to different resonant frequencies for example, head 20-30Hz, eyeball 20 -90 Hz etc. This study outlines a series of acoustic measurements to examine the impact of the low frequency range of sound on the human body. An SBS questionnaire was prepared and symptoms compared, to find the most common problems. Acoustic measurements were carried out in both occupied and unoccupied rooms. The recordings were analysed with the aid of two acoustic filters, an Audio Frequency Spectrometer (giving sound intensities in the audible range 20-20,000 Hz; the A-,B- and C-weighted values and the unweighted linear values) and a Turnable Band Pass Filter which gives intensities in the range 0.2-2,000 Hz. The signals were then passed to a Level Recorder to produce the spectrograms. Low frequency noise around 7Hz was found to occur in several rooms, where many of the occupants had shown high SBS scores on their questionnaire. This would appear to support the theory that these frequencies do contribute to SBS symptoms. However, some people may have a hyper reactive response to some frequencies while other people will not, similar to that of chemical allergens. This is why some people are immediately affected, while others may be in the environment some time before they develop any symptoms. The author asks the question, "If ventilation systems produce infrasound, why has the problem only been apparent over recent years?" A possible answer may lie with the increased tightness in buildings. If a building is tightly sealed, then it becomes a prerequisite for it to have a mechanical ventilation system. The enclosure, then amplifies the low frequency sound, increasing the problem. Most acoustic measurements use the A- weighted decibel value, which gives no indication of infrasound. Solutions to this problem include, changing the fans for the supply air, because, for example, replacing centrifugal fans with mixed flow fans has eliminated the phenomenon of rotating stall and reduced low frequency noise.

Andersson (#9613, 1988) describes a similar study in a user healthy school which was, built with carefully chosen materials and equipped with a very flexible heating and ventilation system to facilitate various combinations of operating mode and settings. The design included a method of reducing the reverberation time of the building and thus reducing the sound level of children playing. To achieve this, rooms were built with non standard type materials, such as, wood panelling on the walls and gypsum panels in the ceilings which lead to reverberation times ranging from 0.3 to 0.5 seconds (in frequency range 500-2000Hz) compared to the standard 6 seconds. The school has been carefully assessed over a three year period and the results of the first year suggest that the achieved objectives are well in line with set goals.

Jokl (#8841, 1995) attempts to justify the use of a new decibel scale as a measure of the indoor air quality. The author notes that TVOC concentrations can affect the indoor air quality over a large range, and that the perception of odours during a time period is a logarithmic function similar to noise perception. The decibel unit is also a logarithm of a ratio between quantity and an agreed reference level. The hearing threshold of 20μPa is used to predict the sound power level. The decibel scale gives a better approximation to the human perception of relative loudness than the Pascal scale, because the ear reacts to a logarithmic change in level, which corresponds to the decibel scale, where 1 dB is the same relative change everywhere on the scale. The author then attempts to equate the acoustical decibel scale as an application to odour constituent. He argues that the weakest odour a healthy human olfactory organ can detect according to Yaglou's Psycho Physical Scale is one, which corresponds to a PPD of about 5.8 and 5 on Fanger's thermal comfort scale. A corresponding value of TVOC is therefore missing. Using the equations outlined in the paper the author estimates the corresponding value for 0.35 decipol (equal to 5.8 PPD), Its detection threshold is 50 μg/m3. The toxic range of TVOC being at 25 000 μg/m^3, and therefore this value could be considered to equate to the threshold of pain by sound (100 000 000 μg/m^3 which equal 134 dB). Thus for TVOC toxic range threshold (ρ=25 000μg/m^3) the odour concentration level equals 135 dB. In conclusion, the author notes that the greatest advantage of the new decibel units should be the possibility of a new microenvironment evaluation. In #8842 (1995), Jokl extends the previous paper and gives examples of how this new measurement system can work. Focusing on the ventilation rate, the author examines the pollution load by occupants, building contractors and from outside. He discusses the ventilation effectiveness and surface deposition aspects before briefly outlining the procedure to determine the required ventilation rate.

Tang et al (#9934, 1996) highlights a recent noise survey in an air conditioned office building in Hong Kong. The authors used a questionnaire to assess the level of noise disturbance present, and compared the results using common noise criterion, namely (Noise Criterion Curves) NC, NR (Noise Rating Curves) and L_{eq} (Equivalent sound pressure Level) The survey was conducted as part of a wider IAQ survey of the building. The study collected 1080 questionnaires from over 30 offices, the results of which found that over 35% of the workers regarded the air conditioning a major source of noise in their office, with noise from human being and telephones being less significant. Throughout the 30 offices the air conditioning system varied, with fan coil units, constant air column and variable air volume systems being common. Results showed that although the workers regarded the air conditioning as a major source of noise, the complaint is only directly related to the type of noise when there is a relatively large low frequency imbalance in its spectrum. Whether the noise is regarded as "rumbly" or "hissy" does not have a direct relationship with NR, NC or L_{eq}. The survey also found that workers are satisfied with their aural environment at a L_{eq} of 53.5 dB(A), corresponding to NC48. However both exceed the recommended international standards.

Wilson et al (#8375, 1994) has undertaken a simultaneous acoustic and thermal comfort study in different climatic regions (Pakistan and United Kingdom) to test the theory that noise is more detrimental to tasks involving "unexpected demands, demanding original solutions". Tolerance to noise may therefore involve an adaptive mechanism and be actively related. The study examined eight office locations in the UK and eight in Pakistan, all naturally ventilated, except for one in Pakistan. Some of the Pakistan offices had window air conditioning units or ducted systems in addition, but because of frequent power failures they rarely worked. Among a number of thermal comfort parameters, sound level was logged every three minutes, from a position that was not too close to sources of noise. Conclusions from the study show that acceptable internal office noise levels in Pakistan are generally higher than in the UK (68.6dB compared to 61.1dB). Suggesting that acceptable office noise levels could be influenced by average experienced noise levels, in the same way that adaptive theory of thermal comfort relates comfort temperatures to external and environmental temperatures. The experienced noise levels will be determined in areas of high temperature and environmental noise by the number of windows open and measures taken to increase air movement.

6. ACOUSTIC MEASUREMENT AND CALCULATION METHODS.

6.1 Acoustic Measurement Frequency Weighting Vs. Frequency Analysis.

Jones (#3516, 1988), from the UK identifies two basic acoustic measurement approaches. The first is a simple frequency weighting system which approximates to the human hearing response. He notes that various weightings have been developed, although the A weighting is most commonly used, and can usually be found as standard on sound level meters, giving a direct reading in dB(A). This approach however, does not provide specific information about the noise spectrum, which can be found by adopting the second measurement approach, frequency analysis. This involves splitting the noise spectrum into a number of adjacent frequency bands, which together show the distribution of acoustic energy over the whole frequency range. The choice of bandwidth depends on the detail required and on the purpose of the measurements. In many cases, the resolution provided by octave band analysis is inadequate. Certain values have been chosen as the geometric centre frequencies for octave bands, for example 31.5, 63, 125, 250, 500, 1000, 2000, 4000 and 8000Hz, this halving and doubling process continues beyond the examples given. A single figure descriptor is used to summarise the plotted results of the spectrum analysis.

The basis of both the noise criterion (NC) and noise rating (NR) methods involved comparing the measured octave band spectrum with a family of curves of sound pressure level against frequency, which resemble equal loudness contours. These curves reflect the reduced low frequency sensitivity of human hearing, and at higher sound pressure levels flatten in shape. The rating value corresponds to the highest curve reached, and therefore is usually determined by the level in a single frequency band. The curves are usually presented graphically in 5 unit steps, interpolation between the curves can increase the resolution to 1 unit. Typical maximum background noise levels in terms of NR and corresponding dB(A) are given as a guide by the author for several common environments. For example, concert halls, opera halls, studios for sound reproduction and large theatres have a NR of 20 and dB(A) of 26, compared with kitchens in hotels, hospitals etc., computer rooms, accounting machine rooms, and swimming pools which have an NR of 45 and dB(A) of 51.

The author stresses that accurate measurements are essential, as well as the appropriate choice and use of equipment. The basic equipment consists of a microphone, connected to an amplifier and octave band filter set. Also, a hand held sound level meter may contain all of these components. Four types are commonly available; type 0 is the most sensitive and is best suited to laboratory and calibration tasks; type 1 or 2 are suited to building acoustics measurement; and, type 3 is the least sensitive. Regular calibration and close attention to manufacturer's instructions, are essential to ensure accurate readings. The author discusses several important points to note when taking room acoustic measurements, including the object of acoustic measurement is to measure the sound pressure level in the undisturbed sound field and the identification and understanding of direct and reverberant sound components is important. In a room which is said to be "live" with hard and reflective surfaces, room reverberant sound will dominate, while in rooms which are "dead", and have absorptive surfaces, the direct field will predominate over a greater distance from the source.

6.2 Acoustic Intensimetry.

More recent analysis of sound parameters has been undertaken by Shelton (#10223, 1995), who examines how sound intensity is measured and its practical applications in building services. Sound intensity represents the energy emitted from a source, expressed as power flowing through a given area in watts per square metre (or decibels re: 10^{-12} Wm^{-2}), it is a vector quantity with both magnitude and direction. The basic theory is more fully outlined by the author. In normal sound fields, simple relationships, such as those outlined above, break down, since reflections from other emitters interfere with individual source emitters and therefore there is no simple way to calculate the sound power from sound pressure measurements. To effectively measure sound intensity, simultaneous measurements of both pressure and particle velocity components are needed. Quality condenser microphones are used to measure sound pressure, although attempts to measure particle velocity have met with some problems. This explains why the measurement of sound intensity is relatively new. The theory behind the measurement of particle velocity is briefly outlined by the author, who then goes on to explain how, in practice, sound intensity is measured. A number of safeguards are used to ensure that accurate measurements are taken. For example, calibration of the condenser microphones, and the use of digital signal processing (DSP) are recommended to calculate sound intensity. This technique minimises any inaccuracies due to phase mismatch. By digitising the two channels of data immediately after the microphone preamplifiers, reduces phase mismatch.

According to the author, two ways of calculating sound intensity digitally have arisen, one in the time domain and the second in the frequency domain. Time domain analysers provide sample by sample calculations using sum and difference and digital integration /averaging. Frequency analysis is achieved by digital filtering, giving results in octaves, third octaves and sometimes 1/12 octave (6%) bandwidths. These are real time analysers and will find their application mainly in acoustic measurements where fractional octave results are commonplace. Frequency domain realisation involves a Fast Fourier Transformation (FFT). These are becoming more common and offer good price performance ratios. Calculating sound intensity is, therefore, a case of scaling a common function in a two channel FFT analyser. These devices have two main applications, sound power determination and source location and source ranking which are discussed in more depth by the author.

The use of intensimetry to measure the sound power levels generated by fans connected to the ductwork of a ventilation system operating in real conditions is outlined by CMHC (#6874, 1991). The aim of this study is to determine the accuracy and limitations of the intensimetry method. Measurement results were compared with those obtained in a reverberant room using the method described in the appropriate Canadian standard (standard AMCA 300). The procedure consists of measuring the sound intensity inside and outside the section of duct located immediately after the fan discharge, with a loudspeaker emitting pink noise at the position of the fan discharge. This was undertaken to perform a calibration of the field conditions and to take into account the sound transmission loss through the duct wall. The measurements outside of the duct, with the fan operating was then repeated and finally the sound power levels calculated using this collected data.

Following experimentation, the author concludes that sound intensity measurements made in the low background noise conditions of the large reverberant chamber, the results of 31 out of the 42 third-octave band sound intensity measurements performed were reliable. The sound power level of the procedure correlates fairly well with the sound power level obtained using the reverberant chamber method outlined in AMCA 300 for the frequency range 50 Hz to 800 Hz, which governs the noise control design for most ventilation systems. Therefore, results suggest that, for low background noise levels, the method outlined here can give reliable results. In mechanical rooms were the ambient noise levels are high, reliable measurements may not be possible using this method. So, further research is needed to allow for accurate intensity measurements in such cases.

6.3 Acoustic Modelling.

Acoustic modelling techniques in the design and installation of HVAC systems are discussed by McCulloch (#10222, 1995). The author explains that, numerical techniques can either be deterministic (based on a numerical model of a physical phenomena of acoustic waves, possibly including vibration waves), or energy based (using a model of acoustic and /or structural system within which the input acoustic and vibrational energy is distributed according to the geometry of the energy transmitting or dissipating properties of the components and their connections). The paper briefly discusses the various deterministic and energy/geometric modelling methods. The main limitations of such techniques being the size of the equation system and consequent computer power needed. McCulloch states that, a rule of thumb requires six elements per acoustic wavelength for good results, hence an upper limit of the valid frequency range can be set for any particular mesh. A finer mesh, with smaller elements can cover a higher frequency, but requires more computer processing power, and consequently, localised modelling such as radiation from vibrating equipment is more common than that of whole rooms. Such 3 dimensional modelling is complex to set up, but can give interesting results. Deterministic methods are better suited to low frequencies, while energy/geometric methods are better suited to high frequencies, although some overlap is apparent. The author outlines several examples of such modelling, including the fan noise of air handling plant is modelled and its application for duct design is shown. In conclusion, he has shown that both deterministic (finite element and boundary element analysis) and energy/geometrical (ray-beam tracing) approaches to acoustic modelling can be used to study the behaviour of building services plant and installations.

Regenerated noise, formed by the interaction of turbulent air flow and duct discontinuities or flow spoilers, occurring on the quiet side of the primary attenuates can lead to serious noise problems, Mak (#10223, 1995). If such noise is not correctly predicted at the design stage, remedial measures are virtually impossible to implement, due to a lack of available space. Current design guidance is based on a limited number of measurements made on a few representative components. Such data is difficult to obtain by conventional measurement techniques, which according to the author, requires the use of an expensive specially combined acoustic and aerodynamic facility. Typically this should consist of a powerful fan system; a high performance silencer, a long test duct and a large reverberant room characterised by a low level of background noise in which the sound power generated is measured. The author discusses a number of investigations that have tried to devise a generalised technique for the prediction of regenerated noise in duct elements by looking for correlation between the obstructiveness of an in duct spoiler and the resulting pressure loss within the duct.

The author notes that further work is needed to refine the equations for more complicated spoiling elements such as bends, transition pieces etc. A more recent development has been the introduction of Computational Fluid Dynamics (CFD) which are used to predict the movement of air. However, to solve the turbulent flow equations with sufficient accuracy, a fine three dimensional mesh is needed large enough to cover the area of interest, but with spacing smaller than the smallest turbulent eddy present in the air (possibly as small as 0.1 mm). Additionally, computations must be made for unsteady conditions with a time step smaller than that associated with the fastest eddies. Therefore, the author believes that, with current computer technology the direct determination of regenerated noise is relatively impossible using this method. An alternative approach would be to use CFD in such a way as to permit regenerated noise levels to be determined indirectly. CFD codes use turbulence models to represent the small scale effects of turbulence. Such models provide an estimate of the turbulence kinetic energy in the vicinity of the flow spoiler.

In generalised prediction techniques there is a need to collapse all data onto a single curve, normally achieved by plotting data against a Strouhal number (Strouhal Number equals (frequency x duct diameter)/(sound speed)). Calculation of this number requires values of frequency, velocity and a "characteristic" dimension. For a given problem using CFD, the author obtained a Strouhal number of 0.185 compared to the experimental values of 0.18-0.19 for the same problem. The author concludes, therefore, that results so far show that work on the application of CFD in the prediction of regenerated noise, is still in its early stages but holds considerable promise for the future.

CMHC (#5520, 1991) discusses an evaluation of the Canadian Standards Association's (CSA) standard laboratory test methods for residential fans to provide air handling and sound emission ratings. The study was performed to evaluate these test methods and to assess the relationship between the laboratory ratings and actual field performance. Although both airflow and noise assessments are dealt with in this paper, only the noise results will be outlined here. Acoustical measurements were made in one third octave bands using an acoustical analyser. Also, an acoustic intensity probe was used to measure the sound power of the fan and the sound pressure level was measured to determine the sound pressure level versus distance from each ventilation device. The measurements were made in three directions at set distances (0.5, 0.7, 1.0 1.4 and 2.0 metres) from the centre of each fan, to provide a measure of the sound levels that users would experience in these rooms when the fans are in operation. The effect of normal furnishings were approximated by using two absorptive panels. Acoustic decay measurements were made at three or more positions in each room. The report gives detailed sound power results for each ventilation device, together with corresponding laboratory data from measurements according to CSA standard C260. The experiments and lab data should good agreement. The kitchen range hoods gave slightly higher sound power levels in the field measurements, but the bathroom exhaust fans had lower sound power in the field. The average deviation in the A-weighted sound power was 1.4 dB. For the frequency bands 250 Hz to 2500 Hz the intensity results typically agreed within 0.5 dB or better. At frequencies from 100 Hz to 200 Hz and above 2500 Hz intensity variations from 0.5 to 1 dB were typical. The report discusses the difference between sound pressure levels and sound power. Where sound power relate to the property of a source rather than the intensity observed when the source s installed in a room. It is the resulting sound pressure level in a room that affects an observers assessment of loudness, which depends not only on the source but also on the receivers location and characteristics of the room. Differences among the results showed that for all fans the sound pressure level decreases with increasing distance from the fan, so perceived loudness depends on typical distance from the source in normal use. Furthermore the difference among the results for the six fans is strongly related to room characteristics, with the highest relative sound pressure level in the smallest room. Therefore in conclusion, the sound power measured for fans in their field installations agreed quite closely with the laboratory results. Any deviations were put down to fan installation or measurement bias. An approximate version of diffuse field expression can predict sound pressure level in typical kitchens or bathrooms with good accuracy. From a design point of view, the tested method would provide a basis for selecting appropriate fans if users were given criteria for acceptable values of fan noise.

7.0 NOVEL USES FOR ACOUSTICS IN BUILDINGS.

Acoustics as a tool to find leaks in buildings or to mask obtrusive noises, represents a novel but positive way that noise generation can work as an aid both in the design process and in real life situations. The papers outlined below show these techniques and where possible, offer design guidance.

7.1 "Active Noise" Systems.

Leventhall et al (#10222, 1995). discusses the use of active noise control in HVAC systems, principally where an anti-noise acoustic field is generated to cancel out the existing noise. According to Leventhall, the best results have been obtained for the cancellation of one dimensional, plane waves travelling down a duct. He explains that an upstream microphone detects and converts the sound pressure waves generated by the fan to an equivalent electrical signal. Using adaptive filtering, the controller creates an electronic representation of the duct. The cancellation signal is sent to the loudspeaker, which radiates 180° out-of-phase sound waves to mix with, and cancel, the noise. The second microphone, also downstream from the loudspeaker, monitors the residual acoustic pressure after cancellation and sends back information to the controller in order for it to adjust itself for optimum results. Important features of such active noise systems include the ability of the system to continuously update the electronic model of duct acoustics by sending a known signal to the cancellation loudspeaker, and using on line calibration to determine the characteristics of the loudspeakers and microphones, as well as the environmental parameters, such as temperature that affect the speed of sound. Another important feature to achieve good results is to ensure that the acoustic delay from input micro phone to cancellation loudspeaker be at least as long as the electrical delay from the input microphone to the radiated cancelling noise of the loudspeaker. A new approach is to combine the active noise attenuation systems outlined above, with more traditional passive systems, absorptive silencers. Such systems can provide attenuation over a full eight octave band range. High frequencies are absorbed, while low frequencies are actively cancelled out. The authors gives several examples of where such systems have effectively been used, and concludes by outlining several advantages of active silencers. These include good attenuation of low frequency rumble noises, they are lighter in weight and occupy less space than their acoustically equivalent passive silencers, and the noise can be cancelled at the mechanical room wall and no external lagging of the duct is required over noise sensitive areas.

The potential of using active noise control in the construction industry to blanket equipment noise is spotlighted by Macneil (#10226, 1993). Such systems have already been successfully employed in industries such as the construction of ships, submarines and performance cars. Although their commercial applicability may be some way off, for the construction industry, research is already underway to further investigate its potential. Traditionally passive noise control strategies have been employed in the construction industry, representing the addition of acoustic absorbing materials, in ductwork, on walls, floors or ceilings etc. However, active noise control, aims to deaden sound by cancelling out the sound pressure wave created by the offending noise, with a sound pressure wave generated in response. A peak in one wave is cancelled out by a trough in the other and vice versa. In the past the electronics were not complex enough to produce the anti sound wave, however advances are making this increasingly possible. This form of noise abatement is particularly interesting in the construction industry, because it is most effective for low frequency sounds, such as those of generators and rotary engines, which are the hardest to control with current passive measures. The paper notes that the problem, is that if the active noise control does not exactly match the opposing noise, the effect, rather than deadening the noise is to amplify the sound. Where the direction of sound is well defined, for example in confined spaces such as ducts, a microphone is placed near the sound source. The signal is sent to a processor, which then transmits an the exact opposite sound through a speaker located in front of the sound source. The potential for using such systems to prevent the passage of noise through thin walls, such as curtain walling requires a more sophisticated approach. For this application the systems would have to cancel out noise arriving from more than one direction, by vibrating the panel in the right place at the right time. This would allow noise control without increasing the mass of the cladding. Tests of an experimental system have achieved up to a 20dB sound reduction, compared to passive systems, which require the wall thickness to be doubled for a 5 dB reduction. The system under test includes sensors built into the wall panels, which send the necessary data to a computer processing unit, which it turn operates the transducers causing the panels to vibrate at the required frequency to cancel the sound. However, before this can be applied to a building, more sophisticated electronics need to be developed that will be able to cope and distinguish with random traffic noise. Although researchers believe that a commercial application will be available around the turn of the century, it is likely to be expensive, and rely quite heavily upon how well it can be installed, with each installation being site specific. The use of such systems in large rooms is still some way of, because in these rooms sound is not predictable, repetitive, nor uniformly directional.

Brister (#10220, 1993) also discusses active noise systems, and explains that sound is composed of sound pressure waves, causing the ear to vibrate, enabling us to perceive noise. If we can create an opposite pressure variation at the same frequency, the two pressure patterns cancel each other out and result in silence. Simple in principle, but complex is practice. However, new technology is nearing the point were such systems are possible, with modern microphones fast enough to implement the control algorithms used in active noise control systems. Information is fed to the controller in the form of an adaptive algorithm from microphones located in the ductwork. For example, they calculate separately the amplitude and phase required for every frequency component of the digital filter. However, the sound wave from the cancelling speaker not only travels down the duct, but also upstream where it can be picked up by the detecting microphone. Therefore, special directional microphones have to be used which only pick up sound waves that are travelling downstream.

The author cites experiments carried out by TNO in the Netherlands, where tests were carried out in a 0.6m by 0.6 m duct, with a 4 m distance between the detecting microphones and anti noise loudspeaker. Anti noise was generated between 60-200 Hz, with the total noise reduction between these two frequencies being approximately 18Hz, which according to the author is very good. These systems, therefore, can cope with low frequency noise, but are not so able to deal with high frequency noise. Research is, however, underway to control the non uniform sound waves which are set up once the limiting frequency is exceeded. Active systems will be more applicable in controlling the high level, low frequency tones generated by fan noise etc., than the current passive systems. The paper continues to highlight a number of applications and concludes with a case study where active systems are used to provide tonal noise control of all prominent tones, with the 60 Hz and 120 Hz tones being reduced to 25dB and 35dB respectively.

Yeung et al (#10212, 1996) discusses and evaluates the active noise application in fan/duct systems. He notes that advances have meant that earlier such active noise systems using analogue electronics for signal processing were only effective for highly controlled steady conditions. Improvements in adaptive signal processing theory and hardware have resulted in a number of commercial products. Yeung briefly describes the digital sound cancellation systems, which consists of a primary noise sensing microphone, an error microphone, a controller/amplifier and a speaker. The authors note that the manuals supplied with this product claim that its fully automatic, requiring no pre programming, training or manual calibration. The paper does not discuss the hardware configuration, and but gives a brief description of its operating principles. The system was compared to conventional duct lining approach. Two pieces of 1mm thick aluminum circular duct was used. One was bare and with the sound concellation system connected, while the other was internally lined with 25mm thick 48kg m^{-3} fiberglass insulation. A net internal diameter of 300mm was maintained for both ducts so as to keep approximately the same in duct air velocity. The broad band noise was provided by a centrifugal fan equipped with a frequency inverter for stepped/flow variation while a noise signal generator was employed to supply a static broad band noise as pure tone to the ductwork. The active noise systems was installed in line with all current recommendations. The study was conducted with and without the duct connected. Where the fan was used in duct sound spectra from 16Hz to 4000Hz in 1/3 octave band intervals were obtained with/without operation of the fan, and with /without the sound cancellation system functioning. Aerodynamic sound spectra were observed during the processes of increasing and decreasing volume flow rates to simulate the operation of a variable air volume system in supply air flow rate to an occupied space is varied according to its cooling/heating load requirements in partial load conditions. In the second stage the effects of the active noise system were studied. Pink noise with an overall sound pressure level comparable to that of fan at full speed was generated to test the performance under no flow conditions.

System behaviour under selected pure tone was also analysed. Calibration was undertaken before and after experiments. The authors found that the active noise concept is applicable in air conditioning systems despite a number of constraints, such as limited effective range governed by the cut off frequency of the ductwork. It can be used to supplement the conventional passive type silencer for cancelling low frequency noise, with the resultant spectrum being more balanced and acceptable to human ears. However the advantages have to be balanced against high cost which cannot be recovered during its serviceable life, despite saving in running coat arising from reductions in system pressure loss through the use of shorter length silencer. Many problems still have to be overcome, but recent advances have already overcome many of the log term problems associated with the initial systems.

7.2 Acoustic Leak Detection.

Acoustic Leak Detection is a qualitative technique in which a steady or oscillating high pitched sound is placed inside a building. A microphone is swept around the external envelope, and detects cracks within the envelope by the identification of increases of volume or intensity of the transmitted sound (#5832, 1993). Ringger and Hartmann (#4929, 1989) undertook an evaluation of acoustic leak detection techniques, in typical constructions using ordinary sound level meters. Their study was based on the simple method outlined above, and aimed to try to obtain quantitative data, with the sound transmission being measured using well defined slits. Experiments were performed through, simple slits of various widths; slits containing a rectangular bend; slits covered with various foils; and; through slits coupled to a damped cavity. Measurements were carried out with a real time 1/3 octave-band analyser, with all bands from 200Hz to 10kHz being considered. The sound pressure levels on each side of the reference beam (wall) were measured through slit widths of 0.5mm, 1.0mm, 1.5mm and 2.0mm. Results were found, by the authors, to be somewhat arbitrary, depending upon the spectrum in the sender room (in this case Pink Noise). However, the authors felt that it was obvious that the overall level differences are neither consistent nor reliable and the method failed on two counts, essentially because of the use of simplistic equipment. Firstly, examination of the spectrum of the sound transmission, the operator would suspect that a foil was located in, or at the end of, the slit. Secondly, in the case of a slit coupled to a damped cavity, it would require a more elaborate acoustic measurement to establish that a degree of sound transmission was still present. This paper ends with a bibliography listing the important papers relating to the general theory of sound transmission through openings, measurements of the sound insulation of openings on everyday building elements, and comparisons between air leakage and sound transmission.

However, according to Oldham and Zhao (#5119, 1991; #5234, 1991), and Oldham et al (#5324, 1991) who conducted a similar study to that highlighted above, found that, as predicted by theory, the dimensions of the apertures determine the magnitude and resonant frequencies of the sound transmission loss curves. They state that it should therefore be possible to size air leakage cracks using the technique they outline. Oldham and Zhao suggest that their work was more successful than that of Ringger and Hartmann (#4929, 1989) because both frequency resolution and sensitivity were lacking. This has been overcome, in this more recent work by using a two channel Fast Fourier Transform Analyser.

According to Oldham et al (#5324, 1991) three measurement techniques have been developed for the measurement of sound transmission loss through walls;

1) Sound pressure measurements, which need two reverberant rooms.

2) Impulse techniques, which use a short duration signal for excitation and avoid the need for reverberant chambers altogether.

3) The sound intensity technique, which requires one reverberant room to provide a diffuse exciting sound field.

Oldham and Zhao (#5119, 1991; #5234, 1991) used the later technique for their experiments of the sound transmission loss of slit shaped cracks in a rigid wall because, according to the authors, it has several advantages over the other methods. These include the need to measure only two parameters (sound pressure level in the source room and sound intensity level in the receiving side). Using this method also means that a reverberant chamber on the receiving side is not needed, because the method provides a direct measurement of the sound energy propagated. These advantages greatly simplify the measurement procedure and make it possible to measure the transmission loss of small holes and narrow slits. The use of a two channel FFT Analyser to measure the sound intensity, enables the frequency characteristics of the transmission loss to be determined with a high degree of resolution

Experiments were conducted on 15 sizes of slit, made of two parallel steel bars of 500mm in length. A diffuse sound field was used on the source side to simplify measurement of the sound energy transmission, and was generated by two speakers emitting 20kHz broad-band white noise. A standard Bruel and Kjaer (B&K) ¼" condenser microphone (B&K 4135) was used to measure the sound pressure level (SPL) in the room. The measured sound pressure level (SPL) in the source room was averaged 500 times by the analyser at each of the 9 measurement positions before the data was recorded, to eliminate random error and improve the signal noise ratio. On the outside of the chamber a B&K 3520 sound intensity probe was used with the analyser to measure the sound intensity radiated from the aperture. The data was averaged 350 times at each point, and eight measurement positions were used along the slit in order to obtain an averaged sound intensity level. According to the authors, results show that the measured transmission loss characteristics of simple cracks are in good agreement with the values predicted by application of the Gomperts-Kihlman equation. Although, in order to size the air leakage cracks, it is necessary to be able to extract the relevant dimensions from measured transmission loss characteristics, with determination of the crack length being relatively simple, but measurement of crack depth is more complicated. They attempt to give some guidance on how this might be done, by performing a Fast Fourier Transform on the transmission loss characteristics. The authors therefore conclude that the sound intensity technique and reverberant sound excitation have successfully been used to measure sound transmission loss through narrow slits in rigid walls. As determined by the theory, the dimensions of the apertures determine the magnitudes and resonant frequencies of the sound transmission loss curves. It should, therefore, according to the authors be possible to size air leakage cracks using the above technique.

As a concluding remark, the authors noted that some sound energy losses were also observed during this investigation, particularly with narrow slits. The effect increased as the area of the apertures decreased and the depth of the opening increased. It is suggested that the effect of these losses were large enough to have an impact on the derived equations. They also suggest that a possibility exists of using the experimental data to determine an approximate relationship between the effects of viscosity and the dimensions technique employed to size air leakage cracks based on acoustic intensimetry.

7.3 Using Acceptable Noise to Mask Annoying Noise.

Rossi (#10223, 1995) explains how background sound can be used to mask noises, such as telephones, printers, typewriters etc., which are unavoidably annoying, principally because of their unpredictability and obtrusive interference into our normal daily lives. In most open plan offices and rooms the general objective of any acoustical measures is to protect the confidentiality of conversations to prevent them from interfering and to decrease the disturbance caused. The use of background noise originating from the aerodynamics of ventilation and air conditioning systems represent a stable wide spectrum noise without timbre or tonal pitch which can effectively be used to mask annoying noise. Such noises have to be carefully chosen, since they can easily provoke strong reactions and are rejected as soon and their level exceeds 40-50dB(A). Therefore, finding suitable acceptable material is vital. The author sets out a procedure to enable such masking white or pink noise to be chosen. The technical specifications of the sound system should be initially defined, thereby fixing the technical objectives and leading to a choice of equipment. Trials should then be run, during a two to four week period including a number of recordings, containing a wide spectrum of musical extracts. Once all the reactions, impressions and comments have been gathered and examined the final recordings can be made. The author makes several comments about the choice of such background music including, chosen material should consist of a main background sound - music and a secondary sound - ambient noise. The mean energy of a piece of sound material must lie in the range 50-55dB(A) with a peak factor of below 6dB(A). The main background material should consist of little known works or pieces, no fashionable hits or popular pieces of music. This is to reduce the risk of rejection through saturation. The author concludes by stating that following the general rules outlined in this paper, an acceptable background piece of music can be chosen that efficiently masks speech and disturbing noises, while being acceptable by the people concerned.

Anon (#10216, 1994) examines the notion some sounds are necessary for us to hear while others can affect our productivity adversely. Background noise in offices is often provided by forced ventilation and outdoor traffic noise, typically providing levels of 35-40 dB(A). In contrast an office ventilated by a displacement vent system typically has a background noise of 20-25 dB(A). The author notes that "interesting background" speech has been found to cause a dip in productivity of 10%. By applying a masking noise of approximately 4 dB above the level of speech can reduce this fall in productivity, although research carried out in a car factory, concluded that noise and temperature do not affect performance. The combined effects on heat and noise on parameters like reaction, aim, vigilance and motor judgement were studied in an environment of between 22°C to 30°C and noise rating of 85dB(A).

The authors examined the CIBSE 1986 recommendations, which state that a background noise rating of 40 dB(A) the typical maximum distance at which normal speech it intelligible is 7 m. The introduction of sound absorbing materials may reduce this distance. The author outlines examples of the balance between background noise and sound insulation above suspended ceilings, indicating levels of privacy. The author goes on to compare sound conditioning with sound insulation. The use of air conditioning to mask background sound has been used for many years. However as air conditioning systems have become replaced by quieter displacement systems, and natural ventilation, engineers have had to deal with the issue of noise and its problems. The author describes an interactive noise control system that allows natural ventilation through an open window without letting in outside noise, by using two opening windows and a combination of internal blinds and louvers to control noise entry. The use of sound insulating partitions provide a solution to distracting noises for cellular offices. However solutions must be tailored to the specific office location. The paper concludes with a case study of a new headquarters office development for a large financial institution. The building employed displacement ventilation chilled beam systems, which was expected to reduce noise levels. Both sound conditioning and improved insulation were compared, with sound conditioning being the preferred choice based on economic considerations. Although in conclusion the author notes that the difference between the two systems in cost terms is usually fairly marginal, thus each system is site specific.

Brister and Bunn (#To be assigned June 1997, 1996) comment on the acoustic challenges that result from the recent trend in many buildings to expose the soft and do away with air conditioning. Two papers are presented, (one by each author) giving examples of different buildings that have overcome these challenges. Brister outlines the design process and acoustic ceiling system commissioned for the UK Ministry of Defense building in Abbeywood. The system leaves 40% of the slab exposed for radiant cooling, while the remaining ceiling is covered by arrays of ceiling modules. These have places for inclusion at some point of chilled radiant panels, and half have factory formed apertures for on-site installation of luminaries. Results from experiments showed that these modules showed an average noise reduction coefficient over the 250-2000 Hz range of 0.67 with peak performance of 0.77 at 500 Hz. Brister notes that these modular units can be installed on a stand alone basis to deal a particular problem in a given areas.

In the second paper, Bunn discusses several examples of new office developments that have employed masking and shaped ceiling coffers to improve the acoustic performance of the designs. He states that removing suspended ceilings and exposing the structural concrete does not improve the sound absorption. However, passive cooling systems do not generate enough background reverberation, typically (NR35/40) created by fan coils or VAV terminals to provide sound privacy. Such problems are also created by the turn down of non powered VAV terminals in winter and openable windows, which may allow individuals to alter the thermal environment slightly, but also allow the intrusion of traffic noise etc. Such noise ingress does nothing to mask conversation noise generated within a busy office. The level of sound privacy or annoyance will determine the level of sound insulation required, such additional features have a cost penalty, which would often wipe out the marginal cost of installing the passive comfort cooling system. The audibility of annoying noise depends very much of the relative level background noise. As the level of background noise falls, the relative importance of annoying sound sources increases. Bunn examines several possible solutions including active noise and masking. The masking system described consists of a stand alone mains powered speaker which sits above the suspended ceiling and directs electronic noise upwards to the soft, this then reverberates and fills the space. Alteration in the speakers bass, treble, and volume can change the tone. The paper notes that each unit will produce enough white noise to cover 5mx5m area. However such systems are expensive. An alternative system utilises several (upto 20) speakers running from one amplifier, with a wider tonal range. The described system produces a pink noise designed to provide speech masking for up to 75m^2 of cellular or open plan office space. The guide given in the paper suggests that such systems would be tuned to match the normal frequency range, between 500Hz to 4kHz.

8.0 CONCLUSIONS.

Legislation exists to cover noise emission from a wide range of HVAC components, whole systems and individual processes taking place inside the built environment. Several papers highlighted in this bibliography set out these guidelines and together with examples provide design guidance to help building professionals understand the acoustic problems and impacts of installing certain equipment. Such guidance is designed essentially to aid the design process by minimising the number and severity of any acoustical problems.

Two basic measurement approaches have been identified, a simple frequency weighting system, commonly dB(A), and frequency analysis. Both these methods are described in this document, as well as the use of acoustic leak detection. This is a method in which a steady or oscillating high pitched sound is placed inside the building, a microphone on the outside is used to identify cracks in the building envelope. Several authors investigate the use and validity of this technique with recent technological advances making this a more accurate and thus potentially important research tool.

The effectiveness of building components, such as walls, floors, windows etc. as sound barriers and transmitters are discussed by several authors. The importance of buffer rooms which can either absorb or amplify sound depending upon design is also discussed. It is agreed that such rooms should not be seen as general solution to traffic noise problems, with noise strategies being source orientated. The use of background sound to mask noise problems is another area of discussion, although careful selection and use of this is essential in order to improve any noise related problem. Failure to adequately design such features will lead to complaints and a degradation of the internal environment. The generation and transmission of heating ventilation and air conditioning (HVAC) noise is a major problem, several authors discuss the variety of problems and offer design guidance accordingly. Identified problems include the transmission of fans noise throughout the building, the control of noise transmission via duct work, including both from the plant room to quite areas as well as cross talk between individual rooms connected by ductwork. The noise created as air enters a room through vents and grilles is another design problem discussed in this document.

Finally the transfer and generation of noise within a building can also be a contributing factor to the quality of the indoor environment, playing a major role in sick building syndrome investigations. Loud noise, as well as noise that is inaudible can lead to a variety of health related problems, making the work environment an extremely dangerous place to be. Several authors discuss a variety of acoustical IAQ problems, including the break down of acoustic absorbent material inside ventilation ductwork, and the low frequencies emitted by some ventilation equipment that can cause disorientation, dizziness and headaches.

9.0 REFERENCES.

#NO 3385 Flair homes project report No.4: A survey of sound levels in five unoccupied houses.
AUTHOR Fisher D, Proskiw G
BIBINF Canada, Energy Mines and Resources, June 1988, 16pp, 1 fig, 4 tabs, 2 refs. #DATE 00:06:1988 in English
ABSTRACT Sound level measurements were performed in five unoccupied unfurnished houses located in Winnipeg. Four of the structures were built to the R-2000 standard while the fifth was a control structure built to conventional standards. Sound pressure levels generated by the heating and ventilation systems were measured and compared to recommend indoor design goals for ventilation system sound control. Measurements were also made of the attenuation of outdoor noise, generated with a gas-powered lawnmower, by the different building envelope types in the houses. The study found that sound pressure levels generated by mechanical systems ranged significantly between houses and, on average, exceeded the acoustical design goal for the "worst case" room which was located directly above the mechanical system. This raised the concern that homeowners may defeat the ventilation system using the "off" switch as a means of controlling noise generated by the mechanical system and thereby lose the benefits of the mechanical ventilation system.
KEYWORDS sound, heating system, ventilation system, mechanical ventilation, window, duct

#NO 3516 Noise measurements in buildings.
AUTHOR Jones A J
BIBINF Building Serv Eng Res Technol, 9(1), 1988, pp.35-38, 5 figs, 2 tabs, 1 ref. #DATE 00:00:1989 in English
ABSTRACT Acoustic design is an important consideration in mechanical services installations of all types and, with this in view, maximum noise levels in buildings are commonly specified by reference to either noise criterion (NC) or noise rating (NR) curves. Although these rating methods have existed forsome years, confusion still arises from time to time regarding their use and appropriate measurement procedures. This Note is intended to assist engineers who are not primarily acousticians, but who are nevertheless charged with taking accurate and representative measurements to monitor and certify performance standards. The origin and applicability of rating indices are summarised and practical guidance given on field measurements.
KEYWORDS design, installation techniques

#NO 3597 Demand controlled air ductwork.
AUTHOR Laine J
BIBINF in:UK, AIVC, 10th AIVC Conference, held at Espoo, Finland, 25-28 September 1989, Volume 2, February 1990, pp397-411, 5 figs, 4 tabs, 7 refs. #DATE 00:02:1990 in English
ABSTRACT A demand controlled air ductwork should be so dimensioned that the flow controllers have good flow and acoustical operation conditions. From the air flows in a room and its highest permissible sound level, the highest differential pressure allowable to the air flow controllers (duct air flow controllers and terminal devices) are selected. The required minimum differential pressure is 50-100 Pa or a higher differential pressure determined according to the outdoor temperature (-20 deg.C), the height of the building and the air conditioning system required to control the thermal disturbing forces. From these differential pressures and the preadjustability of the air flows are determined the average pressure level of the ductwork and the highest permissible pressure losses of the air ducts, which at most may be about half the average pressure level. Also determined on the basis of the pressure level of the ductwork are the airtightness requirements in order to have control over the leakage noise. Suitable duct sizes have been ready-calculated. The pressure losses (bends and branches). Friction losses in the ducts are disregarded. The dimensioning of the ducts should be adapted to the standards of the equipment technology (flow, acoustics, airtightness) that is available. The recommended total pressure loss (ducts and air flow controller) of a demand controlled ductwork should be a maximum of around 200-300 Pa excluding the pressure loss of the central unit.
KEYWORDS demand control, sound

#NO 3724 The effects of building design and use on air quality.
AUTHOR Loftness V, Hartkoff V
BIBINF USA, Occupational Medicine: State of the Art Reviews, Vol.4, No.4, October-December 1989, pp643-605, 2 figs, 11 tabs, 18 refs. #DATE 00:10:1989 in English
ABSTRACT The authors believe that a minimum of six performance criteria can capture the performance qualities that must be balanced in buildings:(1) spatial quality, (2) thermal quality, (3) air quality, (4) visual quality, (5) acoustic quality and (6) building integrity against degradation. Total building performance, therefore, is the simultaneous provision of spatial, thermal, air, acoustic, and visual quality within the integrated setting of the occupied building, and the provision of building integrity for the integrated system or building over time.
KEYWORDS design, indoor air quality, pollutant

#NO 4018 ASHRAE standards: a guarantee of occupant satisfaction.
AUTHOR Davidge R O C
BIBINF in: Managing Indoor Air for Health and Energy Conservation, proceedings IAQ 86, ASHRAE 1986, pp171-177, 7 tabs, 8 refs. #DATE 00:00:1986 in English
ABSTRACT As a result of occupant complaints, an extensive environmental analysis was conducted on a large new government office building in 1980. Recommendations were made to improve performance of the ventilation systems as well as to

restructure the open office layouts so that the illumination and mechanical system capabilities would not be defeated. These recommendations were implemented on two floors as a trial. Environmental tests were again conducted in 1984/85 prior to implementing the recommendations in the rest of the building. In addition, a questionnaire was administered to more than 600 employees on the test floors. With minor exceptions, it was found that ASHRAE ventilation air quality, thermal comfort, acoustic requirements, and IES illumination requirements were met. About 50% of the employees, however, rated their acoustical privacy, ventilation and air circulation very poorly, much worse than other environmental and job-related parameters. The surprising air quality results raise several fundamental questions concerning standards and their application.
KEYWORDS standard, human comfort, office building

#NO 4271 Indoor air pollution control.
AUTHOR Godish T
BIBINF USA, Lewis Publishers, 1989, 401pp. #DATE 00:00:1989 in English
ABSTRACT Practical applications deal with how to conduct indoor air quality investigations in both residences and public access buildings, indoor air quality mitigation practice and case histories. "Indoor Air Pollution Control" will be of use to anyone who is interested in the control and prevention of contaminated air in homes, apartment buildings, office buildings large and small, hospitals, auditoriums and other public buildings.
KEYWORDS pollutant, indoor air quality, residential building, public building

#NO 4298 Noise control.
AUTHOR CMHC
BIBINF Canada, Mortgage and Housing Corporation, Builders' Series, 1987, 33pp, 29 figs. #DATE 00:00:1987 in English
ABSTRACT Poor control of noise between apartments or noise coming into a house from outside is a common cause of complaint from homeowners. For good noise control, proper design is essential. This guide identifies some of the causes of noise control, explains the way noise is measured and recommends several publications that provide good advice on design that will control noise. It also points out the potential problems that will inevitably arise if good noise control design is not used, and recommends construction principles to avoid that happening. This publication is intended only as an introduction to controlling noise in buildings.
KEYWORDS sound, insulation, building design

#NO 4371 Improved performance of ventilation system components.
AUTHOR Strindehag O
BIBINF Norway, Oslo, Norsk VVS, Roomvent 90 proceedings, 13-15 June 1990, paper C, 15pp, 7 figs, 3 tabs, 19 refs. #DATE 00:06:1990 in English
ABSTRACT This article discusses the opportunities available for improving the performance of the components of modern ventilation systems. It is mainly the growing demands on the quality of the indoor air that justify improvements to most of these components. Theincreased thermal loads and the higher consumption of electrical energy in many buildings also justify modifications of certain components of ventilation systems. Components with improved performance, particularly as regards energy consumption, lower sound generation and reduced emission of pollutants, are expected to be in demand in the future. Fortunately, most of the component improvements related to sound generation and emission of pollutants can be implemented without significant increase in the total capital cost of the ventilation system.
KEYWORDS ventilation system, building component

#NO 4929 Evaluation of an acoustical method for detecting air leaks.
AUTHOR Ringger M, Hartmann P
BIBINF Air Infiltration Review, Vol 11, No 1, December 1989, pp 6-9, 7 figs, refs. #DATE 00:12:1989 in English
ABSTRACT This investigation was performed to evaluate the effectiveness of detecting air leaks in typical constructions through the measurement of sound transmission. The sound transmission of various slits was measured. These were designed to simulate field constructions. Due to the fundamental difference between steady air-flow and sound propagation, it was concluded that the method fails, particularly in the case of foil-covered slits and slits coupled to damped cavities.
KEYWORDS air leakage, instrumentation, sound

#NO 5119 The use of acoustic intensimetry to size air leakage cracks.
AUTHOR Oldham D J, Zhao A
BIBINF Air Infiltration Review, Vol 20, No 3, June 1991, pp 7-9, 3 figs, 3 refs. #DATE 00:06:1991 in English
ABSTRACT The sound intensity technique and reverberant sound excitation have been used for the measurement of sound transmission loss through narrow slits in rigid walls. As predicted by theory, the dimensions of the apertures determine the magnitudes and resonant frequencies of the sound transmission loss curves. It should thus be possible in principle to size air leakage cracks using the technique described in this paper.
KEYWORDS measurement technique, air leakage, crack

#NO 5234 The use of acoustic intensimetry to size air leakage cracks.
Akustische Intensitatsmessung zur Grossenbestimmung von Leckageoffnungen.

AUTHOR Oldham D J, Zhao A
BIBINF Air Infiltration Review, Vol 12, No 3, June 1991, pp 7-9, 3 figs, 3 refs, German Translation. #DATE 00:06:1991 in German
ABSTRACT The sound intensity technique and reverberant sound excitation have been used for the measurement of sound transmission loss through narrow slits in rigid walls. As predicted by theory, the dimensions of the apertures determine the magnitudes andresonant frequencies of the sound transmission loss curves. It should thus be possible in principle to size air leakage cracksusing the technique described in this paper.
KEYWORDS sound, measurement technique, air leakage, openings

#NO 5324 The use of acoustic intensimetry to size air leakage cracks.
AUTHOR Oldham D, Zhao X, Sharples S, Kula H-G
BIBINF UK, AIVC 12th Conference, "Air Movement and Ventilation Control within Buildings", held 24-27 September 1991, Ottawa, Canada, proceedings published September 1991, Volume 3, pp 307-318. #DATE 00:09:1991 in English
ABSTRACT Reverberant sound excitation and the sound intensity technique have been used for the measurement of the sound transmission loss of narrow slits in rigid walls. A series of experiments was conducted to determine the transmission loss of slit shaped apertures. The measured transmission loss was in good agreement with existing approximate theories over their accepted ranges of validity. However, the effect of viscosity in small apertures was found to be significant and to vary systematically with the dimensions of the apertures. As predicted by theory, the dimensions of the apertures determine the magnitudes and resonant frequencies of the sound transmission loss curves. It should thus be possible in principle to size air leakage cracks using the technique described in this paper.
KEYWORDS air leakage, crack, measurement technique

#NO 5520 Field measurement of sound from residential ventilation fans.
AUTHOR Quirt J D
BIBINF Canada, National Research Council, Report No CR-5899.2, 18 February 1991, 12pp. #DATE 18:02:1991 in English, French
ABSTRACT A CSA standard was developed for laboratory testing of residential ventilation fans to provide air-handling and sound emission ratings. A study was performed to evaluate these laboratory test methods, and to assess the relationship between the laboratory ratings and actual field performance.
KEYWORDS sound, noise pollution, fan

#NO 5521 Noise ingress through vents.
AUTHOR Jorro S
BIBINF UK, Building Services, November 1991, pp51. #DATE 00:11:1991 in English
ABSTRACT Passive and trickle ventilators can have an adverse effect on the sound insulation of buildings. The article outlines the UK Building Research Establishment's work in assessing the extent of the problem.
KEYWORDS noise pollution, vent

#NO 5832 Air flow patterns within buildings: measurement techniques.
AUTHOR Roulet C-A, Vandaele L
BIBINF UK, Air Infiltration and Ventilation Centre, Technical Note AIVC 34, December 1991 (IEA Annex XX Final Report). #DATE 00:12:1991 in English
ABSTRACT This handbook is concerned with the measurement of those parameters which are important in gaining an understanding of air infiltration and ventilation. The handbook has been designed so that the material suited to your particular level of interest or current expertise, is readily accessible. The flow chart in Figure 1.1 illustrates the structure. The introduction provides a general overview of infiltration and ventilation in buildings. Ventilation studies are discussed and the aims of the handbook outlined. Part I defines the parameters which are important, presents the reasons why they should be measured and gives a guide to the selection of techniques for particular applications. Summaries of the main techniques available are presented, which are cross referenced with the main body of the handbook. Part II presents the theory and practice of measuring the airtightness of the building envelope and its components.Leakage location and leakage path distribution within the building is also examined. Part III presents the theory and practice of measuring air exchange rates and the related contaminant flow rates. Air exchange between a building and the external environment is examined, as is the air exchange between the various internal spaces of a building. Part IV presents some measurement methods which may be useful to qualify the indoor air and the efficiency of the ventilation system. Measurement of contaminant concentrations are however not described, since another book will be necessary to describe all the possible methods to analyze the thousands of possible contaminants. PartV describes measurement methods which are able to qualify a system, namely to measure the flow rates in the ventilation network and to control its airtightness.
KEYWORDS air flow, measurement technique, air leakage, ventilation system, energy efficiency

#NO 6302 Intelligent building: low consumption and increased comfort.
AUTHOR Traver X, Pujol M, Trias A, Millet X
BIBINF Kluwer Academic Publishers, 1991, proceedings "PLEA 91: Architecture and Urban Space", Ninth International PLEA Conference, Seville, Spain, September 24-27 1991, pp 581-588. #DATE 00:00:1991 in English

ABSTRACT The object of this project is to integrate energy-saving technology (with special emphasis on the use of solar energy) with integral control and management technology, with the aim of designing and constructing in the present day homes with levels of comfort which will be in demand in the near future. In the design of the dwellings the concept of integral comfort is applied: thermal, luminous, acoustic, visual and hygienic to this end the following technologies are used: SAV System: Solar Acoustic Ventilated Window; Microporous brick; ICM system: integrated control and management system.
KEYWORDS residential building, building design, passive solar design, human comfort

#NO 6499 Giving designs a grilling.
AUTHOR Holmes M
BIBINF UK, Building Services, July 1992, pp 25-30, 5 figs, 1 ref. #DATE 00:07:1992 in English
ABSTRACT Many factors can determine the performance of room air terminal devices. Mike Holmes looks at test results in this area, and evaluates simple equations that may be adopted to predict diffuser behaviour.
KEYWORDS air conditioning, diffusion

#NO 6528 Atrium design criteria resulting from comparative studies of atriums with different orientation and complex interfacing of environmental systems.
AUTHOR Kainlauri E O, Vilmain M P
BIBINF USA, ASHRAE Transactions, Vol 99, Pt 1, 1993, 9pp, 13 figs, refs. #DATE 00:00:1993 in English
ABSTRACT Atriums have become successful solutions in commercial and institutional buildings when large spaces are provided for various purposes in multistorey buildings. They are often enveloped with large glass wall and roof areas that provide ample daylighting but also result in complex interfacing of heating, cooling, and ventilating, the stratification of air, and problems with indoor air quality, acoustics, and control of the environmental systems. Research of this interfacing is difficult to perform as simultaneous observations and continuous diurnal and seasonal data recordings are needed in order to better understand how the various systems and conditions interact. The analysis of observations and collected data is also a difficult task, as design conditions vary, the orientation of atriums differs, and environmental systems are often designed with inadequate understanding of the complexity of this interfacing. This author has observed various kinds of atriums for a long time and conducted organized research in several atriums for the past six years. On the basis of these observations and results of the research, relevant design criteria are offered for orientation, the building envelope, HVAC systems, avoidance of stratification of air, indoor air quality, acoustics, and general considerations of design, especially regarding the use of an atrium as a return air plenum and for its function as part of the total building performance and relation to surrounding spaces.
KEYWORDS atrium, commercial building, multi-storey building, building design

#NO 6703 Testing of ventilation systems in forced warm air combustion heated houses.
AUTHOR Saskatchewan Research Council, Building Science Division
BIBINF Canada, Canada Mortgage and Housing Corporation, December 1992, 55pp, 16 figs. #DATE 00:12:1992 in English
ABSTRACT This research project was performed to gather field experience with houses that had ventilation systems that were expected to be able to meet the CSA F326 Residential Mechanical Ventilation Systems Standard. The study focused on houses that had central forced warm air heating systems along with central ventilation systems. Two of the houses had air to air heat exchangers, and two had central exhaust fans. The four houses were built between 1983 and 1986. A total of four houses located in Saskatoon were measured for the following quantities: ventilation rates, room air flows, duct leakage, sound levels, fan energy consumption rates and house depressurization levels caused by the operation of the ventilation system. Three of the four houses had ventilation systems that were found to meet a 0.3 air changes/hour capacity. The fourth house had a measured air change rate of 0.22 ac/h. However, only one of the four houses could meet the minimum ventilation requirement of the CSA F326standard based on the individual room supply requirements. Theminimum ventilation supply requirement for the houses varied between 55 and 70 L/s. None of the houses were able to meet the 30 L/s exhaust air flow requirement for the kitchens, and only two of the houses were able to meet the 10 L/s requirement for each of the bathrooms. Using a strict interpretation of the F326 standard, all of the houses would fail the minimum ventilation requirements. Two of the four houses could meet the ASHRAE Recommended Noise Criterion of NC-30 or less. In one house, the central exhaust fan had been running for seven years with no maintenance or cleaning (there was no filter on the fan). Approximately 6 mm of dust had accumulated on the fan rotor. After cleaning the fan, the air change rate was found to increase from 39 to 63 L/s, and the noise level of the fan was found to drop from 40.7 to 37 dBA. Significant air leakage was found to exist in the ductwork in both the warm air distribution system and in the exhaust air system in a number of the houses. One house was found to have 91% leakage in the warm air distribution system (only 9% of the air entered the warm air return grilles, the remainder of the air entered through duct leakage.)
KEYWORDS ventilation system, heating, mechanical ventilation

#NO 6874 A research project to propose and validate a method to measure the sound power levels generated by fans in field conditions.
AUTHOR Morin M
BIBINF Canada Mortgage and Housing Corporation, December 1991, 26pp, 14figs, 9tabs. #DATE 00:12:1991 in English
ABSTRACT This research project, funded by the CANADA MORTGAGE AND HOUSING CORPORATION is a first attempt to validate a method using intensimetry to measure the sound power levels generated by fans when they are connected to the ductwork of a ventilating system, and operating in real conditions. The goal of the study was to determine the accuracy and limitations of the proposed method. To achieve this, the results of the measurements made according to the proposed procedure were compared with those obtained in a reverberant room using the method described in the AMCA 300standard.
KEYWORDS fan, air conditioning, noise pollution

#NO 6927 Insulating masonry walls.
AUTHOR Bradfield M, Szoke S S
BIBINF Proceedings of the ASHRAE/DOE/BTECC Conference, December 7-10, 1992, 'Thermal Performance of the Exterior Envelopes of Buildings', Clearwater Beach, Florida. #DATE 00:12:1992 inEnglish
ABSTRACT The wide variety of wall constructions that incorporate masonry provides many options for insulating masonry walls. These insulation strategies include interior furring with insulation, insulated cavities, insulation inserts, foamed-in-place insulation, granular fills, and exterior insulation and finish systems. The relative performance of these systems, including energy efficiency, fire resistance, sound transmission, and water penetration, is discussed.
KEYWORDS wall, insulation, energy efficiency

#NO 7854 The sound attenuation of passive ventilations
AUTHOR Jorro S
BIBINF UK, Building Research Establishment, EP234, August 1990, paper presented at the Institute of Acoustics meeting on In-Situ Measurements, 9 pp, 6 figs, 12 refs#DATE 00:08:1990 in English
ABSTRACT The acoustic performance of two types of building ventilator was assessed. These ventilators are openings in the external envelope designed to provide the necessary background ventilation in dwellings. Both are passive in operation: on is a trickle flow type mounted in a window frame and the other is a vertical pipe venting the room from the ceiling to the roof-top by the stack effect.This paper describes a number of field and laboratory investigations carried out to examine the sound attenuation of such ventilators. Passive ventilators showed less variation of sound attenuation with frequency than do windows; sound attenuation was generally better at lower frequencies but worse at higher frequencies. both types of ventilator are therefore likely to increase the indoor noise level due to aircraft far more than if it were due to road traffic. Resonance dips in attenuation were more pronounced with trickle ventilators whilst for stack ventilators there was the apparent anomaly of higher transmission above 630 Hz through each of the smaller diameter pipes than its equivalent of larger diameter
KEYWORDS noise pollution, ventilation system, building envelopes

#NO 8262 Access doors as sound barriers in multiple-unit buildings.
AUTHOR Anon
BIBINF Canada Mortgage and Housing Corporation, Technical Series 93-211, 2 pp.
ABSTRACT This factsheet summarizes the results of a project that looked at the soundproofing of the door itself compared with the soundproofing of the perimeter and bottom gasketing. This comparison was done by testing the doors in two modes: as normal (operable) doors and sealed to their frame. The project also tested a simple method to measure the sound transmission loss and sound transmission class (STC) of doors installed on site.
KEYWORDS noise pollution, door

#NO 8841 Introduction of the decibel units to assess indoor air quality. Part I: A new decibel unit proposal.
AUTHOR Jokl M V.
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 I, pp 31-40.
ABSTRACT Weber - Fechner Law about the perception of a noise during a time period by a man as a logarithmic is also valid for the other constituent: odor component used as a criterion for indoor air quality assessment. New decibel units dB (odor) introduced for indoor air quality evaluation are based on TVOC concentrations these being supposed to be the most important indoor air pollutant at present. The weakest odor a healthy human olfactory organ can detect (i.e. the lower limit of a new decibel scale) is, according to Yaglou s Psycho-Physical Scale, of value one, to which corresponds the PD of about 5.8% and TVOC detection threshold concentration of 50 ug/m 3 = 0 dB (odor). Upper limit is determined by the beginning of TVOC toxic range of 25000 ug/m 3 = 135 dB (odor). Optimal value starting from PD=20% and admissible value corresponding to PD=30% are proposed (see Table 3) thus the same numbers as used for the noise assessment can be used for indoor air quality evaluation and even more: The impact of various constituents (acoustic and odor at present) on the resultant environment level can be estimated. Ventilation for acceptable indoor air quality, important for practice especially for air handling system designing and starting from the new

principles, is presented in the second part of this paper.
KEYWORDS indoor air quality, noise pollution, odour, organic compound

#NO 8842 Introduction of the decibel units to assess indoor air quality. Part II: Ventilation for acceptable indoor air quality.
AUTHOR Jokl M V.
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 I, pp41-48.
ABSTRACT Ventilation for acceptable indoor air quality, especially for air handling system designing, and starting from new principles is presented.
KEYWORDS odour, organic compound, indoor air quality

#NO 8878 Evaluation of the global performance of ventilation fans in the residential sector
AUTHOR Michel P, Guarracino G.
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, pp567-574.
ABSTRACT Fan performances in the residential sector are commonly evaluated according to ventilation criteria, i.e. the primary function of this type of equipment. The products proposed by manufacturers have to bring the best ventilation performances according to technical and financial constraints. However, a global approach integrating equality of life and comfort standards in buildings requires to take into account other criteria such as energy consumption and acoustics parameters. The objective is thus to optimise operating costs while keeping nuisance factors to a minimum, without interfering with the purely technical performances of the ventilation system. Multicriteria classifications have been developed in order to initiate such a global approach, with some disadvantages liked to the classification procedure. We propose in this paper to evaluate different methods to estimate the global performance of ventilation fans in the building sector. A data base was first set up with information collected from French manufacturers on over 430 different appliances. This database included technical and geometrical characteristics, as well as main ventilation, energy and acoustics (when available) features. Following a detailed statistical analysis of this large sample, the definition of indexes and ratios enabled us to propose different numerical or graphic methods in order to compare the performance of the equipments: numerical or statistical definition of different performance indicators, plane graphic representation,... These different methods (and possible variants) are presented in the paper, analysed and compared. A syntheses of these comparisons is proposed, based on the possible purposes of such methods: selection, evaluation, standard,...
KEYWORDS fan, energy consumption, noise pollution

#NO 9250 Noise aspects of ventilation systems in dwellings.
AUTHOR Op t Veld P J M
BIBINF Netherlands, Cauberg-Huygen, February 1994, IEA Annex 27 Evaluation and Demonstration of Domestic Ventilation Systems, Report No. 910767-1, 24pp + app.
ABSTRACT Satisfaction with a ventilation system is largely determined by the perceived indoor air quality, thermal comfort (i.e. draft control) and noise aspects. In practice, controlling noise aspects, in particular reducing noise levels, is one of the most important factors that contribute to the satisfaction with a ventilation system. Noise aspects related to ventilation systems can be divided into two main classes: direct noise and indirect noise. Direct noise is noise generated by the system itself. The system is both the source and the means of transport for the noise. Examples are noise generated by fans and by the mounting materials of air ducts (structure borne noise), and noise generated by control valves and grilles (aerodynamic noise). Indirect noise includes all noise of which the source is outside the system. In this case the system merely transfers noise which originates outside the system. Examples are traffic noise, noise from industrial plants, catering establishments and aircraft (outdoor noise), and domestic noise (internal noise sources). Chapters include problem identification, outdoor noise, noise generated by the ventilation system and sound transportation in or between dwellings.
KEYWORDS noise pollution, ventilation system, residential building

#NO 9547 Design criteria of ventilation for healthy buildings.
AUTHOR Seppanen O
BIBINF Healthy Buildings 95, edited by M Maroni, proceedings of a conference held Milan, Italy, 10-14 September 1995, pp 215-238, 10 figs, 6 tabs, 38 refs.
ABSTRACT The purpose of ventilation is to maintain and improve air quality in a building by removing polluted air and supplying fresh air. In principle, the required ventilation rates for desired air quality can be calculated if the pollution loads, outdoor air quality and requested indoor air quality are known. This method is often referred to as an air quality method in ventilation design. A European prestandard Ventilation for Buildings - Design Criteria for the Indoor Environment outlines such a method. The data for the application of the standard is rapidly accumulating through extensive measurements and is soon available for the general application in ventilation design. Because the data are not yet completed for practical use, additional prescriptive requirements and criteria have to be used in the design of ventilation systems. These criteria

include such aspects as the selection of ventilation strategy, ventilation rates, balancing of airflows, ventilation effectiveness, local exhaust systems, cleaning of intake air, location of air intakes, cleanliness of equipment, air recirculation, air tightness, noise control and demand controlled ventilation. The reasoning behind these requirements is presented and discussed in the paper.
KEYWORDS building design, health

#NO 9577 Ventilation performance and energy consumption in European office buildings.
AUTHOR Roulet C-A, Bluyssen M, Ducanne D, et al
BIBINF Healthy Buildings 95, edited by M Maroni, proceedings of a conference held Milan, Italy, 10-14 September 1995, pp 1299-1304, 4 figs, 6 refs.
ABSTRACT Fifty-six office buildings, selected in nine European countries for being as far as possible representative of the building stock, were audited between December 1993 and March 1994. These audits were performed according to a standard procedure, within the frame of the European Audit Project to Optimise Indoor Air Quality and Energy Consumption in Office Buildings , part of the JOULE Programme (CEC-DG XII). The main purpose of office buildings is to provide a comfortable working environment for occupants. This includes, among others, thermal, visual and acoustical comfort as well as indoor air quality. One of the objectives of the survey was hence to assess the actual quality of the indoor environment in office buildings. Measured parameters concerning the quality of indoor environment included occupant satisfaction, sick building symptoms and concentration of contaminants. Yearly energy consumption data were also gathered for each building. Ventilation performance in terms of air flow rate and indoor air quality was compared to a proposed European pre-standard and related to occupant satisfaction and energy consumption. Theoretically, energy is required to control the indoor climate and indoor air quality. Therefore, it is a common perception that energy savings will result in a poorer quality indoor environment. It was interesting therefore to relate energy consumption to various parameters describing the indoor environment. The results show that good indoor environment is compatible with low energy consumption. Good quality energy services do not necessarily incur a high energy use.
KEYWORDS ventilation performance, energy consumption, office building

#NO 9613 A user-healthy day nursery.
AUTHOR Andersson,J,V .
BIBINF DT (Healthy Buildings 88. Vol 3. Systems, materials and policies for healthier indoor air) Sweden Council for Building Research. Stockholm. June 1988 ed Berglund,B, Lindvall,T. 39-48, 1 tab., 6 figs. 697.949.1
ABSTRACT In September 1988 a unique Swedish building research project will have passed the half-way mark of a three year project assessment. The User-Healthy Day Nursery has been designed and built to minimise the risk of indoor climate problems. The materials have been carefully chosen and inspected, and wherever possible, low-risk materials and construction methods have been chosen. The Nursery is equipped with a very flexible heating and ventilation system to facilitate various combinations of operating mode and settings. The resulting ventilation efficiency, indoor air quality, thermal climate and acoustic properties are measured according to a detailed time schedule. The staff at the Nursery is regularly interviewed regarding their impression of the indoor climate. Results from the evaluation of this on-going full-scale experiment are gratifying.
KEYWORDS indoor air quality, nurseries, sick buildings, schools, ventilation

#NO 9689 The Sistine Chapel: HVAC design for special use buildings.
AUTHOR Bullock C, Philip F, Pennati W
BIBINF USA, Ashrae J, April 1996, pp 49-58, 5 figs, 12 refs.
ABSTRACT Environmental control systems for museums, art galleries and other special buildings typically must control more than just air temperature and humidity, and must often provide much tighter control than is expected from conventional air conditioning systems. The priceless artifacts and art treasures housed in such buildings can be permanently damaged if the environment is not continuously controlled. The comfort of occupants also should be considered. Six principle factors are generally considered in the design of such systems: air temperature, air humidity, light, air circulation, air-borne pollutants, and sound level. This paper discusses these factors and how they were addressed in the design of the air conditioning system for the Sistine Chapel, and provides general guidelines for other special buildings.
KEYWORDS ventilation system, public building, museum

#NO 9706 Ventilation techniques integrated in the building's envelope and structure. The SAV system.
AUTHOR Bonvehi F, Trias A, Traver X
BIBINF France, Ecole Nationale des Travaux Publics de l'Etat, November 1994, proceedings of the European Conference on Energy Performance and Indoor Climate in Buildings, held Lyon, France, 24-26 November 1994, Vol 3, pp 860-865.
ABSTRACT The SAV (Solar-Acoustical-Ventilated) approach to the integration of air renewal and ventilation in the skin and structure of the building is designed to provide high standards of Comfort and Indoor Air Quality all year around with low energy demand. A brief description of how the system works and of the main characteristics of the SAV windows is presented. Performance of the system has been assessed in the Agramunts School project. The system is being applied in three developments in

Spain, Italy and Portugal within the Remma (Residential Energy Management in the Mediterranean Area) project supported by the Thermie programme.
KEYWORDS building envelope, ventilation system, passive ventilation

#NO 9850 IEA Annex 27: Evaluation and demonstration of domestic ventilation systems. Assessments on noise.
AUTHOR Op't Veld P, Passlack-Zwaans C
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 217-225.
ABSTRACT The acceptance and appreciation of ventilation systems is mainly determined by the perceived indoor air quality, thermal comfort and noise. Noise in relation to ventilation systems can be divided into three categories: • outdoor noise (entering the dwelling through ventilation openings, cracks, mechanical supply and exhaust openings etc); • noise generated by components of the ventilation system; • the impact of ventilation systems on sound reduction of partitions (between dwellings, rooms etc). Depending on the type of ventilation system, one or more of these aspects are of concern. Noise related to the ventilation system and components, can result in turning off the ventilation system or closing vents etc. This can have a negative influence on ventilation and indoor air quality. In the framework of IEA ANNEX 27 several noise aspects of domestic ventilation systems have been evaluated. Outdoor noise: In noise loaded areas the selection and the applicability of different types of ventilation systems are determined by the noise level on the facades. A simplified tool is developed to select ventilation systems as a function of the required noise reduction of the facade, room dimensions and design and construction of the facade. System noise: Controlling noise levels caused by ventilation systems is in practice one of the most important factors to contribute to the satisfaction with a ventilation system. Air duct systems in dwellings transport noise generated by fans and aerodynamic noise generated by bends, control valves, grilles etc. ANNEX 27 gives basic formulas to estimate sound power levels of fans and grilles, indication of sizes for silencers and guidelines for design. Impact on noise reduction of partitions: The composite sound reduction is the result of different sound channels from one room to the other. One of these sound channels may be the ventilation system (cross-talk). Cross-talk can be brought about through the air duct system, overflow grilles and ventilation openings in partitions, duct transitions etc. ANNEX 27 provides guidelines for sound reductions of partitions and insertion losses for ducts to eliminate the influence of cross-talk.
KEYWORDS ventilation system, noise pollution

#NO 9934 Aural environment survey in air conditioned open plan offices.
AUTHOR Kang S K, Burnett J, Poon C M
BIBINF UK, Building Serv Eng Res Technol, Vol 17, No 2, 1996, pp 97-100, 2 figs, 3 tabs, 17 refs.
ABSTRACT In this study, a field survey of the indoor aural environment was carried out in 30 air-conditioned open-plan commercial offices in Hong Kong, with over a thousand office workers were interviewed. Subjective responses of the office workers towards their aural environment were collected using questionnaires. Physical noise measurements were performed in an attempt to establish a suitable noise criteria for aural comfort. In addition, the nature of the noise from air-conditioning systems is discussed. Results show that the equivalent sound pressure level and noise criterion are better criteria than noise rating when correlated with subjective responses.
KEYWORDS noise pollution, air conditioning, office building

#NO 10212 Active noise control: evaluation in ventilation systems.
AUTHOR Yeung Y N A, Yiu P C H, Chow W K
BIBINF UK, Building Serv Eng Res Technol, Vol 17, No 4, 1996, pp 191-198, 9 figs, 2 tabs, 19 refs.
ABSTRACT Rapid advances in adaptive signal processing are making active noise control products a practicable proposition. One unit available in the industry was chosen in this study to evaluate its application and effectiveness in controlling noise in ventilation systems. Its performance with aerodynamic and static noises was evaluated against the conventional duct lining approach. Experimental results indicate that the system is applicable in air conditioning systems despite the existence of some constraints that have to be taken care of. It is proposed to use the equipment to supplement the traditional dissipative silencer for noise level control and for the achievement of spectrum balance.
KEYWORDS
noise pollution, ventilation system, duct

#NO 10213 Low frequency noise assessment metrics - what do we know?
AUTHOR Broner N
BIBINF USA, Ashrae Transactions, 1994, Part 2, pp 380-388, 9 figs, 1 tab.
ABSTRACT Notes that sound quality in office and other occupied spaces has been of continuing interest since the 1950s. Existing assessment methods do not account adequately for the low-frequency background sound (less than 250 Hz) in particular low-frequency rumble produced by operating HVAC systems. Discusses the results of research in which more than 75 HVAC noise samples were collected, normalised and categorised in terms of sound quality. Proposes a modified set of room sound quality curves.
KEYWORDS noise pollution, office building, ventilation system

#NO 10214 The sound insulation provided by windows.
AUTHOR Tinsdeall N J
BIBINF UK, Building Research Establishment, BRE Information Paper IP 6/94, 4pp, 7 figs, 1 tab, 4 refs.
ABSTRACT The sound insulation provided by similar types of windows varies considerably. This paper describes experiments on a number of elements which affect sound insulation, including the sealing of openable panes, the type of frame material, the size of the window panes, and the spacing of panes in multiple pane systems. It identifies the main factors and lists the potential insulation values for various types of window. This paper will be of interest to architects, planners and acoustic consultants.
KEYWORDS window, noise pollution, insulation

#NO 10216 When quieter is not better at the office.
AUTHOR Anon
BIBINF Noise and Vibration Worldwide, June 1994, pp 40-43, 5 figs.
ABSTRACT Cites research results showing how office noise affects the productivity of every person in every office. As quieter ventilation systems (such as displacement ventilation) become more common in the UK over the next few years, designers will be faced with a choice between providing active background noise sources to create a masking effect to ensure aural privacy and lack of distraction, or much improved sound insulation within offices. Discusses CIBSE office noise ratings for different types of office area. Examines sound conditioning versus sound insulation. Notes new products coming on the market offering a wider range of options for outside noise control. Presents a case study of when sound conditioning is the economic choice in a new headquarters development. Notes the alternatives considered and their costs.
KEYWORDS office building, noise pollution

#NO 10217 Sick building syndrome: the acoustic environment.
AUTHOR Burt T
BIBINF in: Indoor Air '96, proceedings 7th International Conference on Indoor Air Quality and Climate, held July 21-26, 1996, Nagoya, Japan, Volume 1, pp 1025-1030, 13 figs, 10 refs.
ABSTRACT Reports on a case where low frequency noise centred around 7 Hz was found to occur in several office rooms. States symptoms resulting from exposure to infrasound are typical of sick building syndrome. Many of the occupants exhibited such symptoms. Shows that the low frequency component of ventilation noise is often being amplified in tightly sealed rooms. Maintains that repeated or long-term exposure to such amplified infrasound may be triggering an allergic-type response in individuals.
KEYWORDS sick building syndrome, noise pollution

#NO 10218 Thermal and acoustical performance of "buffer rooms".
AUTHOR Mahdavi A
BIBINF USA, Ashrae Transactions, 1993 (1), pp 1092-1105, 12 figs, refs.
ABSTRACT The term "buffer room" refers in this context to spaces built between thermally, visually and acoustically "controlled" indoor rooms and the "noncontrollable" outdoor environment. Examples of buffer rooms are sunrooms, atria, (enclosed) staircases, and air locks. In a long-term research effort carried out in Austria, buffer rooms were studied with regard to their hygrothermal and acoustical performance within a human-ecological framework. Special attention was paid to the problems of temperature fluctuations and risk of overheating, ventilation rates, and humidity control as well as sound transmission. The research agenda included studies under controlled conditions in SHA, a facility dedicated to building physics research in Vienna, Austria, as well as field investigations. Gives a summarised overview of the content and results of some of these studies, focusing on the issues of thermal performance as well as the acoustical insulation effect of sunrooms and its relationship to natural ventilation.
KEYWORDS thermal performance, noise pollution, sunspace, atrium, natural ventilation

#NO 10219 Sound attenuation in long enclosures.
AUTHOR Kang J
BIBINF UK, Building and Environ, Vol 31, No 3, 1996, pp 245-253, 6 figs, 7 refs.
ABSTRACT An intensive review indicates that among the existing formulae on the sound attenuation in long enclosures, only the geometrical reflection model seems relatively practical. Computations with this model show the following for rectangular long enclosures: with a larger cross-sectional size the relative attenuation from a given section is less but the absolute attenuation with reference to the source power is greater; the efficiency of absorbers is higher when there is lass absorption; and to obtain a higher attenuation, the absorbers should be evenly arranged in a section. In conclusion, it is still necessary to develop a more practical prediction method.
KEYWORDS noise pollution, large building

#NO 10220 The sound of silence.
AUTHOR Brister A
BIBINF UK, Building Services, July 1993, pp 43-44, 3 figs.
ABSTRACT Describes the principles of active noise control systems and their performance in practice based on findings of research by the Active Noise Control Department of the TNO Institute of Applied Physics in the Netherlands. States it is the control of high level, low frequency tones where the active attenuator scores over its passive counterparts. Maintains that for the moment, active noise control is likely to find its widest application in enhancing the low frequency performance of passive attenuators. Describes a combined active/passive system developed by TNO in conjunction with ventilation

equipment equipment manufacturer TROX. Points out that the cost of combined systems is around twice that of passive-only solutions although the price will fall as the cost of microprocessors continues to decline. Describes a brief case study from the USA.
KEYWORDS noise pollution, duct, ventilation system.

#NO 10221 A method for the determination of fiber emissions from sound absorbent materials.
AUTHOR Tolvanen M, Gustafsson T, Tossavainen A, Roine J, Salmi T
BIBINF in: Proceedings of Indoor Air '93, the 6th International Conference on Indoor Air Quality and Climate, July 4-8, 1993, Volume 4, pp 123-128, 4 figs, 5 refs.
ABSTRACT To evaluate the health risk posed by particles emitted from sound absorbent materials used in ventilation channels, the number, size, shape and composition of fibers and other particles must be characterized. A method of studying those particle characteristics has been developed. The number concentration of small particles in the testing chamber was measured with a condensation nucleus counter. Both scanning electron microscopical and optical microscopical analyses were possible for filter samples because of the low particle concentration of background particles in the testing chamber. Some sound absorbent material tests indicated that the airborne fiber levels of the materials were very low in comparison with hygiene limits.
KEYWORDS health, particle, test chamber

#NO 10222 Acoustics Part 1
AUTHOR Oldham D (ed)
BIBINF UK, Building Serv Eng Res Technol, Vol 16, No 1, B1-B24, 1995.
ABSTRACT Presents four short articles dealing with aspects of acoustics and building services - 1) Flow and its noise in heating and ventilation engineering, Fry A, 2) Characterisation of sources of structure-borne sound, Moorehouse A, 3) Acoustic modelling techniques in building services, McCulloch C, 4) Active attenuation of noise in HVAC systems, Leventhall H G, Wise S S, et al.
KEYWORDS noise pollution, ventilation system

#NO 10223 Acoustics Part 2.
AUTHOR Oldham D (ed.)
BIBINF UK, Building Serv Eng Res Technol, Vol 16, No 2, B25-B40, 1995.
ABSTRACT Four short articles dealing with aspects of acoustics and building services 1) Towards generalised prediction techniques for regenerated noise in ventilation systems, by C M Mak; 2) The measurement of sound intensity and its practical applications in building services, by J Shelton; 3) Masking speech and noise with masking sound, by M N Rossi.
KEYWORDS noise pollution, ventilation system

#NO 10224 Designing HVAC systems for optimum indoor air quality.
AUTHOR Lizardos E J
BIBINF Energy Engineering, Vol 90, No 4, 1993, pp 7-29, 14 figs.
ABSTRACT States that HVAC system design must address both high indoor air quality as well as energy efficiency. Points out that economic considerations such as installation and operating costs have impaired many conventional system designs to the point of compromised indoor air quality. Discusses many HVAC design parameters that are critical to achieving adequate indoor air quality. Topics include location of building fresh air intakes and exhaust air outlets, economiser systems, airflow tracking, filtering systems, sound attenuation, humidification systems, room air distribution, coil drain pans and condensate traps, duct zoning, localised exhausts and temperature and humidity control.
KEYWORDS indoor air quality, ventilation system, energy efficiency

#NO 10225 Breaking the sound barrier.
AUTHOR Jannan N
BIBINF UK, Building Services, July 1992, pp 30-31, 2 figs.
ABSTRACT Discusses how designing for grille and diffuser noise is of great importance. Looks at data currently provided by manufacturers and provides some design tips.
KEYWORDS ventilation system, noise pollution

#NO 10226 Wall of sound.
AUTHOR Macneil J
BIBINF UK, Building, 22 January, 1993, pp 46-47.
ABSTRACT Describes the use of active noise control, which relies on creating more sound to counter the effects of the offending sound. It has been used in the construction industry to dull sound from generators and fans coming through ducts, and plans are being devised to use it to stop noise entering through curtain walls. One of its main advantages is that it is effective with low frequency sounds which are hardest to control with passive techniques.
KEYWORDS noise pollution

#NO 10227 Controlling HVAC system noise and vibration.
AUTHOR Schaffer M E
BIBINF USA, Ashrae Journal, June 1993, pp 39-44, 5 figs, 9 refs.
ABSTRACT Describes in some detail the aims and contents of a new ASHRAE publication 'A Practical Guide to Noise and Vibration Control for HVAC Systems'. Explains how, by following the guidelines in the book, HVAC designers and other building industry professionals can minimise the number and severity of HVAC system noise and vibration problems. Illustrates installation examples diagrammatically and comments on them.
KEYWORDS ventilation system, noise pollution

9.1. Other Papers of Interest.

#NO 2483 What do the occupants think?
Vad tycker de boende?
AUTHOR Engvall K
BIBINF VVS & energi, No 10, 1986, p71-74, 6 figs. #DATE 00:10:1986 in Swedish
ABSTRACT Reports on social survey interviews being carried out with the purpose of assessing what occupants think of different energy-saving methods. Parameters include: the occupants' opinion of the ventilation during the winter and summer, the occupants' opinion of the temperature during the winter andsummer, what are the occupants' reactions to noise in apartments and its sources; comparison with previous apartment. Considers that not only heating and ventilation are important factors. Project continues and further interviews with occupants will be carried out in Spring 1987.
KEYWORDS energy conservation, occupant reaction, temperature, sound, flat, ventilation

#NO 2995 Insulation handbook.
Isolering mot utendors stoy: Beregningsmetode og data samling.
AUTHOR Homb A, Hveem S
BIBINF Norway, Norges byggforskningsinstitutt, 1988, Handbook 39, 87 pp. #DATE 00:00:1988 in English
ABSTRACT This handbook contains a simplified calculation method for insulation against external noise together with data for sound insulation of different building elements (external walls, windows, ventilation inlets and roof-contructions). The purpose is to calculate either expected indoor noise level in a known situation or necessary noise reduction number for the different building elements involved when the indoor noise level is limited. All the calculations and data are based upon use of a single number value (RA) for characterising sound insulation against road traffic noise according to Nordtest-method NT ACOU 061 "Windows: traffic noise reduction indices". Tables for adjusting variations in noise source and room-dimensions are available. This handbook is a rewritten version of an earlier NBI-publication (Anvisning 19, 1979). The calculation method is improved and the data for building-elements are considerably extended compared to the former edition. The foundation of the calculation-method is verified in the appendixes.
KEYWORDS sound insulation, calculation techniques, standard

#NO 3628 Acoustic insulation in residences. Isolation acoustiques dans les batiments d'habitation.
AUTHOR Anon
BIBINF France, Lois et textes ministeriels, arrete du 14 juin 1969, modifie par arrete du 22 decembre 1975, 15 pp. #DATE 00:00:1975 in French
ABSTRACT French standard describing acoustic insulation in residential buildings.Plus updated version dated 28/4/1997(also in French)
KEYWORDS standard, sound, insulation

#NO 5037 Energy efficient building in a noisy environment.
Energiezuinig schoolgebouw in een geluidsbelaste omgeving.
AUTHOR Straatman J T H
BIBINF Netherlands, Klimaatbeheersing, Vol 20, No 1, January 1991, pp15-23, 5 figs, 6 tabs, 3 refs. #DATE 00:01:1991 in Dutch
ABSTRACT The acoustic requirements of school-facade, can necessitate a balanced mechanical ventilation. An advantage of mechanical ventilation is that the inside environmental quality can be continually guaranteed. One disadvantage however is that the air handling installation increases the electricity costs. The energy used for heating the ventilation air can be reduced by including a heat recovery unit within the mechanical ventilation system. The electricity usage due to lighting can be reduced by switching the artificial lighting off after each lesson and by eliminating certain lighting by sufficient natural light. This article is a summary of the most important conclusions of an experiment of the energy efficient building of the Hoge school voor Economische Studies (HES) in Rotterdam.
KEYWORDS noise pollution, energy efficiency, school, mechanical ventilation, heat recovery

#NO 5796 Acoustic analysis of ventilation networks.
Traitement acoustique des reseaux de ventilation/silencieux et isolation acoustique des reseaux.
AUTHOR Murmann H
BIBINF CFP, No 519 et 520, November and December 1990, pp 127-131 + pp 85-93. #DATE 00:11:1990 in French
ABSTRACT Study of the acoustic behaviour of ventilation and air conditioning installations, and the acoustic muffling due to the different components. Technical description of solutions which reduce noise; use of silences, acoustic wall insulation.
KEYWORDS noise pollution, ventilation system, insulation

#NO 7714 Heat recovery from exhaust air. Long term performance of residental heat recovery ventilators. Varmeatervinning ur franluft. Langtidsfunktion for fix-system i smatlas
AUTHOR Fahlen P, Karlsson M, Kovacs P
BIBINF Sweden, Stockholm, Swedish Council for Building Research, Report R17:1993, 135pp. #DATE 00:00:1993 in Swedish
ABSTRACT During 1983-1990 SP investigated ten one-family houses equipped with mechanical exhaust/supply ventilation including heat recovery (commonly known as heat recovery ventilators,HRV). The purpose of the investigation wasto record the

interrelationship between HRV,Ventilation system, and building during long periods of operation. Measurements included sound pressures , air-pressures inside the building air flowrates and air-leakage from ducts and HRVs. Air-flowrates have changed considerably. Exhaust air flow rates on average changed -38% with individual variations ranging between minus2 and minus64%. Supply air flow rates on the other hand only changed =0% o on average with variations between -4 and =7%. Walk through audits, combined with interviews of the occupants indicated that nine of the ten installations were in relatively good condition apart from dirty exhaust air ducts. Cleaning of the exhaust air ducts in one of the installations caused the exhaust air flowrate to increase by 32%. The ducts appear to have been correctly insulated in the six installationsthat have ducts outside the insulted building envelope. However, even in the case of insulation without any visual defects the heat losses can be significant

KEYWORDS heat recovery, exhaust, air flow

#NO 8140 Ventilation. Conception et calcul des installations de ventilation des batiments et des ouvrages.

AUTHOR Voillot L (editor)

BIBINF France, AICVF, 1992, 273 pp.in French

ABSTRACT This guide is an aid to the conception and diversioning of ventilation installations established from principles first introduced in earlier guides. Three chapters discuss installations in general, eight others concern applications for buildings in the public or private sector with regard to ventilation. Three appendices consider the evolution of air in premises; the structure of official texts, and the subject of acoustics.

KEYWORDS (ventilation system, calculation techniques)

#NO 8144 Ventilation guide: the developer's guide for residential ventilation. Ventilationsguiden: Byggherrens guide for bostadsventilation.

AUTHOR Werner G, Bangens L, Hult M, Kallman O

BIBINF Sweden, Stockholm, Swedish Council for Building, Research, 1993, publication T19: 1993, 48 pp in Swedish.

ABSTRACT Ventilation Guide is a guide which has the object of helping developers and consultants in selecting the ventilation system for new buildings or major conversion schemes. The chances that a ventilation system will work properly are obviously better if it is made clear right at the outset what the indoor climate is to be like. Thisdepends both on the occupants' demands regarding thermalcomfort, air quality and acoustic conditions and on the property manager's demands regarding running and maintenance of the system and system flexibility. With the help of this book, it is possible to specify quality requirements for the various parameters which affect the performance potential of the ventilation system. Theserequirements are broken down into three standard levels,and for each of these the technical and economic consequences of different choices are described. This book is the first one in a series of three. It will be followed by a ventilation guide for sympathetic conversion and by a collection of examples.

KEYWORDS (residential building, thermal comfort, indoor climate)

#NO 8462 Criteria of assessment of indoor stress. Criteri per la valutazione degli stress ambientali interni.

AUTHOR Petrai A

BIBINF Italy, proceedings of Healthy Indoor Air '94, held Anacapri, Italy, 6-8 October 1994, pp 51-56.

ABSTRACT The research deals with environmental strategies for the control of transformations of pre-industrial residential buildings. The leading point of view refers to the integration of systems: outdoor environment; building; indoor environment. The investigation aims to set up a comprehensive tool for the understanding of the global behaviour of indoor environments (Indoor Air Quality, thermics, lights, acoustics). The focus is on the pointing out of eventual stress, revealing the probable existence of conflicts due to the continual modifications of the environmental logic of the investigated building. An integrated model is proposed for the reading of the global behaviour of indoor environments. At present, tests on a number of pre-industrial buildings are in process to check the degree of applicability of the proposed model. The data input scenarios give an informative picture on the conflicts between actual requirements and shown behaviour.

KEYWORDS indoor air quality, residential building

#NO 9301 Developments in air admissions. Les evolutions de la fonction admission d air: les propositions ALDES.

AUTHOR Nouvel J F

BIBINF France, Agence de l Environnement et de la Maitrise de l Energie, (ADEME) 1995, proceedings of Ventilation des Batiments: Etat des lieux - Prospective , held Sophia Antipolis, 25-26 October 1995, organised by GEVRA, Groupe d Etude sur la Ventilation et le Renouvellement d Air, pp 118-124.

ABSTRACT The entry of air into residences will have to evolve significantly in the next few years. The first of these evolutions are linked to the regulatory environment (New acoustic regulations and standards of design and dimension). It is estimated that studies conducted on the perception of ventilation by users will encourage new responses to the air entry question. The article distinguishes between visible and invisible ventilation needs. Invisible needs must be treated without the knowledge of the occupant. In contrast, the occupant can have a role in regulating the visible ventilation, e.g. odours and kitchen fumes etc.

KEYWORDS standard, noise pollution, ventilation needs

#NO 9305 Mechanical ventilation by insufflation; more comfort, less energy. Ventilation mecanique par insufflation: plus de confort, moins d energie.
AUTHOR Grelat A, Charvet M
BIBINF France, Agence de l Environnement et de la Maitrise de l Energie, (ADEME) 1995, proceedings of Ventilation des Batiments: Etat des lieux - Prospective , held Sophia Antipolis, 25-26 October 1995, organised by GEVRA, Groupe d Etude sur la Ventilation et le Renouvellement d Air, pp 175-184, 2 refs.
ABSTRACT A solution simple to put into effect, effective for the treatment of humidity problems in rehabilitated building, this mechanical ventilation has benefited, following research work, recent developments aimed at improving thermal and acoustic comfort of occupants, and to optimise energy consumption via rigorous regulation of entry of outdoor air.
KEYWORDS mechanical ventilation, human comfort, noise pollution

#NO 9449 Displacement ventilation in commercial premises. Ventilazione a dislocazione in edifici destiati ad uso civile.
AUTHOR Skistad H
BIBINF Italy, CDA, No 2, February 1996, pp 172-185, 32 figs, 7 refs, in Italian.
ABSTRACT The recent publication of the new Italian general law on noise pollution (Lay n 44/95) gives even more emphasis to the problem of noise control in HVAC systems. In this paper a preliminary analysis of the possible consequences of this law is carried out and the design tools, mainly of regulatory nature, available to designers and contractors in this field, are reviewed.
KEYWORDS displacement ventilation, commercial building, noise pollution

#NO 9949 Controllable air ingress in dwellings. Les entrees d'air autoreglables dans les locaux d'habitation.
Barbarin L
France, "Ventilation et Renouvellement d'Air", proceedings of a conference held Sophia Antipolis, 20-21 October 1993, pp 159-167.
The controlled entry of air is aimed at ensuring fresh air in dwellings to the principal rooms (bedroom and living room) with mechanical and natural ventilation. It must on the other hand ensure protection vis a vis outdoor noise when the acoustic qualities of the facade demand it. Gives examples of such regulatory systems, and describes installation procedures, dimensioning, and air flow characteristics.
residential building, noise pollution

Reid E (1991) **Understanding Buildings - A Multidisciplinary Approach.** ,Chapter 6 Acoustics p160-177. ISBN - 582 00971 5

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