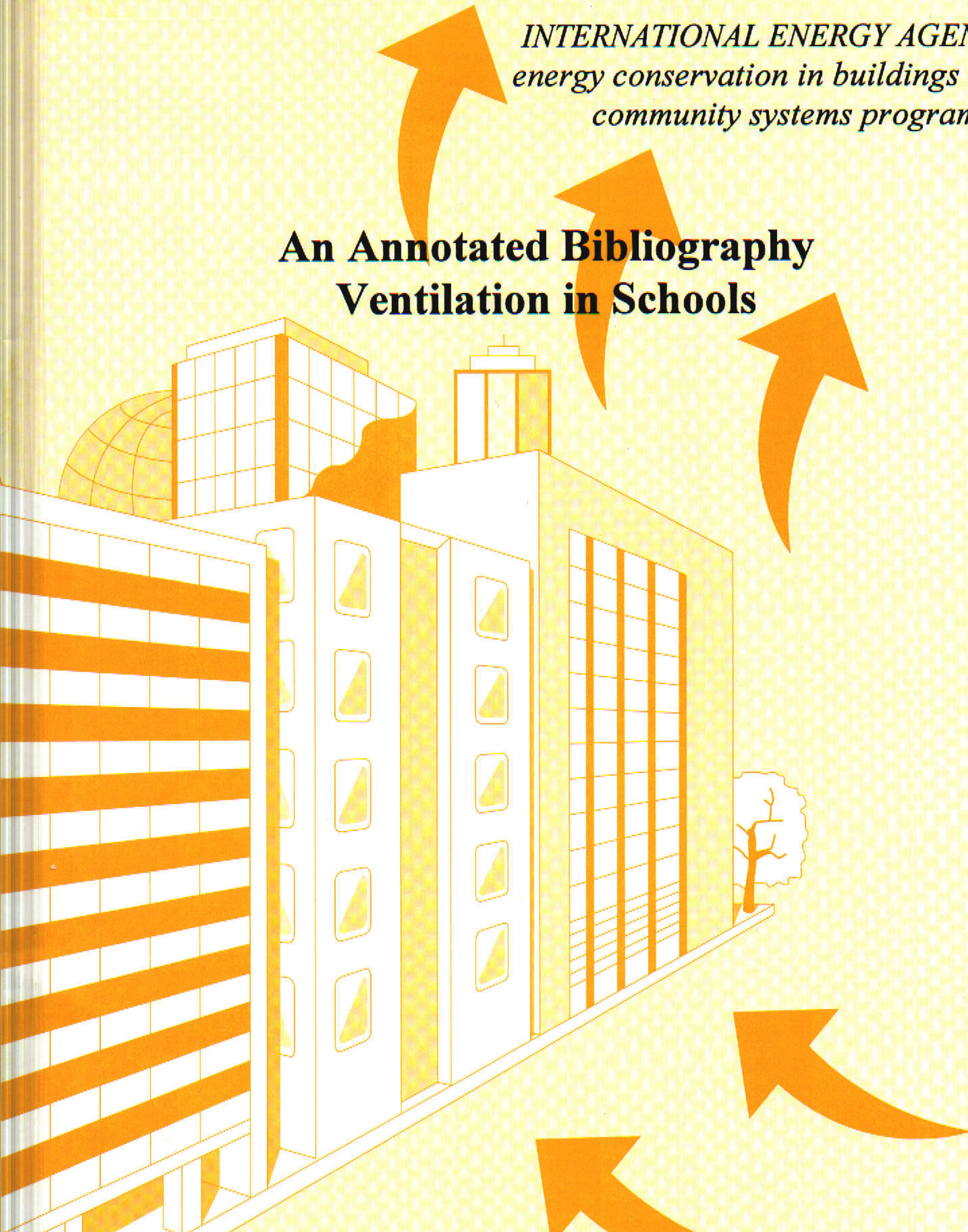
INTERNATIONAL ENERGY AGENCY
energy conservation in buildings and community systems programme

An Annotated Bibliography
Ventilation in Schools



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Ventilation in Schools
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. Seventeen countries have elected to participate in this area and have designated contracting parties to the Implementing Agreement covering collaborative research in this area. The designation by governments of a number of private organisations, as well as universities and government laboratories, as contracting parties, has provided a broader range of expertise to tackle the projects in the different technology areas than would have been the case if participation was restricted to governments. The importance of associating industry with government sponsored energy research and development is recognized in the IEA, and every effort is made to encourage this trend.

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. The Executive Committee ensures that all projects fit into a pre-determined strategy, without unnecessary overlap or duplication but with effective liaison and communication. The Executive Committee has initiated the following projects to date (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*
Annex 20 Air Flow Patterns within Buildings*
Annex 21 Thermal Modelling*
Annex 22 Energy Efficient Communities*
Annex 23 Multizone Air Flow Modelling (COMIS)
Annex 24 Heat Air and Moisture Transfer in Envelopes*
Annex 25 Real Time HEVAC Simulation
Annex 26 Energy Efficient Ventilation of Large Enclosures
Annex 27 Evaluation and Demonstration of Domestic Ventilation Systems
Annex 28 Low Energy Cooling Systems
Annex 29 Daylighting in Buildings
Annex 30 Bringing Simulation to Application
Annex 31 Energy Related Environmental Impact of Buildings
Annex 32 Integral Building Envelope Performance Assessment
Annex 33 Advanced Local Energy Planning
Annex 34 Computer aided fault detection and diagnosis

Annex V Air Infiltration and Ventilation Centre

The IEA Executive Committee (Building and Community Systems) has highlighted areas where the level of knowledge is unsatisfactory and there was unanimous agreement that infiltration was the area about which least was known. An infiltration group was formed drawing experts from most progressive countries, their long term aim to encourage joint international research and increase the world pool of knowledge on infiltration and ventilation. Much valuable but sporadic and uncoordinated research was already taking place and after some initial groundwork the experts group recommended to their executive the formation of an Air Infiltration and Ventilation Centre. This recommendation was accepted and proposals for its establishment were invited internationally.

The aims of the Centre are the standardisation of techniques, the validation of models, the catalogue and transfer of information, and the encouragement of research. It is intended to be a review body for current world research, to ensure full dissemination of this research and based on a knowledge of work already done to give direction and firm basis for future research in the Participating Countries.

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

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1 Ventilation and Infiltration Charcteristics 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.

Ventilation in Schools - An Annotated Bibliography

SCOPE

This bibliography is aimed at researchers, designers and engineers who are seeking an overview of current developments into ventilation designs for schools. It is also aimed at those active in this area and who are responsible for improving energy efficiency and indoor environmental conditions. References quoted in this document are taken from the AIVC's bibliographic database, AIRBASE and, subject to copyright restrictions are available to organizations in AIVC participating countries from the Centre's library service.

1.0 INTRODUCTION

Various factors influence the choice of technique used in the ventilation of schools, not least being an often severe restraint on budget. Ultimately, the need is to design and install efficient, effective and easily maintainable systems. Important design factors include climate, periods of occupancy and the variable nature of occupant activities (e.g. class teaching, physical education and laboratory studies). To ensure a good environment in which the learning process is maximised it is important to consider all these needs.

A review of the scientific and technical literature has revealed a variety of design solutions and case studies. These include mechanical, natural and hybrid ventilation strategies, combined with various heat recovery and cooling methods.

Buildings covered by this report are predominantly schools although some examples of university and higher educational establishments are included.

2.0 PREVIOUS INTERNATIONAL ENERGY AGENCY STUDIES.

IEA Annexes 15 and 18 research

Energy efficiency in schools was covered by Annex 15 of the IEA Implementing Agreement on Energy Conservation in Buildings and Community Systems (#9596, 1992). This study concentrated on the relatively mild climates of Italy and the United Kingdom. In these climates ventilation systems in older schools were found to be predominantly based on window opening, although mechanical systems were used in specific locations such as gymnasiums and swimming pools. Newer schools were found to be more often equipped with mechanical systems, especially in service zones. Schools were also considered as part of Annex 18 on 'Demand Controlled Ventilation' in which various strategies were proposed; these are reviewed in the main body of the report.

A summary of minimum ventilation rates.

3.0 VENTILATION RATE STANDARDS AND REQUIREMENTS.

Based on the AIVC's most recent review of ventilation standards (Limb #7911, 1994) the current minimum ventilation rates for schools in thirteen countries are summarised in Table 3.1. The titles of relevant standards, guidelines and requirements are given in the standards review together with a brief overview of the actual figures quoted.

Table 3.1: Summary of Ventilation Rates for Schools

Country	Ventilation Rates for Schools (As outlined by the various standard, guideline or requirement)	Ventilation Rates for Schools, Normalised to $dm^3.s$-1.p-1
Belgium	General requirement for ventilation of workplaces $30m^3$/h.person	$8.3dm^3$.s-1.p-1
Canada	8 -10 l/s.person	8 to 10 dm^3.s-1.p-1
Finland	6 - 8 dm^3 l/s.person	6 to 8 dm^3.s-1.p-1
France	$15m^3$.h.person	4.2 dm^3.s-1.p-1
Germany	$30m^3$/h.person	8.3 dm^3.s-1.p-1
Italy	1.5 - 5.0 ach	
Netherlands	5.5 dm^3.s-1.person	5.5 dm^3.-1.p-1
New Zealand	8 -10 l/s.person	8 to 10 dm^3.-1.p-1
Norway	General requirement of $7m^3/h.m^2$ or $16.5m^3$/h.person	2 dm^3.s-1.p-1
Sweden	10 l/s.person to 5 l/s.person	10 to 5 dm^3.s-1.p-1
Switzerland	25 - 30 m^3/h.person 12 - $15m^3$/h.person	6.9 to 8.3 dm^3.s-1.p-1(non-smoking) 3.3 to 4.2 dm^3.s-1.p-1(non-smoking)
United Kingdom	5 - 8 l/s.person or 1.0 to 2.0 ach	5 to 8 dm^3.s-1.p-1
United States of America	8 - 10 l/s.person	8 to 10 dm^3.s-1.p-1

New Environmental design guidance

Environmental Design for Schools (Design Note 17), although this is still a draft document these guidelines represent the most up-to-date guidance available in the UK. Section D of this document focuses on ventilation, and briefly states that all occupied areas in a school should have controllable ventilation at a minimum rate of 3 l/s of fresh air per person. All teaching accommodation, medical examination or treatment, isolation, sleeping and living rooms should be capable of providing a minimum of 8 l/s per person. The section further states that natural ventilation is preferred, however supplemental mechanical ventilation may be required in spaces with high functional heat gains, for example kitchens etc. Where mechanical ventilation is required heat recovery can be incorporated to reduce heat losses, although the additional fan energy etc. should also be considered. To account for the unpredictability of natural ventilation air flow, operable windows, grilles and vents should also be provided. The document considers acoustics, lighting, heating and thermal performance, water supplies, and energy (carbon dioxide) ratings.

4.0 MECHANICAL VENTILATION.

Mechanical systems are often necessary in large, complex school buildings and in severe climatic regions where refrigerative cooling and warm air distribution is necessary. In the United States, Zagar (#9603, 1992), for example, concludes that modern schools are very complex and are often utilised for a variety of activities held throughout, and beyond, a normal school day. Such buildings, therefore, may require several different HVAC systems to meet usage requirements. For example, some schools can be open for use, in one form or another, from early morning to 11 pm. Modern schools also have at least one computer area, requiring special environmental consideration. The author stressed the importance of the engineer understanding the needs of a specific school in order to develop and explain the various options to the school administration. He also concluded that it was evident that there is a general lack of HVAC control facilities available in most schools, and if BEMS are present they are often programmed incorrectly with little regard for comfort, building usage or operation. Zagar suggests that in the interests of economy, a number of smaller systems, serving different areas of the school, would be a more efficient alternative to one large system. From an operation and maintenance point of view the author advocates design simplicity in the selection of any system. He also observed that budget constraints usually result in maintenance schedules being changed or postponed resulting in management by crisis. Instead of following an efficient, well planned maintenance schedule, it becomes fragmented and unorganised as staff try to respond to emergencies. Additionally, deferred maintenance will ultimately result in an increase in major equipment breakdowns. Therefore one of the roles of the designer should be to provide formal training in the proper use of the system to the building's staff.

Complex school buildings and extreme climates.

Also in the United States, Robertson (#9604,1992) emphasises the need for value for money and stresses that the demand in the educational sector is for more options such as: better control, longer operational hours, higher efficiency, lower cost of equipment, less maintenance, and, reduced operational costs for less and less. He concludes that the two main problems faced by educational establishments are deferred maintenance on essential systems and lack of understanding of utility rate schedules. He notes that it is important for the designer to select the system that most meets the needs of the establishment, and thus ensure minimum operating costs. Once the system has been installed, regular maintenance is essential to maximise the life of the system and this is where adequate staff training is vital. The utility rate schedules and any incentive programs are also important in reducing

The need for efficient, cost effective systems.

operating costs. This calls for individual understanding of both the system and the school.

Simulation in design.

Becker and Meinking (#4718, 1990) describe a simulation exercise in which an energy analysis program was used to study elementary school energy use as a function of school size and location. Three different size schools, in six different US cities, with varying climates were modelled. Four different heating and cooling systems were simulated; two heat-only and two combination heating-cooling systems. The heat only systems included a steam radiator and a unit ventilator. The combination heating cooling systems modelled were a constant volume multizone system and a constant volume reheat system. In general, results indicated that the reheat system was best suited to locations which experience a mild summer, because it provides good zone control, but it is expensive to operate in cooling mode. The simulation found that, even in San Francisco, this system used between 30 to 40 % more energy than the constant volume multizone type. In both colder and warmer climates the constant volume multizone system is better suited as it provides efficient cooling in warmer climates and better zone control in cold climates, than radiators.

Relation between outdoor air rate and standard of living.

A new formula, which relates the outdoor air rate to the square root of the standard of living is proposed by Jonsson (#9892, 1996). Calculations are presented using this formula which according to the author show that the increase of the outdoor air rate since 1880 in Swedish schools and the increase according to norm values for outdoor air rates in school s, coincide within limits of the accuracy of the calculation methods and within limits of how the norm values are interpreted. This means that the increased standard of living, or the increased value of production per person and year, increases the optimal outdoor air rate. The example of Swedish schools follows this theory. The author notes that this work does not include the profit from installed new ventilation systems in Swedish schools.

Use of ground water heat pumps.

Various case studies illustrate the performance of mechanical ventilation systems combined with ventilation pre-heat, heat pumps, heat recovery and other energy efficiency methods.

Stotz (#9605, 1992) and Stotz and Hanson (#5954, 1992) both describe a method of using a ground water heat pump to provide an economically and ecologically friendly HVAC system for a large school building in Florida, USA. The objective of the study was essentially to design an energy efficient HVAC system to replace the existing system. The climate presented a further problem, because often heating of all classrooms was required in the morning and cooling of some, or all classrooms, was needed in the afternoon. Variations in student load also had to be considered if a uniform temperature was to be maintained. The school, first occupied in 1973, has a student population of more than 2000. It is windowless and includes a single floor of classrooms, shops, band room, library and cafeteria, and a two story gymnasium area. The main building has four and a half acres under one roof. There are four non opening windows on the front of the school and three on the west side. The remaining walls are solid with only double doors to the outside. Inside is like living in a cave, and at the centre of the building you have no concept of the world outside. The building has no skylights either. The original system consisted of two high temperature, hot water, two stage absorption heat pumps which provided cooling, while two natural gas fired boilers provided the necessary heating requirement. Classrooms were provided directly with heat from the central HVAC system, control was only via the central plantroom, large assembly rooms were equipped with more control via the use of room induction units incorporating both heating and cooling coils. The capacity of the boiler was such that it could handle either the heat pump requirement or the combined heating requirement for the building, athletic showers, make up kitchen wash water and swimming pool heating. Although the systems main inflexibility lies with the fact that it could not provide simultaneous heating and cooling to the classrooms, resulting in an uneven temperature distribution within these areas. Cooling load calculations suggested the need for classrooms to be cooled by approximately 40°F (4°C ambient) and the heating requirements could be achieved with ventilation air heated by water in the condensing water temperature range. Three control schemes were developed, normal cooling with reheat, normal heating and early morning warm up. The new system consisted of a more efficient centrifugal heat pump systems arranged in series counterflow. Pumping energy would be reduced, by changing the chilled water range from 42°F to 52°F (5.5°C to 11.1°C), and all control valves were changed from 3 way to 2 way modulating. Heating would involve transferring recovered heat from areas requiring cooling to those areas requiring heating. The aquifer water would provide a heat source /sink by transferring heat to the chilled water during the heating and absorbing heat from the condensor water during the cooling cycle.

The high school operated with its renovated HVAC system for the first time during 1987-88. The new system reduced annual energy consumption by 102,600 BTU per square foot (approx 1,165,536kJ/m^2). Additionally, all classrooms were maintained in a comfortable temperate range. The total cost of conversion was $266,912 (US dollars 1992) which included the cost of drilling two six inch supply wells to a depth of 650 ft (198.12m) and two six-inch injection wells to a depth of 350ft (106.68m). A more convential system would have cost less, however the chosen system had a shorter payback period, even allowing for the higher cost. In conclusion, the authors noted that, where aquifer water in the range of 10°C to 25°C is available, installations using aquifer wells will save energy because of the high COP's produced by heat pumps. For those applications requiring humidity control, such as libraries, museums and computer installations, these systems provide warm water for reheat purposes with no additional expenditure of energy. This configuration is also environmentally friendly with no cooling towers, boilers or furnace.

Heat pumps for winter heating and summer cooling.

A low energy school in the UK equipped with heat pumps and mechanical heating and ventilation, is discussed by DoE&S (#4364, 1986). The schools mechanical ventilation system provides 25% fresh air, which meets the 1985 UK Department of Education's minimum requirement of 30m^3/hr per pupil (8.3 dm^3.s-1.p-1). At startup, the fresh air dampers are closed until the required space temperature has been achieved. The school is heated by warm air which is distributed through a mechanical ventilation system. Three electrically driven air-to-air heat pumps transfer heat from the ambient air to the ventilation air which is then distributed by the ventilation system. Each heat pump has a COP of 2.5 and combined output of 35kW with a 7.5kW auxiliary electric heater arranged in 3 banks of 2.5 kW. This is controlled by a step controller linked to thermostats located outside. The report states that the system in the school operated well without any major maintenance or operational problems. Also, although the annual running costs of the heat pumps where slightly higher than that of a gas fired boiler, it had the advantage of providing summer cooling, resulting in the staff approval of conditions within the school.

Achieves ASHRAE standards with acceptable humidity.

Scofield and Des Champs (#9606, 1993), outline a design concept for a school HVAC system, proposed in response to the ASHRAE 1989 requirement of 15cfm (8 l/s) of outside air per student . This requirement has led to very high relative humidities in classrooms which are located in hot, humid climates and consequently experience high internal heat loads. The resulting poor level of humidity now represents an important indoor air quality issue. The system proposed by the authors outlines a method of both meeting the standard and at the same time ensuring good indoor air quality. The proposed system deals with indoor latent and sensible loads separately, latent loads (room humidity) are controlled by providing ventilation air at a rate which can not only satisfy the particular ventilation standard, but at a temperature that will provide effective humidity control. Space heating and cooling, (representing the sensible loads). is then provided by an alternative system, such as a central hydronic system. The central air conditioning system consists of a roof mounted air handling system with an air-to-air heat exchanger, designed to address daily ventilation requirements and provide adequate humidity control for the classrooms. In summer mode the air to air heat exchanger unit provides sensible precooling and reheating of the outside air while the refrigeration coil effectively reduces the humidifies of the ventilation air. The control of air delivery into the classrooms can be achieved either manually (activated by light switch) or automatically (activated by presence sensors).Outdoor air enters the system, at a design temperature of 94°F Dry bulb, 79°F Wet bulb,(31°C Dry bulb, 23.5°C Wet bulb) it is precooled by heat pipe, and then further cooled by refrigeration to remove moisture. Additional heating required to maintain the desired room temperature is provided by the room terminal unit (hydronic system). Stale air is then returned to the roof mounted unit, and any heat extracted by the heat exchanger. In winter mode air enters the air conditioning unit at a design temperature of 2°F,(-15°C) and is then preheated by the heat pipe, and then by the reheat coil. The outdoor air is then mixed with the air in classrooms to reach the desired 30% RH and 75°F (21.5°C). Exhaust air then passes back into the rooftop unit and recovery of available heat is undertaken using a heat pipe. Any room sensible heating is achieved by the room terminal unit. Also bathroom exhaust air systems can also be ducted into the heat exchanger of these rooftop units for additional energy recovery. It is argued that shifting the sensible load to an alternative cooling and heating system not only saves building space, but also results in substantially lower auxiliary pumping (water vs. air) energy costs. The outside air system can be shut down when the classroom is vacant or the school is closed. It is further argued that the simplicity of the design will aid the quality, frequency and cost of maintenance. The paper also discusses in more detail the manual introduction of ventilation air, activated by sensors or light switches, and the use of heat exchangers to recover heat for the winter situation.

Dutch case studies of energy efficient schools.

Straatman (#5037, 1991), outlines a case study of the Hoge school incorporating an acoustic facade and balanced mechanical ventilation system, in which the internal quality of the environment can be continually maintained. However, the disadvantage with this system is that the air handling installation increases the electricity costs. This can be reduced by including a heat recovery unit within the mechanical ventilation system. Natural lighting can reduce the electrical lighting load of artificial lighting. The project outlined in this paper is the Hoge school voor Econimische Studies (HES) Rotterdam and although this paper is in Dutch it discusses in more detail the school, ventilation and heat recovery system and the energy savings achieved by this investigation.

Combining solar gain with mechanical ventilation.

Bunn (#9608, 1988). describes the Perronet Thompson Comprehensive School in Bramsholme, Humberside, UK, which consists of a steel framework construction, infilled with walls of heavy textured block. The sports hall, library, gymnasium and dinning area form the core of the building and are effectively three stories high, connected by an 80m long glazed barrel vault which forms the roof of the complex. Positioned either side of the core areas lie three, two story teaching blocks positioned around a covered courtyard. Between the internal ceiling and external roof a buffer zone has been created, warm air is extracted from this zone, and distributed the underlying large volume areas, by 14 air handling units, each being responsible for a supplying a particular area, thereby limiting the cross transfer of air as much as possible. Temperatures within this zone have been recorded as high has 25°C during frost conditions, in summer relief vents help to control excessive temperatures. Air enters these zones through high level ceiling diffusers, if the air temperature is too cool, then additional heater batteries help further temper the air, as room or ambient conditions improve the heater batteries cease operating and the vault air is supplied directly to the rooms. If temperatures continue to rise beyond the designed set point, then dampers will reduce the amount of vault air and increase the amount of outside fresh air combination of the supply air, until 100% fresh air supply rate is achieved. The mechanical ventilation system does not serve the perimeter classrooms, but an arrangement of fans allows tempered air from the enclosed courtyards to be transferred between the classrooms and the courtyards. Should additional cooling be required in the covered courtyards, then external vents can be operated. Fresh air is supplied at a rate of 3ach via the stack effect, with extraction being through stacks in the toilets and changing areas. All classrooms have operable windows for further climate control. Under fire conditions material in the transfer grille foams-up, preventing toxic fumes from spreading. Air supply to the auditorium is achieved with a two stage system based on occupancy sensing. The article also discussed electrical services, and heating provision.

Evaporative cooling.

A case study utilising evaporative cooling in place of refrigeration is described by Kimball (#9607, 1989) for a school situated close to Denver, Colorado, USA. The 168,000 sq. ft (15607m^2) school is designed for 1200 students and teachers, and is ventilated and cooled by five two stage direct/indirect evaporative cooled variable air volume (VAV) rooftop units and heated by hot water radiant panels. The author believes that this system not only represents a considerable first cost and operating cost saving over a refrigerated air conditioning system, but also allows the use of 100% outdoor air during the cooling season. With design conditions of 91°F (Dry Bulb) (29.5°C) and 49°F (Wet bulb) (8.5°C), a two stage evaporative cooling system permits 100% outdoor air at 60°F (14°C) to be delivered to the VAV system during the warm portions of the year. The system incorporates an indirect plate type air-to-air heat exchanger as the first stage and a direct Munter's media evaporative section as the second stage. During the cooling season the outdoor air is cooled by the exhaust air first, then the exhaust air is cooled by. spraying the exhaust air stream with water, after which it passes through a plate heat exchanger, with outside air being drawn through the other side. The report undertook an energy analysis of the system and concluded that the configuration described above allows additional amounts of outdoor air to increase ventilation rates during the winter months. It is concluded that this system should be seriously considered for the health advantage associated with the increased flow rate of outside air, coupled with heating cost savings, reduced heating plant size and minimized freeze up problems.

Thermal mass and night cooling

An example of mechanical ventilation combined with high thermal mass and night cooling is described by Rahamimoff et al (#9610, 1987) in which they describe the planning and design of an earth sheltered education building in the Israeli Desert. The building design is intended to cope with both summer and winter conditions, which call for a large thermal mass to moderate diurnal temperature variations. High thermal mass is achieved by integrating building and ground through a combination of excavation and earth bearing. Ventilation plays a critical role in temperature moderation during the summer months. At night when the building is not in use, ventilation fans draw in cool night air through the southern facade of the building and exhaust it through the (open) clerestry windows. This cools off the structure by removing heat that has accumulated during the previous day. During daytime, exterior fans are switched off and a separate set of fans recirculate the interior air in a manner calculated to enhance heat exchange with the night cooled concrete surfaces.

Demand control ventilation.

Various demand control ventilation systems for schools and day nursaries are considered by Mansson and Svennberg (#5249,1991) as part of the IEA Annex 18 programme on demand controlled ventilation (DCV). This focuses on the effect of building layout, and the influence of internal load caused by pupils, on the potential use of DCV systems. They suggest that forced airing during breaks using windows or doors is usually a good solution for schools from an economic point of view, as the necessary time for ventilation is short. However, in some cases this may cause certain inconveniences, such as draughts, outside noise and occasionally some pollution. Although economically attractive, forced air during breaks calls for strict discipline, especially during the winter, as energy use will increase with airing time. As an alternative, it is argued that, DCV systems based on monitoring the concentration of metabolically produced carbon dioxide may be considered where population and activity load varies and energy savings combined with improved indoor air quality can be demonstrated. It is suggested that this control can be achieved either by mechanical ventilation or window opening. Strindehag and Norell (#5604, 1991) and Norell (#5290, 1991) both discuss the long term monitoring of the Jarla School in Nacka, Sweden, which has an installed DCV system. The paper also examines similar systems installed into an auditorium and a conference room. Before the experiment the existing schools mechanical exhaust only ventilation system, gave relatively low airflow rates of approximately 2 l/s per person. This was replaced with a full balanced supply and extract system incorporating heat recovery, where presence sensors are used to control the system operation in each classroom. While the classrooms are not occupied the system supplies basic airflow levels (28 l/s), this is increased to full flow (225 l/s) when the rooms become occupied. This corresponds to 9/s per person with a class size of 25 pupils. Since this new system has been in operation the carbon dioxide content and the airflow to the classrooms have been measured several times. The limit of 1000ppm of carbon dioxide is rarely exceeded, with average carbon dioxide levels of 800ppm being typical during lessons. This compares with the performance of the old ventilation system, which could only maintain levels of carbon dioxide below 2000ppm if windows were opened during the break. The authors therefore conclude that from their experiments an airflow of 8 to 9 l/s per pupil appears to provide a greater amount of indoor air quality control.

5.0 'MIXED MODE' OR 'HYBRID' SYSTEMS.

Some designs aim to take advantage of the benefits offered by both mechanical and natural ventilation systems. These 'mixed mode' or 'hybrid' approaches are designed to operate either on a seasonal basis or on a zonal basis. In either case, the need for fan energy and, often, the complexity of the system itself is reduced when compared with conventional mechanical ventilation. As with various wholly mechanical or natural designs, features are commonly introduced to promote 'passive' summer cooling and the winter pre-heating of supply air. Many case studies in various countries illustrate the success of the mixed mode approach.

Solar preheat ventilation system.

Bowman (#2587, 1986), for example, describes a school that utilises solar ventilation preheat. A mechanical ventilation system is used to transfer this preheated air throughout the various rooms within the school. An additional heating element is incorporated as a backup during the heating season. Ventilation for the summer is provided by roof-top ventilators utilising the stack effect. Ventilators are also provided in the north wall of the classroom.

Water to air heat pumps. The natural stack effect helps increase air movement from the classrooms to the central atrium.

Loxley (#9609, 1992) describes an atrium design school in which the ground floor of the building consists of a ring of comfort controlled rooms situated around a long rectangular courtyard. The upper level of the building centres on an open skylighted area that surrounds the courtyard. The school is equipped with a water-to-air heat pump HVAC system, transferring heat from the warm water circuit to the air circuit. The rooms surrounding the courtyard are divided into ten independent control zones which are served by a specific heat pump. This then distributes filtered air via low velocity ductwork. In summer, a humidistat can be used to actuate the heat pump cooling mode for excess humidity control. All the windows overlooking the courtyard area have fixed glazing and the courtyard doors have automatic closing devices. A natural stack effect forms as air enters the fine cracks around the closed exterior windows. It penetrates the rooms and courtyard before exiting through the cracks around closed rooftop ventilation doors. To enhance natural ventilation the flow of air through the atrium can be controlled by opening the rooftop doors. Vent-door-position indicators and air velocity sensors are provided to give the building operating engineer with positive ventilation control. The author concluded that this preliminary design represents a logical extension of existing building codes and practices. Furthermore, it is claimed that the design demonstrates the immense value of new integrated system philosophy that unites the building ground contact, internal mass, natural ventilation, solar inputs and HVAC equipment in a truly comprehensive machine design.

6.0 NATURAL VENTILATION.

Natural ventilation is common in mild climatic regions.

Natural ventilation is common in mild climatic regions. Wholly natural systems may still make use of local mechanical extractors to deal with specific pollutant zones (e.g. kitchens, laboratories and cloakrooms etc.). The most basic of natural designs are based on window opening. Richalet et al (#7956,1994) for example indicates that the French Regulations governing ventilation in schools do not require that such buildings are equipped with mechanical ventilation except for some class rooms that are devoted to the physical sciences. They conclude that window opening should be sufficient to supply the recommended hygienic air flows.

Guidelines on the use of windows.

Improved guidelines on the use of window opening for ventilation were developed at a UK workshop for local authorities (#2963,1987). This followed some concern that the rate of ventilation was frequently below acceptable criteria. Guidance was based on observations that window opening was largely dependent on outdoor air temperature and that windows are opened less frequently as the size of the room is increased. Recommendations included the need to:

- provide openable windows at both high and low levels to give users reasonable control.
- ensure that windows are well sealed when closed and easy to operate reliably and safely.
- locate openable windows to maximise cross ventilation.
- ensure compliance with health and safety recommendations.
- optimise areas and location of glazing and shading to maximise daylight but minimise the risk of summer over-heating.
- maximise energy efficiency.

Passive solar combined with natural ventilation

The workshop report additionally includes appendices outlining the importance of building shape in relation to energy efficiency and guidance on using a dynamic thermal response model for sizing windows for natural ventilation. The UK Department of Education (#9265, 1994) also offers design guidance for passive solar, essentially naturally ventilated, schools. These guidelines suggest that passive solar features cost no more than conventional design, but can result in at least a 10% reduction in energy use. They also emphasise the contribution renewable solar energy has on the heating and lighting regime of a building, in that it is non polluting and can be effectively used to reduce the energy for ventilation. Guidance is based on analysis of monitored passive solar schools and computer simulation which shows that for significant winter solar gains, windows should face within 30° of due south while the axial orientation of a building, with a central atrium, has little effect on its energy usage. Ventilation in these types of schools is typically controlled naturally, more often than not using a central atrium as the driving engine. Wind and temperature stack ventilation then sucks air through the building and out of the atria at high level. To prevent summertime overheating, it is recommended that approximately 20% of the atrium roof area should be openable. In some instances it is necessary to install ducts and fans to ensure adequate air flow, either as a back-up to natural ventilation airflow, or to provide night cooling. It may also be necessary in rooms such as computer suites or kitchens etc., where good ventilation is vital. Typical examples following these design features are covered in several case studies.

Simulation and natural ventilation design.

Dorer and Weber (#8003, 1994), perform computer simulation analysis on a four storey school building which is passively cooled at night. The authors discuss the operation of the openings on the maximum room temperatures for a hot summer period case. Air flow simulation code COMVEN was coupled with the building and systems simulation code TRNSYS for simulation. For the four storey school building two operation modes are compared, Mode 1, with windows fully opened at night and during the breaks, and in a tilted position during the lessons, and Mode 2, with windows are closed at night, tilted during the lessons and fully opened only for one hour before the morning and the afternoon lessons respectively. Simulation results reveal that for one room during a hot summer period in Lucerne, central Switzerland, the full opening of the windows in the morning rapidly reduces the internal temperature to that of the outside, but due to the higher building mass temperature, in mode 2, the room temperature rises quickly again during the lesson, while in mode 1 the temperature remains on a moderate level. Peak room temperatures differ about 4°C from mode 1 (night cooling) to mode 2. The simulation was repeated, with the same building being retrofitted with a double glazed facade attached to the original structure which remains practically unchanged. Results of this study show that with room windows closed during the night, the rooms are ventilated only through the facade space. Quite large openings are needed to either the staircase or double facade space to cool the building sufficiently by night time ventilation. In the rooms, windows that are openable directly to outside can supply cooler outside air for most of the time during the day and significantly increase the ventilation rate. Therefore for the majority of the time air flow is satisfactory, only for a short period at peak outside temperatures the supply of the uppermost room is from the facade space, which should be avoided. This study has shown that the simulation can help the design of naturally ventilated buildings.

Simulation and atrium design.

Penz (#9597, 1986) describes a school consisting of an unheated glazed atrium surrounded by a hall and classrooms. To aid the design process a thermal simulation study on the proposed building was undertaken. This helped to define a number of additional design features, including the exposure of a large amount of brick work to provide adequate thermal mass. Ventilation preheat was encouraged by leaving the glazed structure and partitions separating the atrium from the classrooms unusually leaky. This was done to allow some air flow between the two spaces. In the real building the authors found that, during the winter, the temperatures in the atrium remained 5 to 9°C higher than ambient, even when the latter was close to freezing. According to the authors this provided confirmation that atria were suitable for providing circulation spaces during winter, and could even be used as a classroom or workroom as the temperature increased. Under summer conditions the stratification of temperatures in the atrium was quite considerable, with a maximum 13°C difference between its roof and floor. Several natural ventilation simulations were performed and it was found that opening the sliding roof and the entrance doors was very effective in reducing the atrium temperatures to almost those of the ambient environment.

Trickle vents and night cooling.

Cohen et al (#9602, 1991) describes an integrated design approach, which provided a combination of climate modifying fabric and energy driven building services. Although all the building s services are discussed by the authors, the ventilation strategy is of particular interest here. In winter, during the occupancy period, fresh air is supplied through large (no further indication of size is given) trickle vents in the classroom walls. Stale warm air flows out at high level through permanently open glazed louvers into the atrium space, and leaves the building via louvres in the atrium ridge. When the building is not occupied in winter, the trickle vents are closed and the ridge ventilator is sealed by manually operated dampers. In warm outside conditions the occupants can open windows to increase the wind pressure or the stack driven natural ventilation air flow rate. During hot weather the building can be cooled by utilising night time ventilation. Manual control is regarded as an important feature. Results indicate that the building operates as designed and has been well received by the occupants.

Brister, for example, (#9598, 1994) outlines the design and services of a new 900 pupil school built in the UK, catering for 11 to 18 year olds. This is a two storey building constructed from a combination of brickwork and exposed steel, all painted white. The anticipated high heat gains from the use of computers in some rooms was an important consideration as was the provision of good daylight. A conventional approach of essentially single sided natural ventilation from openable windows was rejected because of heat load and pupil density. Instead the designers opted for cross ventilation, consisting of openable windows running along one side of each class room and controllable openings discharging into a duct system running along the opposite corridor side. Ventilation chimneys covered with glass were provided to promote the stack effect. For potentially problematic areas such as the library, mixed mode operation was adopted.

Atrium design.

Waterfield (#7526, 1994) outlines a number of schools incorporating natural ventilation and passive solar design. He notes that, although ventilation requirements in schools are higher than some other buildings due to the nature of the occupancy, if fresh air can be passively solar heated, the ventilation heat load may be effectively reduced. Features such as atrium and conservatories address both issues of ventilation preheating and daylighting and have been widely exploited in similar environments. Interestingly, one of the schools outlined in this paper has a 6.2m wide, purpose built, unheated atrium, which is useable for all but a total of about one month during winter, while another has a 5.5m wide heated atrium which is used all year round. Both single story atria provide well lit, popular areas, although problems of overheating have to be monitored. An important aspect was the width of the atrium. Winter loads were predicted to increase only marginally in the extra width of the unheated atrium, although summer overheating could pose problems at over 7m. Increased width of the heated atria, would give rise to both increased winter heating loads and summer overheating.

Piedade et al (#2714, 1987) discusses the use of natural ventilation in Portuguese school buildings, combined with the use of solar collectors as a form of preheater for ventilation air. The normal situation in Portuguese schools means that poor air change rates from inadequate natural ventilation results in thermal discomfort problems. The authors proposed a passive system using natural ventilation, incorporating solar panels integrated into the facades of the building. A numerical simulation was carried out to test their design. The results suggested that the recommended air quality standards, or a considerable improvement of the thermal comfort conditions, were possible using the proposed system, with significant energy savings over a payback period of between 5 and 9 years.

Operational problems.

Some early designs have suffered from some operational and/or comfort problems. The St George's School in Wallasey (now St Mary's), Northern England, for example represents an early attempt in the early 1960's to construct a school using passive solar design. Davies (#2516, 1985); Davies (#2954, 1985) and Hawkes (#9601, 1987) all discuss the school's design and natural ventilation strategy. Various problems relate to the natural ventilation strategy. The building includes opening lights in the solar wall and in the groundfloor classrooms cross ventilation is achieved through high level openings in the corridor partition. On the first floor north facing wall, level louvered ventilators covered by hinged, insulated shutters are used. These permit cross ventilation, but avoid the heat loss problems which north facing windows tend to produce. Summer ventilation for cooling caused problems with teachers expressing dissatisfaction with windows that did not fully open. This feature almost certainly resulted in physical and psychological problems. A proposal was to extend the openable area, thus increasing the air supply rate, and air distribution in the room. Winter ventilation problems were aggravated by the fact that a heating system which rely on solar gain, electric lighting and occupancy heat gains, is incapable of responding to cold ventilation air in the way in which a conventional heating system can. The proposed remedy was to utilise the void in the solar wall to preheat incoming air. It was concluded that while this school did not provide all of the answers to passive solar design, it was innovative and certainly could lead the way to better and more energy efficient designs.

Looe primary school, in Cornwall, Southern England, also presented some problems. Details about this school have been documented by several authors, including Anon (#4369, 1989), Anon (#3793, 1989), Alexander et al (#9600, 1990) and ETSU (#5935, 1991). It incorporates features such as direct solar heating and daylighting of classrooms obtained through a 100% glazed south facade. Across the windows in each classroom are quarry tiled concrete bench tops of blockwork forming a mini Trombewall. The glazed cavity, created by the bench, acts as an accumulator, with ventilation pathways being provided at the bottom and top to promote warm air circulation. Although the design was good in terms of energy efficiency, a number of thermal comfort problems were encountered. Teachers found that opening windows, even a small amount, could lead to extensive draughts across the adjacent workbench, with disruptive effects upon displayed teaching material.

On a substantially larger scale of natural ventilation design is the new School of Engineering at De Montfort University, Leicester, in the UK. The building has been the subject of much study, e.g. Anon (#8222, 1994) and Bunn (#7420, 1993), Ford and Short (#9599, 1994) Ford and Short (1991, #6295). The architects took into account the fact that the building caters for a wide range of activities which have fundamentally different environmental requirements. These include a mechanical laboratory (for experimental hydraulics and thermodynamics) and electrical and electronic teaching laboratories. An in depth analysis of the type of activities carried out within the building seemed to indicate that daylighting and ventilation could be dealt with naturally. Internal heat gains from students, computers and machinery was a major design consideration to avoid over heating in summer.

Natural ventilation in large buildings.

The impact of utilising stack ventilation was thoroughly investigated, using both physical and computer models, by Lane-Serff et al (#6299, 1991), Anon (#7419, 1993), Eppel and Lomas (#6314, 1991). The design of the electrical laboratories included two narrow extraction wings on four storeys with a narrow courtyard between. Low and high level openings are sized to provide sufficient cross ventilation to remove high internal heat gains. Daylighting is controlled partly by light shelves designed to protect occupants from direct sunlight and to reflect light onto the ceiling, providing an even distribution of light across the room. A narrow courtyard provides a source of cool air for the central building in summer, while in winter it provides protection from the wind. The main part of the building is deep plan in design, so the use of natural ventilation had to be carefully considered. Each activity carried out within the building (Classrooms, offices, etc.,) required separate ventilation consideration.

Ventilation shafts from the general laboratory also allow light down into the deepest part of the plan. The main body of the building was originally conceived as five zones, i.e. Zone 1 concourse, Zone 2 classrooms, Zone 3 general laboratory, Zone 4 offices, and Zone 5 drawing studios. Each Zone is ventilated by separate shafts which rise above the general roof level. Preliminary evaluation of heat gains and summertime temperatures in Zones 2, 3, and 4 have shown the benefit of high air change rates in maintaining comfortable internal temperatures and also the importance of avoiding solar heat gains in summer. The concourse and drawing studios are now one zone, ventilated via ridge vents. To combat periodic internal heat gains in the main hall of the mechanical laboratory, ventilation air is introduced at low level via perforated buttresses, which incorporate acoustic quilt to reduce noise transfer. In conclusion, the authors state that the design of this particular building demonstrates how natural ventilation and lighting can be utilised in an urban environment. Also, using traditional building construction, it is possible to produce a building which is economic in both capital and running costs.

Natural ventilation in extreme climates.

Natural ventilation designs have also been attempted in more extreme climates. Roberto and Garcia-Chavez (#8659, 1994) outline a study on how to incorporate natural ventilation and passive cooling alternatives into a library with 1500 occupants, located in Mexico City. Prior to the study, the building had high running costs due to the need for artificial lighting, and reported several thermal comfort problems. The ambient conditions were initially monitored, users were interviewed and solar penetration and shading analysis using scale models was undertaken. The alternatives were then evaluated and it was found that, except for one area, all other areas exceeded 23°C, which is the upper level of the comfort zone obtained for the library. There was a lack of natural ventilation and investigation of the mechanical equipment indicated that it provided insufficient capacity, thus rendering the indoor ambient conditions unbearable for most of the year. In an attempt to remedy these problems, the authors suggested a number of passive cooling alternatives including shading devices, the use of vegetation, landscaping, and the use of thermal mass.

Internal heat gains were reduced by installing highly efficient lighting systems and by the modification of the internal architectural layout, to ensure that heat sources are located to easily dissipate heat outdoors. The stack effect was utilised to dissipate heat from within the building. Using the existing service ducts, air is drawn into the library through the main entrance and leaves through the top of the building, which has an open wind turbine incorporated into the exit. The air movement was further enhanced by the assistance of an air solar collector, facing south and located beneath the wind turbine.

Khafaji and Murta (#4236, 1989), undertook a similar design study for a school in Jeddah, Saudi Arabia. From the initial experimental work, it was found that the use of passive design features, such as convectional air movement, could be utilised in school design, especially cross ventilation during early morning and night to cool the building fabric. Suitable construction materials could also be selected to minimise solar gains, as well as external solar shading devices and the development of shaded areas forming cool pools of air, which could be used to provide cooling. A number of design alternatives were investigated which incorporated these features and the authors concluded that a combination of cross ventilation and active cooling could provide architectural solutions within the original framework. Another suggestion was the creation of cluster groups to improve the existing style of educational buildings in the area. Where conditions are suitable, cross ventilation are proposed. The use of a solar chimney further aids the movement of air through the school, as it draws air from within the building. The authors also stressed the need for thermal mass. Roof design need special attention, to prevent radiation occurring quickly in teaching areas and thus distorting the convectional flow.

7.0 INFILTRATION STUDIES IN SCHOOLS

Air leakage measurements in schools.

Wouters et al (1988, #3150) reports on work undertook in Belgium, where the airtightness of 45 school buildings was measured between 1986 and 1987. The authors found that measured airtightness varied over a wide range at n50 from 0.5 ach to +/- 40 ach, and that the oldest were not necessarily more leaky, with several modern schools found to be very leaky. The point of weakness appeared to be at roof level. The authors found that opening windows was the most common way of providing ventilation, with only one out of the measured schools having mechanical ventilation. Resultant problems caused by poor airtightness levels include, condensation and mould problems, draught problems and insufficient heating power for obtaining comfort temperatures in wintertime in other new well insulated but leaky buildings.

De Gids and Cornelissen (1988) outline a study on simplified methods to predict the infiltration in schools. This simplified tools are used for the calculation of the heating loss due to infiltration and ventilation. Measurements were carried out in several schools, which consist of airleakage, airleakage distribution, infiltration rates by tracer gas and temperatures. The study uses the multizone-model VENCON, and some verification between model results and measurements took place. The comparison of measurements and model results were remarkably good. Some simple tools, like regression type models and simple schemes are given to predict the infiltration of schools. It proved that up until the study took place the assumed infiltration of schools was lower than expected. With results indicating that an average infiltration rate of 0,3 h^{-1} would be quite normal, while 0.6 h^{-1} is exceptional. In conclusion the authors note that these findings make the 0.9 h^{-1} rule of thumb, which was used in the heat load calculations was too high.

In a continuation of the above work Cornelissen and de Gids (1991) outline a report that concerns a model study on the effect of infiltration on energy use of schools, focussed on out-of-school hours. Again using the multizone-model VENCON the following variables were studied: type of school building; number of storeys; air leakage of the school building; the effect of windshielding and the internal leakages. These parameters were investigated over the whole heating season, primairly to obtain information regarding their effect on the energy use.

Six different school types have been investigated, from a normal block type to a so called Carre type with and without patio. The normal block type school and the H type school are also studied with 2 floors. The results showed that the standard school had a volume of 3500 m^3; the average air leakage was 16.9 $dm^3/s.Pa^n$ per m^3 building volume; the minimum value was 3.6 $dm^3/s.Pa^n$ per m^3 building; The highest value was 30.0 $dm^3/s.Pa^n$ per m^3 building.

The study found that the H type school and the normal block type building with 2 floors gave the highest infiltration and energy use, 470 dm^3/s and 457 dm^3/s respectively, suggesting that the number of floors plays an important role. The difference between the block type school one floor and two floors is 66 %. The so called Carre type school with one floor without a patio gives the lowest infiltration and energy use 189 dm^3/s. The difference between the schools with the highest and the lowest in infiltration and energy use is about 240 % .The effect of air leakage is also remarkable. Changing the air leakage from 3.6 $dm^3/s.Pa^n$ per m^3 volume to 30 $dm^3/s.Pa^n$ for the same building the infiltration varied from 107 dm^3/s to 459 dm^3/s. The effect of windshielding is in the order of a factor of two, from exposed to heavy shielding. The influence of internal openings was not very critical unless internal doors were kept open always.

Shaw and Jones (#78, 1979) undertook a program of air leakage measurements in Canadian schools, the results of which were applied to a simplified model of a school building, from which air infiltration and its contribution to total heating consumption could be calculated. Using the 1975 energy consumption figures from 56 elementary schools, eleven were selected, consisting of five of average energy consumption, three of high energy consumption and the remaining three having low energy consumption. Depressurisation measurements were conducted for most schools, and for comparison purposes two schools were tested under both positive and negative pressures. All buildings had an air handling system, and were tested with their respective systems in operation and with them shut down. The authors examination of this limited data, indicated the calculated flow coefficient for the eleven schools, assuming a flow exponent of 0.65 vary from 3.0×10^{-4} to 7.0×10^{-4} $m^3/s.m^2$. The authors conclude that there was no meaningful relation between total energy consumption and the measured air leakage rate. The authors noted that the variation in air leakage from school to school could not be explained by wall construction, since all were similar in design. Further investigation of the school with the highest leakage value, suggested that poor workmanship and lack of concern regarding sealing can lead to high leakage. They also found that with the air handling system shut down, air inlets and outlets contributed between 15 and 43 % of the overall air leakage, with the remainder to the walls. Air infiltration rates calculated from a model school building indicated that those due to stack reaction are significant even for a single storey building. Air infiltration is also shown to be a major contributing factor to annual heat consumption, in that using the model, the annual heating loads were calculated for various combinations of mean annual wind speed acting normally on the long wall and ambient air temperatures between -17.8°C and 23.9°C. The values of air infiltration rates were based on walls of average air tightness.

Shaw (#305, 1980) then undertook further study of two schools from the original eleven selected for the above investigation, schools C and Q. The focus of this study was to investigate wind induced pressure differences across the exterior walls of these two schools. Pressure differences across exterior walls were measured at 7 locations for each school. Pressure readings were taken with the air handling systems operating in both the day and night time modes. Continuous measurement of wind induced pressure differences were conducted for a period of 8 months on 2 schools having different building shapes and wind shielding conditions. Results indicated that pressure difference coefficients caused by wind are a function of wind angle, their magnitudes , varying from one school to another were found to depend on wind direction and the amount of shielding by surrounding trees and structures. Air infiltration at 0 degrees wind direction, using Ottawa annual wind speed data (4.5 m/s or 10mph) with a mean outside air temperature of 1976 heating season (-4 °C or 25 °F) was found to be 0.3 ach for school C and 0.2 ach for school Q.

Air flow simulation combining measurement and modelling.

Galbraith et al (#8240, 1994) outline the variety of techniques used to measure infiltration and ventilation within buildings, including fan pressurisation, and tracer gas techniques. The paper also reviews the various modelling procedures commonly used to mathematically model the physical behaviour of a building under a variety of meteorological conditions, including for example, multi zone and single zones techniques. The authors then outline the work of Srathclyde University in Scotland, UK, who have attempted to combine measurement with modelling data in a dynamic building thermal simulation model known as ESP-r. The use of this model is illustrated by a case study of a large secondary school undergoing refurbishment in Glasgow,. Scotland, UK. The initial objectives of this study was to establish the air leakage characteristics of a typical classroom and to use the test results as a basis for estimating appropriate design ventilation rates for inclusion by the building services engineers into the design calculations. Pressurisation and depressurisation tests were conducted on the classroom in question, which is located at the corner of the school, with exposed facades on the west, south and north, thereby having a large expanse of glazing. Cross leakage tests were also conducted, in additional to fan pressurization tests, to enable the characteristics of the room partition, and ceiling floorslab leakage characteristics to be obtained. This data was then used to formulate a network model of the flow paths relevant to the test room. Examination of the weather data led the authors to accept 10m s-1 as an appropriate wind speed for design conditions. Using this value in conjunction with the results of the computer airflow network simulation for the main test room results in predicted infiltration rates between 2.67 and 6.27 ach. These are well in excess of the CIBSE empirical value of 2 ach, initially assumed by the design engineers for heating plant sizing purposes. The study concluded by suggesting that further window sealing was needed to reduce energy costs to an acceptable limit. Following supplemental draughtproofing further tests were conducted, the results of which revealed a reduction in air infiltration to 1.68 - 2.11 ach. The authors note that the use of empirical data alone can lead to large errors in heating load calculations, such modelling programs can help to actively reduce these errors.

Infiltration and natural ventilation case studies

Schijndel (#8207, 1991) presents the case studies of 20 naturally ventilated Dutch schools which have undergone infiltration tests, using pressurisation test methods. The report is in Dutch but provides an excellent compilation of examples of naturally ventilation Dutch schools.

8.0 INDOOR AIR QUALITY

Chen and Jiang (#6263, 1992) argue that a good indoor environment in classrooms is essential because indoor air quality and thermal comfort are important components influencing the overall level of health and comfort of pupils. Etkin (#9611, 1995), has compiled a report which focuses on the indoor air quality issue in schools. He suggests that schools are particularly vulnerable to indoor air pollution because of cheap construction practices employed in school design. The problems are further compounded by the addition of extra buildings to the original design; poorly implemented energy conservation measures, usually in the form of reduced ventilation and air leakage; high occupant density and tight financial budgets. Etkins' report discusses how to investigate indoor air quality problems in schools, the variety and associated problems of school mechanical ventilation systems, the type of contaminants and their health effects, and Indoor air quality prevention and control strategies. The two main pollutants identified by researchers in schools are carbon dioxide and radon.

Problems arising from poor design, construction and maintenance.

Inadequate ventilation.

Inadequate ventilation has been blamed for many of the complaints associated with poor air quality studies over recent years. For example, Mathisen (#2820, 1987) compared two similar schools in Trondheim, Norway, by studying Sick Building Syndrome (SBS) and absenteeism. One of the schools had lower ventilation rates and a higher incidence of complaints than the other. The author therefore concluded that increased ventilation could be a remedy. Hanssen (#6968, 1993) also investigated the relationship between SBS and the fresh air supply rate in seven Norwegian schools. IAQ experiments were undertaken and questionnaires circulated. Inspection of the HVAC system revealed that many of the air conditioning systems did not work as originally planned. Poor ventilation effectiveness and low fresh air flow rate, combined with a high degree of air recirculation, was typical rather than unusual. The author found that inadequate ventilation (varying from 1 to 8 l/s per person) resulted in poor indoor air quality.

Improving ventilation.

Godish et al (#9612, 1986) outlines a study of a new university classroom building, where many poor indoor air quality complaints had been received. To check how well the ventilation system was working, carbon dioxide levels were measured, using a direct-read infrared analyzer, levels close to, and greater than, 2500 ppm were detected. Further investigation found that the VAV HVAC system was not operating as designed with outdoor air flow rates falling below the required level. Slight modifications to the system were successful in keeping carbon dioxide levels below 1000ppm.

Dealing with high relative humidity and mould.

Downing and Bayer (#8651, 1994) describe the renovation of a school in Augusta, Georgia, USA which experienced a number of indoor air quality complaints, high summer relative humidities and mould problems. The HVAC system delivered 5cfm (2.5 l/s) per student prior to the re-fit, after which it was increased to 15cfm per student (7.5 l/s). This resulted in reducing both pollutant concentrations and corresponding student complaints. A total energy recovery wheel was also installed to control relative humidity to between 30% and 60%. While a larger than average HVAC system was needed it was argued that the recovery system off set any extra energy penalties. Nielsen (#1638, 1984) reports on the results of a study of 11 Danish Schools which examined the relationship between the volume of outdoor air supplied per pupil and their evaluation of the quality of the air in the classroom. During the tests the air flow rate was varied between 3 l/s and 10 l/s. The pupils were then asked to choose the preferred air flow rate. The results of this study found that, in order for 80% of pupils to find the quality of the air satisfactory, an air supply rate of about 10 l/s per pupil was necessary.

Dealing with "Sick Buildings".

Andersson (#9613, 1988) outlines a study of a Swedish day nursery which tried to tackle occupant SBS problems by monitoring and comparing the effects of three different ventilation arrangements. Examinations of similar SBS studies could not find just one cause for the problems, but highlighted a number of possibilities, including excessive moisture, gases and microrganisms, high indoor temperatures, etc. The day nursery tried to identify all of the possible reasons for the SBS symptoms, and provide remedies. The study consisted of two phases, experimental and a three year assessment. The building incorporates a flexible heating and ventilation system to facilitate various combinations of operating mode and settings.

Regard et al (#9065, 1995) extended the work of Richalet et al (#7956,1994), who performed field measurements in four classrooms located near Lyon, France. Richalet showed high CO_2 and aerobiological levels even in classrooms with mechanical ventilation systems. He further found that not only were the air exchange rates insufficient, but also the location of supply and return openings were not always appropriate. This new larger scale study attempted to understand more fully the extent of IAQ problems, and try to improve the situation. Experiments were carried out in a full scale classroom in a secondary school, equipped with mechanical ventilation. The inlet air is a mixture of fresh and recirculated air and experiments were conducted with the ventilation systems turned on maximum speed as to ensure measurable velocities in the classrooms. Three hot film omni-directional probes, an ultrasonic 3-D sensor were used to determine velocities. Tracer gas studies using the decay method were conducted to evaluate the local mean age of air in the room and finally CFD simulations using Fluent was used to solve the non linear time averaged Navier Stokes equation to determine the flow field in the room. In conclusion the authors were able to determine the air quality in the classroom in terms of local mean age of air at different locations within the room. Findings revealed that within the occupied zone of this classroom all seats are ventilated with the same efficiency, although the ventilation rate set for the experiment (200m^3/h) represented twice the normal ventilation rate present under everyday conditions and at the time of Richalets study.

Experiments also compared well with modelled data, and the authors noted that the dynamic behaviour of the decontamination of a given pollutant could be simulated with a CFD code.

8.1 Carbon Dioxide (CO_2) As An Indicator of Poor Air Quality.

Carbon dioxide monitoring.

Metabolic carbon dioxide concentration monitoring is increasingly used as an indicator of deteriorating air quality. In recent years sensors have been used to activate mechanical ventilation. Where IAQ standards for metabolic carbon dioxide exist these are typically set at 1000ppm.

Several studies have been made where carbon dioxide was found an indicator of poor indoor pollution. Awbi and Pay (#8848, 1995), for example, studied four naturally ventilated classrooms and compared ventilation rates with levels of internally generated pollutants, especially carbon dioxide (carbon dioxide). The classrooms were typically occupied for periods of fifty minutes at a time, followed by ten minute breaks. The aim of the study was to investigate why persons entering the classrooms could detect a stale smell during periods of occupation. Classrooms were orientated around a north/south corridor, initial examination of the classrooms leading from the south facing classrooms revealed carbon dioxide concentrations of over 350ppm before occupation, which rose to over 1000 ppm during the first ten minutes of occupation. The corridor outside the classrooms was then tested over a 24 hour period, to study the effects of occupant movement on pollution concentration. Results should that the south corridor experienced a peak carbon dioxide concentration of 2400ppm and the north corridor achieved a maximum of 1350ppm. Tracer gas studies revealed that the air supply rates for the classrooms were poor, resulting in a slow eradication of pollutants. The authors conclude that the base rate ventilation for unoccupied periods was dictated by the need to limit formaldehyde (HCHO) concentrations, emitted from furnishings etc. They, therefore, recommended increasing the ventilation rates to remove occupant generated pollutants, more so than those generated at much lower levels by the surrounding furnishings.

Poor IAQ in modern schools.

Cousins and Collett (#4209, 1989), discussed an indoor air quality study in 12 schools in Alberta, Canada. The aim of this study was to evaluate the relationship between the type of ventilation system, occupant health and comfort, and levels of specific indoor pollutants. Several different categories of schools were studied: those built prior to 1960, those upgraded since 1960, and those constructed after 1960. After conducting an indoor air quality questionnaire study, it was found that the highest prevalence of health and comfort complaints were reported by occupants of schools built since 1960. Three schools were then studied in greater detail, with air quality parameters being physically measured. Results indicated that carbon dioxide concentrations varied substantially with values reaching (2000 to 2800ppm). The authors suspected that the high carbon dioxide values were indicative of the ventilation system being operated ineffectively. Remedial measures included overhauling the outside air dampers, relocating the supply air register and maintaining continuous operation of the ventilation system during periods of occupancy.

The results of a recent survey conducted by Chen and Jiang (#6263, 1992), on the indoor environments of class rooms, indicated that occupants were greatly dissatisfied with: (a) their thermal comfort (80%), (b) stuffiness (70%), and (c) odour concentrations (20%), within classrooms. These complaints were all related to the distributions of ventilation air and pollutants. The main pollutants were found to be bioeffluents and carbon dioxide generated by occupants.

Thermal comfort and stuffiness.

Four classrooms in two secondary schools in Lyon, France, were studied by Richalet et al (#7956, 1994). One school has mechanical ventilation and the other has natural ventilation created by way of openable windows. The study was conducted in order to analyse the indoor air quality and thermal comfort, as well as the behaviour of the occupants towards opening windows. Despite the French regulations advocating the use of natural ventilation for schools, where opening windows are believed to be sufficient to insure the recommended hygenic airflows, the results of this study found that allowable carbon dioxide levels (800-1500ppm) were regularly exceeded during the day, with maximum levels of 7000ppm in the naturally ventilated classrooms, and 3500ppm in mechanically ventilated classrooms. High carbon dioxide levels resulted in occupants opening windows to ease their feelings of unpleasantness. However, the authors do note that no direct correlation could be found between high carbon dioxide concentration levels and frequency of window opening. The recorded openings appear to be associated more with the school timetable than high pollutant concentrations.

Window opening to reduce carbon dioxide concentrations.

Larsson and Olsson (#5982, 1992) have studied the indoor air climate of existing schools in Vaxjo, Sweden. The aim of this project was to determine the influence's of the HVAC systems on the indoor climate in the classrooms before and after the measurements were taken, in order to be able to establish proposals for systems and design guidelines for classrooms for the main environmental parameters including, air flow and temperature etc. Three schools were studied, all having different building constructions and HVAC systems. Preliminary measurements revealed the environmental conditions to consist of high indoor temperatures, low air velocities, high CO_2, low contents of formaldehyde and radon with no abnormal presence of mould and high contents of cat hair in dust. Initially the most obvious problem was over heating. To overcome this sun shading was installed and cool night air was introduced into the building. During the winter on 1991, temperature and CO_2 measurements were made. Carbon dioxide (CO_2) content was related to air flow (in l/s.person) when ceiling supply terminals were in operation. To meet the 1000ppm CO_2 requirement air should be supplied through four air terminal devices at a temperature of 18 °C and at a rate of 6-7 l/s.person. The authors also found that observations of low velocity terminal devices and floor line supply air terminal devices give a lower CO_2 content by the neck of the pupil than the ceiling air terminal

The influence of HVAC systems to reduce carbon dioxide concentrations.

devices. The level is between 100 to 200 ppm lower compared to ceiling air terminal devices at an airflow rate of 6 - 7 l/s per person. Further measurements showed that while the low velocity air terminal device/floor line supply air terminal device gave a better result at the pupils neck level, the CO_2 content was considerably higher by the teacher standing up, which also caused complaints. In conclusion the authors noted that so long as the number and location of ceiling air terminal devices was correctly designed, they would be sufficient to meet the requirement of 1000ppm within the breathing zone, with low air speeds and a small temperature gradient at a flow of 6 to 8 l/s per person. To obtain 800 ppm you will have to double the flow. During the winter with warm radiators cold and double pane windows. low impluse devices and line floor supply air terminal devices will give a somewhat higher content of CO_2 by the neck compared to ceiling devices at a flow of 6 - 8l/s per person. The authors finally recommended airflows of 8 l/s per person, at 18 °C with the number of ceiling air terminal devices at 4 pcs. In conjunction with exteriour shading, ceiling fans and night cooling to reduce indoor temperatures.

The age of pupils affects their susceptibility to poor indoor air quality levels.

Myhrvold et al (#10089; 1996) outline a Norwegian study "Indoor Environment in Schools", the aim of which is to investigate the indoor environment and level of performance in schools of 35 classrooms and about 800 pupils from 8 different schools. Physical measurements were made of the air change rate, ventilation measurements air content of $C0_2$ and VOC as well as air temperature, humidity, radiant temperature asymmetry and air velocity values. Results indicated that mean CO_2 concentrations at the schools at daytime ranged from 601 to 3827 ppm. Closer investigation showed that 49% of pupils were exposed to CO_2 levels between 0 and 999ppm, 25% were exposed to levels between 1000 to 1499ppm and 26% were exposed to levels between 1500 and 4000ppm. The results further showed large CO_2 fluctuations throughout the day, but due to the type of environment this was as expected. However, the authors refer to the SPES performance tests which show significant differences between performance of pupils in environments with respectively low and high CO_2 concentrations. They also found that the older the pupil the better their performance at these tests and the stronger their health symptoms, irrespective of the indoor air quality. More research results are expected from this project in the near future.

8.2 Radon Ingress Into Educational Buildings.

Radon in schools.

Radon is a naturally occurring soil gas that has a potential long term exposure risk. In the United States, an EPA Study (#8537) estimates that 20% of schools have at least one room above on active level of 4 picocuries per litre (Pci/l). Radon problems in schools are also reported in other countries. Three main techniques can be used to prevent or limit the migration of radon into classrooms: 1. Active Soil Depressurisation (ASD) or subslab depressurisation (SSD); 2. HVAC positive pressurisation; 3. Sealing all major radon entry points.

The first two systems have the same goal, i.e. to reverse the driving pressure between the soil and the building, in order to obtain a higher pressure in the lower part of the building than underneath the entire slab, and change the flow of radon away from the occupied rooms. The effectiveness of soil depressurisation is improved by placing beneath the soil floor a clean, coarse layer of aggregate thus allowing air flow and the extension of the field of negative pressure. Several authors, including Leovic (#6432, 1991), Leovic et al (#5515, 1991), Cripps (#8536, 1994), Pyle and Leovic (#5514, 1991) and Grant and Brodhead (#9617, 1991), have studied these systems and their effects.

Radon mitigation.

The interaction between the subslab material and the selected fan is the focus of a study by Leovic et al (#5515, 1991). The authors suggested that essentially, the denser the subslab is packed, the greater the fan power that is required to effectively remove the radon. In the example cited the school had low permeability material (sand) under the slab, requiring a high suction fan to sufficiently depressurise the subslab area to reduce radon. In many slab-on-grade schools the use of utility tunnels is quite common, which may or may not have poured concrete floors. However, even tunnels with concrete floors often have openings to the soil. According to the author, limited studies have looked at utility-tunnel depressurisation for reducing radon levels in the classrooms above. The report also states that, often a significant building negative pressure needs to be overcome due to building mechanical exhausts and the stack effect. Therefore in existing schools active systems are preferred to passive systems.

Subslab depressurisation.

Predicting the impact of radon mitigation.

Cripps (#8536, 1994) also focused on sub slab depressurisation systems or sumps, and stressed the necessity to increase our understanding of how these systems work to ultimately improve the cost effectiveness of their design and operation, and to prevent them from failing. A computer model was used to assess the flows and pressures produced by sumps, and the results compared with measured data, which are then used to predict the likely heating cost of the additional ventilation caused by the sump system.

Pyle and Leovic (#5514, 1991) examined possible radon mitigation measures which are employed in schools with crawlspaces. The authors compared these with natural ventilation, using existing vents in the foundation walls, depressurisation and pressurisation of the crawl space and active soil depressurisation under a polyethylene liner covering the soil. The paper outlined each system and described the measurement procedures and results. They concluded that the soil membrane depressurisation (SMD) technique is the most effective in reducing elevated levels, in both the crawl space and classrooms.

Comparisons of mitigation methods.

Sealing to avoid radon ingress.

Grant and Brodhead (#5452, 1991), outlined an investigation in a school in Pennsylvania, USA that utilised an ASD system with elevated radon levels. The paper described in detail the heating and ventilation system of the school, and the radon testing procedure. The study found that asbestos was present in the old wing of the school, and therefore, prior to any remedial measures being initiated, the asbestos needed to be removed. The authors then recommended the sealing of any unnecessary gaps to reduce radon infiltration.

Building pressurisation.

Another form of radon mitigation technique is the utilization of the building's HVAC system to induce a positive pressure in the interior relative to the subslab area, thereby suppressing radon entry as long as the positive pressure is maintained. Leovic (#6432, 1991) has stated that the additional outdoor air provided to pressurise the building can also help to dilute any radon or other pollutants that are already in the building, or enter through diffusion. One of the main disadvantages of these systems is that some of the rooms in schools, e.g. kitchens, locker rooms, laboratories and auditoriums, operate under negative pressure to exhaust odours etc. Even classrooms designed to operate under positive pressure may develop problems, such as faulty fans, so these effects must be considered when using HVAC systems to control radon levels. Hall (#5513, 1991) stressed that results of investigations have shown that strong, or unequal HVAC effects, can re-distribute indoor radon to areas away from the direct source. In these situations where, for example, sealing is insufficient or radon gas is seeping through porous building materials, alternative measures such as ASD should be considered.

Leovic et al (#5510, 1991) points out that, although ASD systems have been successful in reducing radon levels in some schools, they do rely on having a permeable layer of subsoil. For those schools that do not fullfil the necessary design criteria, but do have an HVAC system, then pressurisation is a possible alternative. Leovic outlines a research program initiated to test the effectiveness of HVAC pressurisation systems in reducing radon concentrations within schools. Four schools were selected in America as part of a nationwide radon program. School layouts and detailed descriptions of their relevant HVAC systems are outlined in the report. Results confirmed the effectiveness of HVAC systems in reducing radon levels. However, this particular study found that the HVAC system did not consistently reduce levels to below 4pCi/L (the US EPA acceptable limit) in all the classrooms monitored.

According to Shaughnessy et al (#7103, 1993), there are other benefits in using HVAC pressurisation systems, which include the ability to control elevated levels of carbon dioxide and other indoor air quality contaminants. To test the effectiveness of the proposed system, two US schools were investigated. Pre- and post mitigation measurements and diagnostics on radon, pressure differentials, the performance of the installed and/or upgraded HVAC systems and specific IAQ parameters, including carbon dioxide, bioaerosols, and VOC's, were conducted at the school sites. The ventilation/pressurisation control strategies implemented in the schools proved effective at controlling radon. Before the system was implemented radon levels ranged from 160 Bq/m^3 to 630 Bq/m^3. However, after system implementation, levels fell to between 19Bq/m^3 to 100 Bq/m^3. Increased ventilation rates resulted in a substantial fall in indoor air quality pollutants.

Comparing radon mitigation methods.

Various other studies have examined the use of these systems as an active radon mitigation method for schools. For example, Witter et al (#4031, 1988) Thompson et al (#5620, 1991) and Brennan et al (#5619, 1991), have all undertaken research in schools and have advocated their use. Witter et al (#4031, 1988) discusses a school in Fairfax County, Virginia while Thompson et al (#5620, 1991) and Brennan et al (#5619, 1991, #5509, 1991) look at studies undertaken in two schools in Maine, USA which both register success using HVAC pressurisation systems.

Several comparisons have been undertaken to establish the effectiveness of ASD and HVAC pressurisation systems in schools. Saum et al (#3784, 1990; #3783, 1990), Leovic (#4205, 1989) both outline work undertaken between 1987 and 1990, in which more than 40 schools in Maryland, Virginia, Tennessee and North Carolina were visited. Characteristics that potentially influence radon entry and impact mitigation system design and performance, were identified. They found that a school's HVAC system can contribute to elevated radon levels, and that pressure control through continuous HVAC fan operation can be an effective, temporary solution in some instances. Also, it was noted that subslab depressurisation systems, similar to those used in houses, can be effective in schools.

Leovic (#6432, 1991) deals with a study which aims to investigate and recommend remedial measures in a New York State school affected by radon problems. The author relates experiences with two approaches to radon reduction and makes a number of general conclusions. Leovic reasons that, in schools that do not have a clean coarse layer of aggregate under the slab to facilitate pressure field extension, it may be necessary to combine ASD and increased air supply to sufficiently reduce highly elevated radon levels. Furthermore, additional radon reductions can be achieved by extracting suction pits and adjusting the flows through individual suction points.

The results of a number of investigations performed in two Belgian schools to define appropriate remedial actions for high radon concentrations are discussed by Cohilis et al (#7298, 1993). The investigations included visual inspections, tracer gas experiments, pressurisation, carbon dioxide and radon concentration tests. The results were used to suggest ways in which to solve the problems. In the first school, the pressurisation method was tested by installing two air supply ventilation systems which produced an overpressure in the rooms. Radon concentrations were measured before and after the ventilation systems were installed. It was found that the use of the ventilation systems were a complete success, in part due to the good airtightness of the rooms. Cohilis suggested that such ventilation systems could be an efficient radon reduction method for schools because their use also allowed the reduction of the high carbon dioxide levels that were measured in the rooms during occupation periods. The second school was fitted with a subslab depressurisation system. It was found that the depressurisations obtained were believed to be sufficient to prevent the entry of radon from the soil. Generally speaking, the authors agreed that both of the methods outlined above provided good radon remedial measures in school buildings, and the simplicity and applicability of the systems were also a positive consideration.

A case study outlined in Indoor Air Quality Update (Anon (#8537, 1995)) described an EPA study of a school's wintertime measurements which showed 18 out of the 19 rooms tested had elevated radon levels above 4pPci/l. Because the schools ventilation system was delivering almost no outside air to the classrooms, investigators recommended some restoration work to correct this. In a follow up test only six of the rooms had high concentrations. The investigators thought that this change was in fact due to the tests being carried out in the warmer, summer months when the stack effect would have decreased and windows might be open.
Craig and Leovic (#5512, 1991) also briefly outlined the various points to consider when regarding the following two main features that are known to affect the rate of radon entry into large buildings: 1. Slab cracks and penetrations; 2. Pressure differentials resulting from the building shell construction and the design and operation of the HVAC system. This paper reiterates much of what has already been said in previous investigations on this subject, such as the intermittent operation of fans leading to elevated radon levels, which can take several hours to dissipate. It focuses on ASD systems, suggesting that they should be the preferred choice for new schools, with potential radon problems, and also discusses various types of sub slab aggregates and size of suction pits in more detail.

Thermal comfort.

Other case studies are discussed by Morth et al (#5517, 1991), who looked at radon measurements in North Dakota schools and Grodzins et al (#5494, 1991, #5496, 1991) and Warren and Romm (#5519, 1991) who discuss the State of Maine School Radon project. All these papers emphasize the high radon levels present in their study schools, but do not recommend any serious remedial measures.

8.3 Other Indoor Air Quality Studies Relating To Educational Buildings.

The thermal comfort of classrooms was the focus of studies by Bischof and Banhidi (#9615, 1984) and Reszegh (#9614, 1983). The former discussed a simulation test which explored the most favourable indoor temperatures for students whilst in a learning environment. Bischof and Banhidi found that the students' performance had decreased by 10am as the temperatures varied from 20 to 24°C, and then again by 11 am when temperatures increased from 24 to 26°C, and finally until 12 noon, when temperatures changed from 26 to 28°C. The most favorable preconditions for mental performance are recorded as being in the range of 18 to 22°C. In the latter paper by Reszegh (#9614,1983) typical lightweight Hungarian school structures are examined.

In these buildings, the internal temperatures can exceed external temperatures and lead to thermal discomfort, especially where there is poor HVAC system operation, design or poor natural air flow. The paper examined a series of theoretical models undertaken to address these issues, and concluded by stating that careful design, orientation and the potential for adiabatic control should be balanced by adequate ventilation.

Humidity problems and fungal contamination.

Bayer and Downing (#9616, 1992) and Anon (#8266, 1994) both recognised the importance of good humidity control in school buildings. They investigated three US school buildings to examine the effects of a lack of humidity control in such buildings. The authors found that each establishment had HVAC systems that provided insufficient humidity control, resulting in favourable conditions for the growth of microbial contamination. This was felt to have contributed to the significant proportion of pupils who complained of respiratory illnesses in each school. The authors noted that, while this report did not represent a controlled study, it did demonstrate the inadequacy of the design and operation of ventilation systems commonly used to meet the needs of humidity control in schools. Anon (#8266, 1994), looked at an elementary school were an IAQ investigation uncovered fungal contamination. Further study revealed that poor maintenance and a lack of understanding of the consequences of neglect was a prime cause.

Types of mould that can be used as an indicator of moisture problems.

A similar study was conducted by Meklin et al (#9964, 1996), who aimed to characterise the microbiological status of four Finnish schools with or without moisture problems. Air and surface samples were taken, and the total concentrations of airborne fungi in three problem schools were 5-530 cfu/m^3 and in the reference school 21-160cfu/m^3. Among the findings of this study the authors noted that children entering the classrooms and corridors increased the concentrations of airborne fungi. Their were higher concentrations of actinomycetes in all of the problem schools and therefore can be regarded as an indicator of moisture problems. The authors also found that among the spores detected in the various samples taken, Aspergillus, Mucor, Stachbotrys and Trichoderma were only detected in samples taken from the problem buildings.

Mould and asthma related problems.

Smedje et al (#9965, 1996) investigated the relation between indoor environment and the occurrence of asthma as part of a Swedish school environment project. The authors tested the theory that asthma was assumed to be related to different characteristics of the school building, fittings, and furniture, pollutants in the classroom air, psychosocial factors in the school environment and personal factors and exposures in the home. Sixty one percent of the schools studied had mechanical supply and exhaust air systems, without air conditioning, and 27% had natural ventilation. Nineteen percent of the classrooms showed signs of damp or had mouldy smells. The mean air exchange rate in the classrooms was 5.5l/s per person. In 41% of the classrooms CO_2 concentrations were greater than 1000ppm. Dog allergen was found in all schools and cat allergen in all but one school. The study concentrated on school employees, and results indicated that asthma was more common among those who had recently painted their dwelling indoors and those who experienced more stress at work. The results of this study agreed with similar studies in finding a relation between asthma and total airborne moulds. In conclusion the authors found that the condition of the school building affects asthma symptoms among school employees. The results stresses the importance of building, maintaining and cleaning the schools to limit the exposure of asthma suffers to microbial growth.

A similar study has been conducted by Masuda (#9966, 1996) who focused on mite allergen levels in dust from carpeted floors in Japanese schools. The introduction of carpets into Japanese schools has been a recent development, associated studies are therefore rare, but the negative effect of carpets on allergic children with asthma and atopic dermatitis is well documented. House dust mites were collected (for comparison), and school dust samples were collected from four typical types of classroom. Results indicated that mite allergen levels in dust samples from convential wooden floored classrooms were less than 10 u g/m^2 and was not dependent upon stories of school grade. Open style classrooms with carpeted floors were as low as convential classrooms and significantly lower than those of house dust from residences. Closed classrooms with carpeted floors had higher allergen levels, with mite allergen being more prevalent in ground floor rooms. Results also indicated that seasonal changes of the highest levels of mite allergen in July or August (moist and hot season in Japan) and low levels in November were observed in classrooms, confirming the importance of humidity to the propagation of mite allergen. The authors conclude that humidity control by ventilation is a vital measure to reduce asthma and atopic dermatitis as well as avoiding carpets in closed - style classrooms.

Outdoor pollution and indoor cleaning products.

A school indoor air quality study by Gusten and Strindehag (#9098, 1995), showed that the quality of the indoor air can depend quite heavily on the sources of outdoor pollution. They also found that the effects of cleaning products can take several hours to dissipate from within a room and more importantly, the outgassing of paint can take several weeks to be removed. Gusten and Strindehag's study, carried out in Gothenburg, Sweden, warned that outdoor air sources, such as traffic, is not only responsible for poor noise conditions, but can also contribute to internal build-ups of pollutants. It is, therefore, essential that HVAC systems are operating properly and are thoroughly maintained. Furthermore, it is suggested that the design of such systems for schools should allow for different teaching methods, such as group working, and should also pay particular attention to the location of air inlets, to restrict the introduction of outdoor air pollutants.

Poor maintenance and operation or under sizing.

It appears that most of the occurrences of poor air quality can be blamed on inadequate air flow rates, brought about by poor maintenance and operation, or under sizing at the design stage. Most of these problems are easily remedied by adjusting the air supply rate to match the required occupancy levels. However, the upgrading or replacement of mechanical ventilation equipment can be costly, which is an important consideration in many of today's schools. This fact makes the choice of the right ventilation strategy a vital design consideration for all engineers undertaking school design.

9.0 CONCLUSIONS

Most educational buildings represent a difficult combination of ventilation problems, many of which have been highlighted in this review. These typically include a relatively transient population where intense periods of work are regularly punctuated by periods of intense movement. Local climate typically dictates the type of ventilation system adopted within educational buildings.

Natural ventilation system commonly occur in schools which experience a temperate climate. Ventilation by windows or by utilising stack driven flow are typical strategies. In some regions where the climate is more favourable, passive solar designs are common. However, a number of general points have been raised in the above review relating to natural ventilation systems For example, there should be adequate number of windows to provide sufficient daylighting. Where these windows are used for ventilation there should be enough at both high and low level, the position of such should enhance the designed ventilation system. They should also give good overall control, being sufficiently airtight to restrict air leakage for energy and comfort reasons, but easily openable for ventilation. Recent studies have suggested that with the extended use of IT and increased pupil density in most modern schools the use of single sided ventilation can not be relied upon to provide the necessary ventilation requirements. Cross ventilation is suggested as being a more appropriate alternative.

Solar overheating in schools with large glazed areas is important consideration. Therefore use should be made of shading, the surrounding area, thermal mass and the use of reflective colours. The use of a central atria to drive this ventilation system is not uncommon. One advantage of these systems is that they address the problem of ventilation preheating, where cool air trapped in these features is heated by solar radiation and is then used to ventilate the remaining classrooms. Several cases studies are discussed in this review which outlines the use and applicability of these different systems.

Infiltration has also been studied with poor workmanship and a general lack of understanding regarding the sealing of air leakage cracks being cited as the main cause of such leakages.

Mechanical ventilation on the other hand, occurs more commonly in areas that experience climatic extremes, such as hot, humid parts of the US. Although the wide range of activities currently undertaken in many modern schools means that mechanical ventilation is capable of meeting these differing needs throughout the whole day, which very often extends beyond the normal school day. In rooms with very high cooling demand, such as computer suites and kitchens which require continual ventilation, which cannot be guaranteed by natural means the use of HVAC systems in these areas are essential.

Due to strict budget constraints that now exist in most schools, a number of vital considerations must be considered by the designer from the beginning, including the most apt and suitable choice of system should be considered for the specific school and above all should capable of being flexible.

Adequate HVAC control must be included and any BEMS must be properly programmed. A good level of maintenance is essential, and thus the system must be as simple as possible. A planned maintenance schedule is also important, with deferred maintenance ultimately resulting in serious major equipment breakdowns. A thorough understanding of the system and its uses can have significant benefits, for example, the way in which the school buys its energy. Utility companies may give special rates or discounts to schools under certain conditions or incentive programs.

Several cases studies are discussed in this section which outlines a variety of different HVAC systems including air conditioning and demand controlled ventilation . Several systems incorporate heat recovery devices, such as heat pumps, and heat exchangers. Although mechanical ventilation systems operate during periods of occupancy, it has been suggested that the air in classrooms is purged during the relatively short break periods, by opening windows and doors. This represents an economically attractive form of ventilation, because the ventilation periods are short. Although it does require strict discipline, especially in winter, to maintain this activity, especially as draughts, noise and outdoor pollution can often present problems.

Indoor air quality concerns in schools centre around high levels of $C0_2$ and Radon, although moisture, thermal comfort and the effect of external pollutants have also been studied. High levels of carbon dioxide have been associated more with insufficient and inadequate ventilation than with excessively high emitance from pupils and staff. Suggested remedies more often than not, include improving the present ventilation system or in some instances upgrading part or the entire system, the effect of which is to increase the ventilation rate. With radon, the solutions are not as straight forward. Pressurisation or suction are the two opposing methods, each being effective for particular individual cases. It would seem that most other IAQ problems encountered in schools can be remedied or avoided by effective design and careful maintenance and investment.

The papers outlined in this review have considered a wide variety of ventilation problems in schools, and have clearly demonstrated that there is no definitive answer as each building is an individual entity and as such may exhibit quite different problems from its neighbour.

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3) Weatherstripping windows and doors. **4)** Caulks and sealants.
5) Domestic air-to-air heat exchangers. **6)** Air infiltration in industrial buildings. **7)** Air flow through building entrances.
8) Air infiltration in commercial buildings. **9)** Air infiltration in public buildings. **10)** Carbon dioxide controlled ventilation.
11) Occupancy effects on air infiltration. **12)** Windbreaks and shelterbelts. **13)** Air infiltration measurement techniques.
14) Roofs and attics. **15)** Identification of air leakage paths.
16) Sick buildings. **17)** Flow through large openings. **18)** Control of cross contamination from smokers. **19)** Location of exhausts and inlets.

Ventilation in Schools Bibliography Update March 1998

#NO 9980 Air flow and thermal comfort simulation studies of wind ventilated classrooms in Malaysia.
AUTHOR Rahman S A, Kannan K S
BIBINF Pergamon, 1996, "Renewable Energy", proceedings of the World Renewable Energy Congress, held Denver, Colorado, USA, 15-21 June 1996, Volume 1, pp 264-267.
ABSTRACT A CFD software called VORTEX is used as a tool to simulate air flow and thermal comfort in naturally wind ventilated classrooms of an educational institution, which are a different locations, have different configurations and slightly differing outdoor environmental conditions. Simulations of the various classrooms are compared to get the most thermally comfortable and uncomfortable naturally ventilated classroom. An analysis of the simulations will be done, taking into consideration, among other, location of inlets and outlets and the sheltering effect of the surrounding built-up environments. Recommendations will then be made on how to improve the ventilation of the least comfortable room, based on hypothetical simulation results.
KEYWORDS air flow, thermal comfort, simulation, school

#NO 9990 Energy efficiency, ambient comfort and sustainable solar technologies for educational buildings.
AUTHOR Garcia-Chavez J R
BIBINF Pergamon, 1996, "Renewable Energy", proceedings of the World Renewable Energy Congress, held Denver, Colorado, USA, 15-21 June 1996, Volume 3, pp 1409-1412.
ABSTRACT The use of passive solar cooling strategies offer real opportunities for improving the ambient comfort conditions in building whilst reducing the energy consumption due to the use of mechanical systems for space climatization. This research examines the potential of passive solar cooling strategies in an educational building. The alternatives proposed for investigation consisted of a wind tower system handling the temperature difference gradient and direct wind pressure effects. A new fenestration system on the south facade, implementation of an integrated energy efficient lighting system (including lamps, luminaries, ballasts and controls), and landscaping[ping features in a micro-climatic approach, to provide a pre-cooling effect, were also proposed as additional strategies. Results have shown that passive solar cooling has the potential to improve ambient comfort conditions in these type of building, dominated by large internal heat gain loads. Energy consumption die to electric lighting and mechanical space climatization was cut off by 60%. At this stage, and after the implementation of the techniques, monitoring of the ambient conditions will be conducted for a period of twelve months. It is also expected that the results of this research can be applied in other buildings with similar conditions in Mexico.
KEYWORDS passive solar design, cooling, school, wind pressure, stack effect

#NO 10035 Distributions of sensory evaluations on thermal and cross ventilation conditions in naturally ventilated temperate climate classrooms.
AUTHOR Iino Y, Hoyano A
BIBINF Indoor Air '96, proceedings of the 7th International Conference on Indoor Air Quality and Climate, held July 21-26, 1996, Nagoya, Japan, Volume 1, pp 1031-1036.
ABSTRACT Using data from a large number of teacher questionnaires distributed to public elementary schools in Kawasaki, Japan, we determined factors having the strongest influence on their sensory evaluations of thermal and cross-ventilation condition in natural-ventilated temperature-climate classrooms. These influential factors were derived from various factors regarding thermal-related environmental control used by teachers and classroom architectural planning factors. Then, using data from student questionnaires, we determined seating-dependent distributions of similar sensory evaluation for groups of classes with respective category of influential factors. AS the result, windows and door were fully opened except being closed for the safety and noise control reasons. The class directional orientation and the window types related to architectural openings had the strongest influence on sensory evaluations. The classrooms facing southward and having window types tend to be fully opened provided the most comfortable thermal environment.
KEYWORDS occupant reaction, cross ventilation, school

#NO 10180 School woes continue, despite $400,000 and two investigations.

AUTHOR Anon
BIBINF USA, Indoor Air Quality Update, December 1996, pp 8-12.
ABSTRACT Case study of a school which has suffered from repeated sick building complaints from students and staff despite remedial measures which had been carried out. Gives a building description, history of symptoms, details of the two investigations carried out, and the results, which revealed numerous deficiencies in the building design and systems which could affect IAQ. Safety violations were also identified in the laboratories in relation to hazardous chemicals. Among the design and system problems were: O/A ventilation rates below state requirements or industry standards; exhaust ducts that were designed but never installed; O/A intakes too close to refuse areas, loading bays and a service road; odour causing activities in rooms which were not designed for them; radon levels above the federal action level; dirty and malfunctioning unit ventilators; recirculating air from exhaust hoods; boarded up O/A intake vents; and malfunctioning equipment. Recommendations and remediation measures taken are also detailed.
KEYWORDS school, sick building syndrome, building design

#NO 10215 The influence of noise on children's hearing level.
AUTHOR Szanto C
BIBINF in: Indoor Air '96, proceedings 7th International Conference on Indoor Air Quality and Climate, held July 21-26, 1996, Nagoya, Japan, Volume 2, pp 379-383, 1 fig, 3 tabs, 9 refs.
ABSTRACT The present study evaluated the hearing threshold level (HTL) in two groups of school children aged between 7-12 living in a noisy (508 pupils) and in a quiet (522 pupils) district of the town. In order to point out the noise induced hearing loss, we eliminated the subjects with serious otis media and genetic hearing loss, remaining for the study 435 and 442 pupils. From the noise assessments within the two school classrooms, results an equivalent level of 56.2 dBA and 46.6 dBA respectively. The increased HTL on high frequencies (7-13 dB in boys and 4-8 dB in girls) registered in pupils from noisy district, cannot be fully explained with the 10 dBA higher background noise level. The interview held among children showed that listening almost daily of loud rock music (80-101 dBA) has the most damaging effect on hearing, from leisure time activities. This activity was found in 68% and 35% of pupils from noisy and quiet district schools. In conclusion it is quite probable that even slight losses in indoor and outdoor environment such as todays classrooms with their high noise background level or noisy leisure time activities, may affect listening and learning procedures markedly.
KEYWORDS school, noise pollution

#NO 10284 Measured field performance and energy savings of occupancy sensors: three case studies.
AUTHOR Floyd D B, Parker D S, Sherwin J R
BIBINF USA, Washington DC, American Council for an Energy Efficient Economy (ACEEE), Proceedings of the 1996 Summer Study on Energy Efficiency in Buildings, "Profiting from Energy Efficiency"
ABSTRACT Occupancy sensors have the potential to significantly reduce energy use by switching off electrical loads when a normally occupied area is vacated. While occupancy sensors can be used to control a variety of load types, their most popular use has been to control lighting in commercial buildings. Manufacturers claim savings of 15% to 85%, although there is little published research to support the magnitude or timing of reductions. Energy savings and performance are directly related to the total wattage of the load being controlled, effectiveness of the previous control method, occupancy patterns within the space and proper sensor commissioning. In an effort to measure performance, energy savings, and occupant acceptance, occupancy sensors were installed in a small office building and two elementary schools. 15-minute data was collected to assess performance. The three sites varied not only in size but also by occupancy patterns, occupant density, and the previous manual control strategies. Aggregate time-of-day lighting load profiles are compared before and after the installation and throughout the commissioning period when the sensors are tuned for optimum performance. For instance, savings on weekdays in the office building were less than 10% prior to the commissioning, although nearly doubled by proper tuning of the time delay setting and correcting false triggering problems. False ``ons" during evening hours also affected savings. Occupant acceptance, sensor performance, and commissioning aspects are discussed as well as some recommendations for improved performance.
KEYWORDS field monitoring, sensor, occupancy effects, office building, school

#NO 10355 Mitigating the impacts of ASHRAE Standard 62-1989 on Florida schools.

AUTHOR Davanagere B S, Shirey D B, Rengarajan K, Colacino F
BIBINF USA, Ashrae Transactions, Vol 103, Part 1, 1997, proceedings of the Ashrae Winter Meeting, Philadelphia, 25-29 January 1997.
ABSTRACT Ashrae Standard 62-1989 effectively raised the minimum outdoor air requirements for ventilating school classrooms by a factor of three. The impacts of Ashrae Standard 62-89 on a typical Florida elementary school were studied by performing annual building energy simulations using computer software. A single prototypical school was modelled for three cities: Miami, Orlando and Jacksonville. The performance of a conventional HVAC system and several alternative technologies were investigated to assess their ability to mitigate the impacts of Ashrae Standard 62-89 while maintaining acceptable indoor humidity levels. In addition, the installed first costs and life cycle costs for all HVAC systems investigated were estimated and compare to identify cost effective options.
KEYWORDS standard, school, outdoor air, modelling

#NO 10418 Research compares airborne contaminants in two classrooms.
AUTHOR Anon
BIBINF USA, Indoor Air Quality Update, February 1997, pp 3-4.
ABSTRACT Describes two research studies conducted in schools which indicated that carpets have little effect on airborne contaminants. One study compared a carpeted classroom with a tile floor classroom and found similar levels of contaminants. The other study looked at complaint rooms and found little association between health complaints and carpetborne contaminants. The researchers in fact found a closer association with high indoor relative humidity.
KEYWORDS school, pollutant, floor coverings

#NO 10443 Investigation finds correlation between symptoms and humidity.
AUTHOR Anon
BIBINF USA, Indoor Air Quality Update, February 1997, pp 5-7.
ABSTRACT Describes a study which monitored six Florida schools' carpeted classrooms for both settled and airborne contaminants. While finding low levels of dust mite and mite allergens in indoor air, as well as generally low fungal concentrations, the study indicated a correlation between humidity levels and reports of allergic-type symptoms among students and staff.
KEYWORDS humidity, school, floor coverings

#NO 10455 Natural ventilation takes off.
AUTHOR Hult M
BIBINF Swedish Building Research, No 1, 1997, pp 8-10.
ABSTRACT In the project "Schools with natural ventilation", seven Swedish schools- four recently built and three modernised - are described and evaluated. Evaluation refers to the indoor environment and to some extent to energy use and costs. This article sets out some of the results of the recently completed analysis of the recently constructed schools. They are all country schools. Staff and pupils consider the air to be healthy. The ventilation systems are silent. The only problem is the possibility of moisture and mould growth which was found where underground pipes entered one school. Average air change rate in classrooms during school hours was 2 ach in three schools and 2.4 in the other.
KEYWORDS natural ventilation, school, mould, moisture

#NO 10624 Educational workplace well-being study.
AUTHOR Kilmartin L F, Porteous C D A
BIBINF France, Centre Scientifique et Technique du Batiment, proceedings of the Second International Conference on Buildings and the Environment, held Paris, June 9-12 1997, Volume 1, pp 317-324.
ABSTRACT The paper describes a pilot-study set up to identify links between internal environmental quality and perceived well-being in a 1970's higher educational building housing the Mackintosh School of Architecture. The supposition is that such links may in turn inhibit/promote greater productivity. The study embraces a variety of working situations for staff and students and explores levels of satisfaction and dissatisfaction by means of questionnaire. Although limited in its size with 180 respondents as well as its scope, since it lacks objective measurements other than those concerning definition of space, the study provides evidence of linkage between such known physical parameters and perception. For example, `satisfaction' to `dissatisfaction' slopes/curves for environmental criteria are evident relative to orientation and distance from windows. Priorities are also ranked, with cramped space the greatest concern.
KEYWORDS school, human comfort, indoor air quality

#NO 10638 The overlooked half of a large whole: the role of environmental quality management in supporting the educational environment.
AUTHOR Lackney J A

BIBINF France, Centre Scientifique et Technique du Batiment, proceedings of the Second International Conference on Buildings and the Environment, held Paris, June 9-12 1997, Volume 2, pp 137-144.

ABSTRACT The management of environmental quality of school buildings has, for too long, been the overlooked half of the larger whole of the strategic educational planning process. This paper examines the changing role of environmental quality management from its traditional operationally based role, to an expanded, more dynamic role in strategic educational planning activities at the local, site-based level. First, a brief review of the state of knowledge concerning the impact of environmental quality on the educational process is presented. Second, the trend toward site-based management (SBM) in schools is discussed in light of the potential opportunities for developing a whole-system process of strategic educational planning that encompasses and integrates environmental quality management. Third, an action research study is presented in order to first illustrate the complex relationship that exists between day-to-day environmental quality management and educational instructional activities in many urban schools, and second, suggest a potential mechanism for drawing school and community representatives into the strategic planning and evaluation process at local school sites. The paper concludes that educators can be trained to collaborate in an environmental diagnostic process in which environmental quality concerns can be identified, prioritized and addressed in such a way as to be congruent with educational activities and goals, and that this process can be integrated within existing facility management decision making framework such as SBM school improvement teams.

KEYWORDS school, indoor air quality

#NO 10663 School sets good example on retrofitting.

AUTHOR Fraefel R

BIBINF CADDET Energy Efficiency Newsletter, No 1, 1997, pp 6-7, 1 fig, 2 tabs.

ABSTRACT Grueningen primary school near Zurich, Switzerland, was built 20 years ago, and energy consumption, in particular for heating and lighting, was unnecessarily high. An unconventional retrofitting procedure involving new chip-wood furnace, interior insulation, mass-coupled ventilation and controlled artificial lighting was adopted. The work was carried out without interruption of normal school operation. The results are very promising and measurements indicate a drop in heat consumption of 70% with standards of comfort raised considerably. Incurred costs proved quite reasonable compared to those of other retrofitting techniques.

KEYWORDS retrofitting, school

#NO 10664 Retrofitting halves school's heating bill.

AUTHOR Bingens L

BIBINF CADDET Energy Efficiency Newsletter No 1, 1997, pp 10-12, 3 figs, 2 tabs.

ABSTRACT The Jandel school in southern Sweden was thoroughly retrofitted in 1994-95. Both lighting and ventilation systems have been designed for high energy efficiency. New windows with excellent insulating performance have been installed. A before and after comparison shows that the energy required for heating has been reduced from about 210 kWh/m2 to about 94 kWh/m2 a year, i.e. a reduction of about 55%. Electricity for building services systems has decreased by about 20%, despite the fact that considerably more computers are used in the school today than prior to rebuilding.

KEYWORDS school, retrofitting, heating

#NO 10727 Passive solar system for a school in a snowy region.

AUTHOR Anon

BIBINF CADDET Energy Efficiency Newsletter, No 1, 1997, pp 20-22, 3 figs.

ABSTRACT Describes how the new buildings of Kaneyama Town Junior High School demonstrate that a well-planned and adequately designed passive solar system can work effectively even in a snowy and cold area. The OM solar system of an air heating type applied here, which is characterised by heat collection through roofs, and underfloor heating and heat storage, provides the pupils with a comfortable thermal environment in winter.

KEYWORDS passive solar, school, cold climate

#NO 10799 Energy, economic and environmental assessment of refurbishment proposals in three Greek schools.

AUTHOR Tzanakaki E, Lytras K, Economides G

BIBINF "Energy and the Environment: Efficient Utilisation of Energy and Water Resources" First International Conference, proceedings, held October 12-14 1997 Limassol, Cyprus, Volume 2, pp 511-520, 8 figs, 7 refs.

ABSTRACT The paper refers to the results of a European SAVE Project aimed at providing technically feasible and economically viable solutions for public school buildings in Greece

using energy conservation, passive heating-cooling and daylight techniques. The case of refurbishment proposals for three characteristic schools, situated in different climatic zones, is examined. The proposed solutions include techniques and equipment applicable to the building envelope and services, which are intended to upgrade human comfort conditions year round by reducing at the same time the energy demand for central heating and lighting. The effect on energy conservation and comfort is analysed with thermal simulation software. The economic assessment of the proposed solutions during their life-cycle is elaborated using Discounted Cash Flow analysis (DCF) indices. The environmental benefit from the proposed solutions is assessed through the reduction of main pollutant emissions and primary energy input.

KEYWORDS schools, comfort, energy saving, technoeconomic assessment, passive heating, passive cooling

#NO 10820 Investigators look to improve ventilation in portable classrooms.

AUTHOR Anon

BIBINF USA, IEQ Strategies, June 1997, pp 6-8.

ABSTRACT Describes how ongoing complaints among teachers in a California school's portable classrooms have led investigators to suspect inadequate ventilation, especially with carbon dioxide concentrations in excess of 2,500 parts per million. The mitigation strategy involved increasing ventilation and installing relief vents in the classrooms.

KEYWORDS school, ventilation strategy

#NO 10824 Nasal mucosal swelling in relation to low air exchange rate in schools.

AUTHOR Walinder R, Norback D, Wieslander G, Smedje G, Erwall C

BIBINF Indoor Air, No 7, 1997, pp 198-205, 5 tabs, refs.

ABSTRACT Acoustic rhinometry and hygienic measurements of indoor air pollutants were applied in a field study on nasal congestion among 27 subjects working in two primary schools. One school had natural ventilation only and a low air exchange rate (0.6 ac/h); the other had balanced mechanical ventilation and a high air exchange rate (5.2 ac/h). The minimal cross-sectional area and volume of the nasal cavity were estimated with acoustic rhinometry. The degree of swelling of the nasal mucosa was measured as the increase of the cross-sectional area after standardized application of nasal spray containing a decongestive adrenergic substance. Reports on weekly symptoms of nasal congestion were similar (33%) in both schools. A significantly increased decongestive effect was noticed for the minimal cross sectional area (MCA2) among personnel in the school with a low air exchange rate. The difference between the schools in decongestive effect on MCA2 was 23%, corresponding to a 3% increase of MCA2 for a difference in personal outdoor airflow of one litre. Indoor concentration of volatile organic compounds (VOC), respirable dust, bacteria, moulds and VOCs of possible microbial origin (MVOC) were 2-8 times higher in the naturally ventilated school. In conclusion, inadequate outdoor air supply in schools may lead to raised levels of indoor air pollutants, causing a subclinical swelling of the nasal mucosa. Our results indicate that acoustic rhinometry could be applied in field studies, and that objective measurement of nasal decongestion might be a more sensitive measure of biological effects of indoor air pollution than symptom reporting.

KEYWORDS acoustic rhinometry, carbon dioxide, indoor air quality, nasal obstruction, school environment, ventilation, organic compound

#NO 10836 The US Environmental Protection Agency's national strategy for radon remediation.

AUTHOR Dyess T M, DeScisciolo S

BIBINF Indoor Air: An Integrated Approach, edited by L Morawski, N D Bofinger, M Maroni, Elsevier Science Ltd, 1995, pp 325-328, refs.

ABSTRACT During the past 10 years the U.S. Environmental Protection Agency (EPA) has pursued a national strategy to address radon remediation in buildings to meet its goals of radon risk reduction. Initially the approach developed and demonstrated remediation methods and techniques in existing residences with specific attention to the effect of regional climate variations and the differences in housing construction. A number of studies and demonstrations were undertaken to accurately characterize and evaluate the effectiveness of several remediation methods and techniques. This knowledge was then later expanded through research on radon control for newly constructed houses with the subsequent development of model standards and techniques. Additionally, other research was initiated to gain a better understanding of remediation approaches in existing and newly constructed non-residential buildings such as schools, commercial office buildings, and hospitals. This paper provides an historical summary of the evolution of EPA's national

strategy for indoor radon remediation, recent developments, and anticipated future directions.
KEYWORDS radon, mitigation, research, soil gas, technology

#NO 10840 Indoor climate and moisture damage in Finnish schools. Koulujen sisailmasto ja kosteusvauriot.
AUTHOR Kurnitski J, Vilkki R, Jokiranta K, Kettunen A V, Hejazi-Hashemi S
BIBINF Finland, Helsinki University of Technology, HVAC Laboratory and Laboratory of Structural Engineering and Building Physics, Raportti B 46, 1996, 71pp.
ABSTRACT The purpose of the study was to gather information about repairs carried out on schools in three towns. Thirty two schools were studied and the typical repairs to HVAC systems and building structure were reported, as well as the measures taken and the faults detected. The procedures carried out led to better results in the aspect of indoor air quality then the other two. Stresses the importance of employing professional designers and consultants for serious problems, and of establishing a sound and ongoing maintenance and inspection programme rather than responding to damage and faults as they are discovered. The greatest problems were found to be the schools' old fashioned or even absent ventilation devices, and the rainwater drainage systems. Indoor air quality problems were commonly "solved" by using different classrooms or additional school buildings. Stresses the importance of planning repairs in full.
KEYWORDS moisture, school

#NO 10917 Design of the indoor environment: a test of application of prENV 1752 for the construction of a school.
AUTHOR Nouwynck J
BIBINF Belgium, Proceedings of Clima 2000 Conference, held Brussels, August 30th to September 2nd 1997, paper 6, 5 figs, 1 tab.
ABSTRACT The draft of the European prestandard 1752, entitled "Ventilation for buildings - Design criteria for the indoor environment" is intended to be a flexible tool for assisting the designer in providing a proper indoor environment for people in ventilated buildings. It specifies how the quality of the indoor environment, comprising the thermal environment, the air quality and the acoustic environment can be expressed. In an informative annex to the standard, the "decipol" unit is proposed for the characterisation of perceived air quality, the emission of each pollution source being expressed by the "olf" unit. The paper will describe one of the first (or the very first ?) test of application of the IAQ (indoor air quality) part of the standard to the design of a building, in this case the third European School in Brussels (2,500 pupils).
KEYWORDS school, building design, standard

#NO 10918 Experimental and analytical evaluation of VAV air conditioning system in an office building.
AUTHOR Wang S, Burnett J
BIBINF Belgium, Proceedings of Clima 2000 Conference, held Brussels, August 30th to September 2nd 1997, paper 7, 14pp, 10 figs, 7 refs.
ABSTRACT Describes one of the first tests of application of the indoor air quality part of standard pr ENV 1752 to the design of a building; the third European School in Brussels (2,500 pupils). The paper comprises three parts: description of the project; summary of the content of the prestandard; application of the standard for the design of the school. The conclusions were that the applications of the standard in the case of low polluting buildings leads to realistic values of ventilation rates, that the "olf-decipol" method enables the designer to calculate either ventilation rate of comfort-category in different and specific situations; and that remaining problems are: the measurement of the sensory pollution load of building materials, the application at reasonable costs of the guidelines for design, construction and maintenance of HVAC systems, and the reliability of the "olf-decipol" method in the case of buildings which are not "low polluting".
KEYWORDS air conditioning, office building, odour, standard

AIVC Air Infiltration and Ventilation Centre

The Air Infiltration and Ventilation Centre provides technical support in air infiltration and ventilation research and application. The aim is to promote an understanding of the complex behaviour of air flow in buildings and to advance the effective application of associated energy saving measures in both the design of new buildings and the improvement of the existing building stock.