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The Role of Ventilation in Cooling Non-Domestic Buildings

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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).

Energy Conservation in Buildings and Community Systems

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

The Executive Committee

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

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

I	Load Energy Determination of Buildings*
II	Ekistics and Advanced Community Energy Systems*
III	Energy Conservation in Residential Buildings*
IV	Glasgow Commercial Building Monitoring*
V	Air Infiltration and Ventilation Centre
VI	Energy Systems and Design of Communities*
VII	Local Government Energy Planning*
VIII	Inhabitant Behaviour with Regard to Ventilation*
IX	Minimum Ventilation Rates*
X	Building HVAC Systems Simulation*
XI	Energy Auditing*
XII	Windows and Fenestration*
XIII,	Energy Management in Hospitals*
XIV	Condensation*
XV	Energy Efficiency in Schools*
XVI	BEMS - 1: Energy Management Procedures*
XVII	BEMS - 2: Evaluation and Emulation Techniques*
XVIII	Demand Controlled Ventilating Systems*
XIX	Low Slope Roof Systems*
XX	Air Flow Patterns within Buildings*
XXI	Thermal Modelling*
XXII	Energy Efficient Communities*
XXIII	Multizone Air Flow Modelling (COMIS)*
XXIV	Heat Air and Moisture Transfer in Envelopes*
XXV	Real Time HEVAC Simulation*

XXVI	Energy Efficient Ventilation of Large Enclosures
XXVII	Evaluation and Demonstration of Domestic Ventilation Systems
XXVIII	Low Energy Cooling Systems
XXIX	Energy Efficiency in Educational Buildings
XXX	Bringing Simulation to Application
XXXI	Energy Related Environmental Impact of Buildings
XXXII	Integral Building Envelope Performance Assessment
XXXIII	Advanced Local Energy Planning
XXXIV	Computer-aided Evaluation of HVAC System Performance

Annex V Air Infiltration and Ventilation Centre

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

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

Contents

1. Introduction

In the majority of non-domestic buildings of the Air Infiltration and Ventilation Centre's (AIVC) participating countries, the designer will need to give careful consideration to cooling and dehumidifying the building to maintain thermal comfort in summer. In some hot and/or humid parts of the world, summer cooling can be a requirement for residential buildings, including single family dwellings. This Technical Note concentrates on the role of ventilation in cooling non-domestic buildings.

Traditionally, cooling has been achieved using air conditioning systems which use fans to distribute mechanically cooled air to each conditioned space. In response to the environmental concerns over greenhouse gas emissions and ozone depletion, there has been a trend to move towards more passive and hybrid approaches to cooling [1]. The following sections aim to set the need for cooling into the context of overall building design, and stress the role of ventilation in meeting the cooling need.

2. Ventilation and Cooling Requirements

The principal purpose of ventilation is to satisfy indoor air quality requirements but it also provides a means for heating or cooling the space which is being ventilated. Warm air heating has been used in many countries but such systems are only one of a number of heating options. Hydronic heating, electric heating and direct gas fired heating are other examples. Until recently, virtually all cooling systems relied on mechanically cooling air which was then forced under pressure into the conditioned space(s).

Figure 1 shows the sensible cooling provided as a function of the flow rate of air for different supply to room temperature differences. For comparison, a typical fresh air supply rate of 12 l/s·person is shown (this relates to an occupant density of 10 m^2/person, which is typical of European conditions). This simple graph highlights a number of key factors:

- The required air flow rate for sensible cooling will usually be much higher than the minimum fresh air requirement. Even with a supply to room temperature difference of 10 K, the minimum fresh air requirement will be delivering less than 20 W/m^2 of sensible cooling. Figure 2 shows a typical range of space heat gains for normal office type buildings and it indicates that in most commercial buildings the peak cooling load will be in the range 30 - 100 W/m^2. The additional airflow to meet the cooling can either be excess fresh air or recirculated air. The outcome of this choice will have different impacts on energy consumption.

- In temperate climates, sensible cooling requirements can be met for much of the year by ventilating with outside air at flow rates of 5 - 10 times the minimum fresh air requirement. This approach is particularly successful if advantage is taken of using the thermal capacity of the structure to store daytime heat gains which can be flushed from the building with night ventilation (see 5.1.2). If mechanical night ventilation is used, then care must be taken to design the ventilation for low pressure drop in order to minimise fan energy consumption (see 5.3).

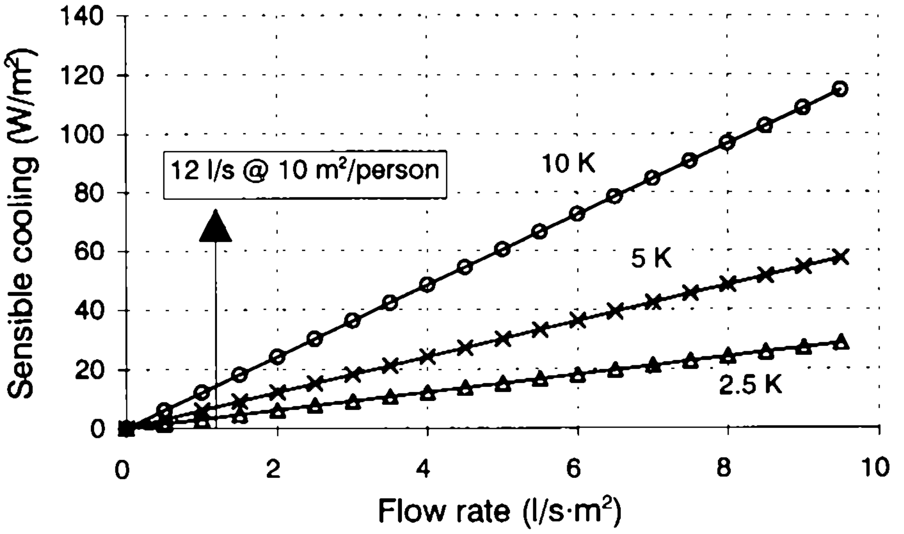

Figure 1 Ventilation for cooling and IAQ

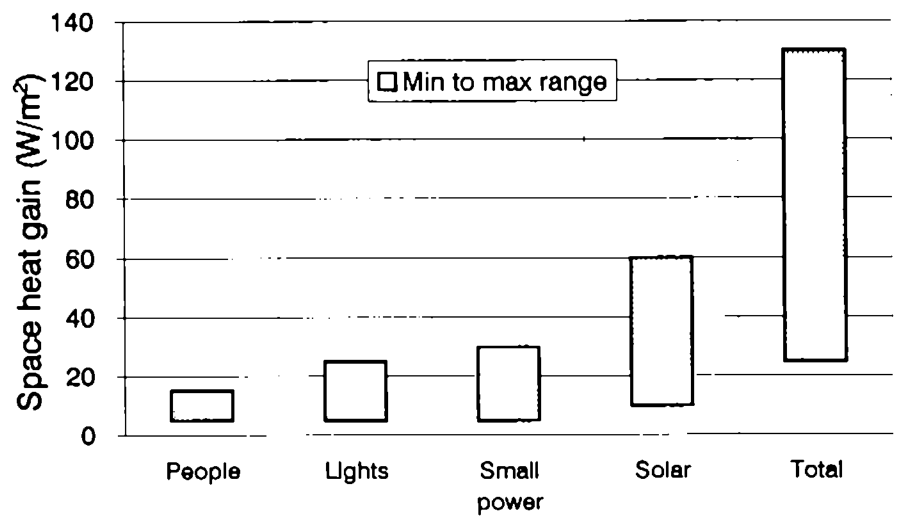

Figure 2 Typical range of space heat gains in office buildings

It is very important to realise that space cooling is often concerned with dehumidifying a space as well as reducing its temperature. In certain climates and for certain specialist applications such as museums and some production facilities, latent cooling issues can be more important. Latent cooling using ventilation can only be achieved by ventilating with air at a lower moisture content than the room air. Moisture can be removed from the air either -

- by cooling the air below its dewpoint. This often requires the air to be cooled to a lower temperature than that required to meet the sensible cooling demand. Consequently the air has to be re-heated after dehumidification, resulting in significant energy usage (see section 5.2).

- using desiccants (solid or liquid). The desiccant has to be regenerated and again this requires energy.

A wide range of cooling systems and strategies have been developed, each of which has its own advantages and disadvantages (see AIVC TN 42 [2].). The selection of the appropriate system is part of the design process and must satisfy the client's requirements for thermal comfort, capital and running costs etc. The issues which influence the sizing and selection of the cooling system are discussed in the following section.

3. Factors Affecting Cooling Load

The cooling load that the system has to meet is determined by three main factors:

- the required internal conditions; the lower the temperature required, the higher the cooling load. Usually the internal conditions are determined by occupant comfort criteria, but in some applications such as computer centres or refrigerated food storage, process requirements may be more critical.

- the rate of heat flow into the space; the greater the heat gains, the higher the cooling load. The heat gains are dictated by the form and fabric of the building envelope, the external climate and the activities going on inside the building(occupant density, lighting levels, equipment gains, etc).

- ,the degree of cooling and dehumidification required to condition the air to meet the room cooling load. This will depend on outside air conditions, the degree of air recirculation, the heat gain from fan pick-up, the room heat gains and any mixing or re-heat losses in the system.

3.1 Internal Design Conditions

In most buildings, the provision of space cooling is in response to the requirement to satisfy occupant demands for thermal comfort. Thermal comfort is a vast subject in its own right, and so reference should be made to various standards which exist [3, 4]. Extensive work in the field is continuing, and this is summarised by reference to the proceedings of a recent international conference on the subject [5]. For the purpose of this document, it is only necessary to note that thermal comfort is affected by a number of parameters:

- four physical, air temperature, radiant temperature, humidity and air velocity, and
- two behavioural, metabolic rate (related to the degree of activity) and clothing level.

The engineering services designer is tasked with developing a systems strategy to meet a defined internal comfort condition when the building is subject to a specified external design condition. This external climate condition is related to a degree of risk (how often those conditions will be exceeded).

Central to the issue of sizing cooling equipment and the cost of the energy to run that equipment, is the question of the space conditions that the system will deliver both at the design condition, and during the whole of the cooling season. As indicated above, the comfort condition is a complex function of many different variables, and acceptable comfort can be provided at a range of internal air temperatures. If the air temperature increases, comfort can still be maintained, provided the thermal sensation is compensated by control of other parameters (reduced clothing insulation, reduced mean radiant temperature, increased air movement).

Figure 3 shows how the same thermal sensation can be achieved at different air temperatures by varying other parameters which control the body's heat balance. The Figure is derived from the data in the ASHRAE Fundamentals Handbook [6], and shows the situation for light summer clothing (short sleeve shirt and light trousers, clo = 0.5) and an activity level equivalent to sedentary office work (metabolic rate of 1 met). The Figure shows that as the air speed increases, the rate of body heat loss increases and so the same level of comfort is achieved at a higher air temperature. If the mean radiant temperature is reduced, then increased radiant heat exchange with

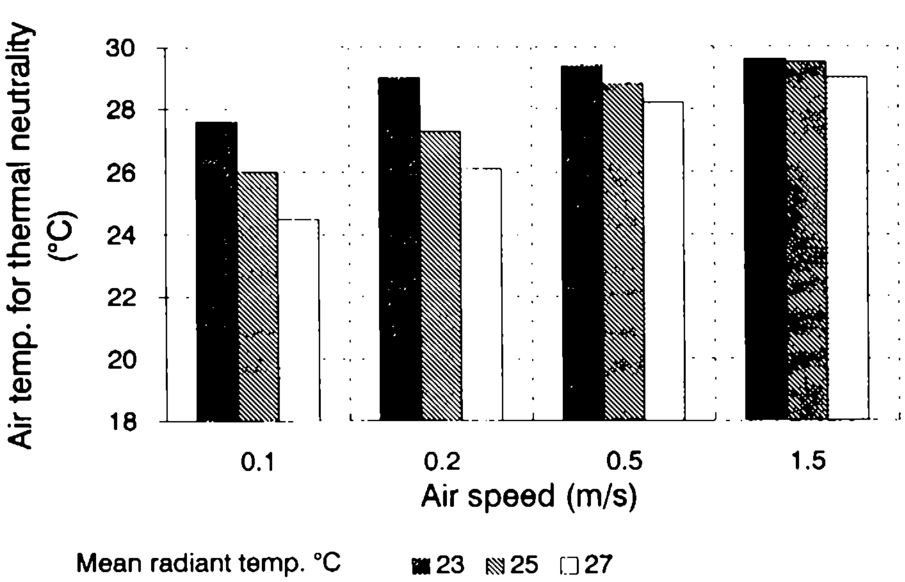

Figure 3 Effect of air speed and mean radiant temperature of the enclosure on thermal comfort

the surroundings also increases the rate of body heat loss. This allows air temperatures to rise even higher for the same perception of comfort.

It must be stressed that there is not unlimited flexibility in the trade off between these variables. However there is quite a wide "envelope" of conditions in which people will be comfortable. Figure 4 shows the ASHRAE thermal comfort zone which shows the range of comfort to meet a 10% PPD (predicted percentage of dissatisfied) criteria as a function of operative temperature and humidity ratio. The operative temperature is a function of air temperature, mean radiant temperature and air speed.

In many European countries there has been a trend away from air conditioning to a more passive building design strategy which allows temperatures to float within a much larger range. This does not necessarily deliver lower levels of comfort. The design concept recognises that in warmer weather, people adapt their behaviour by wearing lighter clothing, reduce mean radiant temperatures by using blinds to cut out solar gain and increase air speeds by the use of desk fans or openable windows. By making small adjustments to all of these parameters, thermal neutrality can be achieved at quite high air temperatures. Detailed field studies reported by Baker and Standeven [7] confirm that occupants use such adaptive opportunities to improve their thermal comfort. The base case measurements show the thermal sensation that an occupant would experience if he carried on as normal. The adapted figures show the different environment that the occupant experiences because of the changes he brings about to improve his comfort. The final row shows the percentage of people dissatisfied calculated using the ISO 7730 model [4] and indicates a dramatic reduction in dissatisfaction. The measured dissatisfaction was in fact even lower. Because all the adaptive opportunities work in the same direction, the cumulative effect of a number of small changes results in a significant improvement in comfort.

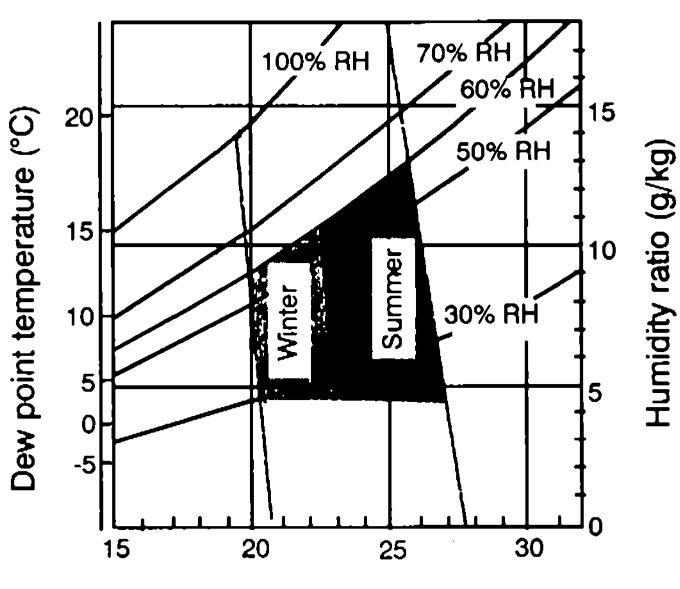

Figure 4 ASHRAE comfort zone

Physical parameter	Base	Adapted
Room air temp. °C	30.5	29.5
Room radiant temp. °C	30.5	29.5
Local air temp. °C	30.5	28.0
Local radiant temp. °C	30.5	28.0
Air speed (m/s)	0.1	0.2
Clothing (clo)	0.5	0.4
Activity (met)	1.2	1.1
Predicted % dissatisfied (PPD)	68.4	17.5

Table 1 Effect of adaption on perception of comfort (Baker & Standeven) [7]

An understanding of these comfort principles is important in designing for cooling by ventilation alone. The cooling potential of ventilation is a function of the inside - outside temperature difference and the flow rate. The outside air temperature cannot be controlled by the designer and so the cooling potential can only be maximised by increasing the flow rate or allowing a higher room air temperature.

As demonstrated above, this approach can be valid provided other aspects of the environment are adjusted accordingly. This can include reduced mean radiant temperatures (by using night cooling coupled with high thermal capacity) and increased air speeds. There are limits which restrict the degree to which these other comfort parameters can be varied. Excessive reduction of the temperature of some of the surfaces can result in radiant asymmetry. Increasing the air speed too much can lead to draughts.

Most important of all, relative humidity levels cannot increase too much. As shown in Figure 4, if RH (relative humidity) levels exceed 60% for significant periods of time, then discomfort levels will increase and dehumidification will be necessary.

The same principles are also relevant to buildings with active cooling. In a space with large radiant heat gains, in order to achieve the same degree of comfort the air conditioning system will need to reduce the air temperature lower than in a space with the same amount of convective heat gain. If a radiant cooling system is used such as chilled ceiling panels, the mean radiant temperature is reduced and the air temperature can increase accordingly.

As an essential part of developing the cooling system design strategy it is clear that the expected and acceptable levels of comfort should be agreed. This may be a particular temperature range for an actively cooled building or a maximum frequency of high internal temperatures in a free running building (e.g. less than 2.5% of occupied hours to be in excess of 26 °C) coupled with an equivalent limit on space RH.

3.2 Sources of Heat Gain

Because the cooling potential of ventilation with outside air is limited, a successful strategy requires the space cooling load to be minimised as much as is practically possible. The cooling demand is the sum of all the instantaneous heat gains, lagged where appropriate by the thermal response of the structure. Sources of heat gain that need to be considered when determining cooling requirements are well documented in standard guides. These heat gains include

- conduction through the building fabric,
- infiltration of ambient air,
- solar gains through the glazed elements, and
- internal gains from lights, equipment and people or animals.

Solar, conduction and infiltration gains will be determined primarily by the form and fabric of the building itself. Solar gains can be very important in determining cooling loads, especially peak loads. The varying solar gain throughout the day and year means that its effects will be felt in different parts of the building at different times of the day. There are a number of methods of controlling solar gains, such as

- coated glasses,
- the use of blinds or shutters,
- overhangs and side fins (or deep window reveals), or
- self shading by other parts of the building.

It is necessary to balance the need to reduce excessive gains in summer with the desirability of providing daylight into the building and of providing a view of the outside world for the occupants. It should be noted that solar gain not only influences perception of comfort by its influence on the internal temperature, but the effect on occupants who are exposed to direct radiation can be significant.

The internal gains, are affected by the use to which the building is put. The required lighting levels for the tasks to be carried out in the building will largely determine the gains from lighting. Good daylighting, the use of low energy light sources and good lighting control can all reduce lighting gains. Control of lighting gains is especially important in the cooling situation, since a reduction in lighting gain saves electricity directly, but also indirectly by reducing chiller demand. Another important contribution to reducing heat gain from lighting is to use air handling luminaires, thus removing a significant proportion of the heat at source.

Levels of equipment gains are determined by the use of the building. While the use of office machinery has risen in recent years, the energy usage of individual appliances is reducing. One major factor involved in the over-specification of air conditioning is excessive assumptions about the levels of heat gain from office equipment. In general, name plate ratings are a poor estimate of the actual heat output from the appliance [8]. Over generous allowances lead to oversized cooling equipment, which then runs for extended periods at part load. This is wasteful on capital costs, as well as energy costs. Many manufacturers are now offering equipment that comply with the "energy star" standard; if such machines are not used for a defined period of time, they switch into idle-mode (e.g. switching of the VDU). This will help reduce both the power demand and the heat gain to the space. Some furniture manufacturers are now providing integrated desks that enable heat emitted from PCs to be removed with the extract air. This removes the heat gain at source and thereby reduces the load on the air conditioning system.

Although such gain reduction measures are essential as part of a ventilation cooling system, such considerations may also benefit an air conditioning strategy. Reduced peak loads and lower diversity will make the systems smaller, more controllable and hence more efficient.

4. Ventilation and Cooling Systems

The range and diversity of ventilation and cooling systems for commercial buildings is vast. In order to set the subject into context, it is necessary to give a brief overview of the principle strategies. More detail can be obtained from a previous AIVC Technical Note (Limb [2]).

4.1 Natural Ventilation

Natural ventilation is the flow of air through purpose provided ventilation openings. The air is driven by the effects of wind pressure and/or density difference between the air inside and outside the building. In many parts of Europe in particular, naturally ventilated buildings are becoming a commonly adopted design strategy and detailed design manuals are becoming available [9]. Typical natural ventilation strategies are shown in Figure 5.

For effective natural ventilation, the building must be relatively shallow plan (up to 5 times the floor to ceiling height from one external facade to the other facade or courtyard / atrium.) This narrow form allows greater utilisation of natural light, further improving the potential energy efficiency. By reducing (or even eliminating) the need for mechanical plant, the capital cost of naturally ventilated buildings is usually no more and indeed is often about 10% - 15% less than the cost of a mechanically conditioned equivalent.

Because the cooling capacity of natural ventilation is limited, great care has to be given to the design of the building envelope to minimise the cooling requirements. Even with careful design to limit solar gains and good control to minimise internal gains, the cooling load will be above that which can be met by day time ventilation alone. The use of night ventilation coupled with a structure with high thermal capacity will be required. In some cases, natural ventilation will not be able to satisfy thermal or air quality requirements at all times of the year or in all parts of the building. In such situations, natural ventilation can be combined with mechanical ventilation as part of the so called mixed mode approach [10].

Natural ventilation alone cannot control humidity, and so in moist climates or situations where there is high internal moisture generation, natural ventilation will not be suitable.

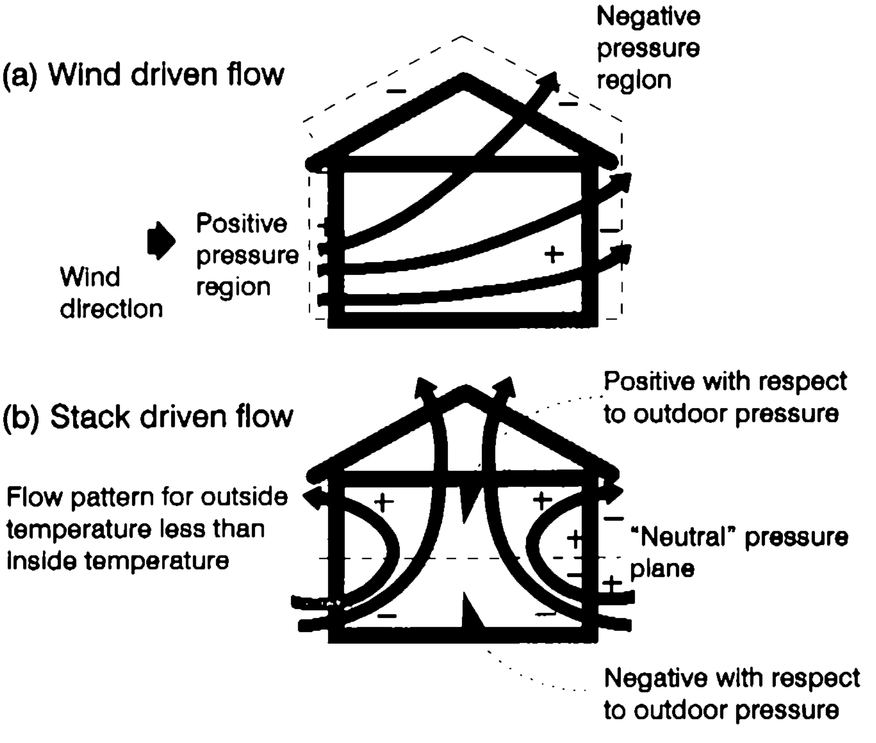

Figure 5 Natural driving forces [11]

4.2 Mechanical ventilation

Mechanical ventilation utilises fans to move the air through the building and systems usually provide heating and filtration. The flow rate of ventilation air and the distribution of that air are much more controllable and the systems can be applied to both deep and narrow plan buildings. The design of energy efficient ventilation systems is discussed in great detail by Liddament [11].

As with natural ventilation, the cooling capacity of mechanical ventilation is limited. Consequently the same importance must be applied to minimising cooling loads and utilising thermal mass as with natural ventilation. The main advantage is that the flow of air is more controllable, but the fans consume electrical energy. Most of this energy will appear as heat in the ventilation air, thereby further reducing the cooling potential unless an extract only ventilation strategy is used.

Another advantage of mechanical ventilation is the ability to apply heat recovery techniques. This can offset ventilation heat loss in winter and can also reduce cooling requirements in extremely hot weather when outside temperatures are higher than that of the building exhaust.

Heat recovery devices allow a further passive cooling strategy to be made possible, i.e. evaporative cooling [12]. This uses combined heat and mass transfer to increase the humidity of an air stream whilst simultaneously reducing its temperature. The air stream that is cooled can either be the exhaust air from the building or an outside air supply. This cooler but moister air is then used to cool the supply air using a high efficiency air to air heat exchanger (Figure 6).

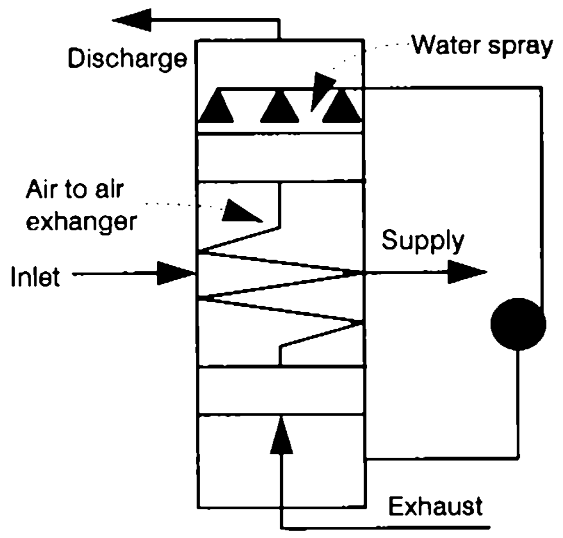

Figure 6 Indirect evaporative cooler

4.3 Air Conditioning

Air conditioning is a further extension of mechanical ventilation in that cooling and dehumidification may be provided in addition to heating, humidification and filtration. As discussed in Reference 2, there are many different system types and many ways to classify those types. For the purposes of this technical note, a simple classification has been adopted, namely

- all air systems where cooling of the air is done centrally and cool air is ducted around the building. A typical example of an all air system is variable air volume (VAV).

- air-water systems where chilled water is circulated to room units which contain a local fan which draws room air into the unit, cools it and mixes it with fresh air before injecting it into the room. The room unit will draw the fresh air either through an outside wall or via a ducted system which may have conditioned the air at the central plant. A typical example of an air water system is a fan coil system.

- all water systems where chilled water is circulated to terminal units which exchange heat with the room via radiation and/or natural convection. Examples of this approach are chilled ceilings (either radiant panels or chilled beams). With such strategies, a separate fresh air system will be needed to satisfy indoor air quality (IAQ) requirements. This is usually a ducted system which conditions the air at a central plant. Humidity control will also be done using this ventilation supply to avoid condensation on the chilled panels or beams. Usually, ceiling cooling systems are used in conjunction with displacement ventilation to extend the range of cooling capacity available with displacement systems. Because cooled ceilings or beams use natural convection and radiation, there is far less disruption to the stratified flow established by the displacement strategy.

The main energy advantage of an all air system is the potential to maximise the use of free cooling (see 5.2 and 5.3.4). The disadvantage is that air has a much smaller heat carrying capacity than water and therefore the transport energy is likely to be greater in an all air system.

Figure 7 shows a comparison of the transport energy for a range of cooling requirements and for a range of typical system pressure drops (air ventilation system of 0.5 - 2.0 Pa/m, chilled water system 100 - 400 Pa/m).

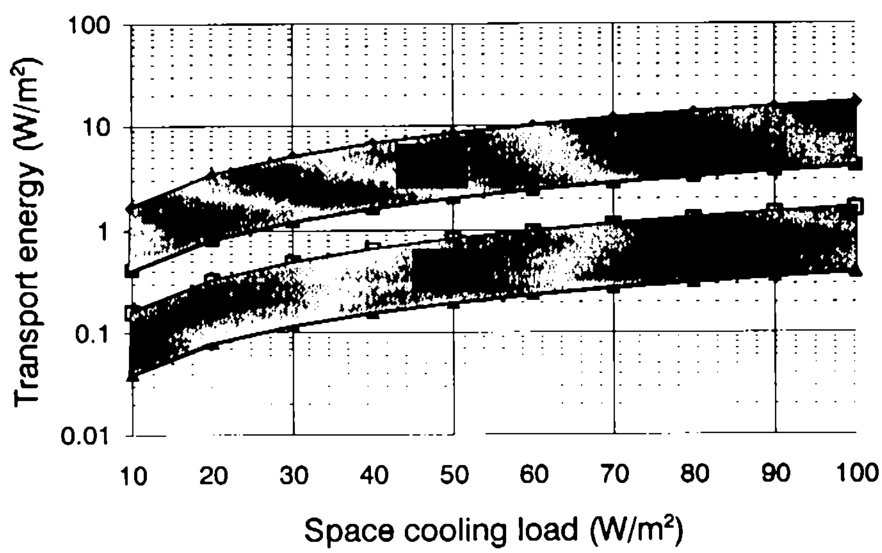

Figure 7 Relative transport energy of air and water

4.4 Range of Applicable Cooling Loads

Each of the different systems described above can cope with different ranges of cooling load. This is one of the factors that will influence system selection. The following table summarises the approximate range of cooling loads that can be handled with each technology. This table is intended to be indicative of scale, and each case should be investigated on its own merits. The natural and mechanical system strategies that rely on ventilation alone are obviously very dependent on climate; the figures quoted are for climates similar to Northern Europe.

System	Typical range of cooling (W/m^2)
Natural ventilation	10 -35
Mechanical ventilation	20 -40
Displacement ventilation	30 -50
Chilled ceiling + displacement ventilation	60 -100
Fancoil air conditioning	80 -150
VAV air conditioning	80 - 150

Table 2 Approximate range of cooling loads applicable to various technologies

5. Energy Issues in Ventilation and Cooling

There are a number of energy issues related to ventilation and cooling. These can be understood by reference to the simplified system sketch shown in Figure 8. The primary energy transfers of interest occur:

- where the air is introduced into the room to provide the cooling effect (the space cooling load).
- at the air handling plant, where the required energy is added or removed from the air stream in order to provide the supply conditions needed to satisfy the space cooling load.
- at the fan, where mechanical energy is input via the fan impeller to overcome the resistance of the ductwork system, including friction and component pressure losses.

The energy issues relating to these processes are discussed in the following sections.

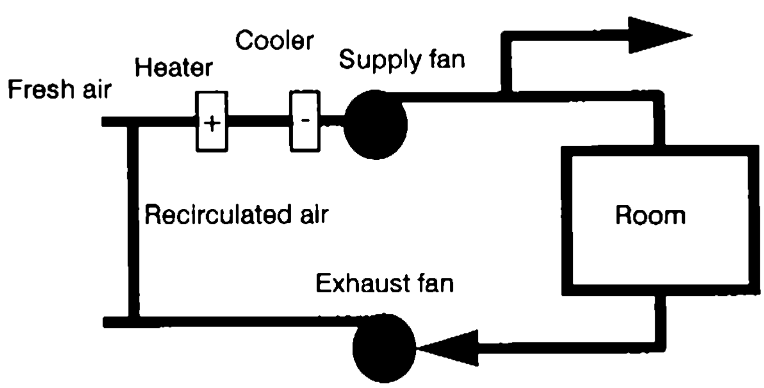

Figure 8 Simplified schematic

5.1 Space Cooling Load

The space cooling load represents the energy that must be removed in order to maintain the space condition at the desired temperature and humidity levels. The space cooling load is determined by the design of the building and the use to which it is put. Good envelope design and careful equipment selection can reduce these gains significantly (see 3.2). It is the cooling load which dictates the volume flow rate of air that is required to be delivered by the system to the individual space. The volume flow rate is related to the sensible cooling load through the simple energy flow equation,

$$Q = \rho \cdot V \cdot C_P \cdot (T_R - T_S)$$

where
V = Volume flow rate (m^3/s),
Q = Space sensible cooling load (kW),
ρ = Air density (kg/m^3),
C_P = Specific heat capacity of air (kJ/kg·K),
T_R = Room air temperature (°C), and
T_S = Temperature of air at supply condition (°C).

The volume flow rate of air that has to be conditioned and supplied is the fundamental parameter that dictates the energy consumption, since all the relevant energy flows are proportional to the flow rate. Consequently good design will aim to minimise the space cooling load as much as possible, thereby reducing the necessary air volumes. This has advantages not only in energy terms, but also in the capital cost of plant items and the space provision for HVAC systems (plant rooms and risers).

Clearly the air flow rates cannot be reduced below the required fresh air rates for acceptable air quality, but in most applications, the design flow rate to provide cooling is considerably in excess of the fresh air requirement (see Figure 1). Therefore there is considerable merit in reducing the cooling load by careful envelope design, and by considering ways to control the internal heat gains.

The design process will need to consider other factors than energy and air quality (aesthetics, space flexibility, etc.). As with all engineering design, the final solution will be a trade-off between initial and running costs, and this will be influenced by climate zone and national construction styles.

5.1.1 Room Supply Temperature Difference

The temperature difference between the space and the supply is a design variable which is related to the type of system selected. For mixed ventilation systems, this temperature difference will be of the order of 10 - 12 K, whereas for displacement ventilation systems, it will be only 2 - 3 K. Although a displacement ventilation system will require a greater volume flow of air to achieve the same cooling effect, such systems do offer other energy benefits. The displacement strategy results in stratification of air in the space (Figure 9), with the warm air rising and being exhausted at high level. Consequently, the air exhausted from the space is at a higher temperature than the air in the occupied zone, resulting in a greater rate of heat extraction for the same supply temperature than with a fully mixed system.

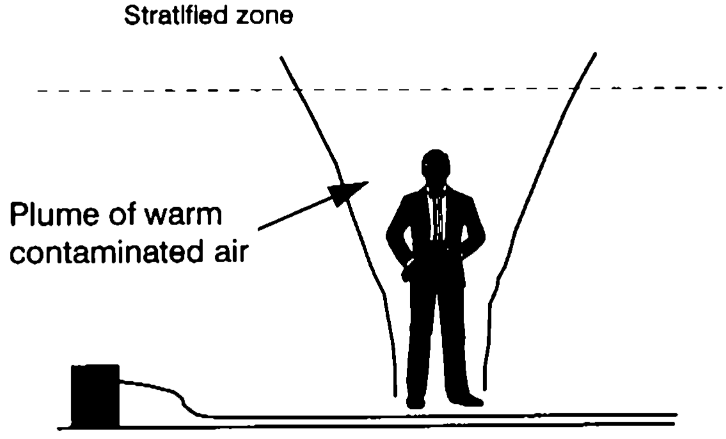

Figure 9 A displacement ventilation system

Figure 10 shows the results of a very simplified analysis where the space is split into two stratified layers. Both layers have a temperature gradient; the gradient in the lower layer is varied between 0 and 2 K/m, the upper layer has a gradient which is double the gradient in the lower layer. The room height is 3 m with the interface between the layers at a height of 2 m. Because the average temperature of the air in the upper layer is greater than that in the lower layer, the heat extraction rate is higher than with a conventional fully mixed system. Over a typical range of temperature gradients in the occupied zone, the heat extraction rate is increased by a factor of 15% - 20% for the same volume flow rate. The cooling available with displacement ventilation alone is limited to 30 - 50 W/m^2. With higher cooling loads, the vertical temperature gradient becomes too steep and discomfort will

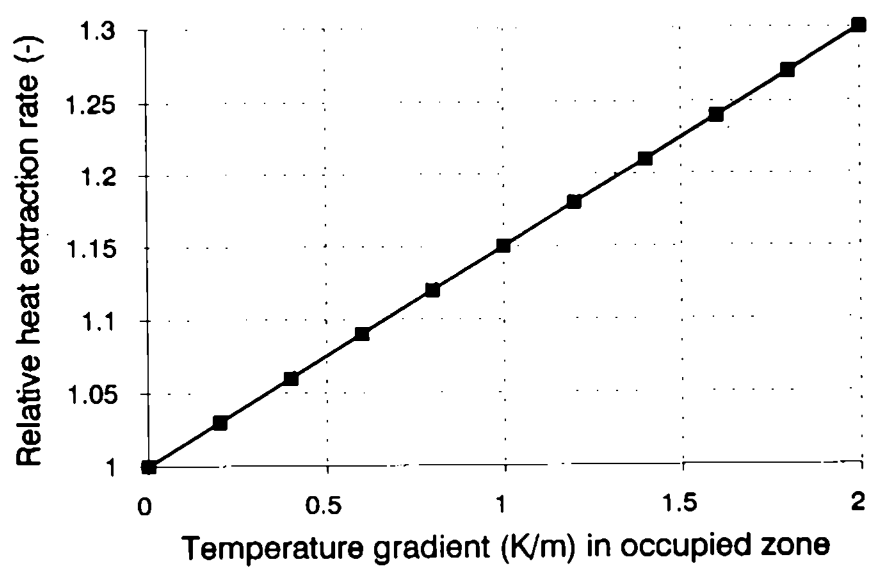

Figure 10 Effect of temperature gradient on heat extraction rate

follow. At higher cooling loads, displacement ventilation is usually coupled with some form of chilled ceiling which can increase the cooling load to approaching 100 W/m^2.

5.1.2 Thermal Mass

In most cases, there is a significant daily variation in space cooling load, resulting in natural variations in the climate induced gains or the occupancy and use of the space. Large variations between the maximum and minimum cooling load makes control more difficult and is likely to lead to plant inefficiencies. One way to generate a more even cooling load profile is by increasing the thermal capacity of the room. This will increase the heat flow into the fabric during periods of high heat gain which can be released back into the space when the gains reduce and the space temperature falls.

The thermal capacity of a room is dependent on the rate of heat transfer between the exposed surfaces of the structure and the air. No matter how much thermal capacity is in the building fabric, if the surface finishes (e.g. a carpet) are insulating, the room will show a lightweight response. Increasing the thermal capacity will often be beneficial

- in an air conditioned building, by reducing the peak cooling load, thereby reducing the required capacity of the chiller and the air handling plant.

- in a mechanically ventilated building by shifting the time when the peak cooling demand occurs to later in the day when external temperatures have dropped from their maximum value and the cooling potential of ventilation increases. As a typical guideline, the use of thermal mass and night ventilation can reduce the peak temperature by 2 - 3 K relative to a similar lightweight building. Figure 11 shows how varying the night ventilation rate beyond about 6 - 8 air changes per hour has little effect on the maximum temperature in the space. The fan power will be increasing very significantly at these higher flows and so the cooling benefit of night ventilation must always be compared with the fan energy consumption to determine the most cost effective strategy. Such systems need very careful design since it is possible to destroy the potential benefits. For example, if the ventilation system has too high a pressure drop, not only is the fan power greater than is necessary but because the run hours are longer, the energy consumption can be significantly increased. Further, the fan energy is seen as a temperature rise across the fan, increasing the temperature of the air delivered to the room and reducing the cooling capacity. For this latter reason, there is advantage in using only the extract fans with natural ventilation inlets to cool the space out of occupied hours although care has to be taken over security issues and the fact that the air will no longer be filtered.

- in a naturally ventilated building the same argument applies as for mechanically ventilated buildings. Indeed it is a common strategy to provide sufficient thermal capacity to allow the daytime heat gains to be flushed from the building by night time ventilation. This requires special ventilation openings which can safely be

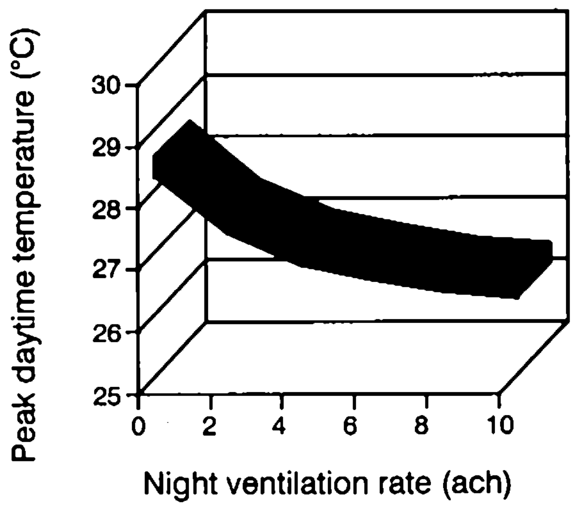

Figure 11 Effect of night ventilation on peak daytime temperature

left open overnight when the building is unoccupied. Natural ventilation eliminates the problems associated with fan pick-up but does place greater demands on the building managers and users to operate the system effectively. The natural reaction is to open windows on a hot day to increase the ventilation rate. Successful utilization of the thermal flywheel requires that the ventilation be increased much earlier when the air was sufficiently cool to discharge the stored heat in the fabric. High ventilation rates during times of peak temperature may be of little value, and may even be counterproductive if the outside temperature exceeds the internal air temperature.

5.2 Plant Load

The space cooling load has dictated the flow rate of air going through the air handling plant, and the psychrometric conditions required at the point of delivery to the space. The duty required by the air handling plant will be determined by the psychrometric processes involved in heating, cooling and de-humidifying the air from the condition of the air coming onto the plant to the required off-plant condition.

Figure 12 illustrates the processes going on through the plant when the requirement is to both cool and dehumidify the air. In order for de-humidification to take place, the air has to be cooled below its dew point. In many cases, this will require the temperature to be reduced below that required to meet the sensible space cooling load. Once the required moisture content has been achieved, the air will need to be re-heated back to the supply condition. This process can be very energy intensive, and highlights the need for very careful consideration of the room conditions that are required to satisfy comfort.

Having determined the supply temperature and the air quantity, the other key parameter is to establish the required supply moisture content in order to provide the

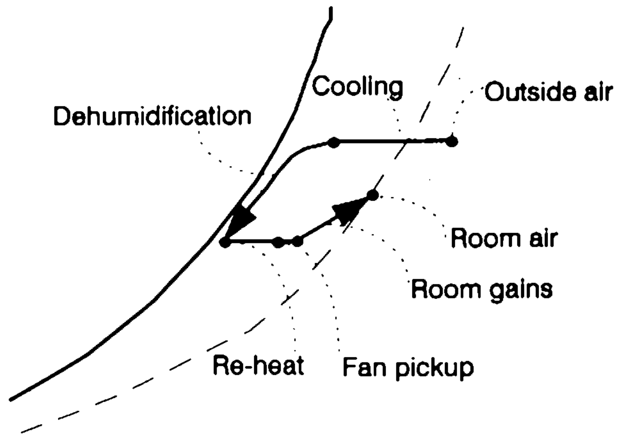

Figure 12 Cooling and dehumidification on a psychrometric chart

required relative humidity in the space. In most applications for occupant comfort, humidity can float within a reasonably wide band (say 35% - 65%), but in some applications, much tighter control is required (e.g. in museums and libraries for the display of historical artifacts and documents). If tight humidity control is required, the psychrometric processes necessary to achieve this can result in significant increases in energy.

Figure 13 shows the results of a series of simulations of an office building in the UK, where the only change between runs is to vary the humidity band. The dramatic increase in steam usage is because of the increased winter humidification requirements. The increased chiller consumption is due to the dehumidification requirement in summer. This requires the air to be cooled below the dew point, a temperature lower than that required to satisfy the sensible cooling load. The air then has to be reheated to avoid over-cooling the space, resulting in an increased boiler demand.

The air condition coming onto the plant will be a function of the outside air

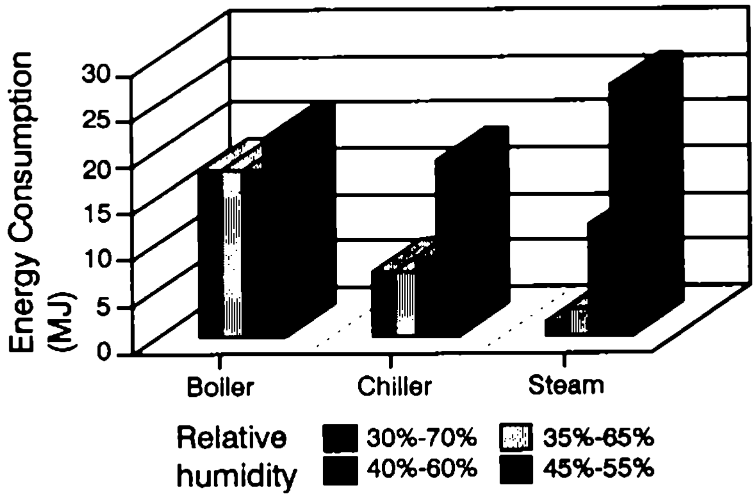

Figure 13 Effect of humidity control on energy consumption

condition, and if re-circulation or heat recovery is used, it will also depend on the exhaust air condition. As indicated in section 3.1, in many buildings, the flow rate required for cooling purposes will be considerably in excess of that required to satisfy the fresh air requirement. The excess air can be drawn either as additional fresh air, or by recirculation of the exhaust air from the building (subject to satisfying air quality concerns over possible pollutants in the air stream).

The balance between using fresh air or return air offers a strategy for energy savings through the so called economiser cycle. This will vary the proportions of outside and recirculated air to minimise plant consumption. In simplistic terms, the strategy aims to mix fresh air and return air in suitable proportions to satisfy the required condition of the plant whilst maintaining the fresh air rate above the minimum requirement. This means that for proportions of the year, no plant heating and cooling is required, and the only energy consumption is the fan power.

Figure 14 shows the cumulative frequency distribution of outside air temperature for the London area. Also marked on the graph are the 'typical' supply temperatures for a mixed flow air conditioning system and a displacement ventilation comfort cooling system. It can be seen that the displacement ventilation system can utilise free sensible cooling for a very much greater proportion of the year, provided the moisture content of the outside air is not too high.

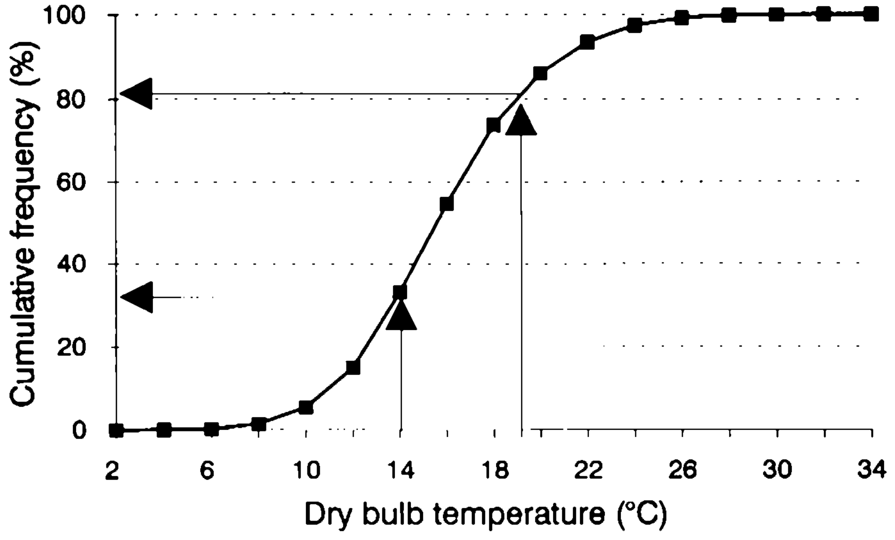

Figure 14 Frequency distribution of temperature for London

5.3 Fan Energy

Fan energy can be a very significant factor in the energy budget of a commercial building air conditioning system. Work reported by BRECSU [13] indicates that the fan often accounts for more than half of the system energy consumption. The design of the ventilation system will therefore have a very significant effect on overall energy performance. The energy consumption of the fan is given by

$$Q_f = \frac{V \cdot \Delta P_f}{\eta_f \cdot \eta_m}$$

where
Q_f = fan energy (W),
V = volume flow rate (m^3/s),
ΔP_f = pressure rise across the fan (Pa),
η_f = fan efficiency (-), and
η_m = motor efficiency (-).

It can be seen that the overall fan energy can be reduced by minimising the air quantity and flow resistance to a minimum commensurate with satisfying the design requirements.

5.3.1 Reduced Flow Rates

For a fixed ventilation system, the flow resistance is approximately proportional to the square of the flow velocity. As flow rate is linearly dependent on velocity for a given duct size, so the overall fan power is proportional to the cube power of the flow rate. In simple terms, this means that a halving of flow rate results in an eight fold reduction in fan power (assuming constant efficiencies). Consequently, reducing the space cooling load (see 5.1) can significantly reduce the required fan power for the same amount of space allocated for distribution ductwork etc.

Another very important design and construction issue is ductwork leakage. The previously described calculations assume that all the air leaving the air handling plant arrives in the zone being conditioned. In reality there will be some leakage of air from joints and seams in the ductwork. The leakage rate will be a function of the static pressure of the system and the construction method.

ASHRAE [6] have produced a leakage classification which defines the leakage as

$$C_L = \frac{720Q}{\Delta p_s^{0.65}}$$

where
C_L = leakage class ($l/s{\cdot}m^2$ at 250 Pa static pressure),
Q = leakage rate ($l/s{\cdot}m^2$), and
Δp_s = static pressure difference inside to outside of the duct (Pa).

Figure 15 shows the important effect of leakage. Taking a typical system length of 100 m and an average flow velocity of 6 m/s, the leakage as a percentage of the system flow can be calculated. The graph shows the results for a leakage category C_L of 6 $l/s{\cdot}m^2$ at different average system static pressures. Regular checks should be made for leakage, particularly in older systems which may lose as much as 25% of their total air volume. To compensate for the leakage, more air will need to be treated. This not only has an impact on fan energy, but can increase the heating and/or cooling load.

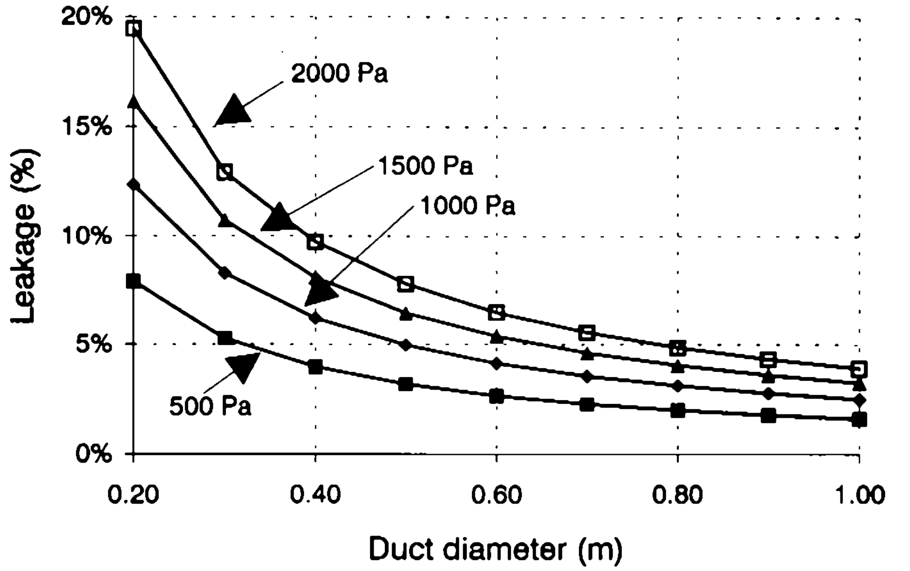

Figure 15 Effect of pressure and size on leakage

5.3.2 Reduced Pressure Drops

The second way to minimise transport energy is through a reduction of resistance to air movement. This can be achieved in two ways

- Reducing the velocity of flow at the design duty. This requires larger duct sizes which increases capital costs for both the ductwork and the building since more space will be required to accommodate risers and horizontal distribution. Reduced velocities will also tend to reduce ductwork generated noise.
- Ductwork should be designed to achieve minimum pressure loss. This requires use of low-loss fittings (swept bends rather than elbows etc).
- Central Plant: plant items such as coils and filters provide a significant resistance to airflow. A careful balance has to be struck between filtration efficiency and pressure drop which both vary with time for a given installation. Where cooling coils reduce the air temperature below the dew point (cooling coils or exhaust side run-around coils) consideration should be given to installing drop eliminators.

5.3.3 Flow Control

It is often necessary to vary the flow rate in a ventilation system. This may be an initial once-off commissioning adjustment, it may be a seasonal change to give different flows summer and winter or it may be a requirement to constantly control the flow rate to maintain a given environmental condition. In a given ductwork system, the fan energy consumption will vary approximately as the cube power of the flow rate; therefore a doubling of flow will increase the fan energy by a factor of eight. It is therefore very important that flow control is achieved in an energy efficient way.

Changes in flow can be achieved by two principal means. The first is to change the effective resistance of the ventilation system. The second is to change the performance characteristic of the fan. The ventilation system will operate at the intersection of the fan and system characteristic curves.

Figures 16 and 17 show how the choice of flow control can influence energy use. In the first diagram, the reduced flow is achieved by increasing the flow resistance through inserting a throttling disc or closing a damper. This moves the operating point back round the fan curve to a higher pressure at the reduced flow. The power absorbed by the fan increases slightly (point A to point B). In the second case, the reduction in flow is achieved by reducing the fan speed. The system pressure drop reduces dramatically, as does the absorbed fan power to point C. Although the flow rate has only been reduced by about 30%, the fan speed control uses about 65% less power than that used by the damper control. This means that although the control mechanism is more expensive, the reductions in energy consumption (and perhaps maximum demand charges) can rapidly pay back the extra initial cost.

Variable air volume (VAV) systems take advantage of the potential reduction in energy use at reduced air velocities by reducing the flow rate at conditions other than the design duty.

The flow rate can be varied by several means. The simplest and cheapest way is by varying the system resistance using a damper. This does not save energy, and excessive pressure drop across a damper may result in increased noise levels. As shown above, the most energy efficient way is to vary the fan performance. Fan speed control (the example used) can be achieved in a number of ways:

- multi-speed or continuously variable speed electric motors,
- variable speed gear boxes,
- fluid coupling, or
- magnetic coupling.

It should be remembered that there will be inefficiencies in the prime mover and drive which power the fan, and this efficiency may well vary across the flow range.

Other forms of speed control include:

- inlet vane control; this method generates a swirl of air in the direction of the impeller rotation.
- blade angle control; in this method, the angle of the fan blades is progressively reduced to reduce the pressure / volume and power curve. This method is only available for axial fans.

For systems requiring only an occasional change in flow rate, it is possible to achieve this by changing one or both drive pulleys on a belt driven fan.

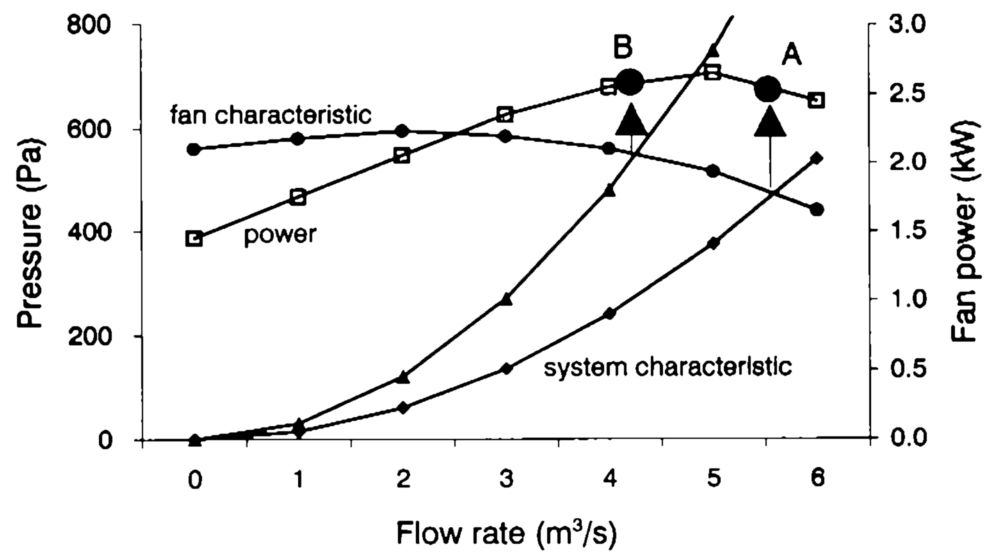

Figure 17 Controlling flow with a damper

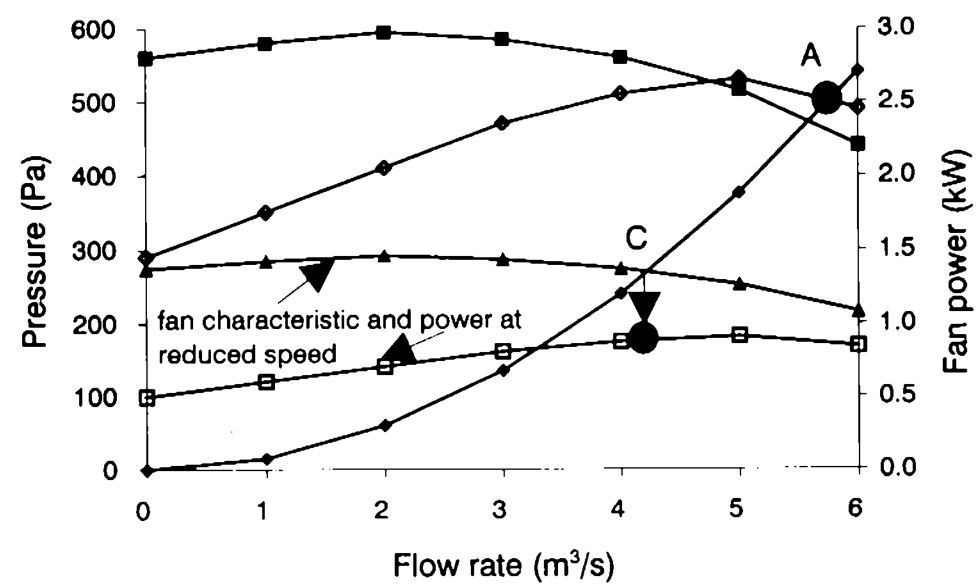

Figure 16 Controlling flow with speed control

5.3.4 VAV and Free Cooling

In a VAV system, at any cooling load less than the design duty, the option is available to cool the air to the design room-supply temperature difference using refrigeration, or to use a greater volume of air at a reduced supply differential. The balance has to be found between increased fan power and increased chiller consumption. This balance is a very difficult one to define, since it will vary enormously from system to system, depending on the flow characteristics of the duct system, the performance of the chiller etc. Figure 18 illustrates the trade off that

must be considered when considering the use of free cooling in a VAV system. This is a very simplified analysis, but it gives a general indication of the likely trends.
The case considers a cooling load of 100 kW. The room temperature is 23 °C, and the design VAV supply temperature is 14 °C. The prevailing outside temperature is 17 °C. Two options exist:

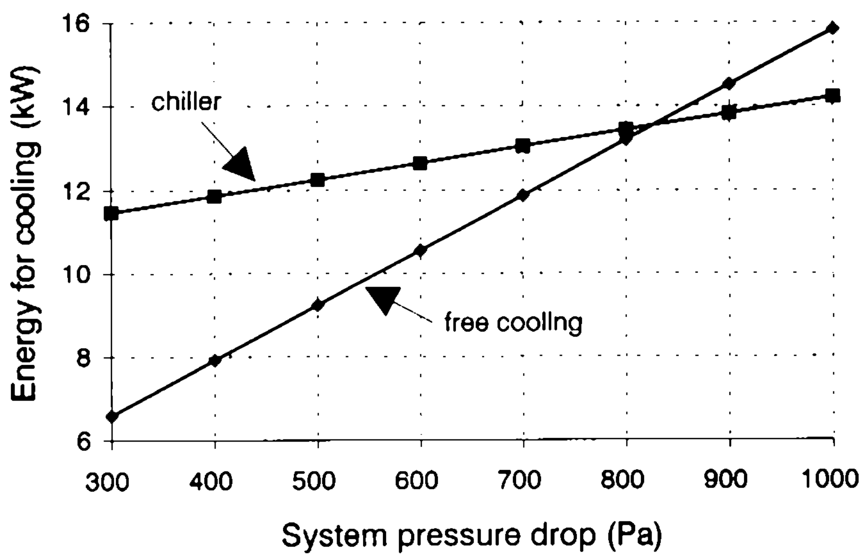

Figure 18 Comparison of free cooling and chiller cooling

- to maintain the VAV supply temperature at 14 °C, and cool the outside air to 14 °C using the chiller (a mean coefficient of performance, CoP, of 3.5 has been assumed).
- to increase the flow rate such that all the cooling is done with outside air alone. This reduces the room - supply differential, increasing the flow rate and the system resistance as a function of the square of the flow velocity. It has been assumed that a fixed pressure drop of 200 Pa is needed at the terminal, but the system resistance varies in proportion to the square of the flow rate.

Figure 18 shows that there is a cross over point where increasing use of "free cooling" results in an increase in overall energy use. This cross over point will be a function of chiller CoP, outside air temperature, fan efficiency etc, but the Figure illustrates the point that the concern should be overall energy use, not just component energy consumption.

Other ways of reducing the air quantity being circulated is to distribute smaller quantities of colder air from the air handling plant, and provide local mixing in the room to achieve the required supply - room temperature differential. This obviously requires lower temperature chilled water which means that the chillers will have to operate at lower evaporator temperatures which is likely to result in lower coefficients of performance. This effect can be balanced by using an ice storage system, where the overnight operation results in lower condenser temperatures. Reducing the primary air volume by distributing at a lower temperature can result in increased plant cooling energy requirements because of the increased latent cooling that will take place (the cooling coil will be below the outside air dew point for a much greater proportion of the year.) The other factor in the equation is that there is a need for local fans in the mixing boxes, and these small fans tend to be much lower in efficiency than large central system fans.

6. Conclusion

This Technical Note has briefly reviewed the primary factors which influence energy use for cooling. It has demonstrated that the key issues are to achieve a good envelope design in order to minimise the cooling load. It has also illustrated the importance of the fan energy consumption in the overall energy balance of an air cooling system. Good design must therefore seek to optimise the ventilation system design and control strategy to deliver the required occupant comfort in an energy efficient way.

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Bibliography of Other AIVC Cooling-Related Publications

Compiled by Malcolm Orme

#NO 5547 An overview and rationale of ventilation, building airtightness and related indoor air quality recommendations and requirements.
AUTHOR Liddament M W
BIBINF Belgium, Leuven, "IEA-EXCO Technical Day Research Presentation, paper from a meeting held November 26 1991. #DATE 00:11:1991 in English
ABSTRACT Ventilation is perceived as playing a key role in maintaining optimum air quality in buildings. At its most basic level ventilation is needed to satisfy the metabolic requirements of occupants. In addition, it is commonly used to dilute and disperse pollutants generated within buildings. During periods in which heating or cooling is needed, ventilation can contribute significantly to energy demand. As the performance of thermalinsulation improves and as the demands on ventilation increase,ventilation may easily become the dominant source of heating or cooling loss in buildings. It is therefore desirable to avoid excessive or unnecessary ventilation. Indoor air quality problems and associated unhealthy indoor environments have become the focus of recent attention, with the result that increasing emphasis is being placed on the role of ventilation incontrolling indoor pollutants. Thus an apparent conflict arises between a desire to limit ventilation, in order to minimise ventilation heat loss, and a need to increase ventilation, in order to avoid indoor air quality problems. As a consequence requirements and recommendations are evolving in many countries covering ventilation performance, building air tightness and air quality needs. The objective of this paper is to highlight someof the activities taking place in the development of requirements and to present a rationale of Standards development. Discussion also focuses on the role of ventilation in providing for a good indoor climate with particular emphasis focused on ventilation needs in relation to occupants, occupant activities and pollutant emissions from internal sources. This review is intended to be illustrative rather than exhaustive. The Air Infiltration and Ventilation Centre is, however,embarking on the production of a comprehensive international Standards Database which is intended to contain regularly updated information on Regulations, Standards and Codes in AIVC and other major countries.
KEYWORDS ventilation requirements, indoor air quality

#NO 5967 METOP - Energy efficient office building.
AUTHOR Laine J, Saari M
BIBINF UK, Air Infiltration and Ventilation Centre, 13th AIVC Conference, proceedings, held Hotel Plaza Concorde, Nice, France, 15-18 September 1992. #DATE 15:09:1992 in English
ABSTRACT A prototype of a low cost, low energy office building was built using a new Finnish component system building technology. Thanks to the energy efficient windows, the thermal insulation of the building envelope and the demand-controlled variable outdoor air flow HVAC system with heat recovery and energy-storing structures, the need for heating and cooling energy has been reduced to such a level that a low energy office can be cooled with outdoor air and with the aid of a heat recovery device. The building is kept warm with the support of its own operations almost throughout the year. It is possible to arrange a good individual indoor climate in this way almost without any purchased heating or cooling energy. There is need for heating only during the coldest but short periods in the night and during the weekends. Even during the summer heat periods, cooling energy produced by refrigerators operating on CFC is not needed.
KEYWORDS energy efficiency, office building, heat recovery, outdoor air, cooling

#NO 5969 An efficient enthalpy exchanger for economical ventilation.
AUTHOR Rose W B
BIBINF UK, Air Infiltration and Ventilation Centre, 13th AIVC Conference, proceedings, held Hotel Plaza Concorde, Nice, France, 15-18 September 1992. #DATE 15:09:1992 in English
ABSTRACT A cross-flow polymer membrane enthalpy exchanger has been designed which provides both heat recovery and moisture dissipation in the ventilation of living spaces. The exchanger is of benefit in providing fresh air during both cooling and heating seasons with minimum loss of energy. A prototype of the enthalpy exchanger has been constructed and tested. The air leakage of the equipment has been found to be negligible; that is, the two air streams are indeed non-mixing. Testing for efficiency of the equipment involved the measurement of dry bulb and wet bulb temperatures in each of the four ports. The measured temperature values were used to calculate the efficiency of the exchanger. The results show a total efficiency of 72%, with 71% sensible heat recovery and 74% latent recovery. These efficiencies were achieved at an air flow rate of 1.7 m3/minute (60 cfm). The measured moisture transfer rates exceedthe predicted moisture transfer rates by factors of two and three.
KEYWORDS heat exchanger, heat recovery, moisture, energy efficiency

#NO 5980 Field measurements of air change effectiveness using tracer gas techniques.
AUTHOR Olesen B W, Seelen J
BIBINF UK, Air Infiltration and Ventilation Centre, 13th AIVC Conference, proceedings, held Hotel Plaza Concorde, Nice, France, 15-18 September 1992. #DATE 15:09:1992 in English
ABSTRACT The present paper reports on tracer gas measurements performed in five large buildings during normal operating conditions. In all buildings air was supplied through ceiling diffusers and returned through a ceiling plenum. The measurements were taken during summer with thesystems in cooling mode, i.e. the supply temperature was lower than the room temperature. The global air change effectiveness and the occupied zone average air change effectiveness were calculated based on the age-of-air concept. The local air change effectiveness i.e., for one point in the space, was calculated in two ways: (1) Age-of-air in the return duct divided by local age-of-air at breathing level, and (2) Age-of-air return grille in ceiling divided by local age-of-air at breathing level. To measure age-of-air the tracer gas step-up method was used. The global air change effectiveness as well as the average air change effectiveness in the occupied zone for all systems indicated complete mixing. The local air change effectiveness showed, however, larger differences, indicating that the air in the occupied zone was not uniform mixed in all buildings.
KEYWORDS field monitoring, air change rate, tracer gas measurements, large building

#NO 5982 Improved indoor environment and ventilation in schools. A case study in Vaxjo, Sweden.
AUTHOR Larsson R, Olsson S
BIBINF UK, Air Infiltration and Ventilation Centre, 13th AIVC Conference, proceedings, held Hotel Plaza Concorde, Nice, France, 15-18 September 1992. #DATE 15:09:1992 in English
ABSTRACT During the last decade several surveys in Sweden have indicated that the indoor climate in existing schools is unsatisfactory, therefore a thorough project was carried out in Vaxjo. The indoor climate was investigated in three schools during 1989. Detailed measurements were made of ventilation (e.g. rates, air exchange efficiency), indoor air quality (e.g. CO2) and thermal comfort (e.g. air velocity). The main results were: high indoor temperatures, low air velocities and high concentration of CO2. Improvements were made in all three schools during 1990. One of the classrooms was rebuilt to have its own separate ventilation system with the possibility to use either ceiling diffusers or floor supply air terminal devices. After the improvements the measurements were repeated. The CO2 concentration and the air temperature were measured at different locations within the classroom, at different air flow rates and at different supply air temperatures. The air exchange efficiency was determined for different air flow rates and different air supply systems. The following recommendations were made for the schools in order to obtain: air temperature 18 Deg C and four ceiling diffusers; circulation fan in the classroom, night cooling with outdoor air during fall and spring. The results of this project will be used to produce a manual "Indoor Climate in Schools".
KEYWORDS school, indoor air quality, thermal comfort

#NO 5986 EBES - Energy efficient residential building.
AUTHOR Laine J, Saari M
BIBINF UK, Air Infiltration and Ventilation Centre, 13th AIVC Conference, proceedings, held Hotel Plaza Concorde, Nice, France, 15-18 September 1992. #DATE 15:09:1992 in English
ABSTRACT The new building and HVAC technology was used when an EBES multistorey residential building was built in Helsinki. In the EBES system the building structures are used as an installation space for the heating, piping, ventilation and electrical systems. Building structures are also used as a storage for heating and cooling energy. The main objectives of the overall EBES system are to improve the indoor air quality and energy economy and at the same time to improve the qualityof the construction process and reduce costs. The ventilation system is a mechanical supply and exhaust air system having efficient heat recovery. It is supported by an intelligent programmable controlling system. The ventilation system is designed so that no adjusting and balancing is required after installation. In the EBES system it is possible to use complex demand-controlled ventilation systems if desired. In this building manual control by residents was used. In each room the indoor temperature is individually controlled and theresident may choose the temperature level desired. All the HVAC components were tested in the laboratory before installation. All phases of the construction were monitored and filmed by video. The field monitoring of the indoor climate, energy consumption and operation of the system are presently in progress. The project will continue upto the end of 1992.
KEYWORDS energy efficiency, residential building, multi-storey building, mechanical ventilation, heat recovery

#NO 5987 Energy recovery in ventilation systems: a worldwide energy saving and environmental protection technology.
AUTHOR Dehli F
BIBINF UK, Air Infiltration and Ventilation Centre, 13th AIVC Conference, proceedings, held Hotel Plaza Concorde, Nice, France, 15-18 September 1992. #DATE 15:09:1992 in English
ABSTRACT For more than 20 years, energy recovery systems have been operated successfully in European countries in comfort and industrial ventilation systems in order to reduce the heating and cooling capacity as well asto reduce the annual

energy consumption for the treatment of supply air.By 1991 the total heating capacity of all installed energy recovery systems in Europe was about 60.000 MW and the equivalent of the annual energy savings was about 10 million tons of oil. This very impressive result of an energy saving technology also includes the annual reductionof emissions of all environmental polluting products: 10 million tons of annual oil savings are corresponding with the reduction of about 50.000tons of SO2 and 40 million tons of CO2. Apart from being an important economic factor both at the private and the national level, energy recovery systems thus also make an important contribution to energy conservation and environmental protection.
KEYWORDS heat recovery, energy conservation

#NO 7013 Ventilation efficiency measurements in a test chamber with different ventilation and cooling systems.
AUTHOR Roulet C-A, Cretton P, Kofoed P
BIBINF UK, Air Infiltration and Ventilation Centre, 14th AIVC Conference, "Energy Impact of Ventilation and Air Infiltration", held Copenhagen, Denmark, 21-23 September 1993, proceedings, pp73-80. #DATE 21:09:1993 in English
ABSTRACT Cooling ceilings are more and more proposed, in order to eliminate excess heat in office buildings without consuming much energy in air transport. On the other hand, piston ventilation is proposed to efficiently eliminate contaminants. These twosystems may however interact and experiments were planned to look at these interactions. Measurements of the age of air and air change efficiency were performed, together with more classical temperature and air velocity measurements, on various ventilation systems installed in the test chamber of SulzerInfra, in Winterthur. The test chamber was arranged to simulatean office room, with heat generated from computers andoccupants. Moreover, the contaminants from one occupant were simulated with a tracer gas and the contaminant removal effectiveness was measured at various locations in the room. Six different series of measurements were performed with displacement ventilation, with two types of cooling ceilings. Two more tests were performed with mixing ventilation, using two different inlet grilles. As expected, both mixing system, measured with the continuous cooling ceiling "on", reach nearly complete mixing, hence an air change efficiency close to 50% and a uniform contaminant removal effectiveness close to 1. Displacement ventilation systems showed a larger air change efficiency in most cases. However, the cooling ceiling counteracts the displacement and important mixing is observed when it is on, mainly if the air flow rate is lower than 5 volumes per hour. A test without cooling showed a strong displacement effect, the local mean age at every occupant location being lower than the room mean age. Except in this particular test, the contaminant removal effectiveness is generally about 1. It should be noted that, for these latter measurements, the contaminant source was not far from the inlet grilles, which represents the worst possible case. It is also shown that systems with a high air change efficiency do not necessarily provide fresh air to the occupants.
KEYWORDS ventilation efficiency, test chamber, cooling, ventilation system

#NO 7017 Some Aspects of Using Jets for Cooling.
AUTHOR Karimipanah T, Sandberg M
BIBINF UK, Air Infiltration and Ventilation Centre, 14th AIVC Conference, "Energy Impact of Ventilation and Air Infiltration", held Copenhagen, Denmark, 21-23 September 1993, proceedings, pp97-98. #DATE 21:09:1993 in English
ABSTRACT The efficiency of removing excess heat by employing mixing ventilation is based on the properties of jets. Therefore the behaviour of jets in enclosures is important. A correct supply design is essential otherwise the jet will separate from theceiling and drop into the occupied zone. This will give rise to unacceptable high velocities. the basic properties of jets in ideal situations like an infinite space are well known. However, in a room the jet interacts with the room air and the room surfaces. Therefore a research program on the basic properties of jets in rooms has been started at the institute. This paper reports the findings from both an experimental study comprising both model studies and full scale studies supplemented by numerical simulations of room flow.
KEYWORDS cooling, mixing ventilation

#NO 7022 Simulation of Displacement Ventilation and Radiative Cooling.
AUTHOR Koschenz M
BIBINF UK, Air Infiltration and Ventilation Centre, 14th AIVC Conference, "Energy Impact of Ventilation and Air Infiltration", held Copenhagen, Denmark, 21-23 September 1993, proceedings, pp131-140. #DATE 21:09:1993 in English
ABSTRACT For thermal comfort and energy conservation reasons, displacement ventilation and radiative cooling systems are increasingly used. Simulation programs are generally not able to correctly simulate such systems because of their one node approach for the air temperature. A procedure for creating DOE-2 inputs to simulate both system types each alone or in combination - without program code change - was developed, based on a more detailed new TRNSYS-Type, and validated against existing experimental data sets. The used approaches in DOE-2 are a two zone model for the displacement ventilation and a 'dummy' zone for the radiative cooling. A sufficiently good agreement shows that this is possible. the new TRNSYS-Type is a one zone model similar to the existing Type 19, but it simulates the temperature gradient in the room with 3 air nodes.
KEYWORDS displacement ventilation, simulation, cooling

#NO 7024 Cooling Ceiling Systems and Displacement Flow.
AUTHOR Mertz G
BIBINF UK, Air Infiltration and Ventilation Centre, 14th AIVC Conference, "Energy Impact of Ventilation and Air Infiltration", held Copenhagen, Denmark, 21-23 September 1993, proceedings, pp149-156. #DATE 21:09:1993 in English
ABSTRACT For several years the technology of chilled ceilings has been a favourite issue among HVAC technicians and underwent a boom in the past few years. According to the survey of a German technical journal, on March the first 1993, a total of 308,490m2 of chilled ceilings had been installed in German buildings, out of which 69 per cent had been installed in new buildings and 31 per cent in modernized projects. Cooling ceiling systems are the ideal application where high demands are placed on comfort requirements and where the energy loads are very high compared to material loads. Given the fact that cooling ceiling systems fulfill only one thermodynamical function, i.e. the cooling requirements, and do not contribute to the renewal of the indoor air, they have to be combined with an additional ventilating system. This article and the poster description describe different cooling ceiling systems in conjunction with ventilating systems, the main focus being on displacement flow.
KEYWORDS cooling, displacement ventilation

#NO 7026 Benefits and Limits of Free Cooling in Non-Residential Buildings.
AUTHOR Bollinger A, Roth H W
BIBINF UK, Air Infiltration and Ventilation Centre, 14th AIVC Conference, "Energy Impact of Ventilation and Air Infiltration", held Copenhagen, Denmark, 21-23 September 1993, proceedings, pp167-176. #DATE 21:09:1993 in English
ABSTRACT In urban non-residential buildings air-conditioning systems are generally required to achieve acceptable air quality. To reduce the energy demand of HVAC-plants free cooling is proposed. The present study deals with free cooling by outdoor air (untreated or additionally cooled by evaporation) during the night. Therefore a sufficient building mass (about 600 to 800 kg/m2) is necessary which stores the heat produced in daytime and which is cooled down at night. In most conventional non-residential buildings, however, the building mass is at about 400 to 600 kg/m2. A reference room which provides optimum conditions for night cooling has been investigated using a dynamic building simulation program. Three variants have been examined: Night cooling by untreated outdoor air and increased heat transfer to cool down the ceiling of the reference room, night cooling combined with evaporative cooling and ventilation through a false floor. The simulation results show that room air temperatures below 28oC can be achieved exclusively by combining night cooling and evaporative cooling as long as the total load does not exceed 55 W/m2. For higher loads night cooling combined with mechanical cooling during the occupied period exclusively. As the ventilation energy demand has a strong impact on the total energy demand decentralized systems with low pressure losses are required. Without mechanical cooling less comfort and poorer air quality are inevitable, as dehumidification of supply air is a presupposition for high comfort and air quality. Night cooling should be realized without mechanical systems, e.g. by using buoyancy forces of an atrium. This requires a close cooperation between the architect and the HVAC-engineer.
KEYWORDS cooling, outdoor air, atrium

#NO 7027 Numerical Assessment of Room Air Distribution Strategies.
AUTHOR Awbi H B
BIBINF UK, Air Infiltration and Ventilation Centre, 14th AIVC Conference, "Energy Impact of Ventilation and Air Infiltration", held Copenhagen, Denmark, 21-23 September 1993, proceedings, pp177-188. #DATE 21:09:1993 in English
ABSTRACT The air distribution in a room is investigated using computational fluid dynamics. Four common methods of supplying air to a room are compared. The effect of air change rate on the ventilation effectiveness for contamination is small, however the effect of room heating or cooling load can be very significant. It was found that air turbulence has a major influence on the air movement, air velocity and dispersion of contaminants in the room.
KEYWORDS air distribution, numerical modelling, computational fluid dynamics, ventilation effectiveness

#NO 7029 The Influence of the Humidity on Thermal Comfort, Heat Load Calculation and Cooling Capacity.
AUTHOR Steimle F
BIBINF UK, Air Infiltration and Ventilation Centre, 14th AIVC Conference, "Energy Impact of Ventilation and Air Infiltration", held Copenhagen, Denmark, 21-23 September 1993, proceedings, pp201-214. #DATE 21:09:1993 in English
ABSTRACT This paper shows the extensive influence of humidity on comfort, cooling load and refrigeration capacity. Modern computer programs allow an effective consideration of humidity in systems.
KEYWORDS humidity, thermal comfort, cooling

#NO 7034 A New Development for Total Heat Recovery Wheels
AUTHOR Dehli F, Kuma T, Shirahama N
BIBINF UK, Air Infiltration and Ventilation Centre, 14th AIVC Conference, "Energy Impact of Ventilation and Air Infiltration", held Copenhagen, Denmark, 21-23 September 1993, proceedings, pp261-268. #DATE 21:09:1993 in English
ABSTRACT Total energy exchangers with a rotating heat storing matrix have been applied to air conditioning systems for more than 25 years with very good results for saving both heating and

cooling energy. The efficiency of the hygroscopic coating of the rotors is very important to recover the latent energy, but there is the risk of cross contamination. To prevent odour transfer, the mechanism of the sorption and desorption process has to be investigated in detail. Selecting the adsorbant accordingly, the rotating heat exchanger can meet the new ventilation requirements in buildings for a high indoor air quality.
KEYWORDS heat recovery, odour

#NO 7036 High Comfort to Reasonable Cost.

AUTHOR Barath B
BIBINF UK, Air Infiltration and Ventilation Centre, 14th AIVC Conference, "Energy Impact of Ventilation and Air Infiltration", held Copenhagen, Denmark, 21-23 September 1993, proceedings, pp281-288. #DATE 21:09:1993 in English
ABSTRACT A new ventilation and cooling system called OKOMAIR has been developed and investigated. The main idea is to separate carrying off cooling loads and providing fresh air to the occupants without mixing it with the return air. Return air is cooled by fan coil devices. The undiluted outside air is provided directly to the working zone and cooled by a cold waterstorage. This storage is charged by cool outside air during night. Use of the new system leads to high comfort for the occupants and reduces cooling energy. These advantages have been proved by measurements, CFD and building loads and energy analysis simulations.
KEYWORDS cooling, thermal comfort

#NO 7067 Multizone cooling model for calculating the potential of night time ventilation.

AUTHOR van der Maas J, Roulet C-A
BIBINF UK, Air Infiltration and Ventilation Centre, 14th AIVC Conference, "Energy Impact of Ventilation and Air Infiltration", held Copenhagen, Denmark, 21-23 September 1993, proceedings, pp567-586. #DATE 21:09:1993 in English
ABSTRACT One of the options to increase the energy efficiency of buildings in the cooling season, is to extract heat from the building envelope during the night by natural or forced ventilation. The exploitation of this technique by architects and designers requires the development of guide lines and a predesign tool showing how the potential cooling power depends on the influence of opening sizes and positions and on theinteraction with the thermal mass. While a single zone model issufficient to estimate roughly the heat extracted from the building, a multi zone extension allows one to predict thedistribution of air and wall temperatures and therefore thedistribution of cooling power over the air flow path (when the zones are ventilated in series). A zonal cooling model based on the principles of mass and energy conservation and coupling ventilation with both heat transfer and a thermal model for the walls. The parameters of the ventilation model are the size and position of the openings, the stack height, and climatic parameters like temperature swing and wind characteristics. The heat transfer is parametrized by the exposed surface area of thermal mass, while the heat storage for heavy weight constructions is only characterized by both that surface area and the thermal effusivity of the exposed wall material. The predictions are compared with measurements for a simple flow path configuration.
KEYWORDS cooling, modelling, energy efficiency

#NO 7958 Natural ventilation through a single opening - the effects of headwind.

AUTHOR Davies G M J, Holmes M J
BIBINF UK, Air Infiltration and Ventilation Centre, 1994, "The Role of Ventilation", proceedings of 15th AIVC Conference, held Buxton, UK, 27-30 September 1994, Volume 1, pp77-92.
ABSTRACT The airflow between a warm room and cool exterior can be significantly affected by an external headwind. Pollutant concentrations within the space depend on the relative sizes of the wind and the undisturbed stack driven flow. Two scenarios are described. Firstly, a space is filled initially with buoyant polluted air. The space is then naturally ventilated through a single opening. In the"no wind" case, a gravity current of external air flows into space. All the polluted air is expelled from the room. At high wind speeds the turbulence associated with the headwind produces mixing just inside the doorway. Under some conditions, ventilation levels are reduced.The second scenario considered is the natural ventilation of a space containing a continuous source of buoyant pollutant. For weak headwinds, fresh external air flows into the room and the pollutant concentration in that lower layer remains close to zero. High headwind speeds again generate doorway mixing. Air flowing into the space becomes contaminated with pollutant. These flows were studied experimentally using small-scale saline modelling techniques. Simple mathematical models are presented which agree closely with the experimental results. In both the transient and continuous cases, an increase in the headwind could lead to reduction in ventilation and an increase in internal pollutant levels.Natural ventilation through a single opening is not necessarily enhanced by wind.
KEYWORDS (natural ventilation, openings, wind effects, air flow, turbulence)

#NO 7976 A design guide for thermally induced ventilation.

AUTHOR Filleux C, Krummenacher S, Kofoed P
BIBINF UK, Air Infiltration and Ventilation Centre, 1994, "The Role of Ventilation", proceedings of 15th AIVC Conference, held Buxton, UK, 27-30 September 1994, Volume 1, pp263-272.
ABSTRACT A design guide for displacement ventilation (thermally induced ventilation) has been

prepared. It is based on quasi stationary experiments carried out in the Sulzer Infra laboratory in Winterthur. The significant design parameters identified by factorial analysis are the air flow rate, the internal load, the convection part of the internal load and to a lesser extent the room height. Using a linearized polynom representation for thetemperature increase near the floor as well as for the vertical temperature gradient in the occupied zone a design nomogram has been obtained. Within its range of application the design nomogram also applies for displacement ventilations systems combined with cooled ceilings. The design guide is published in German and French language and is one of the major outputs of the Swiss research program on "Energy Relevant Air Movements in Buildings (ERL)".
KEYWORDS (displacement ventilation, air flow)

#NO 7979 ventilation and energy flow through large vertical openings in buildings.
AUTHOR Maas J van der, Hensen J L M, Roos A
BIBINF UK, Air Infiltration and Ventilation Centre, 1994, "The Role of Ventilation", proceedings of 15th AIVC Conference, held Buxton, UK, 27-30 September 1994, Volume 1, pp289-302.
ABSTRACT After a short description of the physical phenomena involved, unified expressions are worked out describing net airflow and net heat flow through large vertical openings between stratified zones. These formulae are based on those of Cockcroft for bidirectional flow, but are more general in the sense that they apply to situations of unidirectional flow as well. The expressions are compatible with a pressure network description for multizone modelling of airflow in buildings. The technique has been incorporated in the flows solver of the ESP-r building and plant energy simulation environment. The relative importance of the governing variables (pressure difference, temperature difference and vertical air temperature gradients) is demonstrated by parametric analysis of energy performance in a typical building context and by comparison with experimental data in the literature. It is concludedthat vertical air temperature gradients have a major influence in the heat transferred through large openings in buildings and should be included in building energy simulation models. Finally, it is discussed how the air temperature gradient, an input parameter which depends strongly on the heating and cooling mode, could be predicted.
KEYWORDS (openings, air flow, heat transfer)

#NO 7986 Energy and environmental protection aspects of dessicant cooling.
AUTHOR Dehli F
BIBINF UK, Air Infiltration and Ventilation Centre, 1994, "The Role of Ventilation", proceedings of 15th AIVC Conference, held Buxton, UK, 27-30 September 1994, Volume 1, pp361-370.
ABSTRACT Ventilation and air conditioning systems mainly use fossil primary energies as gas, oil and coal for the heating and cooling processes. Air conditioning means heating and humidifying the supply air during the winter season andcooling and dehumidifying the supply air in the summer season. For these summer operations the supply air ingeneral is cooled down lower than the dew point in orderto dehumidify the air by condensation. Afterwards the supply air is reheated again to reach the required temperature level for room inlet. For this air treatment process cooling and heating energy are used simultaneously. The cooling energy thereby is generated in general in a conventional cooling compressor unitbased on CFC-refrigerants. Due to the threat of an atmospheric ozone depletion leading to a "Greenhouse Effect" mainly caused by CO2 from burning fossil primary energies and the CFC-based refrigerants (1) used as cooling vapour in compressor chillers new developments of cooling equipment have a realistic chance to enter the HVAC market. Today it is necessary to operate air conditioning systems with a minimum of primary energy consumption and low pollutant emissions. At the same time the requirements for the indoor air quality are increasing. Therefore alternative and new air conditioning systems are now introduced using "Desiccative and Evaporative Cooling" (DEC) air treatment processes (2). These units can be operated all over the year and have to be compared under energy andenvironmental operation aspects with traditional air conditioning systems.
KEYWORDS (cooling, air conditioning, humidification)

#NO 8003 Simulation of passive cooling and natural facade driven ventilation.
AUTHOR Dorer V, Weber A
BIBINF UK, Air Infiltration and Ventilation Centre, 1994, "The Role of Ventilation", proceedings of 15th AIVC Conference, held Buxton, UK, 27-30 September 1994, Volume 2, pp531-540.
ABSTRACT In many design cases, energy as well as occupant comfort are the relevant criteria which are studied using computer simulation programs. Comfort evaluations cover air quality, thermal, visual and acoustic comfort. For all these individual aspects, specific simulation programs are available today, but very few programs allow for the integrated evaluation of several or all relevant parameters. The more, heat transport, ventilation as well as lighting are physically coupled and thereforemust be integrally modelled in the simulation process. This paper gives a short description of the concept used for the coupling of the air flow simulation code COMVEN with the building and systems simulation code TRNSYS. Then, two application examples typical for a building design study situation are presented. The first example shows a multi-storey school building which is passively cooled at night-time due to a natural stack airflow. The influence of the

operation of the openings on the maximum room temperature is discussed for a hot summer period case. The facade of the building of example 1 shall be retrofitted with a glazed outer facade. In example 2 the natural ventilation of this building is studied.Ventilation is provided by naturally driven shaft ventilation through the facade spaces. Control strategies for the openings and the blinds are discussed in respect to overheating risk and minimum air flow rates.
KEYWORDS (cooling, natural ventilation, human comfort, simulation)

#NO 8018 Standardised measurements of the cooling performance of chilled ceilings.
AUTHOR Steimle F, Mengede B, Schiefelbein K
BIBINF UK, Air Infiltration and Ventilation Centre, 1994, "The Role of Ventilation", proceedings of 15th AIVC Conference, held Buxton, UK, 27-30 September 1994, Volume 2, pp697-708.
ABSTRACT One important aim for the development of new air conditioning systems is the reduction of the total energy consumption. This can be reached by separation of cooling and ventilation in air conditioning systems, because it is more effective to transport energy by using water systems instead of air to deliver cooling energy to the consumers. This strategy was the base for the development of several chilled ceiling systems during the last years, so that at present there are many different systems on the market. One problem during the design period is to calculate the cooling performance of these systems depending on different operating conditions. So it is necessary for the companies to find characteristicdata to describe the heat transfer of these elements. But an objective comparison of different systems and an accurate planning is only possible, if these data were investigated under comparable boundary conditions.Parallel to the Germany standard organisation (DIN) the working group "Heating and cooling surfaces" of the GermanFGK e.V., in which the leading manufacturing, planning and installation companies of chilled ceiling systems are represented, had outlined a guideline to guarantee standardized measurements under clearly defined boundary conditions. It is planned to discuss the main aspects of this guideline and the conditions for measurements of the cooling performance of open convection chilled ceilingsystems.
KEYWORDS (cooling, ceiling, measurement technique, air conditioning)

#NO 8023 Occupant satisfaction and ventilation strategy - a case study of 20 public buildings.
AUTHOR Donnini G, Nguyen V H, Molina J
BIBINF UK, Air Infiltration and Ventilation Centre, 1994, "The Role of Ventilation", proceedings of 15th AIVC Conference, held Buxton, UK, 27-30 September 1994, Volume 2, pp749-758.
ABSTRACT Summary: Occupant response is a good indicator of the effectiveness of a ventilation system. In a one-year study in the province of Quebec region, 20 public buildings were studied. Occupants were asked to answer questions on their perception of their environment andthe ventilation at their workstation. Annual energy consumption for each building was recorded. The ventilation systems were studied as well as their rates; minimum outdoor air rates and average total air rates, at each workstation and at the ventilation system. Ventilation rates were plotted against energy consumption. Occupant satisfaction was plotted against ventilation rate and against energy consumption. It was found that as outdoor air rates at the work stations increased, the occupants perceived a better indoor air quality, a better ventilation, and a more constant ventilation frequency above 70 l/s/p. No trend was found from their perception of the air movement. As the total air supplied at the diffusers increased, the occupants perceived a better indoor air quality, a better ventilation, and a more constant ventilation frequency above 110 l/s/p. However, all these perceptions decreased to the original values above 130 l/s/p.o trend was found from their perception of the air movement. As the total air flow rates at the ventilation system increased, the occupants perceived a better indoor air quality, a better ventilation, a more constant ventilation frequency, and a better air movement above 200 l/s/p. However, all these perceptions decreased to the original values above 250 l/s/p. As the ventilation efficiency at the workstations increased from 27 to 70%, the occupants perceived a poor indoor air quality, an insufficient ventilation, and an irregular frequency above 25%. No trend was found from their perception of the air movement. As the maximum carbon dioxide concentration at the work place increased, the occupants perceived a worst indoor air quality above 800 ppm of CO , a worst air movement above 1000 ppm. The ventilation strategy resulting in the best perception from the occupants was of the type free cooling, with variable outdoor air supply, variable total air supply, andconstant supply temperature.
KEYWORDS (occupant reaction, public building, ventilation system, outdoor air)

#NO 8024 Natural ventilation strategies to mitigate passive smoking in homes.
AUTHOR Kolokotroni M, Perera MDAES
BIBINF UK, Air Infiltration and Ventilation Centre, 1994, "The Role of Ventilation", proceedings of 15th AIVC Conference, held Buxton, UK, 27-30 September 1994, Volume 2, pp759-770.
ABSTRACT This paper investigates possible natural ventilation strategies to reduce exposure to environmental tobacco smoke (ETS) in dwellings. Particular attention is paid to the migration of tobacco smoke from the living room (usually the smoking room) to the bedrooms which may be occupied by children. This addresses an area of

current concern regarding the possible association between passive smoking and adverse health conditions; in particular the link between parental smoking and respiratory illness in children. The study used the multizoned airflow prediction program BREEZE to evaluate the movement of tobacco smoke from the smoking rooms to the bedrooms in typical detached, semi-detached and terraced dwellings for a variety of natural ventilation strategies. Typical smoking patterns were emulated and contaminant movements analysed, taking into account factors such as wind speeds and direction and air temperatures. Some of the results obtained were compared with limited full-scale measurements acquired elsewhere to provide the necessary confidence in the predictions. Controlling pollutant concentration by ventilation can bean energy intensive process, especially during the heating and cooling season. Since almost all dwellings in the U.K. are naturally ventilated, providing optimum ventilation with minimum ventilation heat loss is of concern only during the heating season. Results from the study indicate three possible strategies to mitigate the effect of passive smoking in dwellings; two which could be used during the heating season and one for theremaining times of the year.
KEYWORDS (natural ventilation, passive smoking, residential building, respiratory illness)

#NO 9040 Energy requirements for conditioning of ventilating air.

AUTHOR Colliver D
BIBINF UK, Air Infiltration and Ventilation Centre, 16th AIVC Conference Implementing the results of ventilation research , held Palm Springs, USA, 18 - 22 September, 1995, Proceedings Volume 1, pp 1-12.
ABSTRACT The energy impact involved between bringing in outdoor air for indoor air pollution reduction and the energy required to condition this air are investigated in this report. Long term hourly weather data from several European and American locations were analyzed to determine the average conditions of air over the period of record of the data. These data were then analysed to determine the psychrometric process theoretical heating, cooling and moisture removal energy requirements for a constant mass of airflow per hour. This paper summarises the information contained in a longer report. It was found that a significant amount of energy is required to condition air which is used for ventilation. The annual energy required per kg-dry-air/hr of airflow varied from 22.1 MJ.h/kg for Los Angeles to 102.5 MJ.h/kg for Omaha. In Europe the range was from 45.6 MJ.h/kg for Nice to 101.1 MJ.h/kg for Saint-Hubert. In Europe most of the energy was used to heat the air to the desired setpoint. In America there were significant amounts of both heating and cooling required. Much of the variation was due to the amount of moisture in the air which had to be removed in air conditioning. In situations where air conditioning is used, a significant amount of this energy is used in dehumidifying the air. For example, in Miami 86% of the energy is used for moisture removal. It was also found that the energy used was highly sensitive to the heating, cooling and relative humidity setpoints.
KEYWORDS energy needs, outdoor air, moisture

#NO 9051 Application of air flow models to aircraft hangars with very large openings.

AUTHOR van der Maas J, Schaelin A
BIBINF UK, Air Infiltration and Ventilation Centre, 16th AIVC Conference Implementing the results of ventilation research , held Palm Springs, USA, 18 - 22 September, 1995, Proceedings Volume 1, pp 127-142.
ABSTRACT In lime maintenance hangars, air planes stay about 2 hours, usually at night-time. The cooling down of the inside air during the opening time of the hangar gates (up to 5 times per night, lasting 1.5 to 30 minutes each) has a considerable impact on the comfort conditions for the workers, and on the energy required for reheating. The time-dependent air flow rates and associated heat loss rates during the door opening and closing cycles is assessed by simple transient thermal models and CFD (Computational Fluid Dynamics) calculations. The results obtained by these models agree well with the experimental data of the transient temperature response during the opening and closing of the door of a real full scale hangar. The effect of using huge air curtains (up to a height of 20m, a width of 80m, and moving air volumes at rates of 400 m3/s) to prevent heat loss was studied numerically by CFD in two- and three- dimensional models for time-dependent conditions. The study covers also transient effects when an aircraft is actually crossing the air curtain, and shows the feasibility of assessing the energy saving potential of such air curtains using CFD.
KEYWORDS air flow, modelling. hangar, openings

#NO 9059 A simple calculation method for attic ventilation rates.

AUTHOR Walker I S, Forest T W, Wilson D J
BIBINF UK, Air Infiltration and Ventilation Centre, 16th AIVC Conference Implementing the results of ventilation research , held Palm Springs, USA, 18 - 22 September, 1995, Proceedings Volume 1, pp 221-232.
ABSTRACT The ventilation of an attic is critical in estimating heating and cooling loads for buildings because the air temperature in the attic is highly sensitive to ventilation rate. In addition, attic ventilation is an important parameter for determining moisture accumulation in attic spaces that can lead to structural damage and reduced insulation effectiveness. Historically, attic venting has been a common method for controlling attic temperature and moisture, but there have been no calculation techniques available to determine attic ventilation rates. Current practice is to use rules of thumb for estimating attic vent areas. Simple

algebraic relationships are developed here, using functions fitted to an exact numerical solution for air flow through attic envelopes. This algebraic model (AVENT) was developed to be easy to use as diagnostic or design tool. Key factors included in the model are: climate (wind and stack effect), wind shelter, leakage distribution and total attic leakage. This paper validates the model predictions by comparing to measured data from two attics at the Alberta Home Heating Research Facility (AHHRF). Average errors for the model are about 15% compared to the measured ventilation rates.
KEYWORDS calculation techniques, attic, ventilation rate

#NO 9063 Effectiveness of a heat recovery ventilator, an outdoor air intake damper and an electrostatic particulate filter at controlling indoor air quality in residential buildings.
AUTHOR Emmerich S J, Persily A K
BIBINF UK, Air Infiltration and Ventilation Centre, 16th AIVC Conference Implementing the results of ventilation research , held Palm Springs, USA, 18 - 22 September, 1995, Proceedings Volume 1, pp 263-276.
ABSTRACT A preliminary study of the potential for using central forced-air heating and cooling system modifications to control indoor air quality (IAQ) in residential buildings was performed. The main objective was to provide insight into the potential of three IAQ control options to mitigate residential IAQ problems, the pollutant sources the controls are most likely to impact, and the potential limitations of the controls. Another important objective was to identify key issues related to the use of multizone models to study residential IAQ and to identify areas for follow-up work. The multizone airflow and pollutant transport program CONTAM93(1) was used to simulate pollutant concentrations due to a variety of sources in eight houses with typical HVAC systems under different weather conditions. The simulations were repeated after modifying the systems with three IAQ control technologies - an electrostatic particulate filter, a heat recovery ventilator (HVR), and an outdoor air intake damper (OAID) on the forced-air system return. Although the system modifications reduced pollutant concentrations in the houses for some cases, the HRV and OAID increased pollutant concentrations in certain situations involving a combination of weak indoor sources, high outdoor concentrations, and indoor pollutant removal mechanisms. Also, limited system run-time during mild weather was identified as a limitation of IAQ controls that operate in conjunction with forced-air systems. Recommendations for future research include: simulation of other buildings, pollutants and IAQ control technologies; model validation; sensitivity analysis; and development of important model inputs.
KEYWORDS heat recovery, outdoor air, particulate, filter

#NO 9070 Air dehumidification by absortive and evaporative cooling.
AUTHOR Roeben J, Kourouma S Y
BIBINF UK, Air Infiltration and Ventilation Centre, 16th AIVC Conference Implementing the results of ventilation research , held Palm Springs, USA, 18 - 22 September, 1995, Proceedings Volume 2, pp 341-350.
ABSTRACT Especially in modern buildings with small capacity of humidity storage it is necessary to reduce the humidity in the supply air. Normally a refrigeration system containing CFC s is used. There are some alternative fluids available, but mostly they show a high global warming potential. These systems all need electrical energy to be driven and therefore it is necessary to consider other possibilities with alternative systems. The most promising systems are sorptive systems which are used in open cycles. In these systems the air is dehumidified by a liquid sorbens and cooled indirectly by evaporating water in an open circuit. In this paper a design of an open cycle liquid desiccant system is shown as well as two possible system configurations. Very interesting possibilities for the regeneration are given in using low temperature energy and also solar radiation in sunny areas.
KEYWORDS dehumidifcation, cooling

#NO 9072 Automatic control of natural ventilation and passive cooling.
AUTHOR Martin A
BIBINF UK, Air Infiltration and Ventilation Centre, 16th AIVC Conference Implementing the results of ventilation research , held Palm Springs, USA, 18 - 22 September, 1995, Proceedings Volume 2, pp 359-368.
ABSTRACT The material presented in this paper highlights some aspects of two research projects, The control of natural ventilation , and Night cooling strategies . The research has led to the development of generic control strategies. These have evolved from consideration of the control strategies used in naturally ventilated buildings utilising Building Management Systems (BMS) control together with experience obtained from monitoring three naturally ventilated buildings. The site monitoring has also led to recommendations being provided for commissioning and fine tuning procedures.
KEYWORDS natural ventilation, cooling, energy efficiency

#NO 9074 Energy impacts of air leakage in US office buildings.
AUTHOR VanBronkhorst D, Persily A K, Emmerich S J
BIBINF UK, Air Infiltration and Ventilation Centre, 16th AIVC Conference Implementing the results of ventilation research , held Palm Springs, USA, 18 - 22 September, 1995, Proceedings Volume 2, pp 379-392.

ABSTRACT Airtightness and infiltration rate measurements in office and other commercial buildings have shown that these buildings can experience significant levels if air leakage. The energy impact of air leakage in U.S. office buildings was estimated based on the analysis of a set of 25 buildings used in previous studies of energy consumption. Each of these buildings represents a portion of the U.S. office building stock as of 1995. The energy impact of air leakage in each building was estimated by performing an hourly analysis over one year, with the infiltration rates varying linearly with the wind speed. The energy associated with each of the 25 buildings was then summed to estimate the national energy cost of air leakage. The results show that infiltration accounts for roughly 15% of the heating load in all office buildings nationwide, and a higher percentage in recently constructed buildings. A sensitivity analysis showed that the heating loads due to infiltration were particularly sensitive to uncertainty in the balance point temperature and night-time thermostat setback. The results also show that infiltration have very little impact in cooling loads in office buildings. The results for office buildings are presented and discussed, along with the implications for the energy impacts of air leakage for the total commercial building stock in the U.S.
KEYWORDS air leakage, office building, infiltration rate

#NO 9083 Criteria for heat recovery and dehumidification.

AUTHOR Dehli F
BIBINF UK, Air Infiltration and Ventilation Centre, 16th AIVC Conference Implementing the results of ventilation research , held Palm Springs, USA, 18 - 22 September, 1995, Proceedings Volume 2, pp 483-492.
ABSTRACT Two factors - CO2 emissions from heating and cooling systems and restrictions on the use. of CFC refrigerants - have accelerated the development and introduction of new and more environmentally friendly cooling systems. These new cooling systems also include the so-called Desiccant Cooling Systems (DCS) [1]. The desiccant cooling systems consist of a rotating dehumidifier, a rotating heat exchanger and evaporative coolers. For design, control and operation of desiccant cooling systems new criteria has to be considered because of the specific properties of these new technologies. Therefore consulting engineers as well as installers of air conditioning systems are hesitating to trust the efficiency and performance of these new components. Dehumidification of moist air is one of the least known and understood thermodynamic processes. On the other hand the same rotating desiccant wheels and the same rotating heat exchangers are used for many years in a similar joint combination in thousands of installations in the field of air dehumidification for industrial processes for heat recovery and cooling. In general the dehumidification rotor is divided into two sectors (Fig 1). One is the process zone where humidity is accumulated. The other zone is the regeneration zone where humidity is removed by the counterflow of heated air. The typical operation is unbalances with a ratio of 1:3 for regeneration to process zone area or air flow. For a balanced ratio the regeneration temperatures can be below 80 degrees C. To reach high efficiency for the dehumidification process the rotor is divided in three sectors to have in a multistep operation an intermediate cooling in the so-called purge sector. In the following a standard design of an industrial air dehumidification system is described in order to show that design criteria as well as experience can be derived and transferred to the desiccant cooling systems in the comfort field application.
KEYWORDS heat recovery, dehumidification, moisture

#NO 9087 Cooling performance of silent cooling systems built by free convective coolers.

AUTHOR Steimle F
BIBINF UK, Air Infiltration and Ventilation Centre, 16th AIVC Conference Implementing the results of ventilation research , held Palm Springs, USA, 18 - 22 September, 1995, Proceedings Volume 2, pp 527-536.
ABSTRACT For the planning of silent cooling systems built by free convective coolers, it is necessary to support characteristic data for the cooling performance and the effect of different installation and operating parameters on the cooling performance. At the Institut fur Angewandte Thermodynamik und Klimatechnik at the University of Essen measurements of the cooling performance of free convective coolers were carried out by using a testing chamber as well as an enlarged and modified testing room with the dimensions near to practice. The investigations have shown that the cooling performance of convective coolers varies with different parameters like dimensions of the room, distribution of heat sources and positioning of the coolers in the room. A realistic investigation of these coolers and an objective comparison with other systems like chilled ceilings is only possible, if the investigation takes place under realistic operating conditions and arrangements of coolers and heat sources. Otherwise, the results from different systems are not comparable. The effects of different installation parameters have shown, that an accurate planning of the installation is necessary to guarantee sufficient cooling performance.
KEYWORDS cooling, test chamber, test room

#NO 9104 Energy requirements for conditioning of ventilating air.

AUTHOR Colliver D G
BIBINF UK, Air Infiltration and Ventilation Centre, AIVC Technical Note 47, September 1995, 36pp, 10 figs, 10 tabs, refs.

ABSTRACT The objectives of this work are: first to determine the theoretical energy requirements per constant mien unit of outdoor air used for ventilation for a number of different climates and locations in North America and Europe; and secondly to determine the variation of this annual ventilation heating and cooling energy requirements due to the set points for temperature and humidity. The energy impact and/or trade-offs involved between bringing in outdoor air for indoor air pollution reduction and the energy required to condition this sir are investigated in this report. Long-term hourly weather data from several European and American locations were analysed to determine the average conditions of air over the period of record of the data. These data were then analysed to determine the psychometric process theoretical heating, cooling and moisture removal energy requirements for a constant mass of airflow per hour (MJ.h/kg). Summary weather data are also provided if it is desired to determine the additional effects of equipment and design. It was found that a significant amount of energy is required to condition air which is used for ventilation. The annual energy required per kg/hr of airflow varies from 22.1 MJ.h/kg for Los Angeles to 102.5 MJ.h/kg for Omaha. In Europe the range was from 45.6 MJ.h/kg for Nice to 101.1 MJ.h/kg for Saint-Hubert. In Europe most of the energy was used to heat the air to the desired set point. In American there were significant amounts of both heating and cooling required. Much of the variation was due to the amount of moisture in the air which had to be removed in air conditioning. In situation where air conditioning is used, a significant amount of this energy is used in dehumidifying the air. For example, in Miami 86% of the energy is used for moisture removal. It was found that the energy used was highly sensitive to the cooling and relative humidity set points.

KEYWORDS energy needs, weather, dehumidification

#NO 9521 Estimating the energy impact of ventilation and infiltration in AIVC member countries.

AUTHOR Orme M

BIBINF UK, Air Infiltration Review, Vol 17, No 1, December 1995, pp 8-11, 3 figs, 1 tab, 18 refs.

ABSTRACT It has been estimated in the Energy Conservation in Buildings and Community Systems Strategy Plan (IEA, 1994c) that about one quarter of all energy is consumed in dwellings within the countries of the Organisation for Economic Co-operation and Development. Also, in dwellings, within the Air Infiltration and Ventilation Centre s member countries, the energy used for space heating and cooling accounts for between 60% - 70% of the total energy consumed. Furthermore, it is predicted (IEA, 1994c) that ventilation and air movement is expected to become the dominant heat and cooling loss mechanism in buildings of the next century. As part of its programme of work, the AIVC has co-ordinated attempts to quantify the part of delivered energy that is specifically associated with infiltration and ventilation of buildings. This has been achieved by means of a workshop, a survey and a conference. The purpose of this paper is to present estimates of the current situation for dwellings. The calculations given here have been performed for each of the member countries. This article expresses the energy impact in terms of both delivered energy and the consequent carbon dioxide production. For some countries the air change-related energy data have been found from published sources, and in other cases, a nominated representative, from a particular country has estimated the situation, or has approved such an estimation.

KEYWORDS air infiltration

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The Air Infiltration and Ventilation Centre provides technical support to those engaged in the study and prediction of air leakage and the consequential losses of energy in buildings. The aim is to promote the understanding of the complex air infiltration processes and to advance the effective application of energy saving measures in both the design of new buildings and the improvement of existing building stock.

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