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ENERGY EFFICIENT VENTILATION STRATEGIES

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INTRODUCTION

Ventilation is the process by which clean air is provided to a space. It is essential for the provision of fresh air to occupants and for the dilution and removal of pollutants. It is therefore at the focal point of building environmental design. In many climatic regions, ventilation air must be conditioned by heating or cooling. Such treatment frequently incurs a heavy energy penalty. In addition, ventilation systems can be complex and involve space, installation costs, maintenance and operating energy. It is these factors that motivate much ventilation research. The ultimate goal is to develop energy efficient, cost effective ventilation technology.

The purpose of this paper is to review progress in domestic ventilation and to illustrate a need for an integrated approach to design.

2 THE RATIONALE OF VENTILATION

At its most basic level, ventilation is needed to supply oxygen to occupants and to remove the products of metabolism (odour, moisture and carbon dioxide). It is also frequently used to dilute and remove other contaminants in the air which are emitted as a product of occupant activities or from furnishings and surfaces within a building. Without added filtration, ventilation cannot be used to remove outdoor pollutants from a space.

Good ventilation design is needed to ensure the adequacy of ventilation and the efficient distribution of fresh air to occupants. Poor design may result in unhealthy buildings and excessive energy waste. Much needs to be accomplished to improve design and to provide solutions that are acceptable to occupants. Good design requires planning for optimum air quality and energy efficiency. There is no unique solution and each design must be based on knowledge of building use, climatic zone and pollutant loads. The steps by which decisions may be made on selecting an appropriate method are outlined in this paper.

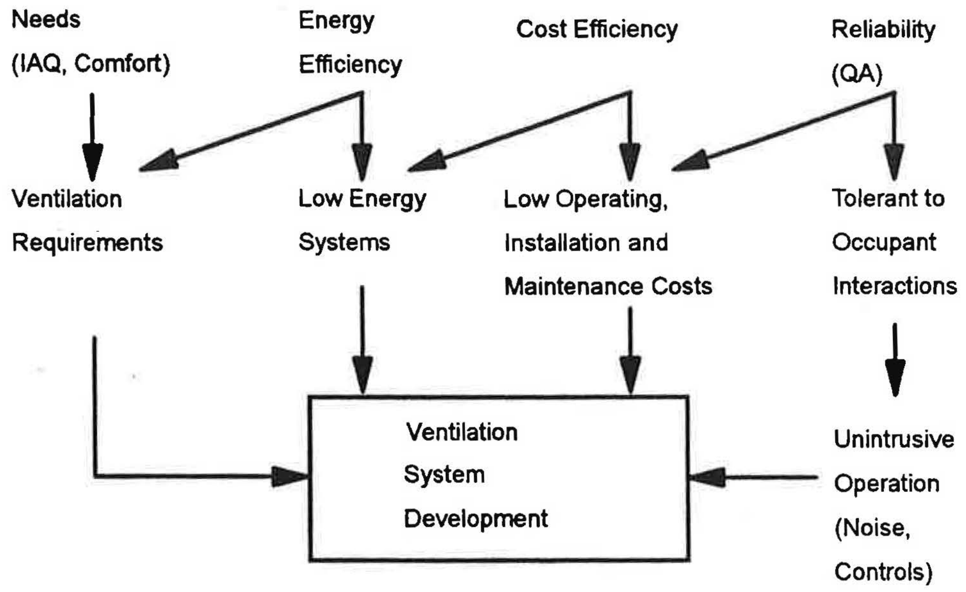
3 DESIGN FUNDAMENTALS

The steps associated with designing and selecting a ventilation strategy are outlined in Figure 1. Of prime importance is identifying the ventilation need (Section 4).

Energy efficiency demands providing ventilation for optimum indoor air quality at the minimum rate of ventilation, therefore design is frequently associated with avoidance of uncontrollable air change. Energy efficiency also focuses on low energy systems and, in many instances, heat recovery. Cost efficiency presents a further design constraint and has important implications on selecting a strategy. Cost effectiveness promotes low energy strategies and focuses attention on low operating and maintenance costs.

Systems must also be reliable in operation and 'transparent' to the occupant. Any discomfort through poor climate or operational noise will result in the system being by-passed or misused. Furthermore, systems must comply with relevant regulations and Best Practice Codes. Ultimately, ventilation systems should be acceptable to the occupant and should have proven reliability.

Figure 1 Energy and Cost Effective Ventilation Strategies - System Design Needs



4 VENTILATION AND INDOOR AIR QUALITY

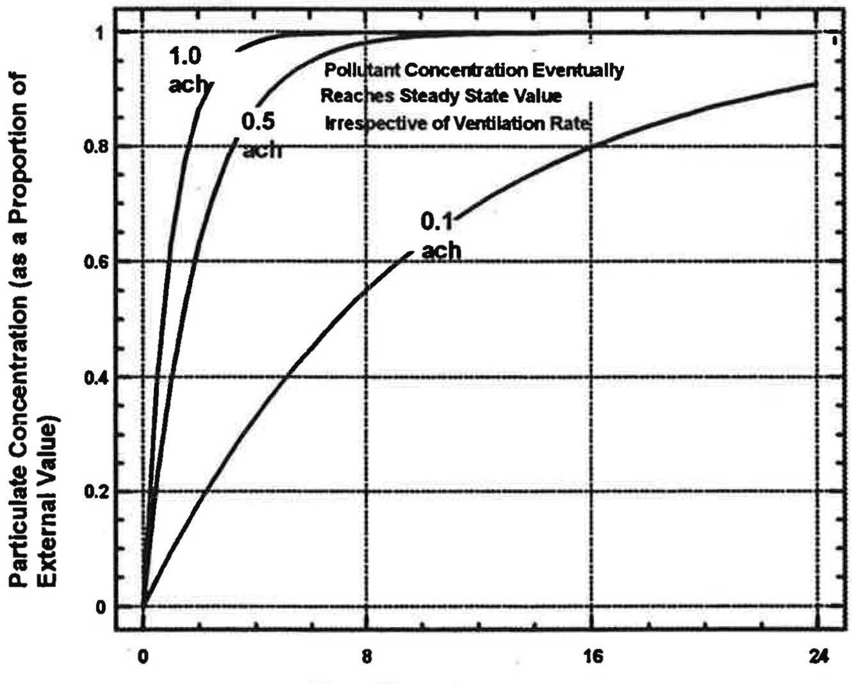
In satisfying the demands of design, it is essential to define the ventilation need. Arguably, the primary role of ventilation is to satisfy the metabolic needs of occupants, although it is also used to dilute and disperse many pollutants emitted within a space. Domestic ventilation should be capable of providing a steady air change rate for metabolism, rapid purging to deal with transient pollution and wet area ventilation to remove moisture.

In the home, ASHRAE Standard 62 (1989) recommends either a minimum ventilation of 0.3 air changes/hour (ach) or a rate of 7.5 l/s for each occupant, whichever is the greatest. In Sweden (BFS 1988) a rate of 0.35 l/s.m^2 of floor area is recommended. These specifications represent the minimum requirement for dwellings. The removal of transient moisture created by washing and clothes drying could add substantially to this requirement. In addition, further outdoor air may be needed to meet the needs of combustion appliances. When identifying the need for ventilation, it is useful to categorise pollutants into avoidable and unavoidable sources of pollutant. Unavoidable pollutants include the products of metabolism and those associated with occupant activities, such as cooking and washing. Avoidable pollutants are those generated through choice. These may include emissions associated with unvented combustion, smoking and emissions from furnishings and fabrics. Sufficient ventilation is needed to dilute the dominant pollutant to acceptable concentrations. When the dominant pollutant is unavoidable, this rate of ventilation represents the minimum acceptable rate. However, if the dominant source of pollutant is from an avoidable source, the reduction or elimination of the pollutant source may prove to be the most cost effective solution. As a general rule, avoidable pollutants should be eliminated although, more often, it falls upon ventilation to minimise the adverse effects of such pollutants. Ventilation Standards invariably give guidance on calculating the ventilation rate needed to control the dominant pollutant or need. Examples are presented in the Appendices to ASHRAE Standard 62 (1989) and in British Standard BS 5925 (1990).

5 OUTDOOR AIR QUALITY

It is quite possible for indoor air pollution to be derived from outdoor sources. Examples include traffic fumes, industrial pollution, ozone and pollen. A continuous emission of pollutant from outdoor sources will eventually result in the building interior acquiring the same pollutant concentration as the outdoor air, irrespective of the ventilation rate. If outdoor pollutant emissions are of a short term transient nature, some benefit may be gained by reducing the ventilation rate to impede the ingress of pollutant. An example is illustrated in Figure 2. Assuming a typical air change rate for a dwelling of between 0.5 - 1.0 ach, the internal pollutant concentration will reach 50% of the outside value within an hour, while the steady state value will effectively be reached within 4-8 hours. Only by reducing the ventilation rate to an inadequate 0.1 ach is there any substantial delay in reaching the steady state value. Ventilation, therefore, is an inappropriate mechanism for dealing with outdoor pollutants and, instead, pollution must be treated by filtration. Filtration methods for the home are comprehensively reviewed by Kadulski (1991).

Figure 2 The Influence of Ventilation on an External Pollutant Source



6 SOIL GASES (RADON, METHANE ETC)

Soil gases such as radon and methane derive from the underlying strata and from the natural decay of organic material. Such gases enter the building through cracks and gaps in the building's foundations. The first line of defence is to ensure an airtight foundation or subfloor zone but this is not always a remedial possibility. Ventilation within the occupied zone by extract fan or even by window opening may exacerbate the ingress of soil gases because the pressure across the foundation is increased. Mitigation has been found to be most successful by ventilating beneath the foundations. Passive stack designs have been developed which require no maintenance and should survive the life of the building (Saum et al 1990).

7 VENTILATION ENERGY

Energy is needed to condition ventilation air and to power mechanical ventilation systems. It is variously estimated that ventilation energy can be considerable and is variously estimated to account for up to 50% of the space conditioning energy used in buildings. A typical ventilation demand of 10 l/s of outdoor air for each occupant requires a continuous thermal energy input of 13 Watts to raise the incoming air through 1 Deg C. Over a 3000 degree day heating period, this equates to 1000 kWh. The energy impact of ventilation is currently being reviewed by the Air Infiltration and Ventilation Centre (Liddament 1992) while the special needs of energy efficient domestic ventilation forms the basis of a recently introduced IEA domestic ventilation Annex (IEA Annex 28, 1993). The inclusion of heat recovery systems as part of the ventilation process and the development of high efficiency fans are significant routes to improved energy efficiency.

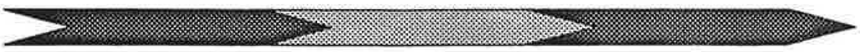
8 ENERGY EFFICIENT VENTILATION STRATEGIES

Many strategies are available to meet ventilation needs; these are based both on natural and mechanical methods. A detailed review of modern ventilation strategies has recently been published by Knoll (1992), who has ranked systems in relation to advantages, cost and applications.

A prime consideration is climate (Figure 3). The severity of climate influences the degree of heating or cooling that is needed to condition the incoming air. In consequence, climate contributes to the complexity and cost of the ventilation system. As a rule, the greater the need to condition the air, the greater is the potential for complex ventilation strategies to become cost effective. A system which is appropriate to one climatic zone need not be appropriate to another.

In mild climatic regions, the ventilation of dwellings is still largely satisfied by natural ventilation. This may be through 'adventitious' ventilation, in which no particular provision, other than openable windows, are provided. Alternatively, natural ventilation may be purpose designed, comprising slot air room vents, frequently combined with passive stack chimneys. Natural ventilation provides the advantages of minimum cost and maintenance. Set against these advantages are poor control of both air change rate and air flow pattern. Passive stacks, terminating in the 'wet' areas of the dwelling, and open to the 'negative' pressure region above the roof assist in improving the flow pattern. Intermittent wall, window or cooker extractors are also a common requirement to ensure the extraction of moisture in naturally ventilated buildings. The uncertainty of ventilation rate combined with the possibility of very high air change rates in cold weather, results in this approach being unreliable and energy wasteful in severe climatic zones.

Figure 3 Ventilation and Climate



Mild	Moderate	Extreme
Few Ventilation Related Problems	Some Air Quality Ventilation Problems	Air Quality and Poor Ventilation Control
Energy Conservation Measures may not be Cost Effective	Airtightness and Improved Insulation can be Cost Effective	Well Sealed Buildings and Heat Recovery can be Cost Effective
Adventitious Ventilation and Window Opening	Purpose Provided Natural Ventilation Using Vents and/or Stacks	Mechanical Ventilation, Air to Air Heat Recovery, Exhaust Air Heat Pumps and Air Conditioning

Mechanical systems can either be extract, supply or balanced. Each has very specific advantages, disadvantages and applications. It is essential that the characteristics of each system are clearly understood.

Extract systems comprise a ducted network in which air is mechanically extracted from moisture producing zones and discharged into the outdoor air stream. Make up air is provided through infiltration openings and through purpose provided vents. Provided the structure is moderately airtight and supply openings are carefully sized, a uniform rate of air change is possible over a reasonable range of weather conditions. The main advantage of the system is that moisture is extracted at source. Furthermore, heat may be recovered by placing a heat pump in the exhaust air stream. This may be used to pre-heat the domestic hot water and/or the domestic heating system. The main disadvantage is that relatively high under-pressures may develop if the system or building envelope has been poorly designed. This may reduce the air change rate, increase fan costs, create unnecessary noise and cause high velocity draughting. It may also induce the flow of radon or other soil gases through the building foundations. Extract systems are not compatible with naturally aspirated combustion appliances, since the induced under-pressures can cause flue backdraughting. Most building regulations address this backdraughting risk.

Mechanical supply ventilation is essentially the reverse of the extract approach. Supply air is ducted to the occupied spaces of the building, frequently after filtration and conditioning. The building is held at an over-pressure, thus preventing outdoor air from entering the building through gaps and cracks. It is rarely used in dwellings because moisture generated within the wet areas can be forced into the building fabric, where it may condense. It does, however, reduce the risk of radon ingress and is useful if cleaning of the outdoor air is needed. No heat recovery of the exhaust air is possible.

Balanced ventilation comprises separately ducted supply and exhaust air. Supply air enters the 'living' spaces and extract air is taken from the 'wet' areas. Both air streams are invariably passed through an air to air heat recovery unit, where 70% or more of the heat in the exhaust stream can be transferred to pre-heat the supply air. Sometimes heat is also recovered from furnace flue gas (Steimle et al, 1992) and further pre-conditioning of the supply air is accomplished by passing the supply duct underground (Trumper et al, 1992). Often, the extract flow rate is held at approximately 10% above the supply rate. This induces a slight negative pressure in the building to avoid moisture ingress into the building fabric. There are many advantages to this system. Apart from heat recovery, the tempering of incoming air is particularly important when outdoor air temperatures are extreme. Furthermore a good flow pattern can be established between the occupied and wet zones in the building. Unfortunately, there are also many disadvantages that have prevented the widespread introduction of this approach except in the severest of climates. Firstly, the building must be effectively sealed to prevent the ingress of air through infiltration. Infiltrating and exfiltrating air will add to the overall building air change rate and will not benefit from heat recovery. This is invariably recognised in countries that use this strategy. Secondly, the system is relatively expensive to introduce and is a difficult retrofit option. The duct system needs to be designed into the building. Ducting through unconditioned zones must be perfectly airtight and well insulated. The capital cost of fans and ducts, combined with operational and maintenance expense can soon make this approach unattractive. Other problems relate to noise in poorly designed systems and the interaction of occupants (eg window opening) in disturbing the efficient operation of this type of system.

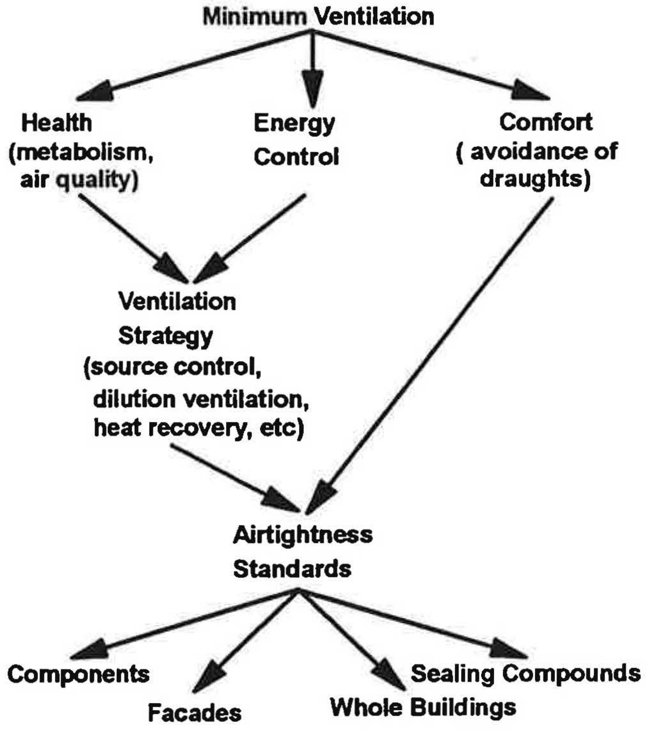
In countries such as Canada and Sweden, central mechanical ventilation systems are beginning to become the normal method of domestic ventilation. Where this has become the case, it is difficult to imagine a return to natural systems. In other countries, improved natural ventilation systems are being developed and a widespread move to mechanical ventilation appears to be equally unlikely.

Much current interest is being focused on the viability of 'demand controlled' ventilation systems. These take advantage of various forms of air quality sensors which are able to track the 'dominant' pollutant in a space and to modulate the ventilation system to prevent a preset threshold concentration of pollutant from being exceeded. Universal air quality sensors are not yet a practical proposition and, therefore, it is incumbent on the designer to anticipate the most likely pollutant. In many transiently occupied buildings such as schools, offices and theatres, the dominant pollutant is often the occupant. In these instances, carbon dioxide detectors have frequently been shown to be effective as a measure of occupant density and, hence, ventilation need. In a recent study by the International Energy Agency (IEA Annex18, 1992), carbon dioxide detectors have also been shown to be a good indicator of domestic ventilation need but, despite a dramatic reduction in the cost of these sensors, they are still a prohibitively expensive option for the home. Domestic systems, therefore, tend to be based on humidity control, since the generation of moisture in dwellings represents a major source of transient pollution. Moisture sensors may normally be incorporated into existing ventilation systems and may typically comprise, moisture sensitive inlet vents and/or humidistats linked to a mechanical extractor. Several studies on the performance of moisture controlled systems were also evaluated as part of the IEA study. Investigations incorporated systems installed in both single family and multi-family dwellings in Canada, Europe, and Scandinavia. The performance of these systems were shown to be variable and depend much on the type of system, building airtightness and occupant interaction. Some of the case studies showed that humidistats tended to be of poor accuracy and hence unreliable in performance. Others showed that well calibrated and well installed humidistat controlled systems offered some reduction in moisture problems. A further system, consisting of a relative humidity sensor placed in either the living room or the exhaust duct of a balanced mechanical ventilation system was found to be effective, but resulted in an increase in energy demand. Moisture sensitive variable area air inlets varied in performance between case studies from ineffective to successful. Other sensors applied with varying degrees of success in this IEA study included passive infrared activity sensors and semi-conductor 'air quality' sensors. At present, it must be concluded that there is good potential for effective demand controlled ventilation systems in the home but further research is needed in devising optimum control strategies. Also, the reliability of sensors must improve and their cost must be reduced.

9 REQUIREMENTS AND STANDARDS

A complex pattern of Codes and Standards has evolved to meet the needs of ventilation (Figure 4). These are reviewed in further detail by Liddament and Limb (1993). Ventilation Standards are imposed to meet the need for fresh air. However, energy and comfort criteria stress the necessity to avoid unnecessary ventilation. Ventilation systems, themselves are subject to various Standards which particularly focus on safety (eg interaction of combustion appliances and avoidance of fire spread). The optimum performance of a ventilation system also depends on the integrity of the building fabric, with each approach being dependent on the magnitude of building airtightness (Section 10). Traditionally, airtightness requirements were restricted to the performance of openable components such as windows and doors. These, however, often contribute to only a small proportion of total building leakage. More recent Standards, therefore, apply to the airtightness performance of entire facades and whole buildings. Recent Standards have also been introduced to regulate the performance and durability of compounds used to seal leakage openings.

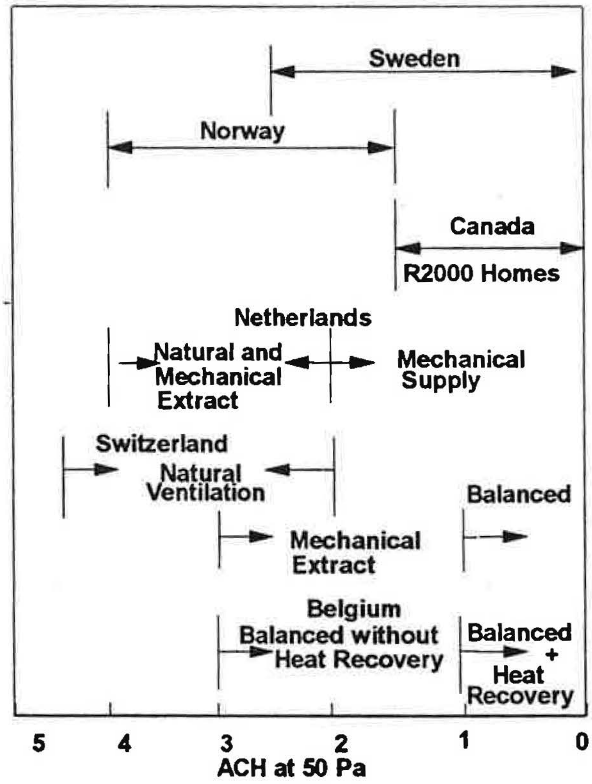
Figure 4 Rationale for Standards



10 BUILDING AIRTIGHTNESS

The optimum performance of a ventilation system as well as energy control and comfort conditions is dependent on the airtightness of the building envelope. Excessively leaky buildings will interfere with the performance of modern mechanical systems and will greatly reduce the net efficiency of heat recovery devices. On the otherhand, naturally ventilated buildings may require higher levels of permeability in order that sufficient ventilation air is provided. Airtightness is frequently expressed in terms of a whole building leakage rate at an artificially induced reference pressure of 50 Pa. The basis of this pressure is that it is sufficiently large to prevent naturally occurring pressures from influencing the result but is not so large that cracks and gaps are distorted by the applied pressure. A summary of airtightness Standards is presented in Figure 5.

Figure 5 Airtightness Standards (Air Change at 50 Pa)



Whole building airtightness values were first introduced into the Swedish 1980 Building Code (SBN 1980) where requirements varied from between 3 ach for single family dwellings to 1.0 ach for high rise apartment dwellings. Requirements in Norway vary between 4.0 ach for single family dwellings to 1.5 ach for apartment buildings. In Canada, high specification "R2000" homes are required to have an air leakage rate of less than 1.5 ach at 50 Pa. Recently, recommended airtightness values have been introduced into the Building Codes of Belgium, the Netherlands and Switzerland. Belgium recommends an air leakage rate at 50 Pa of less than 3 ach for dwellings fitted with balanced ventilation and less than 1 ach when heat recovery devices are fitted. The Netherlands and Switzerland have recommended airtightness values according to the type of ventilation used. In the Netherlands, balanced ventilation is recommended for all buildings with airtightness values below 1 ach. Dwellings fitted with mechanical extract or natural ventilation should have airtightness values between 4 to 8 ach at

50 Pa and 2 to 3.2 ach at 50 Pa. Swiss recommendations are similar with values of between 1 and 4.5 at 50 Pa.

11 CONCLUSIONS

Ventilation is needed for the health and comfort of building occupants. It is specifically needed to dilute and remove unavoidable sources of pollutant such as those derived from metabolism and from the essential activities of occupants.

Systems must be sized to meet the needs of unavoidable pollutants derived from metabolism and day to day activities of occupants.

Avoidable sources of pollution should be eliminated or minimised. Activities such as clothes drying and cooking should be enclosed or semi-enclosed to ensure that extraction of moisture takes place directly at source.

Uncontrolled air exchange has a significant impact on energy use in dwellings. Good ventilation design is essential to ensure optimum ventilation with energy efficiency.

Air for combustion should be provided separately from that needed for general domestic ventilation. Unvented combustion appliances should be discouraged and definitely should not be used in an airtight building.

Foundations should be well sealed and separately ventilated to prevent the ingress of radon or other soil gases into the home.

No single economic solution to domestic ventilation exists. A full cost and energy benefit analysis is needed to assist in selecting an optimum ventilation strategy.

Occupant activities in relation to the control of ventilation must be understood. Window opening, for example, will destroy the benefit of heat recovery systems. There is also a risk that occupants will incorrectly operate ventilation systems or cause harmful pollutants to be emitted within the dwelling space. This becomes a particular problem when airtightness Standards are introduced since there is no margin for indoor air quality safety. Short of banning the use of appliances likely to cause serious health problems in poorly ventilated enclosures it is difficult to know how this problem can be resolved.

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Ventilation Zone Control

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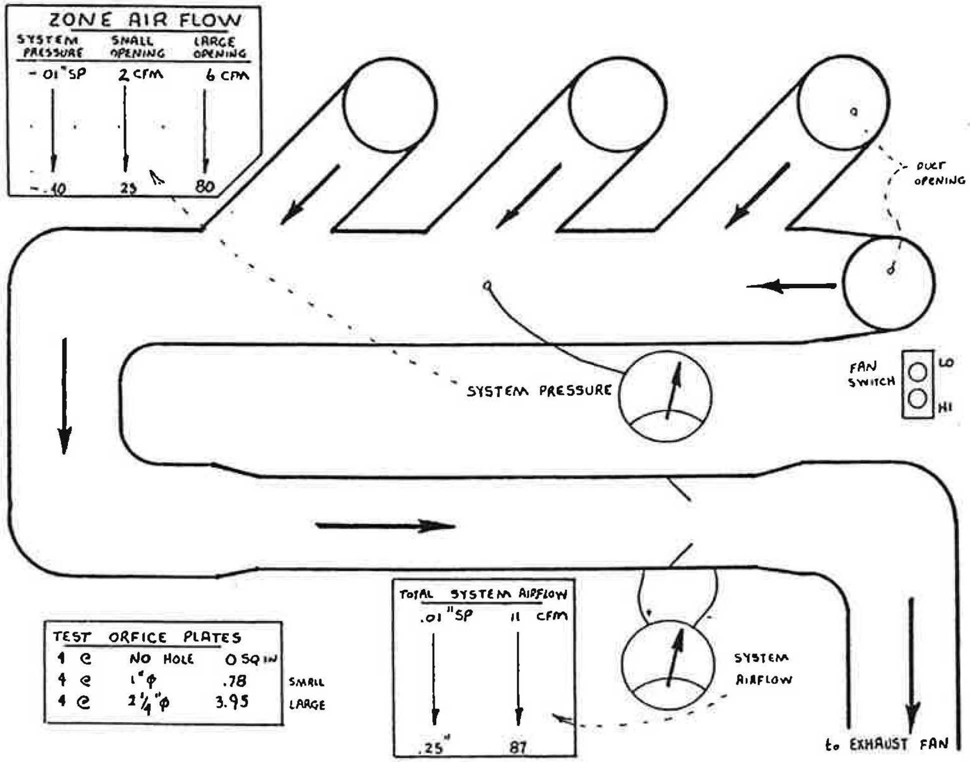

Schematic of Display

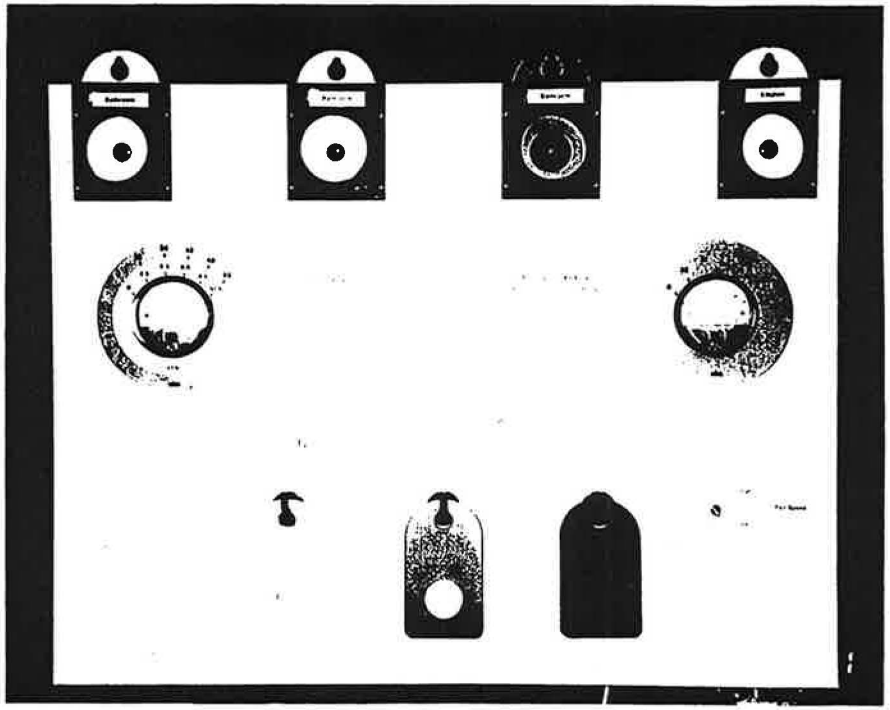

Photo of Interactive Poster Display

Improvement in Energy Efficiency and Indoor Climate in Naturally Ventilated Houses

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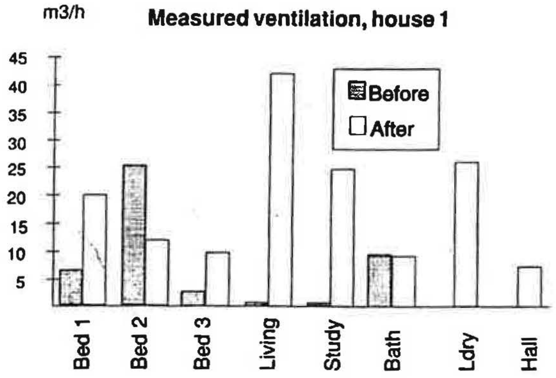

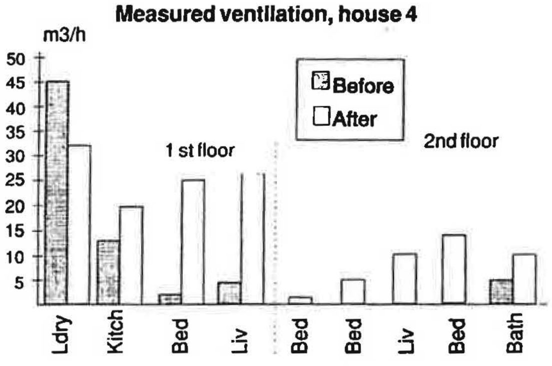

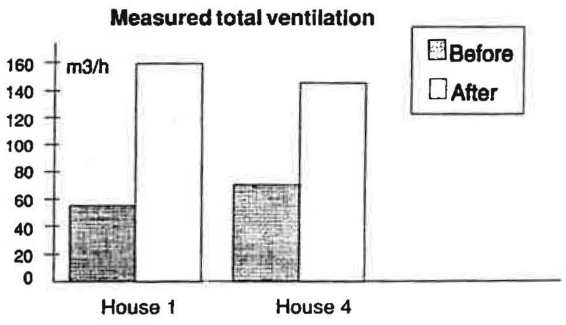

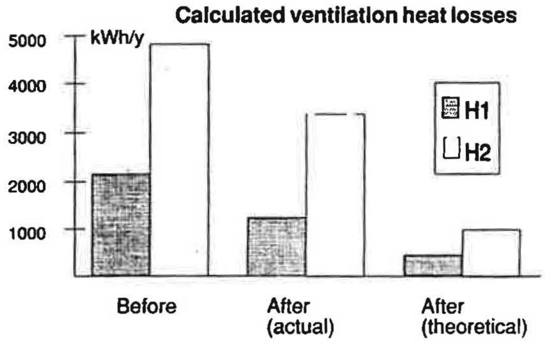

Introduction:

In Sweden, 250 000 one-family houses with electric baseboard heaters were built during the seventies. Their use of electricity is high and they are often naturally ventilated.

The houses tested - before reconstruction:

Six one-family houses of two types: a 1/2 storey detached and a one storey detached. Electric baseboard heaters. Exterior walls of wood-frame construction with 120 mm of mineral wool. Attic insulation of 150 mm of mineral wool. Windows with double panes. Natural ventilation with vertical shafts.

The houses tested - after reconstruction:

An exhaust-fan ventilation system with outdoor air vents. An exhaust air heat pump, for domestic hot water and two central radiators. A new electronic control system for the baseboard heaters. New quadruple-pane windows (U= 1.0 W/m^2 °C). New energy efficient refrigerator/freezers.

photo

Conclusions

It should be technically possible to improve the energy efficiency and the indoor climate in Swedish naturally ventilated houses built before 1980. Using the electricity price of today, the improvements are not profitable, unless they are required by normal maintenance. The energy performance of the six houses could be improved, by improving upon the control system for space heating and the heat pump, increasing the size of the hydronic radiators and locating them in a better position to spread their heat to the building.