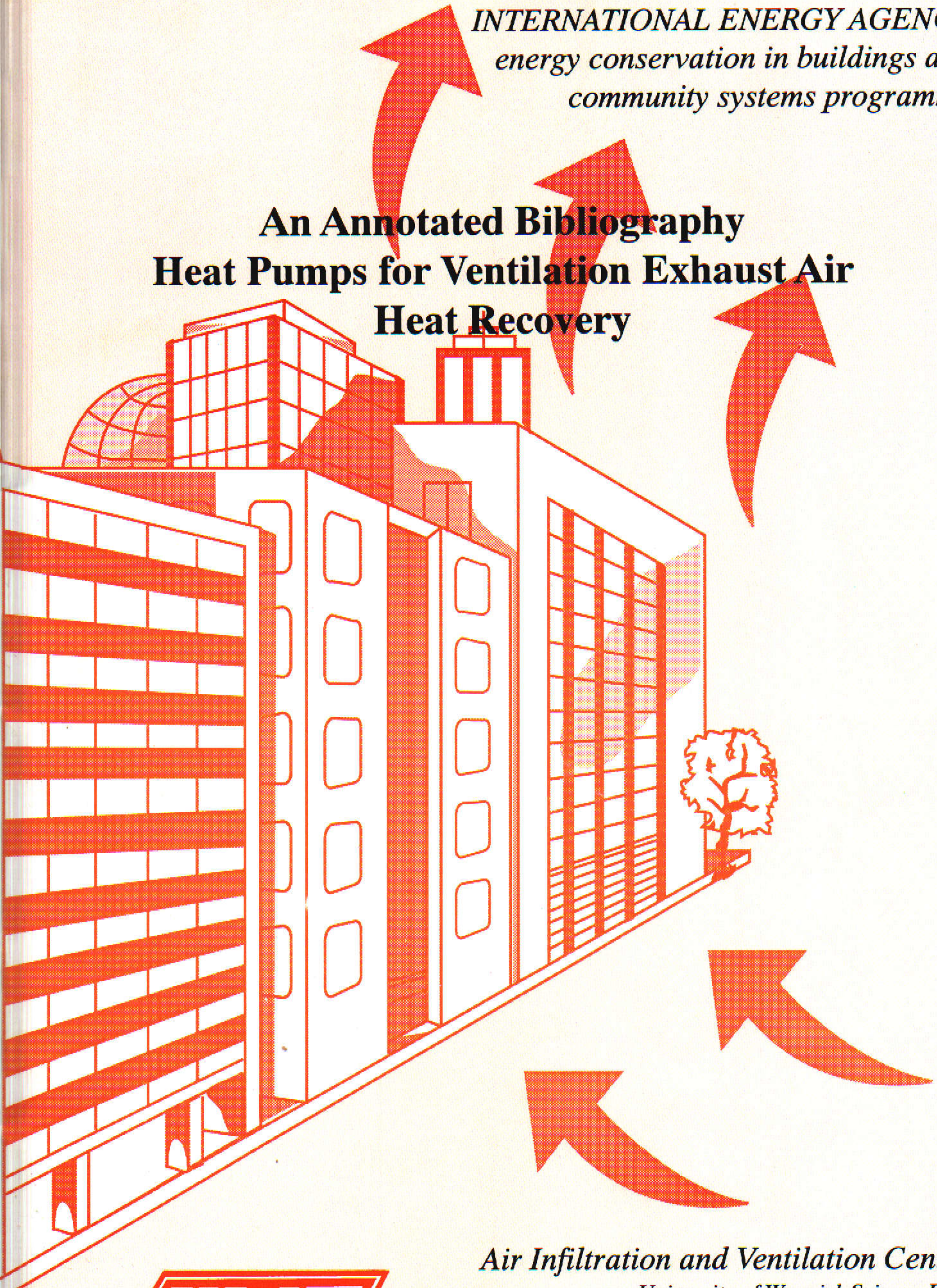
INTERNATIONAL ENERGY AGENCY
energy conservation in buildings and
community systems programme

An Annotated Bibliography
Heat Pumps for Ventilation Exhaust Air Heat Recovery



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AIVC

Heat Pumps for Ventilation Exhaust Air Heat Recovery
An Annotated Bibliography

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Preface

International Energy Agency

The International Energy Agency (IEA) was established in 1974 within the framework of the Organisation for Economic Co-operation and Development (OECD) to implement an International Energy Programme. A basic aim of the IEA is to foster co-operation among the IEA Participating Countries to increase energy security through energy conservation, development of alternative energy sources and energy

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

The Executive Committee

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

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

- I Load Energy Determination of Buildings*
- II Ekistics and Advanced Community Energy Systems*
- III Energy Conservation in Residential Buildings*
- IV Glasgow Commercial Building Monitoring*
- V Air Infiltration and Ventilation Centre
- VI Energy Systems and Design of Communities*
- VII Local Government Energy Planning*
- VIII Inhabitant Behaviour with Regard to Ventilation*
- IX Minimum Ventilation Rates*
- X Building HVAC Systems Simulation*
- XI Energy Auditing*
- XII Windows and Fenestration*
- XIII Energy Management in Hospitals*
- XIV Condensation*
- XV Energy Efficiency in Schools*
- XVI BEMS - 1: Energy Management Procedures*
- XVII BEMS - 2: Evaluation and Emulation Techniques
- XVIII Demand Controlled 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 Daylighting in Buildings
- XXX Bringing Simulation to Application
- XXXI Energy Related Environmental Impacts of Buildings
- XXXII Integral Building Envelope Performance Assessment

Annex V Air Infiltration and Ventilation Centre

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

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

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Heat Pumps for Ventilation Exhaust Air Heat Recovery - An Annotated Bibliography

SCOPE

This bibliography summarises research into the use and application of heat pumps in ventilation heat recovery systems. It does not, however include their use in systems solely for space heating or cooling where no ventilation energy is either utilised or provided. The target audience of this review includes researchers, designers and engineers who would benefit from an introductory overview of research into this subject. References quoted in this document are available to participating countries, from the AIVC's Bibliographic database, "AIRBASE".

1.0 INTRODUCTION

Heat pumps are defined by ASHRAE (1992, HVAC System and Equipment) as devices that extract heat from one substance and tranfer it to another portion of the same substance or to a second substance at a higher temperature. ASHRAE further state that in a physical sense, all refigeration equipment are heat pumps, but in engineering terms a pump refers to equipment that heats for benefical purposes, rather than that which removes heat for cooling only. The amount of heat rejected to the sink corresponds with the amount of heat supplied by the colder source, plus an additional amount equal to the work required to drive the process. In the case of heat pump heat recovery from ventilation, the "source" is the waste heat in the extract air, while the "sink" is commonly the domestic hot water system or alternatively the space heating system of the ventilation supply air. In essense heat pumps have the ability to recover heat from a low temperature source for use in a higher temperature medium by adding high quality energy (exergy).

The thermodynamic principles of heat pumps are not dealt with in this publication. However, further specific information regarding the application or principles of heat pumps can be obtained directly from the IEA's Heat Pump Centre (the address is at the back of this publication) or from a number of handbooks including ASHRAE (1992, HVAC Systems and Equipment) CIBSE (1988, Volume B), Eastop and McConkey (1989) or any good thermodynamic text book. The main focus of this review is concentrated on heat pumps working in combination with ventilation systems. Primarily, this concerns the transfer of waste heat (mainly from the ventilation exhaust air) to either the air used for ventilation, or the hot water used for heating or domestic hot water supply. It excludes the application of heat pumps for use with stand alone heating and cooling systems, where ventilation is provided separately and with full air conditioning systems which may utilise large chillers to cool the air.

2.0 TYPES OF HEAT PUMPS

Vapour compression heat pumps are the most popular configuration (International Heat Pump Status and Policy Review, 1994). They are mechanically driven and consist of a compressor, expansion device and a condenser and evaporator which operate as two heat exchangers. A working fluid or refrigerant is contained within the closed circuit. It is driven around a vapour compression cycle transferring the heat from source to sink.

Absorption heat pumps, while not as popular as vapour compression type, are nevertheless still in operation are. These are thermally driven requiring a small amount of electrical power to drive a pump. As fluid they have a working couple existing of a refrigerant and a solvent (eg water / aqueous lithium bromide solution or ammonia/water). The pressure increase is done in the liquid phase by the solution pump. The waek solution absorbs the refrigerant in the absorber and in the generator the strong solution is releasing the refigerant at high temperature by an external heat supply. The vapour derived is condensed in the condenser, while the absorbent is returned to the absorber via the expansion valve. Heat is extracted from the heat source in the evaporator (useful cooling) and any useful heat is given off at medium temperature in the condenser and in the absorber.

A brief review of the various heat pump types is also included in aforementioned HVAC handbook (ASHRAE 1992), in which heat pumps are discussed in terms of their compression/absorption cycle (for example, closed vapour compression, mechanical vapour recompression with heat exchanger, open vapour compression and waste heat driven Rankine cycle heat pumps) and also in relation to their source/sink types, (e.g. air-to-air, air-to-water etc).

2.1 Heat Pump Efficiency

To be of value the resultant energy derived by the heat pump must be greater than the energy required to drive the process, thus making their application attractive in terms of energy efficiency. The heat delivered by a heat pump is theoretically the sum of the heat extracted from the heat source and the energy needed to drive the cycle. Their performance depends upon a number of factors such as the climate, the temperatures of the heat source and heat distribution system, auxiliary energy consumption, technical standard of the heat pump, the sizing of the heat pump in relation to the heat demand and the operating characteristics of the heat pump.

A heat pump's performance is expressed in terms of a Coefficient of Performance (COP) or Primary Energy Ratio (PER). The IEA Heat Pump Centre's definition of the COP is the Heat output [kW] over the Energy Input [kW] and essentially the higher the better (HPC-AR3). They also note that the PER is a measure of performance used for engine or thermally driven heat pumps, where the energy supplied is then the higher heating value of the fuel supplied. For electrically driven heat pumps a PER can also be defined by multiplying the COP with the power generation efficiency.

Heat pumps operate at their most efficient when the temperature differences over both heat exchanging sections (evaporator and condenser) are high, making the supply of heat to a low temperature medium particularly favourable. The derived heat is often only sufficient to provide preheat, although if it is high enough it can be supplied to several sinks. Where it is of moderate temperature an additional heat source to further temper the required sink is necessary. This is most commonly provided by electrical resistance heaters or a fossil fuel boiler, and does represents an additional cost penalty (including equipment and operational energy (usually electrical)). Brundrett (#9159, 1980) states that both the output and COP of outdoor air heat pumps decline with decreasing outdoor temperature or with increasing the temperature of the heat output. This is because lower evaporating pressures associated with the lower temperatures reduce the amount of refrigerant recirculating and decrease the output, which is in opposition to the requirements of the house. He further states that the actual performance of the heat pump will depend upon whether it is designed to heat or cool.

2.2 Working Fluids and the Montreal Protocol.

Since the Montreal Protocol was signed in 1987 it has undergone two amendments (the London Amendment in 1990 and the Copenhagen Amendment in 1992 (#6708, 1993)). According to the IEA Heat Pump Centre by January 1996, 156 countries had ratified the Montreal Protocol, 65 the London Amendment and 6 the Copenhagen Amendment). The most important working fluids affected by this action are CFC-12, CFC-114, HCFC-22 and the mixtures R-500 (R-12/R-152a) and (R-502 (R-22/R115). It is estimated that the last phase out for HCFC-22 will be 2030, while the CFC's should all be phased out by 1996. Hesse (#9149, 1992) stated that in fact countries such as Austria, Denmark, Finland, Germany, Netherlands, Norway, Sweden, Switzerland and the US all have more stringent regulations than the Montreal Protocol and in most countries earlier phase out dates are anticipated, for example in Germany phase-out is the 1st January 2000. Bouma (#9150, 1994) believes that the heat pump market is certain to be influenced by working fluid regulations and suggests that the current uncertainty appears to be hampering the heat pump penetration in heating dominated markets. HCFC-22 is still the norm for heat pumps, but is viewed in Europe as a near obsolete refrigerant. HFC-134a will certainly play a key role, but because of its non-zero global warming potential, it is already viewed as an intermediate rather than a long term solution by some governments. However, HFC's have not, as yet, been curtailed by any countries regulations. However, the "natural" refrigerants, ammonia, propane and butane have to meet stringent safety regulations in most countries. In particular, in North America and Japan there is a strong emphasis on the immediate safety of refrigerants in the massively applied space conditioning heat pumps.

3.0 RESIDENTIAL VENTILATION SYSTEMS INCORPORATING HEAT PUMPS

The most common residential application of heat pumps in ventilation is to extract heat from the exhaust air and transfer it to either the incoming outdoor air or to a hot water system to provide domestic space heating and/or hot water. Therefore, this type of system incorporates either an air-to-air or air-to-water heat pump, and the following papers demonstrate these principles of ventilation heat recovery and its future potential.

3.1 Residential Air-to-Water Heat Pump Ventilation Systems

Air-to-water heat pumps are typically installed so that the evaporator is located in the exhaust air stream to extract heat from the outgoing air, while the condenser is located in a reservoir tank, to boost water temperature. Occasionally the condenser may be located in a fan coil unit through which indoor air is continuously recirculated and heated (an air-to-air heat pump system). To extract the maximum efficiency, the heat pump output may be split between space heating and domestic hot water heating.

The utilisation of exhaust air heat recovery is proposed for apartment buildings in Sweden (Anon (#1028, 1982). The author suggests that such systems would probably be best suited to displacing heat from the exhaust air to a low pressure hot water circuit. Principally because there are about one million such buildings in Sweden, all equipped with mechanical exhaust air ventilation without mechanical supply. The temperature of exhaust air is high and constant, providing an ideal energy source for heat pumps. The results of long term trials of two buildings in Nynashamn containing 112 apartments, have shown that domestic hot water energy consumption amounts to about 2500 kWh/year for each apartment. Heat is recovered from the ventilation air from 67 apartments and utilised in the domestic hot water supply to 112 apartments. Test measurements have shown that the energy saving is equivalent to 42m^2 of heavy fuel oil per year (approx 25%). The heat pump supplied 96% of the energy for domestic hot water supply, operating at a COP of 3.2. The estimated installation cost was SEK 400,000 (1980) giving a payback period of around 5 years at an energy price of 20 ore/kWh.

Drown et al (#9147, 1992) outlines a similar system designed for a single family airtight house with a superinsulated building fabric and fitted with a controlled ventilation system. During winter operation, stale humid air from the bathrooms and laundry rooms is passed through an air-to-water heat pump which in turn is used to produce all of the domestic hot water. In addition, the clothes dryer is also vented through the ventilation heat pump allowing it to make valuable use of its waste heat. For winter, ventilation cold make up air is taken from the naturally ventilated attic and supplied to the entire house through a forced air ducting system. In summer, the system operates in reverse. The ventilation heat pump removes heat and moisture from outside air while satisfying domestic hot water needs and supplies cool dry air to the house. Air from the dryer and humid bathroom are vented directly to the outside. Results indicated that the ventilation heat pump has adequately supplied all domestic hot water requirements with no back up electric element demand. The ventilation heat pump typically operates two to seven hours a day to provide the necessary hot water for the house. Results indicate that the weekly cost of running this system, including the heat pump, ventilation fan and back-up element, costs an average of $1.06 (1992 prices), to supply all the domestic hot water needs. The authors' state that this is approximately 30% less than a typical system. The energy consumption of the ventilation heat pump hot water heater was 1,538 kWh in the first year and 1,084 kWh in the second year, representing 6.1% of total household energy consumption.

Cane et al (#6469, 1992) examine an exhaust air heat pump using warm ventilation exhaust air as a heat source to preheat service water. These are well suited to buildings with relatively constant occupancy and high continuous domestic hot water loads, such as high rise residential buildings, hospitals and nursing homes. For such systems the authors have noted that payback periods from 4 to 6 years and annual COPs between 3.5 and 5.0, have been reported. The second system deals with heat recovery ventilator heat pumps used in single family buildings where exhaust temperatures are between 20°C and 23 ° C, with ventilation flow rates between 50 and 100 litres per second. Exhaust air is used as the heat source to provide either space and/or domestic water heating. Annual COPs between 1.5 and 2.0 and yearly electricity savings between 1500 and 3000 kWh have been documented. The same report examined the potential for electrical savings using these technologies in Ontario Canada, and estimated that the total potential for annual electrical energy savings is about 7600 GWh for all single family heat recovery applications. The potential winter electrical demand reduction is over 900 MW, while the summer peak demand reduction is estimated to be about 700 MW. For Commercial/Institutional buildings in Ontario, the total potential energy savings for all heat recovery applications examined, is estimated to be about 440 GWh. The estimated winter electrical demand reduction by using heat pump techology compared to not using this technology is calculated to be 110 MW, with the potential impact on summer demand estimated to be 85MW. Therefore, they concluded that significant energy savings can be made by the employment of these technologies.

The residential heat recovery system discussed by Perlman and Mills (#9167, 1986) also transferred heat from the exhaust air to the domestic hot water system. The peak COP of the unit was found to be 2.98 at an average tank temperature of 10°C when the heat pump fan was at 50% operating speed. The average system COP over a temperature range of 10 to 60 °C was 1.98. This system could also be used to heat incoming air, and thus also provide space heating. The unit examined in this paper, is designed to fully supply the space heating requirement of a low energy house, having a rated heat pump capacity of 2.9KW in the heating mode and an additional 6kW electrical resistance heating. Benefits, according to the author, are that the system could be configured to provide a negative indoor pressure during operation and this would reduce both exfiltration of warm moist indoor air and condensation. Such a configuration would also reduce the necessity to make the house very airtight. It is also noted that, due to dilution with dry outdoor air, an exhaust air heat recovery device could reduce indoor relative humidity by about 5% during the heating season. Heat recovery from exhaust air to supply air is a possible consideration, especially in buildings with a full mechanical ventilation system. The study concludes by stating that laboratory evaluations indicate energy savings of between 40 to 60% when compared with conventional electric resistance water heating equipment.

Blomsterberg (#7445, 1985), compared the energy efficiency of two identical apartment buildings in Germany and Sweden. Each building contains three townhouses and eight apartments, built from a modern wood frame airtight design incorporating a high level of insulation, a sunspace and some thermal mass. Both buildings were equipped with hydronic heating, mechanical exhaust ventilation systems (0.5 ach) and air to water heat pumps, transferring heat to the domestic hot water system. Results indicated that the use of electricity for the heat pump was 10kWh/m^2 in the Swedish apartments, while in Germany it was 14kWh/m^2. Heat losses from the domestic hot water system were 4.5 kWh/m^2 and 23kWh/m^2 respectively. These particular test buildings were compared with other similar conventional buildings and it was found that the convential buildings used 80% more energy in Sweden and 150% more in Germany. The author claimed noted that the study had succeeded in demonstrating that the construction of such energy efficient buildings was possible in both Sweden and Germany, and that the conventional heating system and exhaust fan ventilation system provided a comfortable and efficient indoor climate. The high insulation levels and use of heat pumps contributed significantly to the considerable energy savings made.

An indoor air quality study performed on 44 single family Swedish houses, is outlined by Thorstensen et al (#7175, 1993). Forty three of the houses were equipped with exhaust air only heat pumps, and one had mechanical supply, while the heating system in all the houses is central water heating. The study compares the results of ventilation and air tightness measurements taken at the time of construction, with those taken 3-10 years later. The author found that only half the houses still had the required minimum air exchange rate (0.5 ach). Ventilation rates had reduced by an average of 15% since the houses were built. In order to find an explanation for this reduction in ventilation, three heat pumps were chosen and examined. The reduction in ventilation rates were not related to the building year and no correlation was found between the change in ventilation rates and the maintenance routine for the heat pump. The report concluded that the ventilation rate had decreased on average by 25%, and only half the houses still met the requirement of 0.5 ach.The houses were still airtight and met the requirement of a minimum air leakiness of 3.0 ach at 50 Pa air pressure difference, but in most of the houses the air leakiness had increased. Complaints and symptoms concerning the indoor environment were few.

In a further study, Wallman and Fisk (#4885, 1990) and Wallman et al (#3696, 1987) discussed the energy performance of two residential exhaust air heat pumps (EAHP) in use in North America. Exhaust air is drawn from the bathroom and kitchen of the house, causing slight depressurisation. Fresh air is drawn in from outside through cracks in the building shell or alternatively through adjustable vents located in the walls of the bedrooms and living room. In several Scandinavian systems fresh air is driven by a second fan and forced through the space heating unit (fan coil unit) before entering the house. The heat pump extracts energy from the exhaust airstream through a refrigerant evaporator and transfers it by way of a compressor and a condenser to either the indoor air or domestic hot water system. The objectives of the study were to investigate the COP of the EAHP's in typical unsteady state operation and to study and modify the conventional EAHP control system so as to improve load duration (compressor operation) of the heat pump. The authors note that the main control difficulty associated with the EAHP system is one of assigning the correct priority between the two heat sinks. This is due to the fact that the water heat sink has a significant accumulative capability whereas the house heat sink does not. Two heat pump systems were studied, Unit A and Unit B. Unit A has a smaller compressor than Unit B, Unit A has a larger COP, making the rate of energy extraction from the exhaust air nearly identical for the two heat pumps. The authors concluded that unsteady state experiments with one of the tested pumps (unit B) approximately confirmed the simulation results of previous work (Wallman et al (#9160, 1987)). However, this does not conclusively mean that the model used in the simulations is satisfactory in all aspects. It was found that COP's varied non linearly with air flow rate and ranged from 2.0 to 4.2. The control system of the EAHP gives priority to water heating. However based on the results of this study, the authors proposed a new control system that usually places priority on space heating, thus taking better advantage of the capacity to store heat in the water tank. The authors estimated that this new control system may increase annual energy recovery by approximately 1000kWh in Portland Oregon. In conclusion, it was suggested that the total annual energy savings for a near optimal application of an exhaust air heat pump in a typical all electric Portland Oregon house, is approximately 6000-7000 kWh.

The effect of three different ventilation devices on the cost of heating and ventilating a simulated test house were examined by Hawken (#1926, 1984). Simulations were conducted for each system in three typical Canadian climates. Two of the systems, an exhaust fan, and a frosting / non-frosting exhaust air heat recovery heat pump (EAHRHP) are exhaust only systems, the final system, an air-to-air heat exchanger is a balanced system. All were sized to give a ventilation rate of 0.5 ach. In all cases the house relied on a gas or electric furnace as the main heating device. Results indicated that a non frosting space heating application is the most practical for an EAHRUP in a residential situation in cold climates, being more economical and saving more energy than an air-to-air heat exchanger, except where natural gas is cheap. As the climate gets milder the EAHRHP will recover a greater percentage of the energy lost by the ventilation air. This recovered heat can be returned directly to the houses' internal air, or an alternative configuration would be to transfer it to the domestic hot water or spaceheating system. In milder climates, the EAHRHP could become the base line space heating device, with an additional heating system providing the a top up on colder days. It was also found that the EAHRHP could be made reversible for very little extra cost and hence supply cooling and dehumidification to the house during summer. Results indicate that the system can pay for itself in less than five years in many locations, based on its energy savings from exhaust air but it can also function as a small air conditioner and dehumidifier.

The results of a similar study are discussed by Chauhan (#9156, 1985), who summarises a field test of an Exhaust Air Heat Recovery Heat Pump (EAHRHP) prototype installed in an unoccupied conventional Canadian house. The aim of this study was to determine the EAHRHP's effectiveness as a supplementary heater, its effect on house air change rate and its overall performance in actual use. The EAHRHP is a single unit installed inside the house and consists of evaporator coil, condenser coil, compressor, fans and defrost timer. It is an air-to-air heat pump recovering heat from the exhaust air stream, in which the heat absorbed by the evaporator coil from the exhaust air stream, as well as the heat of compression, is transferred to the house via the condenser coil. Heated air is introduced either directly into a room or into the air distribution system of the house. The authors' concluded that during the test period (December to May 1984) the exhaust air heat recovery heat pump did perform as predicted, operating at a lower COP (2.3 to 2.2) and with more defrost cycles. However, despite this the EAHRHP was effective in supplying a significant portion of the heating energy in the test house with an increase in the base infiltration rate of the house.

A study utilizing a heat recovery technique known as "Dynamic Insulation" is described by Dewil (#9166, 1985). Stale internal air is mechanically extracted from the bathroom and kitchen, slightly depressurising the house. The author suggests that the extraction rate of 0.5 ach approximates the winter pressure profile of a house with a flue, where the neutral pressure plane lies above the ceiling. This eliminates the condensation risks associated with exfiltrating moist air. In turn, this depressurisation induces an inward flow of fresh air through the electrical receptacles and imperfections in the drywall seal. The author notes that the path this air has been forced to follow is through fibrous insulation and therefore becomes tempered during its journey, which is different from the adventitious cold air normally associated with cold draughty buildings. Heat recovery from the exhaust stale air is achieved by means of an air-to-water heat pump, which cools the stale air from room temperature to about 39°F (4 °C) before it is discharged to the outside. The heat extracted is pumped into a self contained 227 litre domestic hot water tank. If heating is required and the demand for domestic hot water has been satisfied, a pump circulates hot water through a finned tube coil mounted in the air recirculation loop. In summer the airflows are interchanged by means of a simple ductwork switching device. Air is drawn into the recirculation loop via the registers or delivered to the high wall grilles in the bedrooms. It passes through the evaporator coil of the heat pump and is cooled and dehumidified. The path for the stale air, in the summer is now via the hot water coil. If cooling is required and the domestic hot water demand has been met, hot water is pumped to the hot water coil and this heat is rejected to the outside. Results of the investigation found that this design offered a way of reducing effective space heating energy usage of a house built to Ontario Building Code Standards, by 70% to 80%, each having a recommended ventilation rate of 0.5 ach. No interstitial condensation was found despite not relying on a meticulously installed vapour barrier. Dewil states that the occupants are happy with the economy, comfort, quietness and freshness of the house.

Timusk (#9151, 1990) also examines the performance of a dynamic wall insulation with an exhaust air heat pump. In this study energy demand to satisfy heat transmission losses through the thermal envelope, domestic hot water requirements and ventilation air heating are compared to energy supply, including heat recovery through the dynamic walls, solar gain through the windows and the opaque walls. The author undertook an energy simulation on the house, assuming the ventilation rate is maintained at 0.3 ach, with all ventilation air exhausted through the heat pump at 0°C and 100% RH; the COP of the heat pump was assumed to be 2.25. Timusk found that total predicted energy supply based on average weather conditions exceeds demand by almost a factor of three. Demand, especially the solar energy component of the supply, was however, time variable. Strategies for storing heat recovered by the dynamic wall and the captured solar energy are therefore proposed. In the approach described by the author the building envelope is an integral part of the heating, ventilating, air conditioning, domestic hot water and heat storage system. In conclusion the author stated that energy savings can be made by making minor modifications in the manner in which way houses are built. It was argued that the exterior walls of the building can also become a part of the heat recovery ventilating system with an added solar energy capture capacity.

Humm (#7778, 1994) describes an integrated dynamic insulation and ventilation system installed in Swiss houses built during 1989-90. The heat pumps extract heat from the exhaust air, drawn from the kitchen, bathroom and toilet areas. Outdoor air is filtered through porous material in the roof and is supplied to the living spaces via ducts in the concrete floors. The author explaines that due to the artificially induced air flow, the temperature gradient in the outer layer of the roof material is reduced to nearly zero and this in turn prevents heat conduction. The preheated outdoor air is taken to a collector pipe under the eaves from where it flows via a vertical duct to spiral metal tubes encased in the concrete floors. From these tubes it is transferred to bedrooms. When passing through the roof and floor, the temperature of the supply air is increased to approximately 2°C below room temperature and is extracted to achieve an air change rate of 0.3 ach. The air is then directed to the heat pumps in the cellar with the exception of the air from the kitchen which is expelled outdoors. The exhaust air is fed to a two stage air-to-water heat pump at a rate of approx 300-350 m^3/h. The heat pumps are electrically driven and have a capacity of 5.5KW at a source temperature of 22°C. The heat from the heat pumps is used to preheat the domestic hot water to a temperature of 45°C and provide low temperature floor heating. An extra heat source is available for temperatures below 2°C.

A specific review of air-to-water heat pumps in domestic and commercial developments has been undertaken by the Heat Pump Centre (#6889, 1993). The review contains abstracts of various studies including technology developments and performance, application and field performance, as well as an in depth analysis of the systems and applications contained within the abstracted papers.

3.2 Residential Air-to-Air Heat Pump Ventilation Systems

Air-to-air heat pumps are typically installed into conventional balanced ventilation systems incorporating an air to air heat recovery unit. The heat pump provides additional heat recovery for the system, with the evaporator unit of the heat pump inserted into the extract air duct and the condenser element placed in the supply duct. Any additional heat is transferred from the extract to supply air via the heat pumps vapour compression or adsorption cycle.

Three well insulated experimental houses located in southern Sweden, utilising warm air heating and exhaust heat pumps, were monitored by Blomsterberg (#9163, 1985) from 1983-1985. All three houses have a balanced ventilation system mechanically controlling both supply and exhaust air and use an exhaust air heat pump to conserve heat loss. Ducts supply the houses with fresh air from outside mixed with recirculated air and heated by the heat pump, which also heats the domestic hot water supply. Back up heating of both air and water is provided by an electric heater. All houses were studied to assess the comfort and thermal performance conditions. Results from the study suggested that all of the houses behaved well, using between 10,000 to 13,000 kWh of electricity for space heating, domestic hot water heating and household use. This is compared with approximately 20,000 kWh for a conventional well built house that met the 1985 Swedish Building Code standards, not equipped with a heat exchanger or heat pump. The author suggest that the effect of the heat pump was to decrease the energy consumption by 4600kWh for house A, 5500 kWh for house B and 8300 kWh for house C.

On the other hand, Salvigni and Mazzacane (#9154, 1985) discuss the use of air-to-air heat pumps for some residential flats in Southern Italy to provide warm air heating and mechanical exhaust ventilation. The system consists of two ducts, an extract removing foul air from the bathroom and a supply providing preheated fresh air. Duct sizes are sufficient to ensure air flows between 0.5 and 1.0 ach are achieved for every room at a speed 3 m/s. Air enters the flats at a temperature of 15+-/-1°C. Extracted air is filtered before it reaches the regenerator, then it is passed through the evaporator of the heat pump and subsequently extracted to the outside. The supply air is filtered before being reheated in the regenerator, which is then augmented as it passes through the condenser of the heat pump. It is noted by the authors note that the heat regenerator has an efficiency of 70%, and therefore ventilation losses are substantially reduced resulting in about a 25% reduction on the total energy needs of the building. They also suggest that the primary energy consumption uses 50% less compared with a traditional system. The COP of the heat pumps is estimated to be 3.5.

McIntyre (#1649, 1986; #3345, 1989; #9162, 1986) describes such a system installed in the UK Capenhurst test house, which is equipped with full mechanical ventilation and heat recovery (a combination of heat pump and plate heat exchanger). The evaporator of the heat pump is placed in the exhaust air stream, downstream of the heat exchanger, while the compressor and condenser are placed in the supply air stream. This configuration, according to the author, results in a very high COP being obtained. The heat pump only handles part of the total heat exchange and can therefore be relatively small, thus saving on capital cost. The efficiency of the plate heat exchanger is stated as being 70%, which according to McIntrye can be improved by the addition of a heat pump. However, any saving must be offset against the running cost of fans and the capital cost of the equipment itself. The performance of this heat exchanger and heat pump combination is a function of both indoor and outdoor temperature and so its potential energy savings depend on the pattern of weather over the heating season. The study outlined by the author compares the use of a heat pump and exchanger alone and in combination. Results suggest that there are clear benefits, both in terms of running cost and energy consumption, of the heat pump and exchanger combination. An advantage of these combined systems would be the removal of separate room heaters in bedrooms. This would represent a saving in terms of both space and money, because the two heat recovery devices working in tandem would lead to an increase in the supply air temperature, compared with the heat exchanger operating alone. A further advantage could be the reduction in the size of the main storage heaters, however, it would also reduce the possibility of room by room control. Disadvantages include associated noise, maintenance and defrosting performance. Although McIntrye discusses a number of other problems associated with these systems, and proposes possible remedies. He concludes by stating that the use of an air-to-air heat pump for ventilation heat recovery is effective in reducing energy consumption. He goes on to say that, as long as the COP is greater than the ratio of day/night electricity costs, it will produce running cost savings camparable with storage heaters. The combination of heat exchanger and heat pump offers significant running cost savings coupled with capital cost reductions, and is thus considered to be better than the heat pump alone. The author further states that, for a well insulated house, the heat pump VHR system could provide nearly half the design heat loss. It would then be realistic to deliver most, or all of, the remaining heating with direct acting heaters, giving flexible accurate control. In trials run during winter 1986/87 the heat pump VHR unit described above provided a ventilation air flow of 180m3/h-1 and a gross heat input to the house of 1.7 kW. This figure averaged over time, includes the effect of defrost periods. An overall COP of 3 was achieved (McIntrye (1989, #3345))

Olsen (#4353, 1988) also advocates the installation of combined heat pump, exchanger systems. He considers the application of heat pumps alone is limited, due to the low COP that can be achieved, and suggests that even during the heating season for ambient source heat pumps, the average COP is rarely more than 2.5. Even for exhaust air heat pumps, where a constant supply of high grade (20°C) heat is available, the average COP is not normally higher than 3.5-4.0. However, it is possible possible to achieve average efficiencies higher than these COPs', by combining the heat pump with another heat recovery device, such as a plate recuperator so that heat is recovered before the air reaches the coils of the heat pump. The fresh air is then pre-heated over the recuperator before reaching the condenser coil, where the heat extracted by the evaporator coil from the pre-cool exhaust air is given off to the supply air, together with the compressor energy. The author suggests that in most cases, depending on insulation values and casual gains, the total building heating requirement will be satisfied by this combined unit at ambient temperatures above 8-10 °C. Although the combination system was developed as a heating unit, it could also be used for cooling. Under the reverse condition the fresh air supply is cooled by the heat pump, as occurs in a standard heat pump system. Providing the room temperature is kept below ambient the plate recuperator will also act as a cooling unit, pre-cooling the air before it reaches the evaporator coil of the reversed heat pump. The paper discusses both winter and summer conditions and gives examples of possible energy savings. One such example indicates that a COP of 5.2 could be achieved by such a combined system and that in principle the system can be used wherever a conventional fresh air ventilation system is needed. The degree of economic benefit depends mainly on operating time, air change rate versus building fabric heat loss, and insulation values. Generally, the longer the system is required to operate the greater the air change rate, and the lower the U-values the better the system performs. The main applications are situations where full air conditioning is considered too expensive, but a certain amount of cooling is desirable. In conclusion, the author states that if controlled correctly the system produces significant savings against conventional equipment, with fairly short pay back periods, particularly where connection to a central heating plant cannot be justified on the grounds of low utilisation. The unit is only applicable to full fresh air systems and cannot be used for recirculated air, except in specialist applications such as swimming pools, where the unit functions as a dehumidifier, not as an exhaust air heat pump.

There are a number of systems that incorporate air to air heat pumps, but differ from the typical systems outlined above. For example, Allen (#9169, 1987) discusses an innovative Canadian prototype heat pump that provides food refrigeration, whole house ventilation with heat recovery, space heating and cooling and residential water heating. It is in fact the heat pump cycle of a standard refrigerator which has been expanded to accommodate these additional features as well as refrigeration. The ventilation equipment is located with the refrigerator and during the winter ventilation supply air, can reduce refrigeration loads by lowering the condenser temperatures. Also during winter the unit provides space heating to supply air. The author explains the system's operation thus; the supply air fan coil is located in series after the hot water condenser, and extracts heat to preheat ventilation supply air. After the expansion valve, cooling is supplied to the exhaust air coil located parallel to the refrigerator in the circuit. Where no refrigeration demand exists, the exhaust coil becomes the evaporator, chilling outgoing air. Since ventilation is continuous, heat recovery is always available but is only utilised when there is a space or water heating demand. In the summer, the unit provides space cooling. The reversing valves redirect the refrigerant circuit. The exhaust coil now extracts heat from the loop after the hot water condenser and expels it via the exhaust air to the outside. Similarly, after the expansion valve the supply air coil acts as the evaporator extracting heat from the supply air (but only when refrigeration is not a priority). On the condenser side, heat is primarily transferred to a ventilation air stream (exhaust or supply, depending upon mode). As the supply air drops in winter the COP of the heat pump improves. The reason for the good COP at cold temperatures is that the compressor is being unloaded as the average condenser temperature is lowered. If there is a water heating demand, refrigerant energy is first transferred to the hot water tank before further cooling occurs via the supply air coil. During hot water heating the COP performance is slightly reduced to account for warmer condenser temperatures. In both modes the refrigerator acts as the evaporator and the water heater is the condenser. A simulation was conducted in three climates to establish the energy performance of this system. The report concluded that energy savings from the integrated unit, compared with conventional equipment ranged from 2000 to 12000 kWh/year depending upon house efficiency level and climate. A disadvantage envisaged by the author is that, despite this system being economically and technically attractive, the HVAC equipment is manufactured, sold and installed by a totally separate body from the white goods appliance industry.

Another interesting prototype is the Wates conservation low energy house, built in 1976 and located in North Wales, UK (Anon (#9168, 1977)). This paper briefly outlines the design features of the house, which incorporates a reversible heat pump, one side of which is located in a roof tunnel, with outside air being drawn through by a fan, while the other side is installed inside the house. The heat pump transfers heat from the exhaust air to the supply air or vise versa. Internal air is circulated through air passages formed by the building elements. The house has a central core in which a fan blows the internal air downwards across the ground floor joists. The air then passes through grilles at low level into the various rooms. Additional grilles take the air from the rooms and back to the central core for re-heating or cooling. An extractor fan is located in the kitchen and thus under normal conditions all air is drawn into this room at a rate of 0.25 ach. It is then ducted to the roof and as it passes out of the building it can be diverted over the heat exchanger to recover heat to be returned to the building. This prevents the heat exchanger from icing up in cold weather.

Freund (#9155, 1980) and Leach (#2043, 1976) both describe the UK's Building Research Establishment's Heat Pump House, which is a purpose built low energy test house, similar to the Watts project described above. The ventilation and heating system consists of three heat pumps, of which two supply warm air heating and domestic hot water, and the third (the ventilation unit) extracts air from the kitchen, bathroom and toilet, and preheats a corresponding amount of fresh air. This is then mixed with the air in the wall air heating system. The first two heat pumps are supplied tempered air which enters the roof space at the eaves, passes through a channel formed between the corrugated foil laid over the rafters and is collected in a plenum chamber at the apex. As the air passes through this channel it is warmed by the effects of solar radiation on the blackened roof. From the plenum chamber it is ducted to two air source heat pumps before finally being expelled through a gable end wall. The ventilation unit distributes warm air to each room and recirculated air is taken from the lounge and bedrooms to the heat pumps in the loft. The extract air from the kitchen and bathroom is also taken to the loft and then expelled from the building. In summer, the fresh air inlet may be taken from the north side and the roof could be used as a preheater for the domestic hot water. The comfort control of summertime living space will be achieved by opening windows. Predictions of the likely energy savings possible with this system are not discussed in this report, although the author states they have been undertaken.

Riffat and Shankland (#9145, #1994), describe the use of a rotary storage heat pump which combines an intermittent rotary absorption machine with a vapour re-compression system, using the latent heat of absorption as the primary heating mechanism. The air-to-air storage heat pump consists of an absorber/generator and evaporator disc assembly, a compressor, a motor and refrigerant and solution storage vessels. The unit has two operational cycles. The refrigerant/absorbent solution is separated in the regeneration phase which occurs during the night time low cost period. In the daytime heat is extracted from the warm exhaust air in the evaporator, before it is expelled to the outside. This extracted heat causes the liquid refrigerant to boil, the resultant vapour is then absorbed by the solution which culminates in the emission of heat. It is this type of heat that is used for warm-air heating and wet heating systems. The authors suggest that this combination allows the size and construction cost of the heat pump to be reduced. If a well insulated house is equipped with full mechanical ventilation so that the air is forced to enter the house via a sunspace, the solar heat from the sunspace could provide preheating of ventilation air. The heat gain is then extracted from the exhaust air of the ventilation system. The combined heat source for the heat pump also comprises heat gains from occupants, lighting, cooking and solar heat gain from the roof space of the house. The rotary device placed in the roof space of the house acts as an effective heat recovery unit. The rotary storage heat pump has been thermodynamically modelled using a number of refrigerant/absorbent combinations and COP's achieved were 6.46 (H_2O/LiBr); 4.4 (H_2O/NaOH-KOH-CsOH) and 8.94 (CH_3OH/LiBr-Zn Br_2). Computer simulation (using the Environmental System Performance (ESP) package) showed that the combined use of a well designed sunspace and a mechanical ventilation system provides sufficient enthalpy for the operation of a heat pump.

Another innovative system is described by Wasserman and Reid (#9153, 1984) who outline an experimental and computer simulation of a crawlspace air-to-air heat pump. A single story house, located in Tennessee, USA, was used for the experimental phase. It consisted of a finished heated basement under half the house and a crawlspace under the other half, which is completely below grade. The floor between the crawlspace and house is insulated with 6in (152mm) fiberglass batts. All cracks were sealed with plaster to reduce infiltration and all ductwork insulated with 51mm fiberglass insulation. A vapour barrier was placed on the ground in the crawlspace, preventing ground moisture from entering. During the summer simulation the crawlspace heat pump was operated in single pass mode, that is ambient air was drawn into the crawlspace, channelled through a series of baffles, passed over the outdoor coil and discharged back to the outside. During the winter the system was operated in recirculation mode which involved recirculating the crawlspace air within the space rather than discharging it to ambient. This system, however, has several adventages over the previous mode because, for example, the heat pump acts as a dehumidifier, removing moisture from the crawlspace air and reducing the formation of frost on the coil. Experimental results indicated a 14.5% reduction in purchased energy for the 15 week period of the study and a 26.3% reduction during the peak winter heating load operation. In the Summer, purchased energy was found to be 2.8% more expensive than a conventional system during the 15 week study period, but during peak cooling it was found to be 7.4% less. The paper describes the model (CRAWL) and runs through a simulation under various crawlspace conditions, using the experimental results as validation data. Air is preconditioned by the crawlspace soil before passing over the outdoor unit coil. Results indicated that adding insulation to the walls of an above grade crawlspace only improves performance slightly. Slight improvement was found for a sandy soil over a silty soil. The crawlspace heat pump significantly reduced purchased energy in northern regions compared to a conventionally installed heat pump.

4.0 NON-RESIDENTIAL HEAT PUMP VENTILATION SYSTEMS

4.1 Heat Pump Systems in Commercial Buildings

The configurations of commercial air-to-air and air-to-water heat pumps are basically similar to those used for domestic applications. Air-to-air systems transfer heat from the exhaust air stream to the fresh air supply. The Heat Pump Centre (HPC-AR2) (#6889, 1993) have identified two basic types of air-to-water heat pumps for commercial buildings. The firstly is an ambient air source heat pump, consisting of a condenser immersed in a water tank, with an associated evaporator located either on top of the water tank or at some point further away (a split system), which cools recirculated room or ambient air. Secondly a commercial exhaust air hot water heat pump, which is similar to its residential counterpart, except that the unit is roof mounted over central exhaust air outlets. The water is heated in a water-to-refrigerant condenser and returned to a preheat storage tank located near the central storage water heater. The cooled exhaust air is discharged to the outdoors.

The use of heat pumps in large retrofitted commercial developments is discussed by Blatt and Pietsch (#9146, 1992), who suggest that, with the wide variety of heat pumps available, there is a great deal of flexibility in installation and space configuration for commercial buildings. The authors outline a number of different heat pump systems that they consider would be effective replacements for all types of HVAC equipment. For example, they consider all electric commercial unitary heat pumps would be economical replacements for single package and split system unitary air conditioners with electric resistance heating. Dual fuel heat pumps (unitary heat pumps with gas furnace back up) can directly replace single package and split system unitary air conditioners that have gas furnace heating, without requiring changes in electric or gas service. Water source heat pumps in water loop heat pump systems provide a good alternative to chiller/boiler systems in buildings with more than about 25,000 sq ft (2,300 m2). In some cases water source heat pumps which simultaneously provide heating and cooling capability, can use the existing two pipe distribution system already in place with a heating only hydronic system. However, the authors do emphasise that for these systems to be chosen, when retrofitting, the evidence of their benefits should be made clear to the building's owners, as they may be unaware of the lower cooling and heating energy costs compared with conventional HVAC equipment. In conclusion, the paper suggests that the heat pump market has great potential, not only for the consumer but also for the heat pump specialist.

Various methods of commercial heat recovery, including heat pumps, are outlined by Johnson (#859, 1981). He states that the ambient air is the most commonly used heat source for commercial heat pumps, although under certain circumstances the indoor air could also be a useful heat source for example, where there is a large volume of extract air that could not be recirculated. In this situation the air can be ducted over the evaporator coil of the heat pump to use as a heat source. Unlike other heat exchangers, a heat pump's recovery ability is limited only by its potential to extract heat from the specified source with a reasonable COP, and within the other constraints related to the vapour compression cycle. However, frosting problems can still result if the evaporating temperature is set too low to maximise its heat recovery potential. Also, problems can occur if the extract air is discharged adjacent to the outdoor coil, rather than ducted over it, since the evaporating temperature must be low enough to pick up sufficient heat from the outside air as well as that part of the exhaust air which drifts over it. Johnson suggests that it is possible to overcome this problem if the evaporating temperature is higher than 32°F (0°C) and provided the quantity of heat is available from the exhaust air, then then air-to-air heat pump operating in heat recovery mode will run at higher COP than one using outside air as a source. This usually requires a situation where air change rates and internal heat gain are high. It is important to ensure that the times when heat is available and is required coincide. In many situations where the factors are favourable, there is a need for air conditioning rather than heat recovery for most of the time. With a condenser heat recovery system, the heat is not rejected to outside, but it is first used to heat water for washing purposes or to warm supply air. Only when these are satisfied is the remainder rejected. This demonstrates a simultaneous need for heating and cooling. For example, a freezer store might have a requirement for hot washing water for food preparation, or a pub might require a beer cooler and hot water for washing glasses, etc.

A report by Prista (#6472, 1992) outlines the new opportunities for electrically driven heat pumps in Swiss retrofit commercial buildings. The system incorporates two central electric air-to-water heat pumps, working together in a bivalent parallel operation in conjunction with an oil fired boiler, to reach the temperatures required. For the boiler, the heat pumps use a mixture of flue gas and outdoor air, depending on whether the outdoor temperature is higher than the balance point temperature. If the outdoor temperature is below this balance point, the oil fired boiler is switched on and flue gases mixed with fresh air reject their heat to the evaporator. The design allows for both heating and cooling, with the heat produced used for space heating and domestic hot water, while the cold is used for air conditioning. Results have indicated that 85% of the heat demand (space and water) is delivered by the heat pumps, resulting in total annual energy savings of about 60%, and annual savings in fuel oil consumption of about 20 tonnes. The study concludes that a COP of 3 is possible with such a system and indeed is well worth considering in place of the conventional boiler installation.

The heat pump system installed in the Amsterdam World Trade Centre is discussed by Leijendeckers (#9148, 1990). It operates as a heat pump in the winter, chiller in the summer and an emergency power supply whenever necessary. The gas engine drives the screw compressor of the chiller, which while being part of the refrigeration equipment, also functions as a heat pump whenever the heat can be used efficiently to heat the building. Heat is recovered from the ventilation air before it leaves the building and waste heat from the gas engine's cooling system and the exhaust gases, are also used. The heat pump has a capacity of 3MW or 37.5% of the estimated heat required to heat the building. The cooling capacity is 1.95MW or 40% of the total cooling load. The gas engine has a shaft power of approximately 550kW, which continuously drives a 420 kW electric emergency generator and a screw type compressor, via an electromagnetic coupling, to cover the cooling load. The screw compressor is disconnected while the engine is providing emergency power. When the system functions as a heat pump, the heat from the condenser and the heat from the jacket cooling is supplied to the central heating system. Heat is then recovered via the chiller's evaporator from the exhaust air and the buildings chilled water circuit, which is installed throughout the building to provide local cooling. In the summer, this system, together with an electrically driven cooling compressor, both cool the building. Results of experiments have shown that during office hours the heat pump can provide approximately 92% of the heat requirement, and 71% of the cooling requirement. The authors estimate that about 34% primary energy can be saved by using this system compared to that of a conventional design with boilers and an electrically driven cooling system. The occurrence of high internal heat gains from office equipment during the winter, has led to an unexpected reduction in the estimated gas consumption of about 30%.

The heating and cooling requirements of a clothing store, in Manchester, UK (ECR, #9161, 1981) are provided by eight rooftop air-to-air heat pumps, two serving each floor. A motor drives two centrifugal fans which provide fresh indoor air to the building. Recirculation, fresh air and exhaust dampers enable the return air to be tempered, depending upon the situation. The exhaust air is expelled below the outdoor coils and is calculated to give an increase in COP and a reduction in defrosting. A step controller (located on each floor (four heating and four cooling stages)), and two outside thermostats (set at 5°C and 12°C), operating the fresh air dampers, control the heat pumps. Although two of the six heat pumps were monitored, only one performed in line with the manufactures specifications. Therefore, the report assumed that this particular heat pump reflected the normal running conditions more accurately then the others. The COP of the "normal" heat pump was found to be between 2.4 and 2.9 for a two stage operation between -1°C to 12°C ambient, whereas the single stage COP's were found to be between 2.0 and 2.4. For cooling the COP of between 2.6 and 2 were measured for ambient temperatures between 12°C to 24°C taking the compressor and outdoor fan energy input. For the compressor only the COP would be 2.85 to 2.6. The additional unmeasured latent cooling could be expected to add 20% to the figures, giving a maximum of around 3.4. In conclusion, the study found that, although the predominant requirement for the building was cooling, which was provided free during the winter, the heat pumps satisfied both the large fresh air requirements and mechanical cooling and heating as well taking up less plant room space and requiring no separate heating system.

Heat pump ventilation applications can also be seen in a number of other buildings. For example, a low energy school in the UK which has a mechanical heating and ventilation system with heat pumps, is discussed by DES (#4364, 1986). The schools mechanical ventilation system provides 25% fresh air, which meets the 1985 UK Department of Educations' minimum requirements of 30m3/hr/pupil. At startup, the fresh air dampers are closed until the required space temperature has been achieved. The school is heated by warm air which is distributed through the mechanical ventilation system by three electrically driven air-to-air heat pumps, with ambient air being the heat source. Each heat pump has a COP of 2.5 and a combined output of 35kW with a 7.5kW auxilary electric heater arranged in 3 banks of 2.5kW, controlled by a step controller linked to thermostats located outside. During the summer the heat pump cycle can be reversed to provide comfort cooling when necessary. The report stated that the system in the school operated well, without any major maintenance or operational problems. Also, even though the annual running costs of the heat pumps where slightly higher than that of a gas fired boiler, it had the added advantage of providing summer cooling, resulting in the staff approval of conditions within the school.

Kajl (#7286, 1993) described a study to determine the energy efficiency of an air conditioning centrifugal water chiller which operates as a heat pump during the winter. The unit, installed in a university building in Montreal, Canada, transfers energy from the warm exhaust air and uses it to preheat air supplied for the buildings air conditioning system, and to preheat the domestic hot water. During the summer, a portion of the heat rejected by the chillers condenser is recovered and serves the domestic hot water. However in winter, the operation of the chillers is reversed to that of a heat pump by adjusting it to 40% of its maximum capacity, thus producing a cooling capacity of 691kW. Furthermore the heat rejected by the condenser is 869kW. The system was monitored for one year's operation, and during this time the author noted that the centrifugal water chiller (1,730kW cooling capacity) operating in the winter as a heat pump, saved 1100,000m^3 of gas.

4.2 Swimming Pool Heat Pump Systems

Swimming pools are ideally suited to the use of heat pumps, principally because of the problems of removing excess moisture and odour (Anon (#9170, 1981)). Ventilation is the only answer in a pool where all the heat is provided by a boiler. To avoid condensation this requires large volumes of air to be blown through the pool hall. To maintain comfort within the pool, the water is heated to about 80 °F (26.7 °C), which leads to more moisture evaporating from the pool, which in turn has to be removed. The air brought in to ventilate the pool hall is usually too cold for comfort and must therefore be heated before it enters the pool area. Quite simply, considerable volumes of cold air have to be heated and a large tank of water has to be kept warm, resulting in high boiler output and fuel consumption. However, if the large air volume is dehumidified and the latent heat reclaimed by means of an air-to-air heat pump, it then becomes possible to reduce high fresh air circulation and rely on a much smaller volume to keep odours under control. The energy made available by the heat pump is more than enough to heat the small amount of outside air required by the building, with enough surplus to heat both the swimming pool water and showers. The author describes a heat pump system installed at the Eastbourne Leisure Pool complex, in the UK. The dehumidification part of the air cooling process is achieved by two air-to-air heat pumps situated in a roof plant room space; these also provide the heat for the re-heat coils in the adjacent air supply unit. The heat pumps supply heat to the pool water cooled condenser heat exchangers and to the hot water supply system for showers through the heat exchangers in the basement plant room. The main pools are maintained at 80 °F (26.7 °C) whereas learner pool water is kept at 84°F (28.9 °C). Because most of the air is recirculated the process is only one of dehumidification, with minimum heating to offset fabric and fresh air heating losses during winter. Electrical energy consumed by the heat pumps to effect this dehumidification is retained with the heat exchange system. The energy lost from the pool water by evaporation (latent heat) is reclaimed by the heat pumps and returned to the pools via the condenser heat exchangers. The author noted that, during the first three months of operation, an actual saving of 54% in energy terms had been made compared with a system operating a continuously running ventilation and gas fired boiler.

In traditional indoor swimming pools, the control of odours and humidity is achieved by extracting moisture laden air and heating the fresh air to maintain temperatures of around 29°C, resulting in a substantial energy consumption for ventilation. Weller (#9157, 1983) described the refurbishment of a swimming pool in the UK which incorporates a gas fired dehumidification system. Two engines supply motive power for two refrigeration compressors and recovered heat is used for the heating system. The paper outlines the original pool services and explains the effects of a number of improvements. Increasing energy costs have led to energy consumption being reduced by using various systems to control the ventilation rate and to recover heat from ventilation exhaust. The need for ventilation has been reduced in two ways. Firstly by changing the primary sterilant for the pool from chlorine to ozone thus minimising the generation of odours, and secondly, reducing humidity by the use of dehumidification equipment. Natural gas drives the two automotive engines, which each drive rotary refrigeration compressors. The refrigerant system cools the pool air below dew point (20°C) causing dehumidification and the compressed refrigerant gas is then used to reheat the air and heat the pool water so that energy consumed by evaporation is returned to its source. Air from the pool hall is passed through the dehumidification process and returned again. From a temperature of 29°C, the air is cooled to around 21°C by a static heat exchanger before being further cooled to 14°C by refrigerant cooling coil. Condensation from the heat exchanger and cooling coil is returned to the pool tank. The dehumidified air is returned to the heat exchanger to pre-cool the pool hall air and in so doing is heated to about 25°C. The hot refrigerant is then used to heat the air to 35°C as necessary before it is returned to the pool hall. A central heating coil in the supply air handling unit enables the system to be heated initially and to provide additional heat when needed.

McCall (#9158, 1983) discusses the monitoring and performance of the system described by Weller (#9157, 1983). The COP of the system averaged 1.7 and the PER 2.5. During January 1983, total evaporation water loss was observed to be 0.055 KG/s. Also when operating on full air recirculation about two thirds of the moisture had been removed by the cross flow heat exchanger and a remaining third by the evaporator. This would indicate that the cross flow heat exchanger was playing a significant role within the system and one would therefore expect a similar system without a cross flow heat exchanger to require a much larger evaporator duty. Preliminary monitoring and analysis during the period suggested that the energy running costs of the present gas engine installation were considerably less than would be realised with an alternative electrical system operating under winter conditions and normal tariffs.

Braham (#9164, 1975) also advocates the use of heat pumps in swimming pools. The heat pump cooling coil reduces the air temperature and therefore reclaims the sensible heat, but the drop in temperature also condenses the moisture (the latent heat) out of the air. Therefore, the exhaust air leaves the cooling coil stripped of 60% of the sensible and latent heat. This heat is then pumped by the refrigeration compressor to the heating coil in the incoming air system, or to a water heat exchanger, where the heat is given up to the air and water respectively. A heat pump is used here because of its ability to reclaim heat simultaneously from the exhaust air cooling coil, the shower water and the filter water. However, it can also use the heat simultaneously for air heating, space heating, pool water heating and shower water heating. The heat pump system has a number of advantages, including the ability to reclaim heat from multisources and to use it over a wide range of functions. It was also convert latent heat into a usable sensible heat and reclaim dry heat. The heat pump is also a temperature amplifier unlike heat exchangers which reduce the temperature of the transferred heat. Heat pumps increase the temperature and can therefore reclaim heat from typical room air or shower water temperatures and amplify that heat to a useful temperature level, such as from 40°C to 45°C.

According to Watts (#9144, 1995) who compared the use of boilers with electrically driven heat pumps for swimming pools, to prevent excessive condensation the heat lost from the pool water by evaporation must be replaced, and the moisture being added to the air must be removed. Watts suggests that the ideal solution is to reverse the evaporation cycle by taking the moisture and the latent heat out of the pool air and put it back into the pool water. This can either be achieved by using by using a heat pump or the correct amount of fresh air. The author suggests that given the average temperature and moisture content of the air in swimming pools this would require 117kg of air to remove 1kg of moisture from the pool hall. To heat this mass of air from 10 °C to 28 °C would require 0.59 kWh of heat. If a 90% efficient condensing boiler is used, burning gas at 1.5p/kWh, the same amount of dehumidification and heat input can be achieved as the heat pump system, but at a lower cost. The main emphasis of the paper is to advocate the use of gas fired boilers over HP systems. However, a letter that later followed the publication of this article suggests that the public swimming pool owner should be on a commercial electrical user tariff, thereby reducing the cost of the heat pump system by 30%, and making the system cheaper than the gas fired boiler system.

Harrison (#9152, 1976) outlined a design concept for a new swimming pool using exhaust air heat recovery which utilises a run around circuit in the exhaust and fresh air ducts. This is particularly advantageous because of the very high moisture content of the exhaust air, a large amount of dehumidifying takes place over the exhaust coil. This produces a large heat recovery which inturn increases the amount of heat that the run around system can supply to the incoming fresh air. In the report the author works through the design calculations for the system in the paper.

5.0 CONCLUSIONS

Heat pump technology allows a proportion of, what would have been wasted ventilation exhaust heat, to be captured and transferred to either the buildings' hot water supply, or outdoor air flowing to the building. Heat pumps can be installed into domestic exhaust only systems, including passive stack, as well as balanced residential and commercial buildings without taking up to much space for additional ducting etc. Indeed the studies outlined above demonstrate that for typical residential air-water heat pumps, COPs of between 2 to 3.5 are possible, and in extremely favourable cases they can be as high as 5. While for residential air-to-air heat pumps COPs of between 2 to 5 were reported. Where combined heat pumps and heat exchangers are utilised COPs can reach the slightly over 5. For commercial buildings, typical COPs range from 2 to 3, while for swimming pools examples have quoted around 1.7. These examples demonstrate the potential for heat pump technology to further enhance the energy efficiency of our buildings.

6.0 REFERENCES

#NO 859 Commercial heat recovery - an appraisal.
AUTHOR Johnson A.J.
BIBINF Refrig.Air Condit.Heat Recovery October 1981 vol.84 no.1003 p.44-56,66,89 10 figs. #DATE 01:10:1981 in English
ABSTRACT Considers the options which could be described as heat recovery and which are open to building services designers and operators. Treats fundementals for heat recovery, inadvertent heat recovery, deliberate heat recovery, air recirculation, passive heat exchangers, active heat exchangers, heat pump systems, heat recovery systems, incremental systems, heat distribution in central plant heat recovery systems, controls, heat recovery in air conditioning systems, bivalent heating, the actual application process of heat recovery.
KEYWORDS heat exchanger, heat recovery, heat pump, review,

#NO 1028 Energy and the built environment.
AUTHOR Olofsdotter B.
BIBINF Swedish Council for Building Research Report D9:1982 75pp. #DATE 01:01:1982 in English
ABSTRACT Provides a brief summary of Swedish energy policy. Covers current knowledge and research in Sweden concerning low-energy buildings and building services, energy supply, the built environment and heat pumps.
KEYWORDS energy policy, tight house, heat pump, energy conservation,

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

#NO 1926 A comparison of ventilation strategies for tightly constructed houses in cold climates.
AUTHOR Hawken P J
BIBINF Technical Report 1984/09, TR-LT-007, NRCC 24082. Ottawa: National Research Council of Canada, 1984. 40p. 4 figs, 12 tabs, 10 refs. #DATE 00:00:1984 in English
ABSTRACT This report examines three devices (exhaust fan, air-to-air heat exchanger and exhaust air heat recovery heat pump) which could be used to increase the ventilation rate of a tightly constructed house to a level sufficient to keep indoor air pollutants and moisture to acceptable concentrations. Various types of heat pumps were examined and the non-frosting, space heating type was deemed to be the most practical for colder climates. The space heating, non-frosting heat pump and the heat exchanger were each compared to the exhaust fan to determine the most economical choice of device for a range of Canadian climates. Based on current energy prices, the heat pump was found to be the most attractive, except in the case where space heating is undertaken by low cost gas: in which case an exhaust fan only is indicated. It was found that a heat pump could supply a substantial portion of the annual heating requirements for an energy efficient house.
KEYWORDS tight house, mechanical ventilation, heat pump, fan, heat exchanger

#NO 2043 Energy Conservation in Buildings;
AUTHOR Leach, S J
BIBINF Building Services and Energy Division, Building Research Establishment, U.K. #DATE 01:09:1976; Physics in Technology, Vol7 pp195-201 in English
ABSTRACT Building services accounts for some 40-50% of the UK's consumption of primary energy. The potential for energy saving through the adoption of such schemes as district heating, combined heat and power, heat pumps and solar energy could make a major contribution to the country's energy balance.
KEYWORDS energy conservation, energy use, energy losses, heating

#NO 3345 Interzone air movement and its effect on condensation in houses
AUTHOR Riffat S B
BIBINF Applied Energy, No 32, 1989, pp49-69, 13 figs, 2 tabs, 22 refs. #DATE 00:00:1989 in English
ABSTRACT The work is concerned with measuring interzone air movement and investigating its effect on condensation in traditionally built houses. Air flows through a doorway between the lower and upper floors of a house were measured using a tracer gas technique. To study the effect of the temperature difference on interzone air flows, the lower floor of a house was heated to various temperatures in the range 18-35 deg.C using thermostatically controlled heaters. The upper floor was unheated. Two portable SF6 systems fitted with electron-capture detectors were used for measurements of interzonal air flow. The doorway coefficient of discharge was found to be a function of the temperature difference between the two floors of the house. In the second part of the paper, the effect of interzone air movement on condensation is considered. A two-zone moisture transfer model was established and the effect of a kitchen extract fan on the air flow patterns in the house is discussed.
KEYWORDS air movement, condensation

#NO 3696 Exhaust air heat pump study. Experimental results and update of regional assessment for the Pacific Northwest.
AUTHOR Wallman P H, Fisk W J, Grimsrud D T
BIBINF USA, Dept of Energy, Bonneville Power Administration, December 1987, 65pp, 12 figs, 5 tabs, 3 refs. #DATE 00:12:1987 in English
ABSTRACT This paper describes an evaluation of a mechanical ventilation technique that has recently been introduced in the United States, exhaust ventilation employing a heat pump to recover energy from the exhaust air stream. The objective of this study was to experimentally evaluate the energy performance of three EAHP systems. Two of the systems supplied heat only to the domestic hot water. The third system (which is a modified version of the first system) contained a second condenser so that heat could be supplied to the air within the building. The experimental data obtained in this study was required to confirm and allow updating of a computer model used for the previously mentioned preliminary evaluations of this ventilation technology.
KEYWORDS heat pump, mechanical ventilation

#NO 4353 Plate recuperators used with air/air heat pumps in building ventilation systems.
AUTHOR Olsen H R
BIBINF UK, Building Serv Eng Res Technol, Vol 9, No 3, 1988, pp99-104, 13 figs, 4 tabs, 4 refs. #DATE 00:00:1988 in English
ABSTRACT The economic viability of stand-alone heat pumps for space heating is limited by the achievable coefficient of performance. By combining the heat pump with a plate recuperator in full fresh air systems the average heating season efficiency can be increased to the equivalent of a COP of 6. The system works both as a heating and cooling system and will provide over 90% of annual energy requirement, making the use of central heating plant for back-up heating uneconomical. The resulting capital cost saving can be used to offset in part or in full the extra capital cost of the heat pump equipment.
KEYWORDS heat pump, ventilation system

#NO 4364 Use of heat pumps in rural schools.
AUTHOR DES
BIBINF UK, Department of Education and Science, Broadsheet 22, December 1986, 4 figs, 4 tabs. #DATE 00:12:1986 in English
ABSTRACT A heat pump can be an attractive and cost effective alternative to gas central heating for rural schools, and Broadsheet 22 describes two successful installations in rural schools in Yorkshire and Devon.
KEYWORDS heat pump, school

#NO 4885 Exhaust-air heat-pump performance with unsteady-state operation.
AUTHOR Wallman P H, Fisk W J
BIBINF Heat Recovery Systems & CHP, Vol 10, No 3, 1990, pp 231-241, 10 figs, 4 refs. #DATE 00:00:1990 in English
ABSTRACT The energy performance of two residential exhaust-air heat pumps (EAHP) with different condenser designs was studied experimentally in a laboratory with a focus on transient heat-pump performance associated with time varying requirements for water and space heating. Experimental variables included the total daily volume of hot water required, the schedule of hot-water demand, the temperature of water entering the hot-water tank, hot-water delivery temperature, and the temperature and flow rate of air entering the auxiliary refrigerant-heated fan coil supplied with one of the EHAP units to permit space heating. Based on the data, for a wide range of operating conditions, we derived linear correlations between the heat-pumps' time-average coefficient of performance (COP) and appropriate spatial and temporal average temperatures in the hot-water tanks. With the refrigerant-heated fan coil, the COP varied non-linearly with air flow rate. COPs ranged from 2.0 to 4.2. The control

system of the EAHP with two condensers (one is the fan coil) gives priority to water heating. Based on the data, results from our previous hourly modeling of EAHP performance, data from field studies in Sweden, and new calculations, we propose a new control system that usually places priority on space heating and, thus, takes better advantage of the capacity to store heat in the water tank. We estimate that this proposed control system may increase annual energy recovery by approximately 1000 kWh if the EAHP is used in a Portland, Oregon house. Total annual energy savings due to EAHP operation in an all-electric house (compared to the same house with electric resistance space and water heating) is estimated to be approximately 6000-7000 kWh.
KEYWORDS heat pump

#NO 5833 Advanced ventilation systems - state of the art and trends.
AUTHOR Knoll B
BIBINF UK, Air Infiltration and Ventilation Centre, Technical Note 35, March 1992, 100pp. #DATE 00:03:1992 in English
ABSTRACT Increased health standards and the need to save energy in colder climates caused residential buildings to advance to the modern airtight and well-insulated dwellings we have today. In these dwellings ventilation has become a dominant factor, both from an indoor air quality and an energy conservation point of view. This situation asks for consciousness on the part of applied ventilation systems. The report presents a review on present and advanced systems for basic ventilation and notes possible trends. It focuses on residential ventilation systems for basic needs, regarding ventilation as a means of removing human generated pollutants to achieve acceptable indoor air quality. It does not consider ventilation as a means of reducing the effects of highly avoidable pollutants, nor does this report consider special ventilation appliances or alternative techniques such as filtration or air cleaning.
KEYWORDS ventilation system, standard

#NO 6708 Montreal Protocol revised in Copenhagen.
AUTHOR Miro C R, Cox J E
BIBINF USA, Ashrae Journal, February 1993, p 14. #DATE 00:02:1993 in English
ABSTRACT In a major victory for the U.S. negotiators and the HVAC&R industry, environmental ministers and other officials from over 80 countries agreed to a phaseout schedule for HCFCs that permits continued production of the refrigerants for refrigeration, air conditioning and foam insulation until the year 2030. In addition, the phaseout date for CFCs was brought into alignment with the deadline set a year ago for the United States by President George Bush.
KEYWORDS air conditioning, cooling

#NO 7175 Indoor air quality in Swedish dwellings: a follow-up study of 44 single-family houses built in 1982-89.
AUTHOR Thorstensen E, Nilsson I, Rosell L
BIBINF Proceedings of the 3rd Symposium on Building Physics in the Nordic Countries: Building Physics '93 (Bjarne Saxhof, editor), Thermal Insulation Laboratory, Lyngby, Denmark, 1993, vol 1, pp 509-516, 4 figs, 1 tab, refs. #DATE 00:09:1993 in English
ABSTRACT Indoor air quality and durability of the building and its components were studied in 44 single-family houses of the Hjaltevad type built between 1982 and 1989. The investigation comprised measurements of ventilation rate, air tightness and volatile organic compounds (VOC), as well as inspection of the houses and a questionnaire study. The dwellings have exhaust air heat pumps. Ventilation rate and air tightness were checked in all houses when they were new. These measurements were repeated in this study. From the start all houses met the requirements in the Swedish Building Code of a minimum ventilation rate of 0,5 air changes per hour. The houses were initially also very airtight. Now, 3-10 years later, the ventilation rate in practically every house has decreased; on an average 25%. The air tightness is still good, but the result showed on an average a slight deterioration.
KEYWORDS air tightness, residential building, exhaust, heat pump, questionnaire, organic compounds

#NO 7286 Energy recovery and increasing energy efficiency of a building.
AUTHOR Kajl S.
BIBINF USA, Ashrae, 1993, "Building design technology and occupant well-being in temperate climates". International conference, held February 17-19,1993, Brussels, Belgium, pp 114-119, 4 figs 1 tab, 1 ref. #DATE 00:02:1993 in English
ABSTRACT The heat recovery from the exhaust air always presents a considerable energy savings in heating, ventilating, and air-conditioning installations. This paper describes a system that uses a chiller as a heat pump during the winter. This system is installed in a university building in Montreal. Energy from warm exhaust air is used to preheat air supplied for the building's air-conditioning system and to preheat the domestic hot water. This system is coupled in series with the solar domestic hot water (SDHW) system. The

goal of the SDHW is to preheat domestic hot water and use it as a testing bench in numerous classes. The test results of SDHW and the energy savings due to the heat recovery system during one year of functioning are presented in this paper.
KEYWORDS heat recovery, heat pump, university.

#NO 7445 A Swedish - German energy efficient apartment building with attached sunspace.
AUTHOR Blomsterberg A, Eek H.
BIBINF Germany, Stuttgart, Fraunhofer Institut fuer Bauphysik, 1993, proceeding, International Symposium Energy Efficient Buildings, Leinfelden - Echterdingen, Germany, March 9-11, 1993. #DATE 00:03:1993 in English
ABSTRACT Two identical apartment building were built, one in Germany, and one in Sweden, in 1986. The idea was to create energy efficient housing at a low cost, using Swedish building technology and German heating and ventilation technology. The Swedish building code, which is more stringent in terms of energy conservation than the German one, was applied in both countries. The paper examines the performance of the buildings. The energy consumption (1987-89) for space heating was 45% less than for a building built according to the Swedish building code and 60% less than a building built according to the German building code. These energy saving were achieved by insulating the buildings very well and by installing an exhaust air heat pump. Less than 5% of the total energy savings were due to the sunspace and the thermal mass. THe energy efficiency can be further improved.
KEYWORDS apartment building, energy efficiency, sunspace, passive solar building.

#NO 7778 Dynamic insulation - using transmission losses for building heating.
AUTHOR Humm O
BIBINF Netherlands, CADDET Energy Efficiency Newsletter, No 2, 1994, pp 10-12, 3 Figs, 1 tab #DATE 00:00:1994 in English
ABSTRACT Dynamic insulation integrated with the ventilation system is the centrepiece for a comprehensive,low energy, heating concept for two houses in Switzerland. Low velocity, reversed air flow through dynamic insulation in the roofs of the houses allows a large amount of transmission heat losses to be recovered. Exhaust air from the ventilation system is used as a heat source for the heat pumps
KEYWORDS insulation, heat loss, controlled ventilation, heating

#NO 9144 Swimming Pools: Boilers or Electric Heat Pumps?
AUTHOR Watts W
BIBINF Building Services Journal Feb 1995, pp41-42
ABSTRACT The author asks the question whether the use of electric heat pumps as dehumidification devices for swimming pools is really justified on cost grounds, or is it cheaper to make up the heat lost through evaporation by burning fossil fuel?
KEYWORDS Swimming Pool, heat pump

#NO 9145 Rotary storage heat pump
AUTHOR Riffat S B, Shankland N J
BIBINF (Heat Recovery Sys. CHP,) July 1994, vol.14, no.4, 421-426, 4 figs, 2 tabs, 5 refs.
ABSTRACT Describes a chemical storage device combined with a vapour-recompression system designed to operate using the cheap rate Economy 7 electricity tariff. States the rotary storage device employs process intensification which exploits centrifugal fields. The heat pump uses exhaust air from a ventilation system in which fresh air is supplied via a sunspace of a house as its main heat source. States the heat pump has been analysed thermodynamically using various refrigerant/absorbent combinations.
KEYWORDS Heat pumps, energy storage, tariffs, electric heat pumps, preheating, energy sources, housing, calculating,

#NO #9146 Retrofitting commercial buildings with heat pumps
AUTHOR Blatt M H, Pietsch J A
BIBINF (Heat.Pip.Air Condit. Condit.) July 1992, vol.64, no.7, 63-67, 1 fig, 3 tabs, 9 refs.
ABSTRACT States that heat pumps offer the same benefits in retrofits that they bring to new construction, and for the forseeable future, retrofits are more likely to present more opportunities to the HVAC industry in the USA than new construction. Notes that heat pumps are effective replacements for all types of HVAC equipment and gives examples. Summarises in a table opportunities for heat pumps in the commercial replacement market. Describes a three-pronged approach to marketing heat pumps adopted by Ohio Edison Co., an electricity supply company. Summarises the percentage of HVAC equipment in all commercial buildings and in commercial buildings more than 22 years old. plus the percentage of HVAC equipment shipped to new construction and to retrofits and replacements in 1990. Describes the new heat pump equipment now available.
KEYWORDS Heat pumps, commercial, buildings, heating, air conditioning, ventilation

#NO 9147 A Ground Coupled Storage Heat Pump System with Waste Heat Recovery
AUTHOR Drown, David C; Kast, Timothy P and Den Braven, Karen R
BIBINF ASHRAE Journal February, 1992 p20-24
ABSTRACT The paper describes an experimental single family residence which demonstrates the integration of waste heat recovery and seasonal energy storage using both a ventilating and a ground coupled heat pump. The house combines a superinsulated home construction with ventilating hot water heater and ground coupled water to water heat pump.
KEYWORDS Heat Pump, domestic

#NO 9148 The Amsterdam Wolrd Trade Center's (W.T.C) Heat Pump
AUTHOR Leijendeckers, P H H
BIBINF IEA Heat Pump Centre Newsletter, Vol 8, No 3 September 1990.
ABSTRACT This article describes the integration of a gas engine-driven heat pump system in the air conditioning and heating system of the World Trade Center premises in Amsterdam. The heat pump provides for both cooling and heating during the summer and winter periods and also provides emergency power in the case of interrupted public power supply.
KEYWORDS heat pump, commercial

#NO #9149 Influence of the CFC regulations on the design of heat pumps and air conditioning systems
AUTHOR Hesse U
BIBINF (Indoor Air Quality, Ventilation and Energy Conservation. Proceedings, 5th International Jacques Cartier Conference) October 1992, Montreal, Haghighat:F., Ed., 664-675, 4 figs., 3 tabs., 9 refs.
ABSTRACT Discusses the influence of CFC regulations on the design of heat pumps and air conditioning systems. To avoid the use of CFCs in air conditioners and heat pumps, a new system design must be found. These systems can be designed to use alternative working fluids to replace CFCs or use alternative processes. Gives alternative working fluids and processes.
KEYWORDS regulations, fluorocarbons, heat pumps, air conditioning, refrigerants, heat exchangers,

#NO 9150 International heat pump policy review and opportunities for collaboration
AUTHOR Bouma J W J
BIBINF (Utilities perspectives on heat pumps for retrofit and new applications in buildings. Workshop proceedings), Baden, Switzerland, September 1994, IEA Heat Pump Centre, Report No. HPC-WR-14, 51-58, 621.577
ABSTRACT Refers to an analysis carried out during 192-94 by the IEA Heat Pump Centre and the International Institute of Refrigeration to provide a thorough assessment of the technological and market status of heat pumps, related policy matters and areas for international collaboration. The analysis is based on reviews of the heat pump situation in 25 countries. States the assessment showed that significant developments with an impact on the heat pump market include a decrease in heat demand in buildings, a growing need for forced ventilation and heat recovery,improving power generation efficiency and growing attention to process integration. Considers the role and perspective of governments and utilities concerning energy and environment policies relevant to heat pumps. Considers prospects for international collaboration.
KEYWORDS Heat pumps, international

#NO 9151 The dynamic wall as a solar collector
AUTHOR Timusk J
BIBINF (Workshop. Low-energy buildings, 2nd Generation. CIB W 67 Annual Meeting) Fraunhofer Institute for Building Physics, Heidenheim, May-June 1990, Erhorn:H. Ed., 11.1 - 11.13, 6 figs, 6 refs. 697.113
ABSTRACT Examines the performance of a dynamic wall house with heat pump heat recovery from the exhaust air. States that of particular interest is the ability of the dynamic wall to capture solar energy. Compares energy demand to satisfy heat transmission losses through the thermal envelope, domestic hot water requirements and ventilation air heating to energy supply, including heat recovery through the dynamic walls, solar gain through the windows and the opaque walls. Finds the total predicted energy supply based on average weather conditions, exceeds demand by almost a factor of three. However demand, and especially the solar energy component of the supply, are time-variable. Therefor proposes strategies for storing heat recovered by the dynamic wall and captured solar energy. In this approach the building thermal envelope becomes a part of the heating, ventilation, air conditioning, domestic hot water and heat storage system.
KEYWORDS Performance, housing, walls, thermal insulation, heat pumps, heat recovery, solar energy, solar

#NO 9152 Thermally efficient indoor swimming pool.
AUTHOR Harrison P

BIBINF Construction. June 1976, no.18, 8-12.
ABSTRACT Describes generally basic design approach for indoor pools. Illustrates pool diagrammatically and its energy balance at -2 outside temperature. Provides calculation of maximum percentage saturation and required ventilation rate. Treats and illustrates design of run-around exhaust air heat recovery system calculated using Trane Coil Heat Recovery Loop program. Further discusses preliminary studies into solar heating of pool water. Treats advantages of solar heating, solar panel area, determination of percenatage saturation and costs.
KEYWORDS Swimming pools, energy conservation, indoor, humidity, air change rate, heat recovery, run around coils, heat pumps, heat pumps, solar heating, water heating

#NO 9153 Modelling and simulation of the crawlspace heat pump.
AUTHOR Wasserman D, Reid R
BIBINF (ASHRAE Trans) 1984. vol.90. part 1A, 312-334, 15 figs, 3 tabs,
ABSTRACT A simple and inexpensive way to increase the efficiency of heat pumps used with houses built with crawlspaces is to use the soil beneath the crawlspace as a heat source or heat sink for the outdoor unit of the heatpump. Air is preconditioned by the crawlspace soil before passing over the outdoor unit coil. A model of heat transfer in a crawlspace was developed, and a computer program written to calculate time dependent soil and air temperatures in a crawlspace containing a heat pump. Latent heat transfer resulting from soil vapour diffusion was included in the model. Various assumptions regarding vapour diffusion in soils were made in order to match simulated soil and air temperatures. This model, together with the seasonal performance factor heat pump model, was compared with data from an instrumented house and then used to predict heating season crawlspace heat pump performance for crawlspaces different from the experimentally evaluated crawlspace.Results included, a single pass system is not suited for winter operation, adding insulation to the walls of an above-grade crawlspace only improves performance slightly, a crawlspace heat pump in a northern region of the United States could significantly reduce heating season purchased energy compared to a conventionally installed heat pump.
KEYWORDS heat pumps, crawl spaces

#NO 9154 A new heating system with heat recovery and mechanical ventilation for residential buildings
AUTHOR Salvigni S, Mazzacane S
BIBINF (CLIMA 2000. 8th World Congress on Heating Ventilating and Air Conditioning) VVS Kongres - VVS Messe. Copenhagen 1985. Vol.6. Heating, Ventilating and Air-conditioning Systems. , pp303-308, 2 figs, 1 tab, 3 refs.697(063).
ABSTRACT A new central heating system for prefabricated residential buildings is described. The central unit consists of a regenerator and a heat pump, allowing the new air to be heated by the exhaust air. This unit provides a background heat of 15 degrees C whilst permitting the user to adjust his area to his desired temperature. An energy comparison is presented between the suggested system and a traditional heating system for 30 flats in Southern Italy.
KEYWORDS heat recovery, flats, domestic, heat recovery, heat exchangers, heat pumps

#NO 9155 The BRE low-energy-house laboratories
AUTHOR Freund. P
BIBINF Dom.Heat and Air Condit. May 1981, vol.14, 15-18, 5 figs, 1 tab. (in English)
ABSTRACT Describes four houses and their heating systems, which are being tested under simulated occupancy. 1. The heat reclaim house contains conventional gas central heating, mechanical ventilation, passive heat exchanger in the loft and waste water heat recovery using a domestic hot water heat pump. 2. The solar house contains solar panels on roof, seasonal water heat store, with heat used only for space heating. 3. The heat pump house contains south facing conservatory, solar roof, and air to air heat pumps for space heating and domestic hot water. 4. The underfloor heating, house contains air source heat pumps for space heating, conventional water heating and supplementary gas heating. Brief details of performance are given.
KEYWORDS housing, heat recovery, mechanical ventilation, heat pumps, solar

#NO 9156 Field test on an exhaust air heat recovery heat pump
AUTHOR Chauhan, R B
BIBINF Canada National Research Council #RS (Canada NRCBR note 226) Ottawa, February 1985, 12pp., sp662.99:621.577
ABSTRACT Summarises the results of field testing an exhaust air heat recovery heat pump (EAHRHP) prototype which was installed in an unoccupied conventional house, (House H3 of the HUDAC Mark XI Project Series), to determine its effectiveness as a supplementary heater, its effect on house air change rate and its overall performance.

KEYWORDS heat pumps, heat recovery, exhaust air

#NO 9157 The design and operation of the gas engine dehumidification system at Farnborough swimming pool.

AUTHOR Weller, J W

BIBINF (CICC conference Heat pumps for buildings) University of Nottingham. 1983, Sherratt:A:F:C., Hutchinson, 1984, 188-217

ABSTRACT Describes the application of automotive engines to drive the refrigeration plant, instead of the usual electric motors. The principles are discussed and the old and new services illustrated. Dehumidification is enhanced by a passive heat exchanger which reduces the refrigeration load in the recirculation/ventilation system. Two engines fuelled by natural gas drive refrigeration compressors at varying speeds with heat recovery from the refrigerant, engine blocks and exhausts. Electronic controls minimise the predicted system operating costs.

KEYWORDS heat recovery, swimming pools, heat pumps, gas engine heat pumps, dehumidifiers, air conditioning, heat exchangers

#NO 9158 The gas engine driven heat pump dehumidification system at the Farnborough Recreation Centre

AUTHOR McCall, M J

BIBINF (CICC conference Heat pumps for buildings) University of Nottingham. 1983, Sherratt:A:F:C., Hutchinson, 1984, 188-217

ABSTRACT Describes a 12 month monitoring period which has demonstrated that the performance of a gas engine driven dehumidification system for an indoor swimming pool at the Farnborough Recreation Centre has exceeded design expectations and achieved a 70% saving in heating energy. Assessment of the installation's operation has revealed that future gas engine heat pump systems could provide even greater savings by the use of fresh air ventilation. Illustrates and describes the installation. give the monitoring results and discusses the economics.

KEYWORDS Heat pumps, gas engine, dehumidifying, swimming pools,

#NO 9159 Heat pump opportunities for the home.

AUTHOR Brundrett, G W

BIBINF Effective use of electricity in buildings. Institution of Electrical Engineers. Power Division) London, 1980.

ABSTRACT Deals with air-to-water heat pumps.

KEYWORDS heat pumps, domestic

#NO 9160 Assessment of residential exhaust-air heat pump applications in the United States

AUTHOR Wallman, P H et al

BIBINF (Energy) June 1987, vol.12, no.6, 469-484, 9 figs, 5 tabs, 14 refs.

ABSTRACT Concentrates on the trade-off between adequate ventilation and energy efficiency. Studies electric exhaust air heat pumps for domestic hot water heating with an option for space heating, which provide ventilation in a controlled manner and also yield energy recovery. Simulates detailed system performance for a full year for two typical houses equipped with the heat pump for three climates in the US. Compares ventilation and energy performance with the same houses equipped with air to air heat exchangers and naturally ventilated houses. Finds greater energy saving with the heat pumps than with heat exchangers. Notes the effect of climate on efficiency of heat pumps and heat exchangers.

KEYWORDS heat pumps, heat exchangers, domestic

#NO 9161 A study of large air to air heat pumps in a clothing store

AUTHOR Anon

BIBINF Electricity Council. Environmental Engineering Section, Report ECR/R1446 May 1981, 39pp.

ABSTRACT This report describes the field trial undertaken at a Manchester clothing store with a gross floor area of 5950m2, served by eight rooftop air to air heat pumps. The heat pumps have a design heat output of 61 kW each, and the data complements that which has been derived from earlier trials with smaller units. Energy consumptions are shown for a period of one year, with typical demand curves and the annual running costs. Total electrical energy was similar at Manchester to two other stores in the same chain, employing central plant air conditioning and oil heating, but the heating energy was considerably lower, due to the lower specific heat requirement. The predominant requirement was for cooling, which in the winter months is satisfied by free cooling. Coefficients of performance for the heat pumps were found to be similar or slightly lower than others previously measured with a seasonal heating COP of 2.3-2.4. Attention is drawn to the distribution energy for the store, which at 68.6 kWh/m2 per annum contributed 35% of the electrical energy, and which it is felt could be reduced if a different approach to ventilation design were adopted.

KEYWORDS heat pumps, shops, commercial,

#9162 The case for heat pump ventilation heat recovery

AUTHOR McIntyre, D A
BIBINF Electricity Council Research Centre Research Memorandum ECRC/M 2083, November 1986, 14pp, 6 figs, 3 tabs
ABSTRACT States that full house mechanical ventilation with heat recovery (VHR) has already been shown in practice to reduce house heating costs and improve internal air quality. Notes it is possible to augment this system by adding a small heat pump in conjunction with the air-to-air heat exchanger. This combination gives a high coefficient of performance and reduces installed capacity and hence cost of the compressor when compared to an air-to-air heat pump used without a heat exchanger. Considers the application of heat pump VHR to to full house mechanical ventilation.
KEYWORDS Heat pumps, heat recovery, heat exchangers, housing, mechanical ventilation,

#NO 9163 Superinsulation and warm-air heating in Sweden
AUTHOR Blomsterberg, A
BIBINF (Thermal performance of the exterior envelopes of buildings III. Proc. of ASHRAE/DOE/BTECC Conference) Florida, 2-5 December 1985. ASHRAE SP 49. 1033-1041, 9 figs., 2 tabs., 5 refs. ISBN 0 910110 45 X. 697.13
ABSTRACT Three well-insulated experimental houses in Sweden, utilising warm air heating and exhaust air heat pumps, were monitored during 1983-1985. The most energy efficient house has U-values below 0.10 W/m2C. Four pane windows are used throughout the three houses. A balanced ventilation system is coupled with a very tight envelope. Heat recovery is provided for by an exhaust air heat pump. The investigation has shown that the simplified warm air heating system led to a comfortable indoor climate, with fresh air, comfortable temperatures and little noise.
KEYWORDS warm air heating, heat pumps, energy consumption, balanced ventilation, heat recovery, comfort, low energy housing

#NO 9164 Environmental services in swimming pools-the future.
AUTHOR Braham, D
BIBINF British Ceramic Tile Council/Sports Council symposium on swimming pools. London 1975, 55-65, 725.74.
ABSTRACT Discusses problems of operating swimming pools to conserve energy. Illustrates practical solutions from two swimming pools in South Germany. Notes that pools and leisure centres are highly serviced buildings and gives recommendations for plant layout and planning to reduce operating and energy costs, including heat recovery systems,, heat pumps, and plant location.
KEYWORDS Swimming pools, space heating, energy conservation, heat recovery, heat pumps

#NO 9165 Monitoring heat pumps in use. Controle de pompes a chaleur en service
AUTHOR Goodall, E G A
BIBINF Bldg.Res.Prac. January/February 1981, vol.9, no.1, 24-33, 5 figs, 6 tabs, 3 refs.
ABSTRACT States that although much is expected of heat pumps as efficient converters of energy, actual monitored results show that considerably more energy is used by the supplementary electric heaters than theory would predict and hence the theoretical energy savings are likely to be optimistic or misleading. Describes simple analysis which takes into account the more practical aspects of heat pump operation in actual buildings - hours of occupation, preheat, ventilation and lighting for day/week and hours/day. Carries out analysis for a heat pump installation in school, shop, bank and office. Tabulates comparison of actual and calculated energy consumptions. Finds in particular that undersizing of the unit and inadequate controls of preheat and supplementary heating can lead to costly results.
KEYWORDS supplementary heating, heat pumps, energy consumption, energy conservation, preheaters

#NO 9166 An integrated approach to energy-conserving house design - a report on the first year of occupancy
AUTHOR Dewil J M.
BIBINF (Thermal performance of the exterior envelopes of buildings III. Proc. of ASHRAE/DOE/BTECC Conference) Florida, 2-5 December 1985. ASHRAE SP 49. 1076-1087, 4 figs., 3 tabs., appendices.
ABSTRACT Discusses the construction, indoor environment and energy consumption of an air tight super insulated house built in Canada, which has a cold climate. It includes exhaust ventilation with an air to water heat pump.
KEYWORDS low energy housing, air water heat pumps, energy consumption, conservation, occupancy, exhaust air ventilation, heat recovery, air quality, indoor, radon, formaldehyde,

#NO 9167 Residential heat recovery
AUTHOR Perlman M, Mills B E
BIBINF (ASHRAE J.) June 1986, vol.28, no.6, 28-32, 4 figs, 1 tab.
ABSTRACT Treats a research programme involving the laboratory investigation of a new gen-

eration of heat pump-based devices capable of providing mechanical ventilation, controlled humidity and improved indoor air quality while recovering a large part of the exhaust air energy for space and/or domestic hot water heating. In addition treats waste water heat recycling for domestic hot water production. Illustrates the results in graphs and a table. Concludes the systems are efficient and reliable. Estimates energy savings of 40% to 60% in comparison with conventional electric resistance water heating equipment.
KEYWORDS heat pumps, domestic, heat recovery, space heating, exhaust air

#NO 9168 Wates conservation house.
AUTHOR Anon
BIBINF (Bldg. Tech. Mgmnt.) April 1977, vol. 15, no. 4, 14-17, 10 figs.
ABSTRACT Describes house built at Machynlleth for National Institute for Alternative Technology to maintain comfort conditions with much reduced energy consumption. Illustrates schematically much increased thermal insulation to reduce heat gains and losses, use of heat pumps in forced ventilation system for summer cooling and winter heating, intensive use of heat pumps and thermal insulation for pipes to conserve and recover heat from waste water, and power supply by 2kW wind generator expected to supply 15kW hours of electricity a day at 110 volts D.C. some of which is stored. Treats provisions to cope with condensation.
KEYWORDS Housing, energy consumption, insulation, heat pumps, heat recovery, energy, condensation, thermal comfort

#NO 9169 The HVAC refrigerator - a promising combination appliance
AUTHOR Allen G and Kani M.
BIBINF (Proceedings, 12th Passive Solar Energy Conference) American Solar Energy Society, Solar Energy Society of Canada, Portland, Oregon, June 11 - July 16, 1987, Andrejko:D:A., Hayes:J. Eds, 574pp, ISBN 0 89553 203 4, 461-465, 3 figs, 3 tabs, 4 refs. 523.72
ABSTRACT Describes an innovative heat pump that provides food refrigeration, whole house ventilation with heat recovery, space heating and cooling plus residential water heating. Treats the application of a detailed computer model simulate annul energy performance for three types of houses in three different northern climate. Energy savings were from 110 to 560 dollars, with paybacks ranging from zero to three years.
KEYWORDS Heat pumps, refrigeration, housing, heat recovery,

#NO 9170 Costs dive at hundredth swim pool heat pump installation
AUTHOR Anon
BIBINF Refrig.Air Condit. March 1981, vol.84, no.996, 26-29, 2 figs
ABSTRACT Describes the Leisure Pool at Eastbourne, which is the 100th pool in the UK employing electric heat pumps to reclaim energy that would otherwise be wasted. Treats the advantages of heat pump operation, where the large air volume involved in ventilating swimming pools is dehumidified and the latent heat is reclaimed by an air to air heat pump, making it possible to reduce the normal high fresh air circulation and rely on a much smaller volume to keep odours under control. The energy that the heat pump then makes available is more than enough to heat the small amount of outside air required by the building with sufficient in hand to heat both swimming pool water and shower water. Notes energy savings of 54 the first three months of operation of the system giving a payback period of three years.
KEYWORDS Heat pumps, energy conservation, heat recovery, dehumidifying, swimming pools,

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ADDRESSES

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8) Air infiltration in commercial buildings. **9)** Air infiltration in public buildings. **10)** Carbon dioxide controlled ventilation.
11) Occupancy effects on air infiltration. **12)** Windbreaks and shelterbelts. **13)** Air infiltration measurement techniques.
14) Roofs and attics. **15)** Identification of air leakage paths.
16) Sick buildings. **17)** Flow through large openings. **18)** Control of cross contamination from smokers. **19)** Location of exhausts and inlets.

*For list of participating countries see preface.

Heat Pumps for Ventilation Heat Recovery
Bibliography Update
March 1998

#NO 9252 Pools at the Palace.
AUTHOR Ashley S
BIBINF UK, Bldg. Serv. CIBSE J., May 1995, Vol 17, No 5, pp 15-19, 3 figs, 1 tab.
ABSTRACT Describes the modem indoor swimming pool at Hamilton, near Glasgow. It comprises a standard pool and a leisure pool with an outdoor section. Highlights the open plan nature of the building with its large curved roof specially developed to overcome acid condensation and acoustic problems. Notes the space and domestic hot water heating and the different water treatment regimes for the two pools. Deals with ventilation systems, energy conservation strategies including passive heat recovery for the pool hall air handling plant, air recirculation in the pool hall air handling heat and power, high efficiency gas condensing boiler plant and refrigeration heat pump in association with the pool hall air handling unit discharges and pool water heating systems. Summarises the main features of the building in a table.
KEYWORDS sports building, condensation, noise pollution, ventilation system

#NO 9261 Modelling of a rotary absorption heat pump.
AUTHOR Keinanen A, Karola A, Siren K
BIBINF Finland, Helsinki University of Technology, Laboratory of Heating, Ventilating and Air-Conditioning, Report B41, Espoo, 1995, 128pp.
ABSTRACT A computer model for a rotary absorption heat pump was developed. The system is based on a combination of a rotary absorption machine with a vapour recompression system. The model does not presently include the effect of rotation, but the model is built so that it can easily be taken into account, if necessary. The absorption system is based on technique known as process of intensification, which exploits radial flow driven by centrifugal force. The rotary system is environmental friendly it avoids the use of CFCs and could be driven by a gas engine with the possibility of waste heat recovery from the engine. In this model water is used as a refrigerant and lithium bromide/water solution as an absorbent. The rotary absorption heat pump system model consists of the component sub models i.e. evaporator, absorber, solution pump, heat exchanger, compressor and throttling valve. The component models are designed so, that changes to the components or working fluids can be made easily. The component models include two kind of parameters which describe the construction and adjustment of each component: construction parameters. which describe the size, efficiency and construction of the component, and operation parameters, which describe the adjustable settings of the components. The effect of four construction parameters and two operation parameters to the efficiency of the system was analyzed. The construction parameters analyzed were the UA-value of the evaporator, the UA-value of the absorber, the UA-value of the heat exchanger and the UA-value from the condenser coil to the generator. The operation parameters analyzed were compressor outlet pressure and the evaporator temperature. Results show that the absorber UA-value and the evaporator UA-value define the size of the absorption heat pump system. These UA-values should be in balance. The UA value of the heat exchanger and the UA-value of the condenser coil affect the efficiency of the system. These values should be as good as can be technically and economically made. Although, their effect to the Primary Energy Ratio can be seen only, when both the evaporator and the absorber UA-values are high enough. The optimum of one value is always dependent on the values of the other parameters, and the environment conditions. Compressor outlet pressure should be as low as is technically possible.
KEYWORDS modelling, heat pump

#NO 9508 Energy considerations in heat pump technology. Energetische Betrachtungen zur Waermepumpentechnik.
AUTHOR Granryd E
BIBINF Germany, Ki Luft- und Kaeltetechnik, No 1, 1996, pp 9-14, 9 figs, 5 refs.
ABSTRACT Different applications and systems are discussed from an energetic efficiency point of view. Refrigerants and important losses of compression type refrigerant cycles are exemplified and a general overview is given of different heat sources and of primary energy demand for heat pumps. Finally an example is given related to heat pumps for domestic house heating. By means of computer simulations the influence of a number of different design

parameters of the heat pump system have been analysed and the result are exemplified.
KEYWORDS heat pump, energy efficiency

#NO 9509 Heat pumps.
AUTHOR Anon
BIBINF Canada, Solplan Review, November 1995, pp 5,8.
ABSTRACT General introduction to the use and value of heat pumps.
KEYWORDS heat pump
#NO 9510 International heat pump status and policy review. Part 1 - analysis.
AUTHOR Stuij B, Stene J
BIBINF Netherlands, IEA Heat Pump Centre, 1994, 141 pp.
ABSTRACT Covers basic factors; energy and environmental policies relevant to heat pumps; heat pump technology status and RD&D; heat pump markets; international activities. There are appendices giving general information on heat pumps, heat pumps and the greenhouse effect; and the Montreal Protocol - phase-out schedule for ozone depleting substances. A second section gives national position papers.
KEYWORDS heat pump

#NO 9604 Emerging trends in school and university HVAC
AUTHOR Robertson,W,K .
BIBINF Heat.Pip.Air Condit. March 1992, vol.64, no.3, 40-42, 47-54, 5 figs, 3 refs.
ABSTRACT Notes the increasing numbers of schoolchildren in the USA, the need to meet expectations of high environmental standards and the problems of deferred maintenance on essential systems and lack of understanding of energy supply to companies schedules, which both apply equally to universities. Explores the concepts of innovative engineering, new HVAC technologies and creative cash procurement and financing. Among the newer technologies being applied to schools, discusses gas fired air conditioning, thermal storage and ground heat pumps. Addresses indoor air quality and the conversion of schools from nine-month to year-round operation.
KEYWORDS Schools, universities, heating, ventilation, air conditioning, soil heat pumps, indoor, air quality

#NO 9915 Natural ventilation in office buildings - a good idea? Natuurlijke ventilatie van kantoorgebouwen - een goed idee?
AUTHOR Bronsema B
BIBINF Netherlands, TVVL Magazine, No 9, 1996, pp 42-46, 5 figs, 17 refs.
ABSTRACT In this article an electronically controlled system is described, which works as effectively with no outdoor wind pressure as with wind effects, and incorporates a heat pump system, which relieves the thermal load of cooling in summer conditions.
KEYWORDS wind effects, natural ventilation, high rise building

#NO 10172 The influence of the occupants and the construction period on the resulting indoor environment.
AUTHOR Bratsberg G, Sorlie R, Hanssen S O
BIBINF Finland, Helsinki, Indoor Air '93, proceedings of the 6th International Conference on Indoor Air Quality and Climate, 1993, Vol 6, pp 303-308, 2 tabs.
ABSTRACT This study, in progress in Trondheim, Norway, deals with the connection between energy economy and indoor air quality in detached houses. It includes 41 new houses, all equipped with balanced ventilation and heat-pump for energy savings.The study includes both questionnaires and various measurements, and will be finished in 1994. Comparing the new and old housing, 90% of the occupants are more satisfied with the indoor quality in their new home, than their old home.Nevertheless there have been some problems and there are reasons to emphasize the importance of responsibility in the building period and advice on operation and maintenance of the technical installations.
KEYWORDSenergy efficiency, indoor air quality, single family house, heat pump, questionnaire

#NO 10239 Heat pump energy efficiency regulations and standards. Analysis report HPC-AR4.
AUTHOR Lannus A, Tighe C, Wendland R D
BIBINF Netherlands, IEA Heat Pump Centre, June 1996, Analysis Report No. HPC-AR4, 129pp.
AUTHOR This study deals with energy efficiency regulations, labelling requirements, methods of testing for rating capacity and efficiency, and electrical and mechanical safety standards governing heat pump and air conditioning equipment for buildings. Covers the heat pump equipment used for building space heating, space cooling and domestic or service water heating.
KEYWORDS heat pump, energy efficiency, standard

#NO 10272 Field measurements of efficiency and duct retrofit effectiveness in residential forced air distribution systems.

AUTHOR Jump D A, Walker I S, Modera M P
BIBINF USA, Washington DC, American Council for an Energy Efficient Economy (ACEEE), Proceedings of the 1996 Summer Study on Energy Efficiency in Buildings, "Profiting from Energy Efficiency"
ABSTRACT Forced air distribution systems can have a significant impact on the energy consumed in residences. It is common practice in U.S. residential buildings to place such duct systems outside the conditioned space. This results in the loss of energy by leakage and conduction to the surroundings. In order to estimate the magnitudes of these losses, 24 houses in the Sacramento, California, area were tested before and after duct retrofitting. The systems in these houses included conventional air conditioning, gas furnaces, electric furnaces and heat pumps. The retrofits consisted of sealing and insulating the duct systems. The field testing consisted of the following measurements: leakage of the house envelopes and their ductwork, flow through individual registers, duct air temperatures, ambient temperatures, surface areas of ducts, and HVAC equipment energy consumption. These data were used to calculate distribution system delivery efficiency as well as the overall efficiency of the distribution system including all interactions with building load and HVAC equipment. Analysis of the test results indicate an average increase in delivery efficiency from 64% to 76% and a corresponding average decrease in HVAC energy use of 18%. This paper summarizes the pre and post retrofit efficiency measurements to evaluate the retrofit effectiveness, and includes cost estimates for the duct retrofits. The impacts of leak sealing and insulating will be examined separately.
KEYWORDS field monitoring, duct, retrofitting, air distribution

#NO 10275 Advanced retrofit: a pilot study in maximum residential energy efficiency.
AUTHOR Titus E
BIBINF USA, Washington DC, American Council for an Energy Efficient Economy (ACEEE), Proceedings of the 1996 ABSTRACT Summer Study on Energy Efficiency in Buildings, "Profiting from Energy Efficiency"
In an effort to optimize the energy performance of existing single-family housing, the Advanced Retrofit pilot program was sponsored by Massachusetts Electric and administered by Conservation Services Group. The intent of the program was to advance the direction of energy conservation by achieving the highest energy savings possible, by combining field experience with innovative technologies in electrically heated homes. Cost-effectiveness was not a constraint in this pilot program. A random sample of electrically heated homes which had previously been treated through MECO's Residential Space Heat program received treatment. The treatment included advanced analysis and modeling of air flows and energy consumption, maximum air sealing of the building shell, and installation of a wide range of energy efficient measures, such as replacement windows and doors, insulation, efficient lamps and light fixtures, electronic thermostats, and ventilating heat pump water heaters. Billing analysis comparing pre-and post-treatment energy consumption was used to evaluate the savings. Preliminary results indicate that reductions in energy consumption of 25% can be achieved. The lessons learned from this pilot may point the way to greater potential cost-effective savings in conventional residential energy efficiency programs.
KEYWORDSretrofitting, energy saving, air sealing

#NO 10322 The performance of a prototype commercial building balanced ventilation heat pump.
AUTHOR Green R H, Taylor M S, Fletcher P G
BIBINFUK, CIBSE, 1995, National Conference '95, Eastbourne, 1-3 October 1995, Volume 2, pp 36-43.
ABSTRACT Existing designs of balanced ventilation heat pump heat recovery units suffer from poor utilisation of the heat pump, when used in well insulated commercial buildings having significant internal heat gains. A new balanced ventilation heat pump is now under development, with the aim of increasing the utilisation of the heat pump, by enabling it to be used during the unoccupied pre-heat period as well as during the occupied period. This report details the results of laboratory tests, performed at EA Technology in the UK, on the prototype unit developed jointly by EA Technology and the Eaton-Williams Group. The results are compared with the design predictions for the unit. The tests have shown that the unit works well and, having undergone a few minor modifications, the unit is now undergoing field trials in a commercial building.
KEYWORDS heat pump, commercial building, ventilation performance

#NO 10534 Evaluation of residential duct sealing effectiveness.
AUTHOR Yuill G K, Musser A
BIBINF USA, Ashrae Transactions, Vol 103, Part 2, 1997, proceedings of the Ashrae Summer Meeting, Boston, 29 June - 2 July, 1997 [preprint].

ABSTRACT This project evaluated duct sealing as a means of reducing the energy consumption of hot air distribution systems in houses heated with forced air electric heat pump systems. The heat pump energy consumption, the supply air temperature, and temperature were monitored. A test was also performed to measure the leakiness of the ductwork. The ducts were then sealed, and another test measuring the leakiness of the ductwork was performed to determine changes in duct leakage characteristics. Finally, the heat pump energy consumption was monitored and the results were compared to the previous monitoring period to determine the impact of the duct sealed retrofit on energy consumption.
KEYWORDS duct, sealing, heat pump

#NO 10726 Energy recovery using a heat pump in heating and air conditioning systems.
AUTHOR Donjerkovic P, Balen I
BIBINF in: SITHOK-2 International Congress on heating and airconditioning of buildings, proceedings, edited by J Krope, P Novak, Slovenia, University of Maribor, proceedings of a conference held 11-12 May 1997, pp 30-37.
ABSTRACT In this paper, theoretic review of a heat pump use and operation is given. Further, the possibilities of a heat pump use in heating and air-conditioning is analysed, specially considering the tourist and catering facilities. The economic and environment protecting effects of a heat pump use as an energy source (conditionally speaking) in the air-conditioning process is pointed out. It is shown that these effects make a heat pump use justifiably attractive. In the end is pointed at the complexity of microprocessor regulation system which enables the heating and cooling capacity balance, when heat is used for both heating and cooling simultaneously.
KEYWORDS heat recovery, heating

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