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Energy Recovery in Ventilation Systems - A Worldwide Energy Saving and Environmental Protection Technology.

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ENERGY RECOVERY IN VENTILATION SYSTEMS A WORLDWIDE ENERGY SAVING AND ENVIRONMENTAL PROTECTION TECHNOLOGY

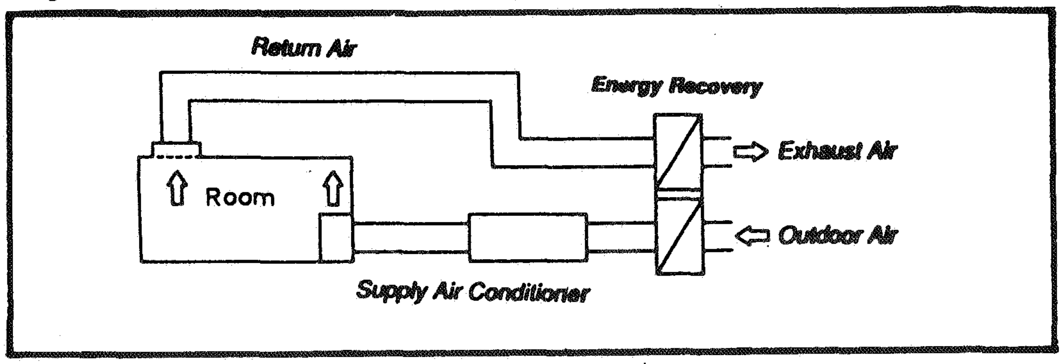
1.0 Energy Recovery

For more than 20 years, energy recovery systems have been operated successfully in European countries in comfort and industrial ventilation systems in order to reduce the heating and cooling capacity as well as to reduce the annual energy consumption for the treatment of supply air. By 1991 the total heating capacity of all installed energy recovery systems in Europe was about 60.000 MW and the equivalent of the annual energy savings was about 10 million tons of oil. This very impressive result of an energy saving technology also includes the annual reduction of emissions of all environmental polluting products: 10 million tons of annual oil savings are corresponding with the reduction of about 50.000 tons of SO_2 and 40 million tons of CO2 Apart from being an important economic factor both at the private and the national level, energy recovery systems thus also make an important contribution to energy conservation and environmental protection [1].

As shown in Fig. 1, energy recovery in HVAC systems wants the use of sensible as well as latent energy contained in the exhaust air for outdoor air treatment to the greatest possible extent. Therefore the main advantages of energy recovery systems are:

- Reduction of the heating and humidification load demand, which in turn reduces the necessary size and thereby the capital costs of heating plants (boiler, piping, etc.)
- Reduction of the heating energy demand, which reduces operating expenses
- Reduction of the cooling and dehumidification load which reduces the necessary size and thereby the capital costs of the cooling equipment (such as compressor, cooling tower, etc.)
- Reduction of electric energy for refrigeration
- Reduction of air and water pollution due to reduced energy consumption needed for heating and cooling

Fig. 1: Air Conditioning System with Energy Recovery



As the exhaust air conditions hardly change during the annual operation time of a HVAC system it is in general the outdoor air which governs the design, operation and economic efficiency of this energy saving technology. Worldwide there are three different climate regions suitable for the application of energy recovery: moderate climate (wet or semi-dry summers, subpolar), desert climate (dry) and tropical climate (permanent high humidity).

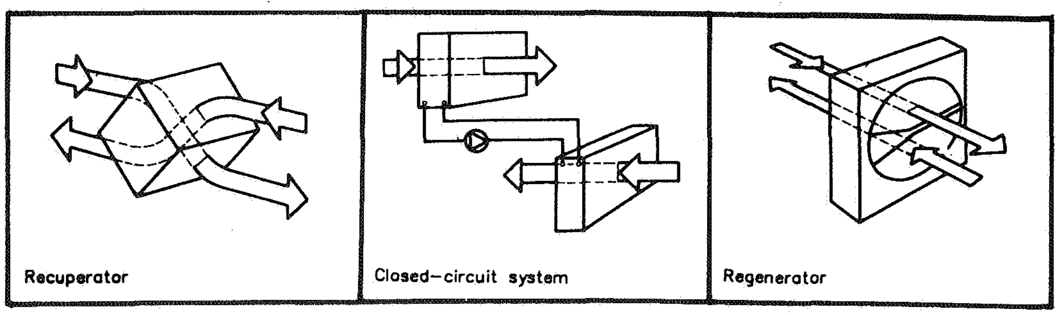
In the past 20 years high energy prices together with high dependence on imported fuel required efficient use of energy, and this in turn resulted in highly developed engineering of ventilation and air-conditioning systems in two parts of the world: Europe - especially in the German-speaking countries and Scandinavia - and the Far East, i.e. Japan [2]. The common feature of these regions is, that these are highly industrialised countries, with their dynamic business-life depending largely on the import of primary energies such as crude oil, natural gas and coal.
As energy prices in the USA and Canada are still comparatively low, the importance of efficient energy utilisation has not yet been fully recognised in these countries, and this is the reason why fewer heat recovery devices are used compared to Europe and Japan.

Heat recovery devices can be applicated in the following fields [3]:
- High comfort buildings (office buildings, schools, hospitals, hotels, department stores etc.)
- Industrial buildings (production halls and workshops in various industrial branches, e.g. automobile industry, electronic industry, pharmaceutical industry, etc.)
- Process air handling systems (paint-spraying booths, driers and extraction facilities, etc.)

It is necessary for all applications to operate with a high outdoor air rate in order to meet the problems of indoor air quality caused by internally generated pollutions, known as "Sick Building Syndrome" [4].

In accordance with Eurovent 10/1 standard [5] heat recovery devices in Europe are divided into 3 categories (Fig.2):

Fig. 2: Types of Energy Recovery Systems



- Recuperators with plates or tubes, preferably for very small systems and process air handling systems with sensible energy recovery only
- Closed circuit systems with finned heat exchangers connected by pipes, used primarily for modification and retrofit of existing buildings with sensible energy recovery only
- Regenerators with rotary heat storing matrix and combined transfer of heat and humidity, for all fields of application with total energy recovery

The matrix is fabricated in a honeycomb structure of corrugated aluminum or ceramic fiber material with hygroscopic or non-hygroscopic surface.

Based on the experience acquired during many years in regions of moderate climate, and as a result from a growing demand for energy saving HVAC systems, a trend is now noticed towards exporting energy recovery systems from Europe and Japan into countries where different conditions prevail. These are desert countries[6] and the tropics in particular. It has to be mentioned in this context, that the buildings with the lowest specific energy consumption values worldwide are located in Europe and Japan: The office buildings of the NMB Bank in Amsterdam and the Ohbayashi Corporation in Tokyo with a remarkable 110 kWh/m2·a energy consumption for heating, cooling and electric energy supply. In both buildings energy recovery with rotating total energy exchangers, solar energy application and computer control operation are the most important energy saving technologies. The average energy consumption of office buildings today is around 300 to 350 kWh/m^2·a [7][8].

2.0 Facts and Figures

In the following, the result of energy recovery in an office building application is calculated for four typical locations worldwide. According to the psychrometric chart and the annual energy consumption diagramm, all reduction of capacities, annual energy consumptions, investment costs and the environmental pollutions are derived. As operation time is 8760 hours per year for shorter operation time, equivalent results can be calculated individually. For the environmental pollution the specific figures of a German study on environmental protection [9] are used according to Fig.3

Fig. 3: Specific emissions Kg/MWh final energy

	SO_2	NO_x	Dust	CO_2
Oil fired Boiler	0,4	0,31	0,01	370
Gas fired Boiler	0,03	0,16	--	272
Coal fired Boiler	2,82	0,38	0,31	547
Electricity (Oil)	0,6	0,58	--	630
Electricity (Coal)	0,75	0,71	0,09	929

Energy Recovery in Berlin/Germany

Climate Conditions: Moderate Climate

Outdoor Air Rate ($50 m^3/h$ Person; $10 m^2$/Person) $5\ m^3/h\ m^2$

Energy Supply for Buildings: 60% Oil, 30% Gas, 10% Coal

Energy Recovery (Total Heat Exchanger, 75% Eff.)

Heating Period	5 mths
Cooling Period	2,5 mths
Reduction Boiler Capacity	75%
Reduction Chiller Capacity	30%
Annual Heating Energy Recovery	190 kWh/m^2 a
Reduction of Annual Heating Energy	90%
Annual Cooling Energy Recovery	5 kWh/m^2 a
Reduction of Annual Cooling Energy	15%

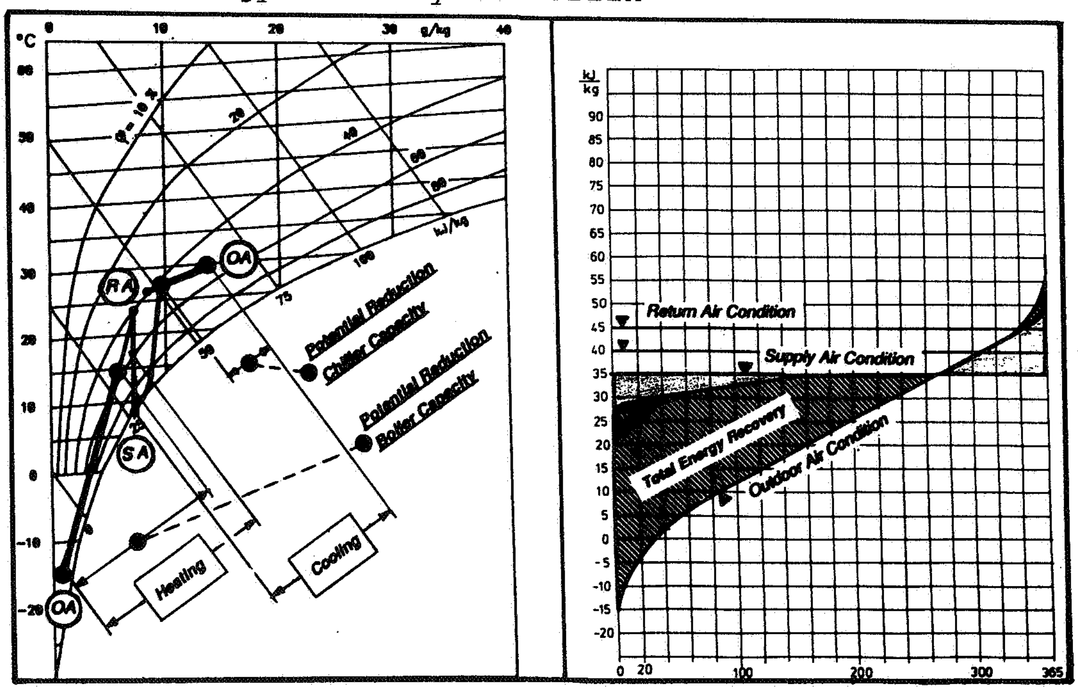
CO_2-Reduction

CO_2-Reduction Heating	67 kg/m^2 a
CO_2-Reduction Cooling	5 kg/m^2 a
Total CO_2-Reduction	72 kg/m^2 a

Reduction Energy Recovery Investment Costs

Red. Boiler Capacity (200,- US$ per kW)	12,- $\$/m^2$
Red. Chiller Capacity (400,- US$ per kW)	7,- $\$/m^2$
Invest. Energy Recovery (1,40 US$ per m^3/h)	7,- $\$/m^2$
Total Investment Reduction	12,- $\$/m^2$

Fig. 4: Energy Recovery in Berlin



Energy Recovery in Tokyo/Japan

Climate Conditions: Moderate Climate, wet and humid summer season

Outdoor Air Rate ($50 m^3/h$ Person; $10 m^2$/Person): $5\ m^3/h \cdot m^2$

Energy Supply for Buildings: 70% Oil, 30% Gas

Energy Recovery (Total Heat Exchanger, 75% Eff.)

Heating Period	4 mths
Cooling Period	5 mths
Reduction Boiler Capacity	100%
Reduction Chiller Capacity	50%
Annual Heating Energy Recovery	160 $kWh/m^2 \cdot a$
Reduction of Annual Heating Energy	90%
Annual Cooling Energy Recovery	25 $kWh/m^2 \cdot a$
Reduction of Annual Cooling Energy	35%

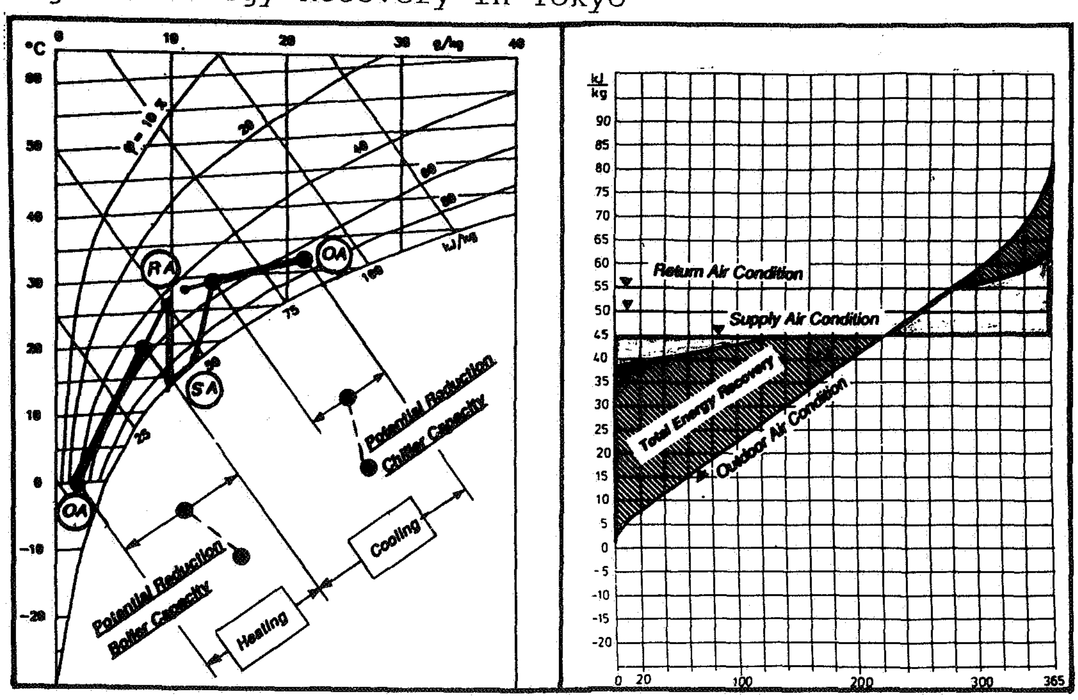
CO_2-Reduction

CO_2-Reduction Heating	54 $kg/m^2 \cdot a$
CO_2-Reduction Cooling	9 $kg/m^2 \cdot a$
Total CO_2-Reduction	63 $kg/m^2 \cdot a$

Reduction Energy Recovery Investment Costs

Red. Boiler Capacity (200,- US$ per kW)	15,- $/m^2$
Red. Chiller Capacity (400,- US$ per kW)	13,- $/m^2$
Invest. Energy Recovery (1,40 US$ per m^3/h)	7,- $/m^2$
Total Investment Reduction	21,- $/m^2$

Fig. 5: Energy Recovery in Tokyo



Energy Recovery in Riyadh/Saudi Arabia

Climate Conditions: Desert climate, dry and little rain, daily and annual extreme differences of outdoor air temperature

Outdoor Air Rate (50 m^3/h Person; 10 m^2/Person):	5 $m^3/h \cdot m^2$
Energy Supply for Buildings:	100% Oil

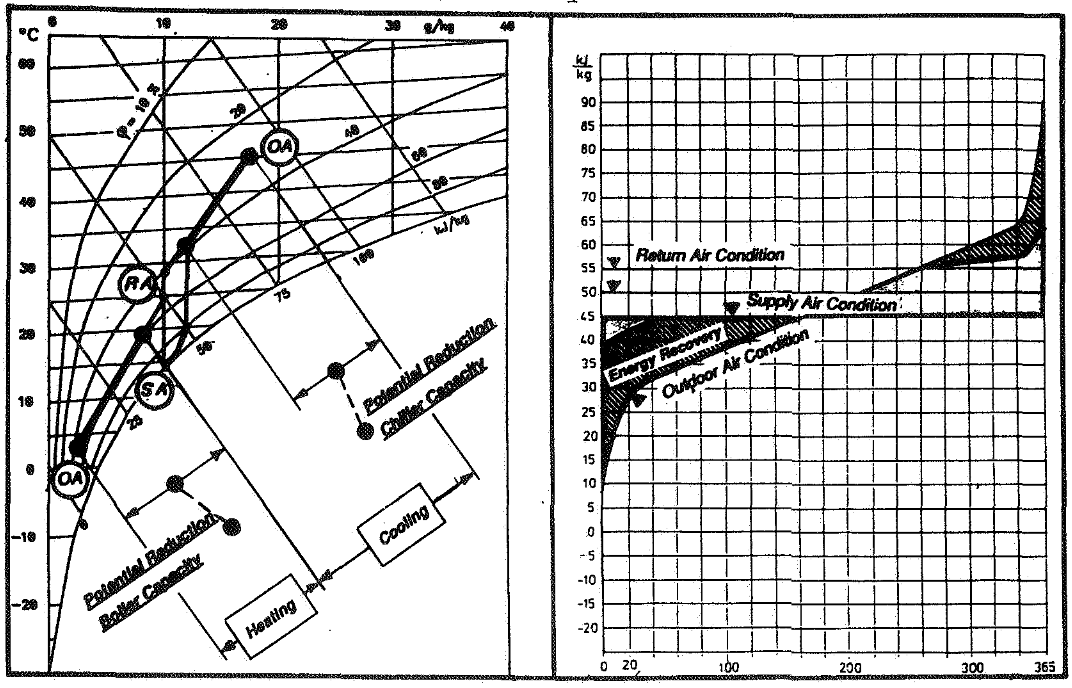
Energy Recovery (Total Heat Exchanger, 75% Eff.)	
Heating Period	1,5 mths
Cooling Period	7 mths
Reduction Boiler Capacity	100%
Reduction Chiller Capacity	50%
Annual Heating Energy Recovery	60 $kWh/m^2 \cdot a$
Reduction of Annual Heating Energy	90%
Annual Cooling Energy Recovery	30 $kWh/m^2 \cdot a$
Reduction of Annual Cooling Energy	25%

CO_2-Reduction	
CO_2-Reduction Heating	22 $kg/m^2 \cdot a$
CO_2-Reduction Cooling	8 $kg/m^2 \cdot a$
Total CO_2-Reduction	30 $kg/m^2 \cdot a$

Reduction Energy Recovery Investment Costs

Red. Boiler Capacity (200,- US\$ per kW)	11,- \$/m^2
Red. Chiller Capacity (400,- US\$ per kW)	15,- \$/m^2
Invest. Energy Recovery (1,40 US\$ per m^3/h)	7,- \$/m^2
Total Investment Reduction	19,- \$/m^2

Fig. 6: Energy Recovery in Riyadh



Energy Recovery in Singapore

Climate Conditions: Tropic climate, permanemt high humidity, only little difference of temperature and humidity

Outdoor Air Rate (50m^3/h Person; 10m^2/Person):	5 m^3/h·m^2
Energy Supply for Buildings:	100% Oil

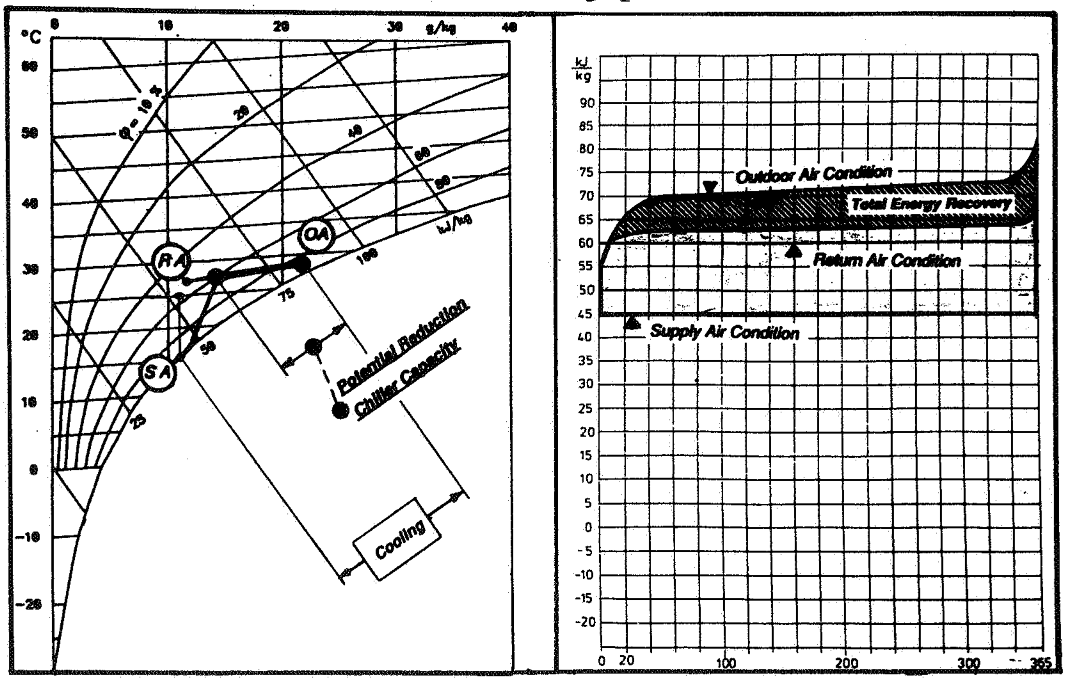
Energy Recovery (Total Heat Exchanger, 75% Eff.)	
Heating Period	- mths
Cooling Period	12 mths
Reduction Boiler Capacity	- %
Reduction Chiller Capacity	50%
Annual Heating Energy Recovery	- kWh/m^2·a
Reduction of Annual Heating Energy	- %
Annual Cooling Energy Recovery	130 kWh/m^2·a
Reduction of Annual Cooling Energy	35%

CO_2-Reduction	
CO_2-Reduction Heating	- kg/m^2·a
CO_2-Reduction Cooling	48 kg/m^2·a
Total CO_2-Reduction	48 kg/m^2·a

Reduction Energy Recovery Investment Costs

Red. Boiler Capacity (200,- US$ per kW)	$/m^2
Red. Chiller Capacity (400,- US$ per kW)	13,- $/m^2
Invest. Energy Recovery (1,40 US$ per m^3/h)	7,- $/m^2
Total Investment Reduction	6,- $/m^2

Fig. 7: Energy Recovery in Singapore



3.0 New Development of Total Heat Recovery Wheel

When using rotating heat exchangers to recover both sensible and latent heat in countries with high relative humidity of outdoor air one has to be aware that those types of heat exchangers are so effective because they adsorb the moisture of outdoor air with high efficiency. The surface of the heat exchanger is therefore made hygroscopic, either by a special treatment of the aluminum material to aluminum oxide or by covering the surface with desgicants like silica gel or zeolite powder. Generally, all these adsorbants have a very good adsorption capacity for moisture, but can also adsorb odourous chemicals of outdoor or indoor air at the same time. This effect can cause cross contamination of odours from return air to supply air, especially when the relative humidity of outdoor air increases rapidly during the rainy seasons or a downpour. The moisture purges out the odourous chemicals which have been adsorbed and accumulated in the pores of the adsorbants by pore condensation. Thus, purged odours would be mixed into the supply air and delivered into the inside of the room. By selecting a special type of silica gel with a defined pore diameter, the pore condensation can be prevented and no odour transfer [10] will happen. This very new type of total heat exchanger has been developed in Japan and is now being applied with very good results without any odour transfer. So all the advantages of the rotating energy recovery systems can be used especially for the reduction of the latent and sensible cooling capacity without any restriction. As shown before in the psychrometric charts of the four locations, only a rotating energy recovery system can meet the requirements of total energy recovery.

4.0 Desiccant Cooling with Energy Recovery Wheels

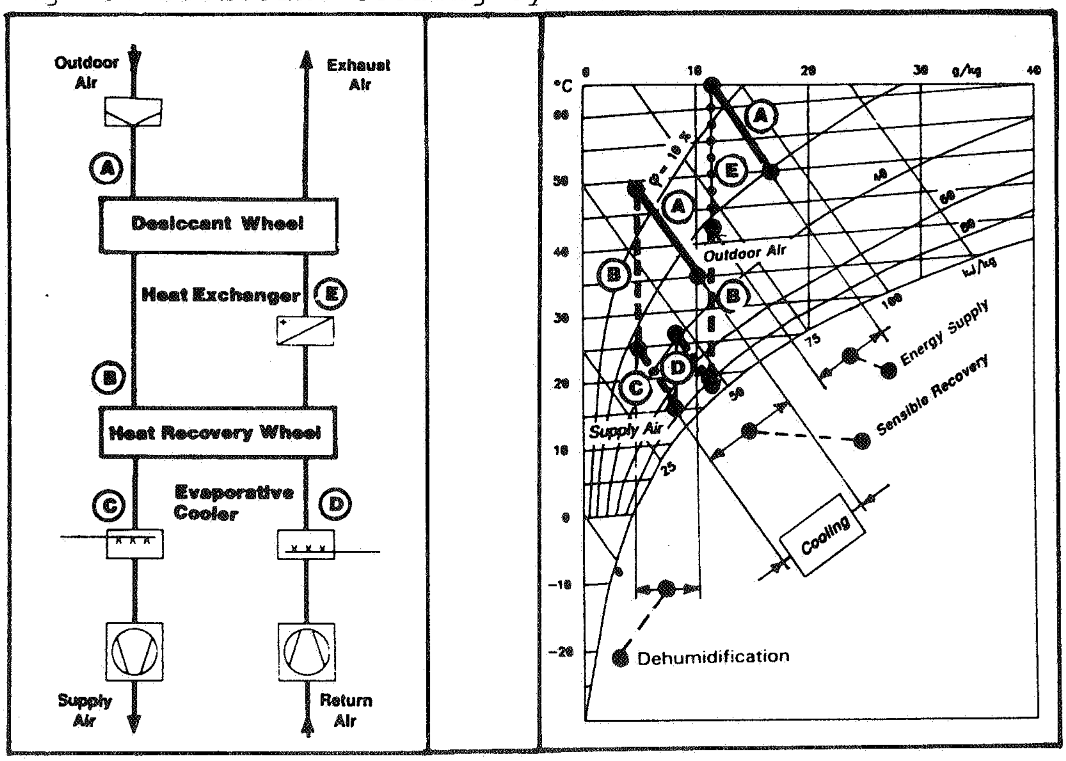
Due to the threat of an atmospheric ozone depletion leading to a "Greenhouse Effect" mainly caused by CO2 from burning fossile primary energies and the CFC-based refrigerants used as cooling vapour in compressor chillers [11] new developments of cooling equipment have a realistic chance to enter the HVAC market and may force changes. The main strategy is to replace the standard refrigeration equipment by using the principle of desiccant cooling in order to eliminate the electric power generation in power plants. The desiccant cooling technology as described in Fig. 8 is now available with two rotating energy recovery wheels with extremely high efficiencies for adsorption and heat exchange [12].

The unit consists of three well-known air processors: a desiccant air dehumidifier, evaporative coolers and a rotating sensible heat exchanger. The individual function of these principal components is as following: the desiccant wheel "A" rotates within the outdoor air stream and removes the moisture from it. The rotor is fabricated of silica gel reinforced with inorganic fibres and formed into a honeycomb shape. Active silica gel is synthesized and combined in the honeycomb shape by chemical reaction. It has an excellent water adsorbing ability [13][14]. The adsorption of moisture on the silica gel causes the temperature of the air to rise. The heat generated during the drying step is removed from the air by a rotating heat recovery wheel "B" with high efficiency. This heat recovery wheel is non-hygroscopic and fabricated of corrugated aluminum. The evaporative cooler "C" humidifies the dried air to further reduce the dry bulb temperature of the supply air stream.

For the reactivation cycle the return air is used by first reducing the dry bulb temperature in the evaporative cooler "D". The heat originally generated during dehumidification of the supply air is then removed and transferred back into the reactivation cycle by the heat recovery wheel "B". As an additional energy source any kind of solar, waste or fossile energy is used in the heat exchanger "E" to bring the reactivation air to the required temperature for desorbing the desiccant wheel. Due to the new synthesized silica gel this temperature could be set at a minimum of 60^{o} C, which allows to use low level waste heat available from many heat processes especially in summer season.

Numerous installations according to this desiccant cooling principle were realised during the last five years in the USA, Japan and Germany.

Fig. 8: Desiccant Cooling System



5.0 Summary

Energy Recovery is today routinely incorporated into the ventilation systems of office buildings, hospitals, schools, hotels, industrial processes etc. Because of high efficiency for both sensible and latent energy recovery the rotating heat exchangers are superior to the other types of heat exchangers. Therefore they are also very advantageous for the important growing application in the Third World Countries, where the energy consumption in the future is expected to grow dramatically. These countries have mainly desert or tropic climates.

The benefits of energy recovery and related technolgies like desiccant cooling are:

- Reduced investment costs due to smaller size of boilers and chillers
- Reduced energy costs for heating energy (90%) and for cooling energy (30%)
- Reduced CO_2 emission due to reduced energy input
- Additional cost reduction if taxes on energy consumption and/or CO_2 emission are introduced
- Higher and more economic outdoor air rate possible to meet the indoor air quality problems
- Reduced dependence on fuel imports
- "Least Cost Planning" technology for public utility services

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