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Chapter 5

Heat Recovery and Adiabatic Cooling for Energy Efficient Air Conditioning

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INTRODUCTION

Minimising energy consumption in air conditioning systems

With increasing heat loads in factory, office and leisure environments, more air conditioning systems are being used to create conditions where people can work comfortably, productively and efficiently. Conventional air conditioning units meet these requirements using large amounts of primary energy and refrigerants thereby resulting in greater environmental pollution.

In preparing a 'design brief' for the features to be incorporated in a low energy air conditioning unit perhaps the following parameters or characteristics would be considered:

- ❑ Very high average heat recovery efficiency, say 75% or greater

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- Fresh air operation for free cooling during the daytime or for pre-cooling the building at night
- No refrigerants used for cooling, if at all possible
- No electricity or gas consumption during cooling if at all possible
- Low energy fans to eliminate belt drive losses and dynamic pressure
- Low internal resistance
- Efficient filtration of fresh and return air
- Recirculation facility when the building is not in use
- Must operate successfully across the full range of possible outdoor temperatures
- Minimum service and maintenance costs

ADIABATIC OR EVAPORATIVE COOLING

Ancient civilisations recognised and understood the effects of evaporative cooling and the word 'adiabatic' is derived from the Greek language.

Evaporative cooling is not new in the air conditioning industry. In arid climates water is sprayed into hot fresh air to pre-cool it before passing across a chilled water coil.

Under cooler UK conditions there is no benefit in this combination. If we use evaporative cooling alone, the fresh air will be cooled but we would create an unacceptable rise in humidity. Therefore evaporative cooling has largely been confined to cooling towers and spray coils.

If the adiabatic cooling effect can be utilised without increasing the supply air humidity, significant environmental and energy advantages would be achieved.

Many buildings could then be cooled without the heavy building services infrastructure and energy consumption associated with gas or electric refrigeration based chiller installations. Where cooling loads are higher, adiabatic cooling could be used to meet the base cooling requirement, minimising the capacity of refrigeration based cooling systems.

KIMBERLIN LIBRARY, DEMONTFORT UNIVERSITY

The Kimberlin Library extension was completed in 1997 and features an air conditioning unit with indirect adiabatic cooling operating in conjunction with TermoDeck active thermal storage.

Winter operation

Heat is retained in the tightly sealed, highly insulated building structure. Heat produced by occupants, lighting and equipment radiates to the hollow core slab.

In winter when the building is unoccupied and the temperature is low, the Adsolair unit runs on recirculation and heating, thereby allowing the slab temperature to be raised for the next occupied period.

When the building is in use, fresh air must be introduced. The Adsolair unit achieves a heat recovery efficiency of up to 80% in winter by means of a double plate heat exchanger. Heat is transferred from the exhaust air to the incoming fresh air and the installed heating capacity and energy consumption is significantly reduced.

At very low outdoor temperatures locally controlled radiant heating offsets transmission heat losses under windows.

Mid-season

In mid season, when the heating requirement is lower, the heating valve closes. Eventually the point is reached where the full potential of heat recovery is no longer required. The bypass dampers above and below the double plate heat exchanger now open and the heat recovery rate can be regulated.

Free Cooling

When the slab temperature is too high, fresh air is introduced to free cool the pre cast ceiling slabs. At night time, the Adsolair system runs when the when the outdoor temperature is lower than the return air and slab temperature. The building is thereby pre-cooled prior to the next occupied period.

Air blown through the slabs during the day is cooled by the stored night cooling and at the same time the ceiling itself acts as a direct radiant cooling system.

Indirect adiabatic cooling

When the slab temperature is high and free cooling is no longer possible because the outdoor temperature is too hot in summer, the Adsolair unit uses adiabatic cooling to meet the peak heat gains. The fresh and exhaust air bypass dampers close and so the fresh and exhaust air pass through the double plate heat exchanger once more. The water spray system operates directly over the double plate heat exchanger in the exhaust air stream.

The sprayed water evaporates into the exhaust air stream taking heat from the exhaust air and at the same time cooling down the double plate heat exchanger. This cooling effect is transferred to the incoming fresh air. The cooling effect of this process can be seen in Table 5.1.

Table 5.1 MENERGA Adsolair Adiabatic cooling performance with TermoDeck active thermal storage

Supply air volume	10.0m³/s	10.0m³/s
Fresh air temperature	29°C db 19°C wb	34°C db 20.5°C wb
Supply air temperature	19.0°C	19.8°C
Return air temperature	22.0°C	22.0°C
Adiabatic cooling	119.2kW	164.0kW
Cooling pump input	2.0kW	2.0kW
Cooling efficiency	59.6 to 1	82.0 to 1

There is no moisture gain or moisture removal from in the supply air. Sensible cooling only takes place in the supply air. The construction of the double plate heat exchanger is airtight and watertight and so there is no transfer of moisture from the exhaust to supply air.

Conventional aluminium or steel plate heat exchangers cannot be constructed to be watertight and so these materials are unsuitable for an indirect adiabatic cooling system. Furthermore, water in contact with these metals would result in corrosion and additional cross contamination.

The plate heat exchanger technology used in the Adsolair system relies heavily on experience in swimming pool heat recovery. The all welded plastic double

plate heat exchanger was originally developed to resist acid attack in the aggressive swimming pool environment.

Water consumption

There would be little purpose in substituting a large electricity bill for cooling with heavy water consumption. However the water consumption is very modest during cooling operation. Typically, the water cost would be approximately £10.00 per year per m^3/s design air volume.

HUNGARIAN PARLIAMENT BUILDING

The Hungarian Parliament building on the banks of the Danube in Budapest was built in 1904. A displacement ventilation system supplied air at low level in the main hall and radiant heating met the transmission heat losses.

In summer, ice was poured into a sump in the fresh air inlet chamber. The hot humid air was cooled and dehumidified as it passed over the ice and blown into the building.

During a later refurbishment, the ice based cooling system was replaced with a direct evaporative cooling system. Water was sprayed directly into the supply air and whilst some cooling was achieved, the moisture content of the supply air was very high.

The complaints about high humidity were well documented over many years. Also, with increasing lighting loads it was resolved to modernise the ventilation and air conditioning to the Parliament Building. The design brief was to

- ❑ retain the existing displacement ventilation system
- ❑ incorporate high efficiency heat recovery in winter
- ❑ utilise non-refrigeration based cooling as far as possible in summer

In 1997 a Menerga Adsolair unit was installed. The system achieves a heat recovery efficiency of up to 80% under winter design conditions. In summer, indirect adiabatic cooling reduces the fresh air temperature by up to 10°C without increasing the humidity of the supply air.

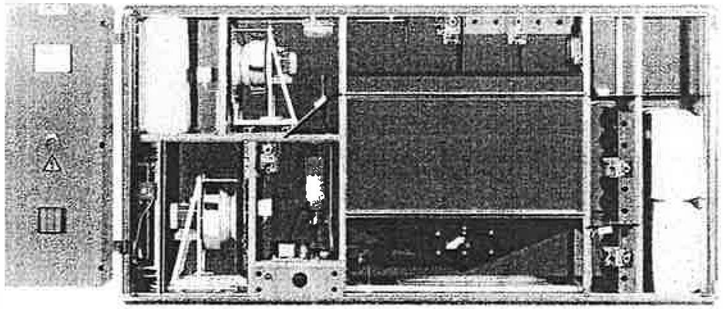

Figure 5.1 Menerga Adsolair air conditioning unit with indirect adiabatic cooling.

Table 5.2 MENERGA Adsolair Adiabatic cooling performance with displacement ventilation

	Displacement cooling only	Displacement cooling & reheat
Supply air volume	10.0m³/s	10.0m³/s
Fresh air temperature	29°C db 19°C wb	29°C db 19°C wb
Air off evaporator	18.0°C	13.0°C 95% rh
Supply air temperature	18.0°C	18.0°C
Return air temperature	26.0°C 47% rh	26.0°C 44% rh
Adiabatic cooling	104.6kW	108.4kW
DX cooling	41.9kW	107.3kW
Total cooling	146.5kW	215.7kW
Cooling pump input	2.0kW	2.0kW
Compressor input	7.5kW	23.3kW
Total cooling input	9.5kW	25.5kW
Cooling efficiency	**15.4 to 1**	**8.5 to 1**

Table 5.3 Conventional chiller cooling performance with displacement ventilation

	Displacement cooling only	Displacement cooling & reheat
Supply air volume	10.0m³/s	10.0m³/s
Fresh air temperature	29°C db 19°C wb	29°C db 19°C wb
Air off evaporator	18.0°C	13.0°C 95% rh
Supply air temperature	18.0°C	18.0°C
Return air temperature	26.0°C 47% rh	26.0°C 44% rh
Compressor input	41.7kW	66.6kW
Air condenser fans	6.1kW	8.0kW
Chilled water pump	0.7kW	1.0kW
Total cooling input	48.5kW	75.6kW
Cooling efficiency	**3.0 to 1**	**2.85 to 1**
Reheat	0.0kW	59.0kW

INDIRECT ADIABATIC COOLING AND DISPLACEMENT VENTILATION SYSTEMS

Once the outside temperature exceeds the supply air temperature set point for displacement ventilation (say 19°C) a traditional ventilation system must then use refrigeration based cooling to prevent the room temperature from rising further.

Indirect adiabatic cooling can be used instead of refrigeration based cooling to achieve the required cooling effect. As the outside temperature rises, the adiabatic cooling effect increases and so supply air temperatures in the range of 19-22°C will be achieved during UK summer conditions. The supply air temperature can be determined by a computer model based upon return and fresh air temperatures, humidity and air volumes.

When indirect adiabatic cooling is used alone, the indoor temperature will track the outside condition. Where greater control or dehumidification is required, indirect adiabatic cooling can be used in conjunction with a very small integral direct expansion cooling system.

The pre-cooling effect of the indirect adiabatic cooling means that the power input for the cooling duty can be reduced by 80% compared with a traditional chiller and AHU solution.

A comparison of cooling efficiencies is shown in Tables 5.2 and 5.3.