Desiccant & Solar Assisted Cooling

Gaia Research

Warwick University, Coventry
Monday 6th April 1998

The seminar forms part of a
Department of the Environment, Transport & the Regions
'Partners in Technology' Project

and is sponsored by Gaia Research & Munters
& co-sponsored by CIBSE & SEDA

Conference Proceedings for the Seminar on 6th April 1998

Desiccant & Solar Assisted Cooling

Contents

Programme

Desiccant & Solar Assisted Cooling Seminar

....

9:40 **Coffee**

....

10:00 **Introduction: Solar Air Conditioning Project**
Sandy Halliday: Gaia Research

10.15 **Desiccant Cooling System Type Desicool**
- Operation method, performance, some experience to date
Dr Hans Hagberg: Munters Europe AB

10.30 **Liquid Desiccant Technology- State of The Art**
Andrew Mongar: Albers

10.50 **Technical Trends in Solar Cooling**
- Options for solar air conditioning
Ken Thompson: University of Warwick

11:10 **Cool Comfort in Buildings and the Impact of Climate**
Change
Dr David Arnold: Troup Bywaters + Anders

....

11:30 **Coffee Break & Discussion Session**

....

12:00 **Solar Assisted Desiccant Air Conditioning**
- Simulation of hot water production plant
Sandy Halliday: Gaia Research

12:20 **The Potential for Solar Powered Desiccant Cooling**

....

12:40 **Discussion & Lunch**

....

People

Sandy Halliday:- Principal of Gaia Research, is a mechanical design engineer and has worked for several years within the construction industry as a consultant and research manager developing and disseminating information on passive design, efficient & clean technologies, benign materials and processes.

Dr Hans Hagberg:- Segment Manager, Desicool, with Munters - a company committed to the development of environmentally friendly ventilation and humidity control.

Andrew Mongar:-Vice President with Albers whom he joined in 1992 to commercialise liquid desiccant air conditioning. He has spent most of his career developing technology strategies.

Ken Thompson:-As a senior research manager at British Gas Ken specialised in air conditioning psychrometrics and chemical aspects in engineering including desiccants. He is presently undertaking research at the University of Warwick into activated carbon - ammonia adsorption systems for air conditioning cycles.

Dr David Arnold:- A Partner of Troup Bywaters + Anders since 1973 and a CIBSE Past-President, David has been intimately involved in design of services for many major buildings. He has a particular interest in low energy design.

Dr Clive Beggs:- a lecturer in Building Services Engineering at the University of Leeds. He specialises in the energy analysis and design optimisation of HVAC systems, and has published a number of papers on this subject.

Solar Air Conditioning Project

Sandy Halliday: Gaia Research

Solid Desiccant Technology - State of the Art

Desiccant Cooling System Type Desicool™

Dr Hans Hagberg: Munters Europe AB

Liquid Desiccant Technology - State of the Art

Andrew L Mongar: Albers

Technical Trends in Solar Cooling

Options for Solar Air Conditioning

Ken Thompson, Research Fellow: University of Warwick

1. Introduction

In the UK, as in most of the world, air conditioning depends on the use of electrically driven vapour compression refrigeration units as the source of cooling. At present they are seen as the most developed and the lowest capital cost option. Heat driven absorption cycles make only a minor contribution to the air conditioning load. In Japan, however, and to a smaller extent in the USA, the installation of absorption units is becoming more prevalent. This change is because of the support of government or electricity utilities to reduce demand for electricity and transfer the load to gas firing.

Absorption refrigeration is a cycle that can be driven by heat. Although the gas firing option has been popular and has been marketed by the gas utilities, any source of heat at the appropriate temperature can be used. A possible source of heat is solar energy. Solar heat collectors have been developed as sources of hot water for hot water services and for space heating. In these duties they can be successful but heating is required more in winter when solar energy is at its least availability. The connection between solar energy and air conditioning is more natural.

Absorption is not the only refrigeration cycle that can be driven by heat or solar energy. This paper considers thermodynamic cycles that can be driven by heat energy and discusses the temperature and availability requirements of the heat. In addition, it compares solar collectors with other sources of heat.

2 Heat Driven Cooling Systems

There are principally four heat driven air conditioning systems, some examples of which are catalogued in the Natural Gas Cooling Equipment Guide[1]. These are based on absorption refrigeration cycles, adsorption refrigeration cycles, desiccant systems and heat driven engines driving conventional vapour compression systems.

2.1 Absorption Systems

Absorption refrigeration systems are the only alternative to vapour compression systems that are fully commercially developed and are currently available for installation in the United Kingdom. These systems can be classified in two ways:

- the working fluids, absorption systems use a refrigerant/absorber pair in the cycle. Two pairs are used in currently available commercial machines, these are ammonia/water and water/lithium bromide solution, although other pairs have been described for units that are at present under development..

- the effect, this describes the numbers of cycles that are cascaded together. A single effect machine is a simple cycle whereas a double effect machine uses the heat given out at the condenser of a high pressure cycle to drive the generator of a low pressure cycle. The external input energy is used twice and the efficiency of the unit is approximately doubled. Work is in progress to develop triple effect machines.

Water/lithium bromide chillers are available from all major US and Japanese manufacturers of air conditioning equipment. They are manufactured as both single effect and double effect. The single effect machines have a cooling efficiency of around 0.6. The double effect machines can achieve efficiencies of up to 1.2. Units are available in capacities from a minimum of around 70kW of cooling up to the megawatt range.

Although the single effect machines can operate using hot water at temperatures as low as 80°C, double effect machines need water or steam at temperatures in excess of 120°C. Single effect machines are therefore used where cheap low temperature process heat is available, such as from the cooling of the engine in combined heat and power systems, whereas double effect machines are operated from more expensive heat sources such as direct gas firing or steam boilers.

Ammonia/water absorption chillers are only available from one manufacturer. Only single effect machines are manufactured as double effect machines would require very high pressures. The unit is available in one size only, 10 - 17kW of cooling, but these can be manifolded together in packages of up to 4 units giving 70kW. The temperature required to drive this system must be at least 130°C.

The ammonia/water units have a cooling efficiency based on gas input of around 0.45 but a new unit with an increased efficiency of around 0.6 is currently being introduced to the market. This unit uses what is termed GAX technology whereby heat can be recycled within the refrigeration cycle to increase the efficiency. Other developments have been underway to use this technology, in particular by Carrier, but no product has yet reached the market.

There has been much endeavour to development of other absorption systems with the intention of replacing electrically driven vapour compression machines with gas fired alternatives at the residential/ small commercial end of the market. None of these units is commercially available The units are designed with gas firing as the heat source and no consideration has been given to alternative sources of heat energy.

2.2 Adsorption Systems

Adsorption air conditioning systems are similar in their operation to absorption machines but use a refrigerant/solid adsorber pair rather than a refrigerant/liquid absorber pair. Although many pairs are potentially available, ammonia/activated carbon and water/zeolite are the most commonly used in current developments. A majority of these developments are not as yet commercially available.

The ammonia machines have the potential for a compact efficient unit at low cost. A development by WaveAir, Atlanta, utilizing a thermal wave system is perhaps closest to the market whilst work on an alternative design is advancing at the University of Warwick. These units are being built as potential gas fired replacements for residential and small commercial air conditioning, particularly in the USA, where there is a high potential market. The units require temperatures in excess of 150°C, preferably 200°C, to drive them and aim to have a cooling efficiency of 1.0.

Water/zeolite machines need to be larger due to the low specific volume of water vapour in the operating pressure range of the cycle, 0.6 to 10kPa. Units are sold by GBU, Germany, and can be operated with source temperatures of 85°C.

2.3 Desiccant Systems

Desiccant air conditioning systems are open systems performing the cooling directly on the air to be supplied to the building rather than the indirect heat exchange from the evaporator of other cycles. The systems are of two types:

* solid systems, which use a desiccant rotor, a honeycomb support on which is impregnated a desiccant substance such as silica gel, molecular sieve or lithium chloride,
* liquid systems, which use a liquid spray of a desiccant solution such as lithium bromide,

Both systems operate by drying the ambient air by passing it through the desiccant where it exchanges the latent heat for sensible so becoming drier but warmer. The extract air from the building is meanwhile evaporatively cooled so becoming moister but cooler. The two resulting air streams are then passed through opposite sides of a heat exchanger, the supply air stream being cooled to close to below the room temperature. This cool dry supply air can be further cooled evaporatively to lower temperatures but at the expense of higher moisture content.

The energy input is in the form of heat into an air stream to regenerate the desiccant system by driving off the moisture that it has absorbed from the incoming ambient air.

Solid desiccant systems are being installed in many countries throughout the world principally by Munters in Europe and Engelhard/ICC and La Roche in the USA. These are essentially proven technology and are particularly valuable where the latent component of the ambient air is very high. In areas of low humidity, however, the evaporative cooling element enables low supply temperatures to be achieved and 'free' cooling to be utilized, the desiccant system only being used at high load. The COP of desiccant systems is very dependent on the ambient air condition and the supply temperature required but set point values up to 1.0 are possible. The seasonal COP is enhanced by the ability to make use of 'free' cooling giving values, depending on the weather conditions, in the region of 1.5.

Liquid desiccant systems are potentially more efficient than solid desiccant systems. This is because, rather than dehumidifying and heat transfer cooling sequentially, the two operations can be performed simultaneously. This has been demonstrated in the Albers' Genius system where countercurrent supply air and extract air streams are sprayed with desiccant solution and water respectively. Heat transfer occurs through the partition wall resulting in a supply air stream that is both drier and cooler than could be achieved in a solid desiccant system. As yet, no liquid desiccant system has been proved in field performance trials but independent laboratory tests have shown that a COP of over 2.0 is possible at ambient conditions of 35°C and 40% RH.

2.4 Stirling Engine Driven Cycles

The Stirling engine is an external combustion engine that can be driven from an external heat source. This engine could then be used to drive a conventional vapour compression cycle through an electrical circuit. Stirling engines, however, need high temperatures to operate efficiently and normally use temperatures of hundreds of degrees at the limit of the construction material properties, 650°C to 800°C. Units are being developed that use parabolic solar collector dishes to focus solar energy at high intensities on the heat exchanger of the Stirling engine.

The units are seen as power generation units for remote rural communities in developed or third world communities and generate up to 25kW of solar power. To operate continuously such machines require direct continuous sunshine as no storage of heat energy is possible. Efficiencies of up to 30% have been achieved for electrical energy against heat input and so combined with a vapour compression cycle of COP 3.0, an overall cooling efficiency of almost 1.0 is achieved.

The units are expensive technology and must be controlled to point continuously at the sun

2.5 Photovoltaics

Photovoltaic panels are used to generated electricity that could in turn be used to drive a vapour compression cycle. Although they are an option to obtain air conditioning from solar energy they are not considered further as they are not a heat driven cycle and at present they would be a high cost option.

3. Conclusions

1. Solar air conditioning systems are a possibility using technologies that are current and proven.
2. Desiccant technology is particularly appropriate as it can give good coefficient of performance and can operate on relatively low temperature thermal heat.

References

1. American Gas Cooling Center,
Natural Gas Cooling Equipment Guide - 3rd Edition
Arlington, Virginia, 1996

Table 1 Heat Driven Refrigeration Systems

Kenneth.Thompson@warwick.ac.uk
Tel: 01203 528017
Fax: 01203 418922

Cool Comfort in Buildings and the Impact of Climate Change

Summary of a Presentation
by
David Arnold: Troup Bywaters & Anders

In March of 1996, the Department of the Environment published the second review of the potential effects of climate change in the UK[(1)]. It defines climate scenarios for the decades of the 2020s and 2050s and assesses the potential impacts of these on a range of resources and activities, including the construction industry. The current predictions are that mean summer temperatures, will have increased by 1.7 degrees in the south and 1.2 degrees in the north by the year 2050. In addition it is predicted that:

- the mean annual frequency of days above 25°C will increase
- cooling degree-days in some areas will increase to twice their current value.
- relative humidity will increase
- summer solar radiation in the South will increase

The predictions have a considerable impact on providing cool comfort in buildings and particularly on the services necessary to maintain suitable indoor environments. As the report emphasises, we are currently designing buildings to last well beyond the 2050s and the vast majority of the existing stock will still be in use then.

The report includes the following observations:

- The most important climate change impacts on buildings and other types of construction are likely to arise from higher summer temperatures, increased winter rainfall, and, in the north of the UK, increased extreme winds.

- Thermal conditions in winter are likely to improve. The energy needed for space heating in fully heated buildings is likely to decline by around 20%. The lower mean winter indoor-outdoor temperature differential will favour greater use of passive solar energy in buildings.

- Summer conditions in large towns and cities, in the southeast of the UK especially, will become less acceptable as there will be more hot days, and the urban heat island will make conditions worse. Pressure to expand the use of air conditioning will mount This pressure can to some extent be resisted through climatically sensitive design using natural cooling techniques. However, urban traffic noise and pollution will continue to make it difficult to find acceptable solutions in town centres.

- The life of buildings now being erected will extend beyond 2059, the end year of the climate change scenario period in this report. New construction should be designed with the probable climate of the decade 2050/59 in mind. However, clients and their designers do not presently have the appropriate information to approach the implicit problems objectively in terms of costs and benefits.

BSRIA are currently involved in a collaborative research project [(2)] to scope the likely impacts on the building services industry to these forecast changes. In this presentation I will review the potential impact on techniques to provide cool comfort in non-domestic buildings. The challenge is to provide cool comfort that at least matches current standards using less energy and with lower CO_2 emissions than at present. Currently air conditioning is mostly associated with prestige offices. We cannot be certain that large prestige offices of the type we know today will continue to be required in the next century. They are, after all only a 20^{th} century phenomenon. What we can be more certain about is that the buildings will be retained in one form or another and the services are more than likely to be replaced at least once in the next fifty years. Therefore it is more important to get the building right than the services.

The oil crises of the 1970s and more recently the concern over the global environment have provided the impetus to produce low energy mechanically cooled buildings. The low energy is intrinsically linked with the building design. In the presentation I will present several examples of recent buildings that, I believe, point the direction towards meeting the challenge of climate change and providing cool comfort for building users.

References:
1. "Review of the Potential of Climate Change in the United Kingdom", Department of the Environment. HMSO March 1996
2. "Impact of Climate Change on the Building Services Industry" Report to be published by BSRIA later this year.

da/desicool/1
27 March 1998

Model and Opportunities

Clive Beggs: University of Leeds

The Potential for Solar Powered Desiccant Cooling

S.P. Halliday
GAIA Research, Edinburgh, Scotland, UK

C.B. Beggs
School of Civil Engineering, University of Leeds, Leeds, UK

Abstract

By using solar/gas hybrid desiccant cooling and dehumidification technology it may be possible to offer a benign solution to cooling of buildings, in new as well as refurbishment situations, and significantly reduce greenhouse gas emissions.

Desiccant cooling is a potentially environmentally friendly technology which can be used to condition the internal environment of buildings. Unlike a conventional air conditioning system which relies on electrical energy to drive the cooling cycle, desiccant cooling is a heat driven cycle. This paper investigates the possibility of using solar energy to drive the desiccant cooling cycle. Through the use of a parametric study, the paper investigates the energy consumption and costs associated with desiccant cooling.

1.0 Introduction

Desiccant materials such as silica gel have long been used to dehumidify air. In such processes, moist air is passed over a surface which is coated with the desiccant substance. As the moist air passes across the surface the desiccant material absorbs moisture from the air, thus dehumidifying the air stream. In order to drive off the moisture absorbed by the desiccant surface, the desiccant then has to be physically moved into a dry hot air stream. In the case of desiccant wheels (one of the most commonly used desiccant systems), the moisture laden section of the wheel slowly rotates (i.e. at 16 revs/hour) from the moist air stream to the hot dry air stream where it is dried out in a process called 'regeneration'.

In a typical desiccant cooling system a desiccant wheel is coupled to a thermal wheel in a single air handling unit (AHU), to produce a system which is capable of heating, cooling, and dehumidifying air, with little or no need for refrigeration(1). Because it is a heat driven cycle, such a system has the potential to reduce both energy costs and environmental pollution, when compared with conventional vapour compression based systems(2). Electrical energy consumption is replaced by heat consumption, which in most countries produces much less carbon dioxide (CO_2). In the UK the burning of natural gas in a boiler produces 0.21 kgCO_2/kWh whereas delivered electricity produces 0.68 kgCO_2/kWh(3). In addition, the significant reduction in size, or elimination, of refrigeration plant, results in reduction in the refrigerant charge required. Desiccant cooling affords an opportunity to utilise waste heat and the regeneration temperatures required mean that theoretically they could be coupled to solar collectors to produce an extremely benign cooling system.

2.0 The System

A typical desiccant cooling system is illustrated in Figure 1, and comprises a thermal wheel and a desiccant wheel located in series. On the supply air side of the AHU, a cooling coil and/or an evaporative cooler is located after the thermal wheel. A heating coil may also be located after the thermal wheel, for use in winter time if required. An evaporative cooler is located in the return air before the thermal wheel to enhance the heat transfer across the wheel. For the purpose of driving the cycle and regenerating the desiccant wheel a heating coil is located between the thermal wheel and the desiccant wheel.

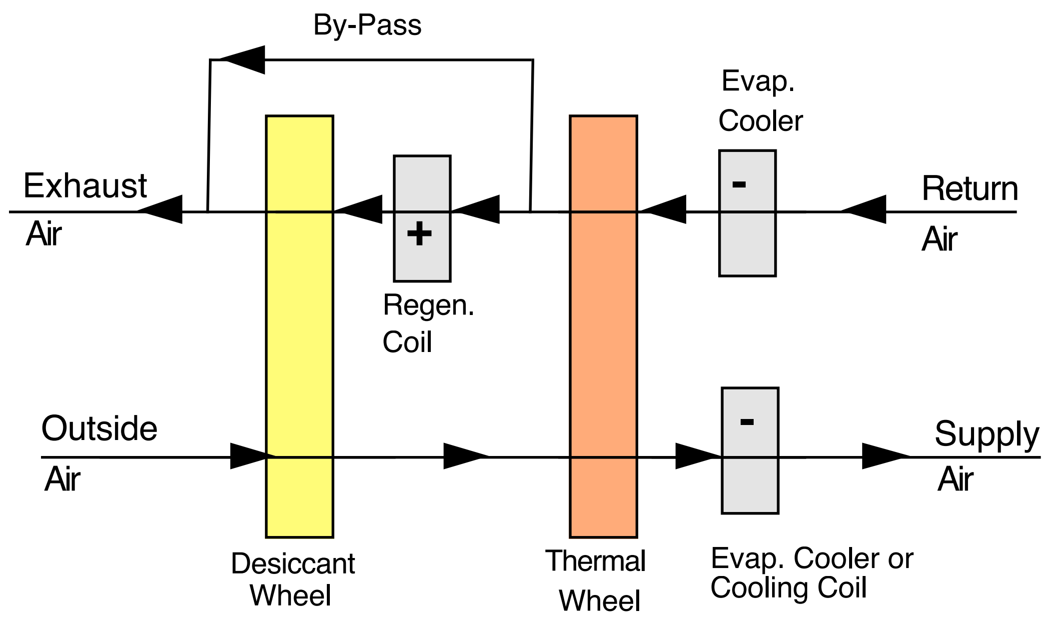

Figure 1: A typical desiccant cooling air handling unit

The cooling/dehumidification process is illustrated by the psychrometric chart shown in Figure 2. During the summer time, warm moist air at for example 26°C and 10.7g/kg moisture content is drawn through the desiccant wheel so that it comes off at say, 39°C and 7.3g/kg moisture content. The psychrometric process line for the air passing through the desiccant wheel on the supply side, has a gradient approximately equal to that of a wintertime room ratio line of 0.6 on the psychrometric chart. The supply air stream then passes through the thermal wheel where it is sensibly cooled to say, 23°C. The air then passes through a small direct expansion (DX) or chilled water cooling coil and is sensibly cooled to the supply condition of say, 17°C and 7.3g/kg moisture content. It should be noted that if humidity control is not required in the space, then the cooling coil can be replaced by an evaporative cooler with an adiabatic efficiency of approximately 85%. In which case, air may be supplied to the room space at say, 16.2°C and 10.2g/kg moisture content.

On the return air side, air from the room space at for example, 22°C and 8.6g/kg moisture content is first passed through an evaporative cooler so that it enters the thermal wheel at approximately 16.2°C and 10.8g/kg moisture content. As the return air stream passes through the thermal wheel, it is sensibly heated to approximately 35°C. The air stream is then heated up to approximately 55°C in order to regenerate the desiccant coil. It should be noted that in order to save energy approximately 20% of the return air flow by-passes the regenerating coil and the desiccant wheel(4).

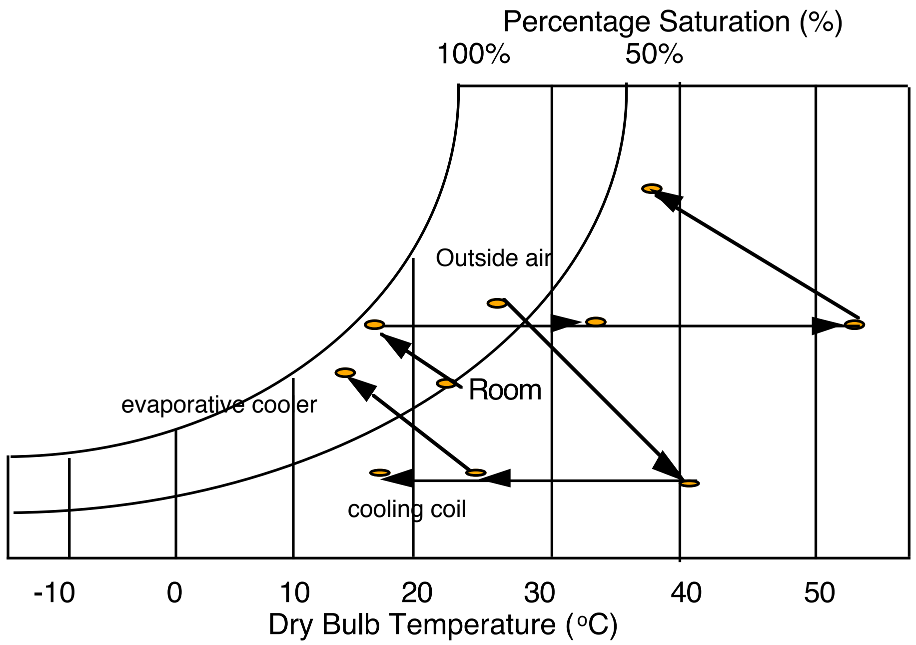

Figure 2: Desiccant system in Cooling/Dehumidification mode

3.0 Evaporative Cooling

Through the use of a desiccant cooling air handling system it is possible to both dehumidify and sensibly cool the fresh air supply. However, this often requires the installation of a small DX or chilled water cooling coil in the supply air stream. Whilst the installation of a cooling coil might result in an overall energy saving, the downside from the environmental perspective, is the introduction of refrigerants into the system. It is possible to avoid the use of a cooling coil, by installing an evaporative cooler in the supply air stream, to provide the required sensible cooling. However, this strategy has two major drawbacks:

- The air supplied to the room space is humid. Consequently, although the system might achieve the required degree of sensible cooling, it may not be able to provide adequate latent cooling, with the result that the occupants may find the environment uncomfortable. In addition, the high humidity in the room space is likely to lead to condensation problems.

- In order to achieve the required degree of sensible cooling, it is often necessary to perform a large amount of dehumidification on the desiccant wheel. This high level of dehumidification necessitates a high regeneration temperature, and consequently the energy consumption is increased dramatically.

The above drawbacks are significant and as a result most desiccant cooling systems incorporate some form of cooling coil. However, it is important to note that this cooling coil will be considerably less than that which would be incorporated into a conventional fresh air dehumidification system.

4.0 Solar Application

Since desiccant cooling is a heat driven cycle, it would appear logical and synergistic that it might be powered by solar energy. However, the use of solar energy introduces constraints on the application of desiccant cooling. Assuming a ratio of solar collectors to building floor area of 1:10, then the available heat (in northern Europe) to power the cooling cycle will be (conservatively) in the region of 25 to 50 W/m^2, depending on the climate, type and orientation of the solar collector. Consequently, the heat must be harnessed effectively. The desiccant cooling cycle is an open cycle, which rejects moist air at a high temperature, which is unsuitable for recirculation. Also the parasitic losses may be significant. The greater the air volume flow rate supplied to the room space, the greater the fan power required and the heat energy consumed. Therefore, if desiccant cooling is used in an all air application, the regeneration heat load is many times greater than the available solar energy. However, if the bulk of the sensible cooling within a space is carried out using a water based system such as a chilled ceiling, with the desiccant AHU dehumidifying and 'tempering' the incoming fresh air, then the air volumes handled will be much less and the 'solar energy' may make a significant contribution.

Theoretical work by Beggs and Warwicker has shown that desiccant cooling is best applied to installations in which the bulk of the sensible cooling is performed by a system such as a chilled ceiling(2). In such an application the desiccant system treats only the incoming ventilation air. Because chilled ceilings are designed to have a dew point of approximately 17°C, it is possible to use low grade chilled water which can be produced using evaporative cooling towers. This avoids the need to install vapour compression refrigeration machinery.

5.0 The Solar Desiccant Model

In order to investigate the potential for coupling a desiccant system to solar collectors in a European application, a solar desiccant computer model was developed at the University of Leeds. The model simulated the psychrometric and thermodynamic processes associated with desiccant cooling, using the following assumptions:

- The desiccant cooling system was employed solely to dehumidify the incoming fresh air supply, and to provide when required supplementary sensible cooling. It was assumed that the bulk of the sensible cooling would be performed by a separate water based system.

- The desiccant cooling system did not contain a cooling coil. The required degree of sensible cooling being achieved through the use of an evaporative cooler.

- The desiccant cooling system contained a solar heating coil located directly before the regeneration coil.
- The desiccant cooling system incorporated a 20% bypass on both solar heating and regeneration coils.

• Regeneration and supply air temperatures were specified, and the room condition was allowed to vary.

The solar desiccant cooling model considered only the primary and delivered energy consumption associated with the thermal aspects of the desiccant cooling cycle. The associated fan energy consumption was ignored.

6.0 Methodology

In the theoretical study, the system shown in Figure 3 was analysed in order to determine the running cost, primary energy consumption and CO_2 emissions attributable to a desiccant cooling system on a m^2 of floor area basis.

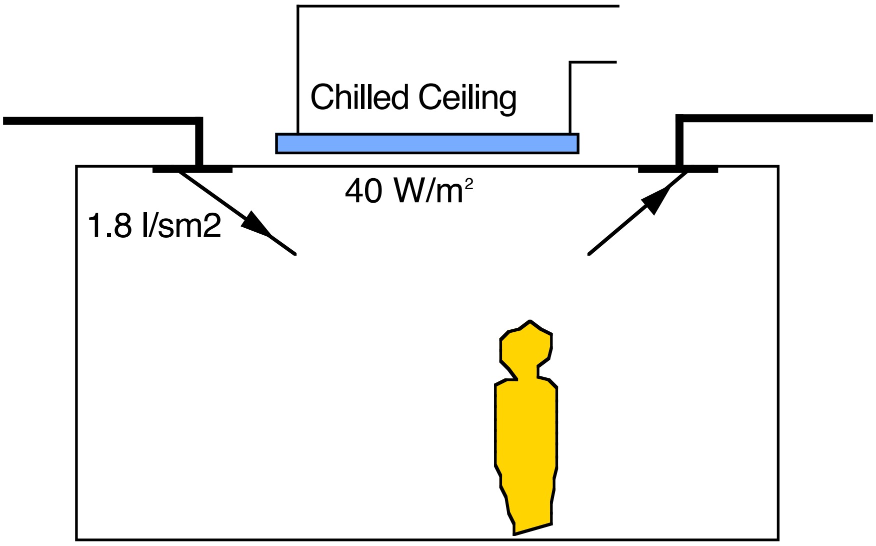

Figure 3: A chilled ceiling application in an office building where fresh air is introduced at high level

The system was analysed in cooling mode only, under the part-load conditions shown in Table 1. The study focused solely on the energy consumption of the desiccant fresh air system. In the study the energy consumption of the chilled ceiling was ignored, since this cannot be connected to a solar energy supply. The maximum sensible cooling output of the chilled ceiling was assumed to be 40 W/m^2. It was assumed in the study that under peak load conditions the desiccant cooling system would make-up the 10 W/m^2 short fall in sensible cooling. However, under part load the desiccant system would supply air to the space at room temperature. The psychrometric processes involved in the study are shown in Figure 4.

Loading	Sensible Heat Gain (W/m^2)	Latent Heat Gain (W/m^2)	Outside Air Temp (°C)	Outside Air Percent. Sat (%)	Outside Air Moist.Cont. (g/kg)
Peak	50	7	30	50	13.7
Mid	40	7	26	50	10.7
Low	30	7	22	50	8.4

Table 1: Part-load data used in Parametric Study

Throughout the study it was assumed that the solar heating coil was connected to solar panels via insulated pipework, containing a glycol/water mixture having a specific heat capacity of 3.7 kJ/kgK. The glycol/water flow rate was assumed to be 0.0016kg/s per m^2 of floor area, which equated to a solar collector to floor area ratio of 1:10. The glycol/water flow and return temperatures were assumed to be a constant 60.1°C and 53.9°C respectively, providing 36.7 W/m^2 of heat energy to the desiccant cooling system. In reality this value would vary considerably depending on time, solar insolation, orientation and collector type. However, the purpose of the study was to investigate the feasibility of using solar energy to drive a desiccant cooling installation, and so a constant relatively pessimistic value was chosen.

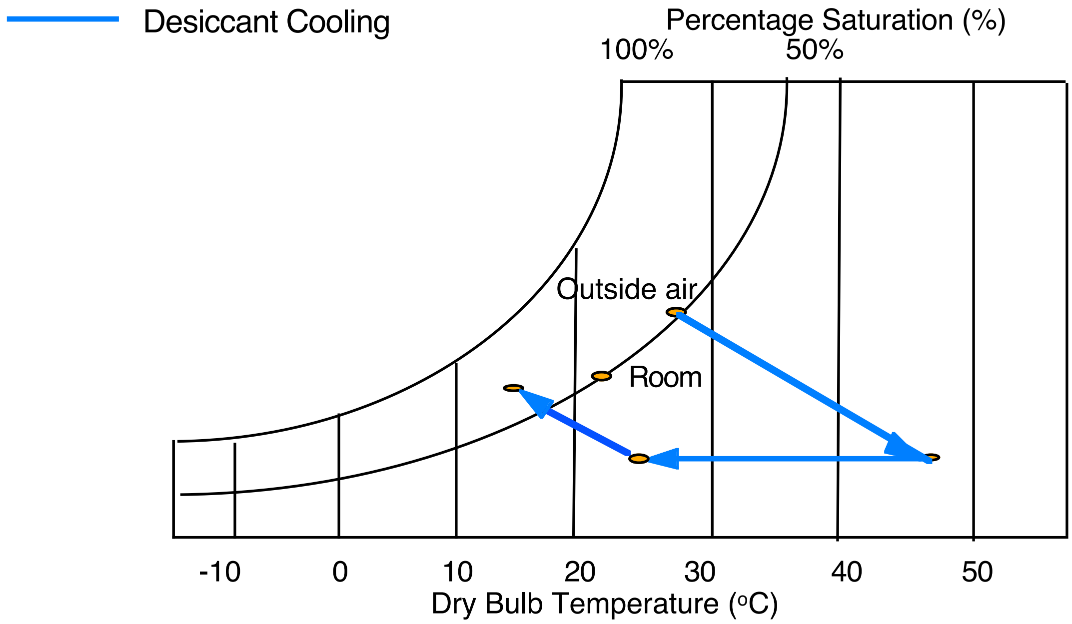

Figure 4: Psychrometric process (For the clarity the return air cycle is omitted)

The operating data for the study is shown in Table 2. It should be noted that the degree of sensible cooling achieved by the desiccant cooling system is governed by the degree of dehumidification achieved by the desiccant wheel, and that this in turn is governed by the regeneration air temperature. In short, the greater the regeneration air temperature, the lower the supply air temperature achievable to the room space. In order to determine the impact of varying the regeneration air temperature on the energy consumption of the cycle, the peak load condition simulation was carried out twice; once with a regeneration temperature of 55°C and a supply air temperature of 20.5°C, and once with a regeneration temperature of 75°C which enabled the supply air temperature to be reduced to 20°C. There was no benefit to be gained from raising the regeneration air temperature - Section 7, and the remaining part-load simulations were undertaken using a regeneration air temperature of 55°C. The energy data applied in the study is shown in Table 3.

Loading	Supply Air Supply Air Volume Flow Rate (l/sm^2)	Regen Air Temp. (°C)	Moisture Cont. Leaving Desic. Wheel (g/kg)	Ceiling Cooling Output (W/m^2)	Sensible Cooling From Desiccant Cooling System (W/m^2)	Condition Peak
Peak	1.8	55	10.2	40.0	10.0	20.5°C & 13.8 g/kg
Peak	1.8	75	7.7	40.0	10.0	20.0°C & 12.2 g/kg
Mid	1.8	55	7.3	40.0	0.0	22.0°C & 8.4 g/kg
Low	1.8	55	5.1	30.0	0.0	22.0°C & 5.1 g/kg

Table 2: Operating data for the various loadings

Unit cost of gas	1.50 p/kWh
Unit cost of electricity	5.00 p/kWh
Efficiency of heating system	70 %
COP of DX/chilled water coil system	2.5
Electrical generation efficiency	35 %
CO_2 coefficient for gas consumed	0.21 g/kWh
CO_2 coefficient for electricity consumed	0.68 kg/kWh

Table 3: Cost and energy data used in analysis

7.0 Results

The results of the study are shown in table 4.

Regen. Air & System	Supply Air Condition Temp. (°C)	Room Air Condition	Regen. Coil Duty (W/m^2)	Delivered gas ($Wh/h/m^2$)	Cost per hour ($p/h/m^2$)	CO_2 produced ($kg/h/m^2$)
Non-solar (Peak)						
55	20.5°C & 13.8 g/kg	25.0°C & 15.2 g/kg	30	43	0.07	0.009
Solar (Peak)						
55	20.5°C & 13.8 g/kg	25.0°C & 15.2 g/kg	1	2	0.00	0.000
Non-solar (Peak)						
75	20.0°C & 12.2 g/kg	24.5°C & 13.5 g/kg	54	77	0.12	0.016
Solar (Peak)						
75	20.0°C & 12.2 g/kg	24.5°C & 13.5 g/kg	25	35	0.05	0.007
Non-solar (Mid.)						
55	22.0°C & 8.4 g/kg	22.0°C & 9.7 g/kg	38	54	0.08	0.011
Solar (Mid.)						
55	22.0°C & 8.4 g/kg	22.0°C & 9.7 g/kg	9	12	0.02	0.003
Non-solar (Low)						
55	22.0°C & 5.1 g/kg	22.0°C & 6.4 g/kg	45	64	0.1	0.013
Solar (Low)						
55	22.0°C & 5.1 g/kg	22.0°C & 6.4 g/kg	16	22	0.03	0.005

Table 4: Analysis results (system incorporating evaporative cooler)

It can be seen from the results presented in Table 4 that coupling the desiccant cooling system to solar collectors produces significant savings in both running cost and CO_2 emissions. The greatest saving was achieved at peak load. This is because the return air leaves the thermal wheel at a higher temperature, and consequently, the solar heater is almost able to achieve an air temperature of 55°C without much help from the regeneration coil. However, despite the impressive energy savings achieved, based on these assumptions, the results indicate that operation of the system without a cooling coil is quite impracticable for most applications, since it results in high room air humidities. Indeed, for the installation shown in Figure 3 the results indicate that for much of the year condensation would occur on the surface of the chilled ceiling. However, this problem can be overcome by replacing the evaporative cooler by a small DX or chilled water cooling coil. If the study is repeated using a cooling coil instead of an evaporative cooler, then the results achieved are those shown in Table 5.

System	Regen. Air Temp. (°C)	Supply Air Condition	Room Air Condition	Regen. Duty (W/m²)	Delivered gas (Wh/h/m²)	Delivered electricity (Wh/h/m²)	Cost per hour p/h/m²	CO_2 kg/h/m²
Non-solar (Peak)	55	17.5°C & 10.2 g/kg	22.0°C & 11.5 g/kg	32.1	7.0	45.8	0.10	0.014
Solar (Peak)	55	17.5°C & 10.2 g/kg	22.0°C & 11.5 g/kg	2.5	7.0	3.6	0.04	0.006
Non-solar (Mid.)	55	22.0°C & 7.3 g/kg	22.0°C & 8.6 g/kg	38.9	0.4	55.6	0.09	0.012
Solar (Mid.)	55	22.0°C & 7.3 g/kg	22.0°C & 8.6 g/kg	1.1	0.4	1.6	0.00	0.001
Non-solar (Low)	55	22.0°C & 5.1 g/kg	22.0°C & 6.4 g/kg	45.0	0.0	64.2	0.10	0.013
Solar (Low)	55	22.0°C & 5.1 g/kg	22.0°C & 6.4 g/kg	16.0	0.0	22.9	0.03	0.005

Table 5: Analysis results (system incorporating cooling coil)

Table 5 shows that the inclusion of a refrigerated cooling coil increases CO_2 production under peak-load conditions, however for most of the year it will be inoperative and thus the overall increase in CO_2 would be minimal. It should also be noted that despite the removal of the supply air evaporative cooler, the solar collectors are still able to significantly reduce the overall energy consumption, and CO_2 emissions of the system.

The results in Table 5 indicate that for most of the operating year the conditions achieved in the room space would be acceptable. However, the peak load results suggest that condensation might still be a problem if a regeneration air temperature of 55°C is used. Consequently, under peak load conditions it would be advisable to increase the regeneration air temperature to say 75°C which would achieve an acceptable room air condition of 22°C and 9.1g/kg moisture content. If the operating conditions of the solar panel are optimistic then it is likely that these regeneration temperatures could be achieved during peak demand.

8.0 Conclusions

The energy study reported in this paper represents an initial study to determine feasibility of coupling solar collectors to a desiccant cooling system in an northern European application. To this end the study has been successful, since it has demonstrated that the inclusion of a solar heater into the desiccant cooling cycle can result in large energy savings. In deed, under the mid and low load scenarios the thermal energy costs are negligible.

The main conclusions to be derived from the energy study are as follows:

(i) The inclusion of a solar heater into the desiccant cooling cycle can lead to significant savings in primary energy consumption and associated CO_2 emissions.

(ii) Due to desiccant cooling being an open cycle, solar energy can only be effectively used in applications where the supply air volume flow rate is small. This effectively limits its application to installations where the bulk of the sensible cooling system is undertaken using a water based system.

(iii) The regeneration air temperature should be kept as low as is practically possible, in order to minimise fossil fuel energy input.

(iv) There is little or no benefit to be derived from using an evaporative cooler on the supply air side. The inclusion of such a devise can result in increased energy consumption and unacceptably high air humidities in the room space. It is preferable to include a small refrigerated cooling coil, which is only used under conditions of peak load.

The study is at an exploratory stage and further work will investigate the consequences of varying supply volumes and regeneration temperatures. Solar data from a sample site will be used to provide realistic profiles of water supply temperature.

Acknowledgements

Gaia Research would like to thank the The Construction Sponsorship Directorate of the DETR for their support for the research project.

References

1. Busweiler U.(1993) *Air conditioning with a combination of radiant cooling, displacement ventilation, and desiccant cooling*, ASHRAE Transactions, pp. 503-10
2.Beggs C. B., and Warwicker B. (1998) *Desiccant cooling: Parametric Energy Study* Building Services Research and Technology, Vol. 19, Number 2.
3. Smith J.T., and Webb B.C. (1995) *A comparison of the CO_2 emission rates of gas-fired and electrically driven chiller/heater machines under dynamic loading* Proceedings of the CIBSE National Conference, Eastbourne, pp. 151-9
4. Munters Ltd. (undated) *MCC - Series Cooling Cassette*

Solar Assisted Desiccant Air Conditioning - Simulation of Hot Water Production Plant

Dr Tariq Muneer: Napier University
Sandy Halliday: Gaia Research

The Potential For Solar Powered Desiccant Cooling

Sandy Halliday: Gaia Research

Seminar Attendees

Name	Company
Andrew Mongar	Albers Corporation
S Brown	BG Technology
Ian Freeman	BG Technology
Roger Hitchin	BRECSU
Andrew Martin	BSRIA
Andy Pearson	Building Services Journal
Dr Helen Sutcliffe	CIRM - DETR
Dr G Marshall	Colt Group Ltd
Eoin Clancy	Coventry University
Sandy Halliday	Gaia Research
Mark Thomas	Halcrow Gilbert Associates
Christopher Jessop	March Consulting Group
Jin Yee Lim	Max Fordham & Partners
Dr Hans Hagberg	Munters Europe AB
Des Barry	Optima BES Ltd
Mike Stych	Ove Arup & Partners
Terry Seward	Temperature Ltd
Dr David Arnold	Troup Bywaters & Anders
P N Surendran	University of Hertfordshire
Dr Clive Beggs	University of Leeds
Hussein Shehata	University of Nottingham
Dr Bob Critoph	University of Warwick
Gareth Davies	University of Warwick
Alistair Lawry	University of Warwick
Elaine Lewis	University of Warwick
Zacharie Taninot-Telto	University of Warwick
Ken Thompson	University of Warwick
Dr Roger Thorpe	University of Warwick
Charles Madden	Wind-Ways Ltd

The Gaia Group

Gaia Research is the newest part of the Gaia Group, founded in 1996. It specialises in construction ecology - developing environmentally sound solutions for the building industry - with research projects in passive solar design, innovative building membranes and environmental labelling of building materials and products by a range of life cycle analysis tools. Gaia Research also undertakes consultancy including energy and materials design advice, brief setting and continuing professional development for clients, project managers, engineers & architects striving to create sustainable strategies for the built environment.

.

Gaia Architects was founded in the early 80's on the twin expertise of ecological design and community consultation. It comprises four offices (two in Scotland and two in Norway) with 14 trained architects in total. The practice works on social and private housing and recreational initiatives and specialises on working with communities throughout the UK and Scandinavia to develop projects which are economically, environmentally and socially sustainable. Amongst the environmental aspects passive solar design, efficient systems and benign materials are standard and in addition the practice has developed technically innovative design with respect to timber treatments, earth building, breathing walls and dynamic insulation. The practice has won a number of awards including the 1993 Green House of the Year and other environmental and civic trust awards.

Gaia Planning was formed in 1994 to provide environmentally sound approaches to strategic, large-scale and training projects. It brings together experience in Urban Design with Ecological Design. The practice specialises in workshop methodologies and involving communities in regenerating their own areas in partnership with public agencies and the private sector. Increasingly this has involved Agenda 21 consultation and the development of a model, The Sustainability Game. The practice has carried out work for the Scottish Office, community groups, local authorities and the private sector including a research study on Energy Conservation & Planning.

The Gaia Group are members of Gaia International, a federation of architects, planners and related professionals who work together on promoting ecological design worldwide.

If you would like additional information on Gaia Group activities then please return this form by fax or post.

Return To:
Gaia Research at sandy@gaiagroup.org
~~Unit 12 Abbeymount~~
~~2 Easter Road~~
~~Edinburgh EH7 5AN~~
~~phone: 0131-661-1589; fax: 0131-661-3451;~~
~~E-mail:GaiaGroup@aol.com~~

Please indicate if you would like further information on:-

Solar Air conditioning
Dynamic Insulation
Practice Environmental Training
The Sustainability Game
Agenda 21 Workshops

GAIA Architects
GAIA Planning
SEDA
Other research
Environmental Consultancy

Alternatively contact
Sandy Halliday @ Gaia Research