

THE SOLAR DESICCANT COOLING CYCLE

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ABSTRACT

The desiccant cooling cycle is a novel open heat driven cycle which can be used both to cool and dehumidify air. Being a heat driven cycle, desiccant cooling affords an opportunity to utilise heat which might otherwise be wasted. It can therefore be coupled to solar collectors to produce a cooling system which, in theory, should be extremely environmentally friendly. This paper discusses the feasibility of using solar energy to power the desiccant cooling cycle and also presents the results of a recent study, in which a solar desiccant cooling model is used to evaluate a theoretical installation located in the southeast of England. The paper demonstrates that solar powered desiccant cooling is a feasible solution for cooling and heating buildings in the United Kingdom (UK).

KEYWORDS. Desiccant, Cooling, Solar, Heat driven cycle

1.0 INTRODUCTION

The desiccant cooling cycle was first developed in Sweden and has been used successfully for a number of years in Scandinavia. Recently a number of buildings in the UK have been successfully fitted with desiccant cooling systems. However, the knowledge base on the utilisation of desiccant systems is small and no published guidelines exist for the design and operation of such systems. Over a number of years the authors of this paper have investigated the application and operation of desiccant cooling systems (1, 2, 3, 4). In particular, studies have been undertaken which demonstrate the potential in the UK for using solar power to drive the desiccant cycle. These studies corroborate the findings of similar studies in the USA (5) and Sweden (6), which also demonstrate the potential for using solar energy to power desiccant systems. This paper presents an overview of the findings of these studies and also presents the results of a new study of a theoretical installation located in the southeast of England.

2.0 THE DESICCANT COOLING SYSTEM

A typical desiccant cooling air handling unit (AHU) is shown in Figure 1. It is a heat driven cycle which comprises a desiccant wheel in tandem with a thermal wheel, with an evaporative cooler in the return air stream before the thermal wheel. A regeneration coil located in the return air stream drives the whole cycle.

The psychrometric chart shown in Figure 2 illustrates the cooling/dehumidification process. For example, during the summertime warm moist air at 26°C and 10.7 g/kg moisture content may be drawn through the desiccant wheel so that it comes off at say, 39°C and 7.3 g/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 7.3 g/kg moisture content. It should be noted that if humidity control is not required in the room space, 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 10.2 g/kg moisture content.

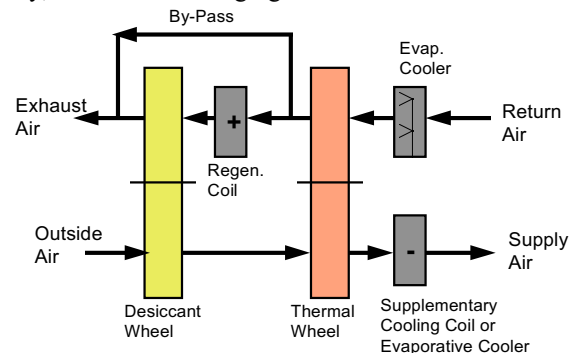


Figure 1. A typical desiccant cooling air handling unit

On the return air side, air from the room space at for example, 22°C and 8.6 g/kg moisture content is first passed through an evaporative cooler so that it enters the thermal wheel at approximately 16.7°C and 10.8 g/kg moisture content. As the return air stream passes through the thermal wheel, it is sensibly heated to approximately 33°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 by-passes the regenerating coil and the desiccant wheel (7).

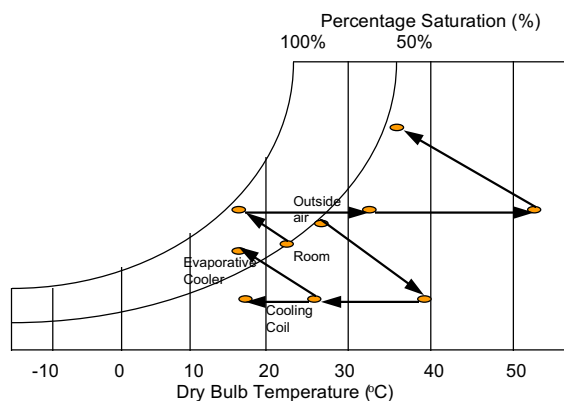


Figure 2. Desiccant system in Cooling/Dehumidification mode

3.0 APPLICATION

Although desiccant cooling process can be applied to *all air* applications, it is best suited to installations in which the bulk of the sensible cooling is performed by a water based system, such as a chilled ceiling (1). Unlike conventional ducted air cooling systems, which are able to recover substantial amounts of *coolth* from the exhaust air stream, in desiccant cooling systems the exhaust air is extremely humid and cannot be easily reused. It is therefore preferable to restrict the desiccant cooling system to performing dehumidification of the incoming ventilation air, while allowing a water based system to perform room sensible cooling.

Through a parametric study Beggs and Warwicker (1) demonstrated that desiccant cooling systems are less well suited to applications in which low supply air temperatures are involved. This is because supplementary cooling is usually required to achieve low supply air temperatures (e.g. 16°C), with the result that the overall energy efficiency of the desiccant cycle decreases. Consequently, desiccant cooling is best suited to those applications such as displacement ventilation, where supply air temperatures are close to the room air temperature. In such applications it possible to achieve energy cost savings ranging from 14 % to 50 % depending on the cooling load (1).

4.0 SOLAR POTENTIAL

Being a heat driven cycle, desiccant cooling affords an opportunity to utilise solar energy. The desiccant system can be coupled to solar collectors to produce a cooling system which, in theory, should be extremely environmentally friendly. However, the use of solar energy puts constraints on the application of desiccant cooling. For example, if the ratio of the solar collector area to the building floor area is 1:10, then the available heat per m² of floor area (in a northern European application) to drive the cycle will be in the region of 25 w/m² to 50 W/m², depending on the climate, type and orientation of the solar collectors. Consequently, if solar heat is to be harnessed effectively, desiccant cooling systems must be applied in the correct fashion. The desiccant cooling cycle is essentially an open cycle, which rejects moist air at a high temperature, which is unsuitable for recirculation. Consequently, 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 going to be extremely large, 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 so the solar energy can make a significant contribution.

Halliday and Beggs (2,3) through a number of theoretical studies demonstrated the feasibility of using solar energy to power desiccant cooling systems in a UK context. These initial studies indicated that energy savings in excess of 50% should be achievable. The main findings of these studies were:

- (i) Solar powered desiccant cooling is feasible in the UK, with significant savings in primary energy consumption and associated CO₂ emissions being achieved.
- (ii) The regeneration air temperature should be kept as low as is practically possible, in order to minimise fossil fuel energy input. This implies that over-dehumidification should be avoided.
- (iii) Because the desiccant cooling is an open cycle, solar energy can only be effectively used in applications where the supply air volume flow rate is relatively small. This effectively limits its application to installations where the bulk of the sensible cooling system is undertaken using a water based system.
- (iv) In applications where the bulk of the sensible cooling is being performed by water based systems, it may be necessary to supply larger than normal fresh air volume flow rates, in order to perform the required degree of latent cooling. Supply volume flow rates in the order of 1.8 l/s per m² of floor area should be acceptable for most applications.

5.0 THE SOLAR DESICCANT MODEL

The initial studies by Halliday and Beggs (2,3) demonstrated the potential opportunity for harnessing solar energy to drive desiccant systems in the UK and in northern Europe. Although these studies yielded some good results, they concentrated only on the summertime operation and did not use actual insolation data. Consequently, it was decided to repeat the original studies, in a modified form, using real UK meteorological and insolation data in order to verify the findings of the earlier studies.

In order to investigate the potential for coupling desiccant systems to solar collectors, a solar desiccant computer model was developed (3,4). This model coupled solar collectors indirectly to a desiccant system via a water storage tank and solar coils. The solar heating coils were inserted in the supply and exhaust air streams as shown in Figure 3.

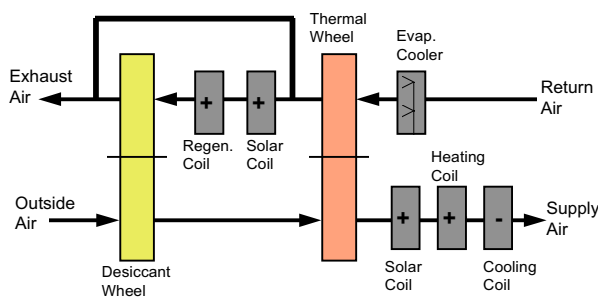


Figure 3. Solar desiccant cooling system used in model (4)

In the solar desiccant model the psychrometric and thermodynamic processes associated with desiccant cooling were simulated. It was assumed that the desiccant cooling system was employed solely to dehumidify the incoming fresh air supply, and also to provide when required supplementary sensible cooling. The bulk of the sensible cooling being performed by a separate water based system. In order to reduce energy consumption, a 20% by-pass around the return air solar pre-heating and regeneration coils was incorporated into the model. It should be noted that 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.

The validity of the solar desiccant model was tested against results obtained from a monitoring programme undertaken in the DCM Building at the University of Lincoln, which assesses the performance of a desiccant cooling AHU (4).

6.0 SOLAR COOLING STUDY

A theoretical computer study was undertaken for a site at Heathrow in the southeast of England in order to establish potential energy savings that could be achieved through utilising solar energy. The study used historical meteorological and insolation data, and took a similar format to an earlier study for a site in the East Midlands of England (4). The aim of the study was to determine and quantify the energy savings that could be achieved by coupling solar water heaters to a desiccant cooling system.

For the purpose of the study the 'standard' desiccant cooling system shown in Figure 3 was created and then modelled for a site at Heathrow near London. The parameters used in the study are presented in Table 1.

The meteorological data used in the study, was for the year 1991 and consisted of hourly temperature, humidity and insolation data. Two data files were created; one for a hot day (i.e. 29th July 1991) and another for a cold day (i.e. 15th January 1991) (see Table 2).

For each of the study days the operation of the desiccant system was modelled in two modes, once assuming that no solar power was utilised and then assuming that solar power was utilised. The solar heated water temperatures used in the analysis, were generated for the study days, by feeding the hourly insolation data into a separate solar collector program. The energy cost and efficiency data used in the study is presented in Table 3.

The solar desiccant system used in the study utilised two solar pre-heating coils; one located before the regeneration coil in the return air stream and the other before the main heating coil in the supply air stream. The technical specification of these solar coils is shown in Table 4.

Table 1. Study parameters

	SUMMER MODE	WINTER MODE
Room dry bulb temperature	23.0°C	21.0°C
Room wet bulb temperature	14.9°C	14.9°C
Room moisture content	7.2 g/kg	7.2 g/kg
Room latent heat gain	7 W/m ²	7 W/m ²
Supply air vol. Flow rate	0.00217 m ² /s/m ²	0.00217 m ² /s/m ²
Supply air temperature	23.0°C	21.0°C
Plant start time	07.00 hours	07.00 hours
Plant stop time	18.00 hours	18.00 hours

Table 2. Heathrow meteorological data

Time (Hours)	15 th January 1991				29 th July 1991			
	Dry Bulb Temp. (°C)	Dew Point Temp. (°C)	Wet Bulb Temp. (°C)	Solar Water Temp. (°C)	Dry Bulb Temp. (°C)	Dew Point Temp. (°C)	Wet Bulb Temp. (°C)	Solar Water Temp. (°C)
01.00	2.6	-0.4	1.5	51.0	17.5	14.5	15.6	47.4
02.00	2.1	-0.7	1.1	50.9	17.7	14.8	15.9	47.4
03.00	1.6	-1.2	0.6	50.8	17.6	14.8	15.8	47.3
04.00	1.0	-1.0	0.3	50.7	17.2	14.7	15.6	47.3
05.00	0.9	-1.4	0.1	50.6	16.9	14.7	15.5	47.2
06.00	0.4	-1.6	-0.3	50.6	17.8	15.0	16.0	47.2
07.00	0.4	-2.0	-0.4	50.5	19.4	15.6	16.9	47.1
08.00	0.4	-2.3	-0.5	50.4	20.9	15.8	17.5	44.0
09.00	0.5	-2.2	-0.5	50.3	23.5	15.0	18.0	44.8
10.00	1.7	-2.4	0.3	50.3	25.2	15.0	18.6	48.2
11.00	2.5	-3.4	0.5	46.2	26.2	15.0	18.9	52.9
12.00	3.5	-3.1	1.2	45.3	28.5	13.9	19.1	57.9
13.00	4.0	-3.6	1.4	45.8	28.1	13.6	18.8	62.3
14.00	4.5	-3.6	1.7	46.8	27.6	12.5	18.1	64.7
15.00	4.4	-4.5	1.4	48.2	27.3	13.7	18.6	60.3
16.00	3.0	-3.4	0.8	48.1	25.5	12.8	18.5	55.2
17.00	1.2	-4.4	-0.7	48.1	26.6	15.7	19.4	55.1
18.00	0.3	-4.4	-1.2	48.0	26.0	14.4	18.5	55.1
19.00	-0.2	-4.7	-1.6	47.9	24.8	15.0	18.5	55.0
20.00	-0.2	-4.0	-1.4	47.8	23.9	15.2	18.2	55.0
21.00	0.1	-4.3	-1.3	47.7	23.1	15.2	18.0	54.9
22.00	0.6	-3.0	-0.6	47.7	22.4	15.7	18.0	54.8
23.00	-0.4	-3.8	-1.5	47.6	22.1	15.8	18.0	54.8
24.00	0.3	-3.9	-1.1	47.5	21.8	16.0	18.0	54.7

Table 3. Energy cost and efficiency data

Unit cost of gas (p/kWh)	1.50
Unit cost of electricity (p/kWh)	5.00
Efficiency of heating system (%)	70.0
COP of supplementary cooling coil	2.50
Electricity generation efficiency (%)	35.0
CO ₂ coefficient for gas (kg/kWh)	0.21
CO ₂ coefficient for electricity (kg/kWh)	0.68

Table 4. Solar heating coil specification

	Solar Pre-heating Coil	Solar Regeneration Coil
Solar heated water mass flow rate	0.0005 kg/s/m ²	0.0005 kg/s/m ²
Spec. heat capacity of glycol/water mixture	3.7 kJ/kgK	3.7 kJ/kgK
U value of coils	35.0 W/m ² K	35.0 W/m ² K
Surface area of coils	0.060 m ² /m ²	0.060 m ² /m ²

Table 5. Results for Heathrow daily energy analysis

	15 th January		29 th July	
	Standard System	System with Solar Coils	Standard System	System with Solar Coils
Delivered Gas (kWh/m ²)	0.1431	0.0000	0.8682	0.5298
Delivered Electric (kWh/m ²)	0.0000	0.0000	0.0062	0.0062
Energy Cost per Day (p/m ²)	0.2147	0.0000	1.3333	0.8258
Primary Energy (kWh/m ²)	0.1431	0.0000	0.8859	0.0548
CO ₂ Produced (kg/m ²)	0.0301	0.0000	0.1865	0.1155

7.0 THE RESULTS

The results of the simulations for the Heathrow site on the 15th January and 29th July 1991 are presented in Table 5.

It can be seen from the results presented in Table 5 that considerably more energy is consumed by the desiccant system in summer than in winter. In July, it is necessary to use the supplementary cooling coil to achieve the summertime supply air temperature of 23°C. However, the contribution made by the supplementary cooling coil is modest in comparison with the heat energy input.

The contribution made by the solar heating coils in summertime is substantial, with a 40% gas energy saving being achieved on the 29th July. The contribution made by the solar heating coils in wintertime is so great that on the 15th January no additional gas energy is required. This implies that during wintertime the solar collectors provide most of the heat required to heat the ventilation air.

8.0 DISCUSSION

The Heathrow study confirms the findings of earlier studies (2, 3, 4). In particular, the Heathrow study reveals very similar results to the East Midlands study (4), which found that a 70% reduction in annual 'desiccant' gas consumption could be achieved by incorporating solar heating coils into the desiccant system. The magnitude of this reduction suggests that in the UK, most desiccant systems will be operating in heating mode for much of the year. When operating in heating mode the combination of recovered heat from the exhaust air stream and solar energy appears to be capable of supplying most of the heat energy required during the winter months. The Heathrow study shows that solar energy is capable of supplying most of the heat required to drive the desiccant cooling cycle. This finding corroborates an earlier Swedish study (6), which found that by using solar collectors at a ratio of about 7-10 m² of collector area per 100 m² building area and a water store of 75 l/m² of collector area, it is possible to meet total cooling load with excess capacity to spare.

9.0 CONCLUSIONS

The results of the study described above demonstrate the potential for using solar energy to drive desiccant cooling systems in the south of England. The results confirm the findings of earlier theoretical studies (2, 3, 4). Together, these studies conclusively demonstrate that solar powered desiccant cooling is viable in a UK context, provided that it is utilised in appropriate manner.

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References

1. Beggs CB, Warwicker B. Desiccant cooling: Parametric energy study. Building Services Engineering Research and Technology, Vol. 19, Number 2, pp 87 – 91, ISSN 0143-6244 (1998)
2. Halliday S, Beggs CB. The potential for Solar Powered Desiccant Cooling. CIB World Building Congress, Gavle, Sweden, June 1998 pp 713 – 722, (1998)
3. Beggs CB, Halliday S. A theoretical evaluation of solar powered desiccant cooling in the United Kingdom. Building Services Engineering Research and Technology, Vol. 20, Number 3, pp 113 – 117, ISSN 0143-6244 (1999)
4. Halliday S, Beggs CB, Sleigh PA. The potential for solar desiccant cooling in the UK. CIBSE/ASHRAE Conference, Dublin, Sept. 2000
5. Davanagere BS, Sherif SA, Goswami DY. A feasibility study of a solar desiccant air-conditioning system - Part II: Transient simulation and economics. International Journal of Energy Research. 23 (2) Feb. 1999, pp 103 – 116, (1999)
6. Dittmar J. Solar desiccant cooling: A pre-study of possibilities and limitations in Northern Europe. Master thesis E136, Chalmers University of Technology, Göteborg, Sweden. August 1997
7. Munters Ltd. MCC - Series Cooling Cassette

