THE POTENTIAL FOR SOLAR DESICCANT COOLING IN THE UK

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ABSTRACT

This paper presents the results of a recent study, in which a solar desiccant cooling model is used to evaluate the potential for using solar energy to drive a desiccant cooling system at a public building in the East Midlands of England. The model utilises real meteorological data to compare the actual performance of the case study system with predicted results for a solar thermal driven system. The desiccant cooling model used in the study is validated using data gathered from the study building. The paper conclusively demonstrates that solar powered desiccant cooling is a feasible solution for cooling & heating buildings in the UK.

1.0 INTRODUCTION

The desiccant cooling cycle is an 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 that 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.

Beggs and Warwicker (1) have shown that desiccant cooling is best applied to installations where the bulk of the sensible cooling is performed by a water based system, such as a chilled ceiling. In such applications, desiccant cooling should be used to treat the incoming ventilation air.

Initial studies by Halliday and Beggs (2,3) have demonstrated the potential opportunity for harnessing solar energy to drive desiccant systems in northern Europe and the UK. These studies yielded good results, and demonstrated that for much of the cooling season most of the regeneration heat required could be provided by solar energy. However, these studies were limited and utilised assumed insolation data. Consequently, it was decided to modify the solar desiccant model and to repeat the original study, in a modified form, using real UK meteorological and insolation data for a 12 month period. This paper describes this study, together with validation of solar desiccant model.

2.0 THE DESICCANT COOLING SYSTEM

A typical desiccant cooling system is shown in Figure 1.

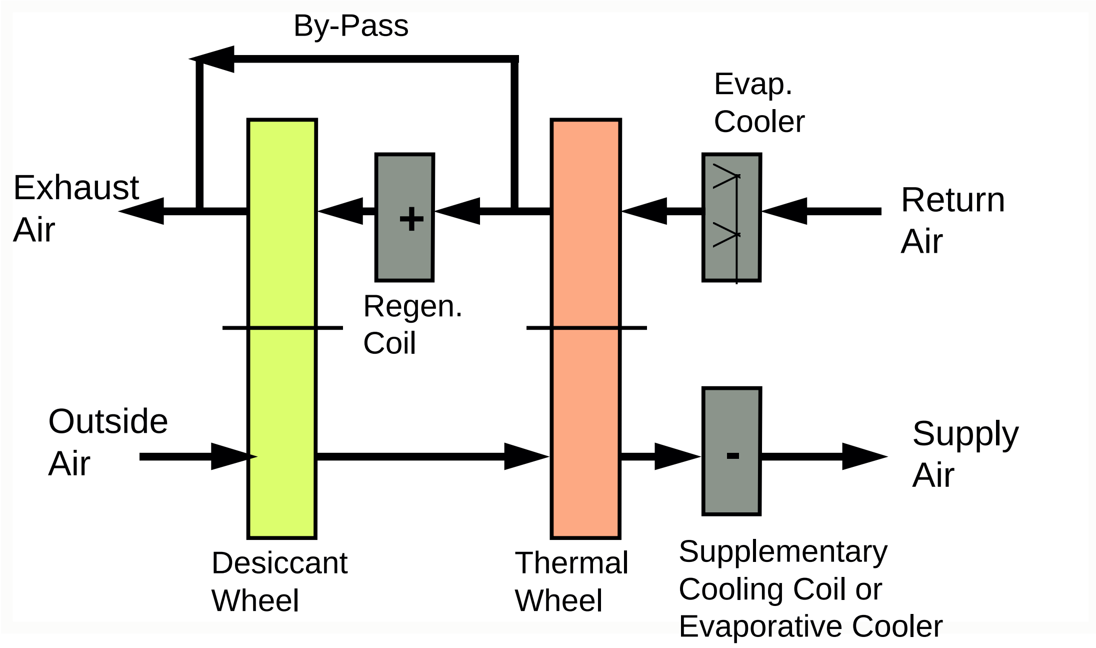

Figure 1: A typical desiccant cooling air handling unit

The psychrometric chart shown in Figure 2 illustrates the cooling/de humidification process. During the summertime warm moist air at for example 26 ^{o}C and 10.7 g/kg moisture content is drawn through the desiccant wheel so that it comes off at say, 39 ^{o}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 ^{o}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 ^{o}C and 7.3 g/kg moisture content. It should be noted that if humidity control is not required in the space, then the cooling coil could 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^{o}C and 10.2 g/kg moisture content.

On the return air side, air fro m the room space at for example, 22 ^{o}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 ^{o}C and 10.8 g/kg moisture content. As the return air stream passes through the therma l wheel, it is sensibly heated to approximately 33 ^{o}C. The air stream is then heated up to approximately 55 ^{o}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).

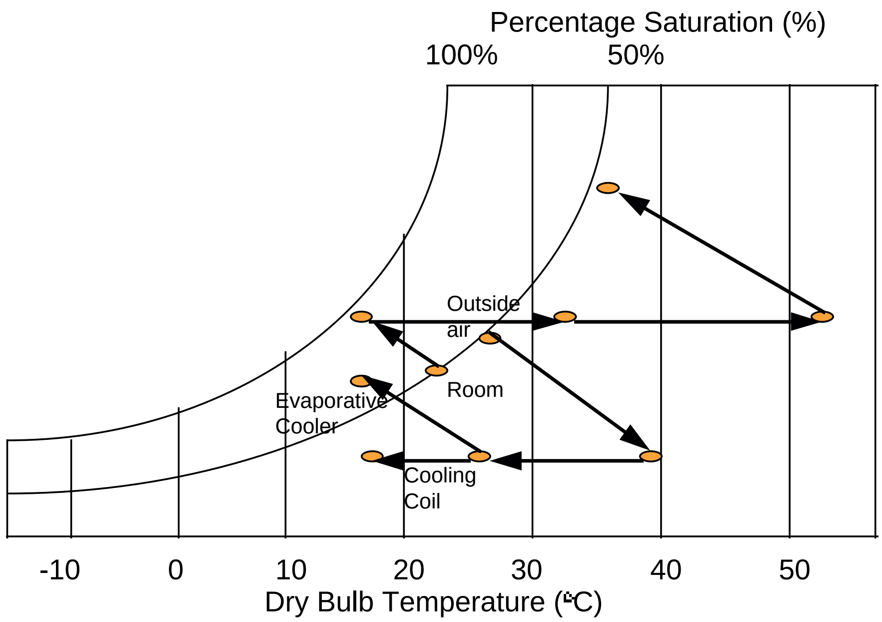

Figure 2: Desiccant system in Cooling/Dehumidification mode

3.0 THE SOLAR DESICCANT MODEL

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

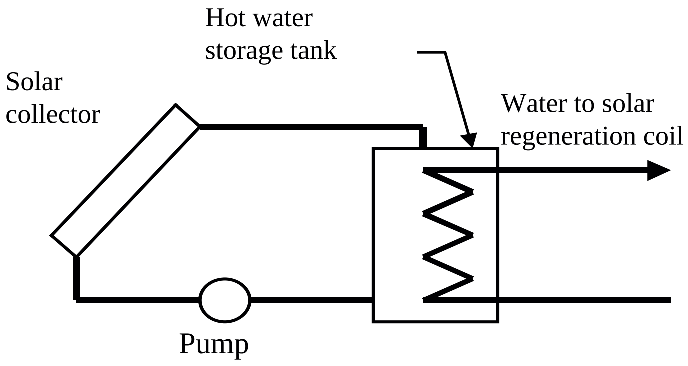

Figure 3: Solar Collector Arrangement

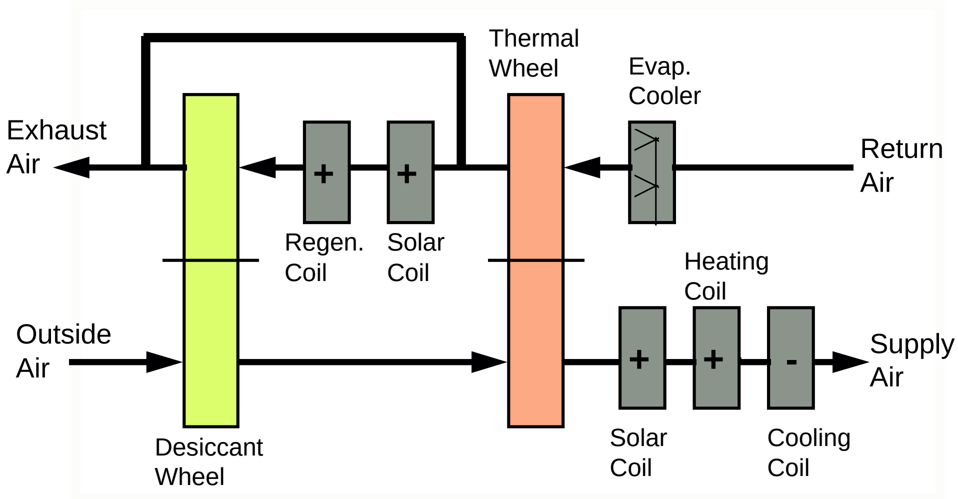

Figure 4: Solar desiccant cooling system used in model

In the solar desiccant model the psychrometric and thermodynamic processes associated with desiccant cooling are simulated, and the following assumptions are made:

- The desiccant cooling system is employed solely to dehumidify the incoming fresh air supply, and to provide when required supplementary sensible cooling. The bulk of the sensible cooling being performed by a separate water based system.
- The desiccant cooling system contains a small cooling coil after the thermal wheel in the supply air stream.
- Solar pre-heating coils are located directly before the regeneration coil in the return air stream and before the heating coil on the supply side.
- The desiccant cooling system incorporates a 20% by-pass around the return air 'solar' pre-heating and regeneration coils.

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

4.0 VALIDATION OF THE DESICCANT MODEL

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, in which the performance of a desiccant cooling air handling unit (AHU) is being assessed. The monitored AHU provides the fresh air supply to approximately 50 % of the DCM Building (i.e. approximately 5,000 m^2 of floor area and 1,000 occupants). The AHU contains a desiccant cooling system which has the configuration shown in Figure 5 and does not contain either a supplementary cooling coil or a supply side evaporative cooler.

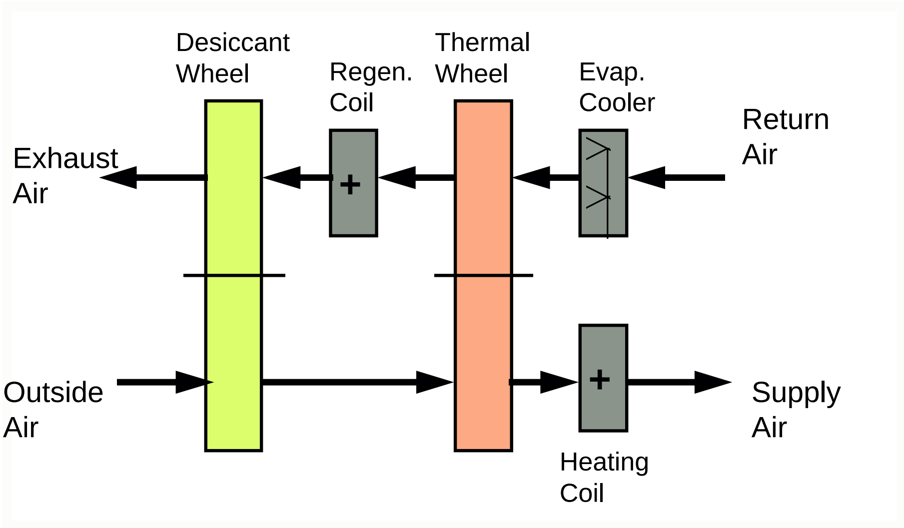

Figure 1 AHU 1 configuration

The AHU contains variable speed supply and return air fans, which discharge an air volume flow rate which varies between a minimum of 2.0 m^3/s to a maximum of 11.8 m^3/s. The system is primarily designed to provide room latent cooling and to supply fresh air to the building occupants. The room sensible cooling for the building is provided by a combination of passive chilled beams and exposed concrete floor soffits. The installation is designed to achieve an internal design air condition is 24 ^oC and 50 % RH when the external design air condition is 28^{o}C and 50 % RH. In particular, the desiccant system is designed to supply a constant all year round supply air temperature of approximately 20^{o}C.

In order to validate the solar desiccant model, the actual performance of the system at Lincoln was compared with that predicted by the model for a summer day. Figure 6 shows the air conditions achieved by the Lincoln desiccant system on the afternoon of 15th June 1999 and Figure 7 shows the predictions made by the computer model using the same input data. The computer simulation assumes that the evaporative cooler has an efficiency of 68 % and that the efficiency of the thermal wheel is 74 %.

Lincoln 15th June 1999 : 14.00 hrs

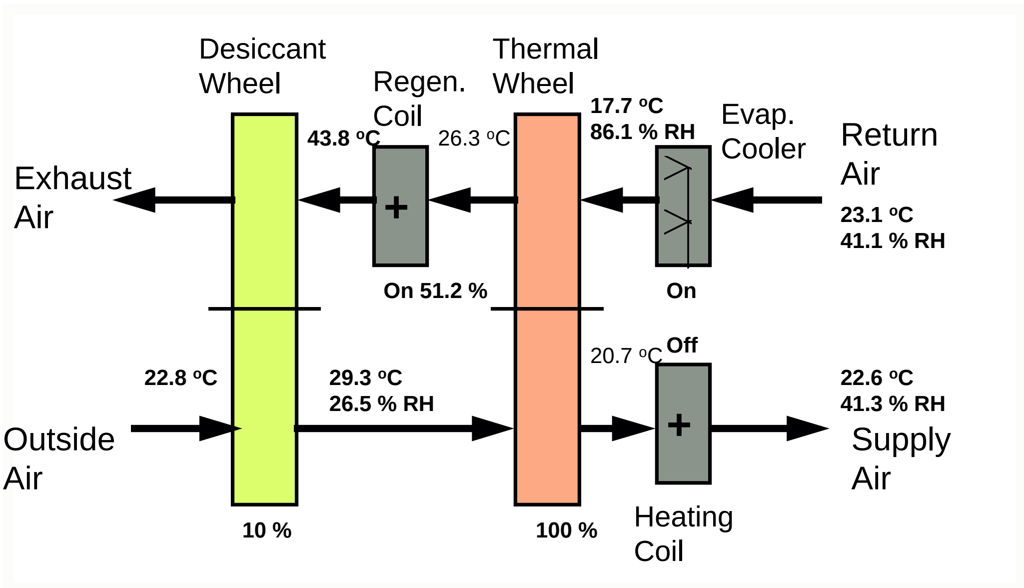

Figure 6: System operation for 2.00 p.m. on 15th June

Lincoln 15th June 1999 : 14.00 hrs (Computer prediction)

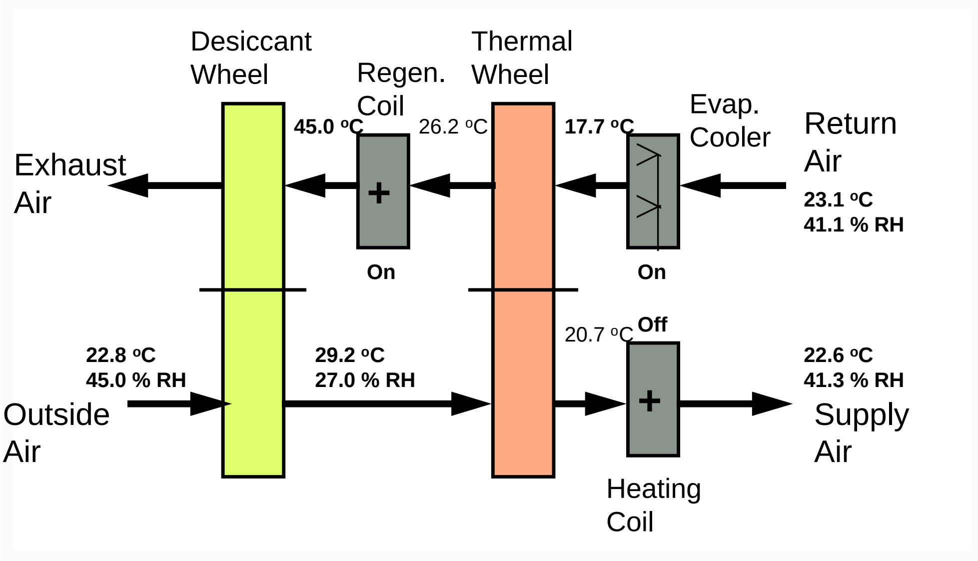

Figure 7: Computer generated data for 15th June 1999 at 2.00 p.m.

Comparison between Figure 6 and Figure 7 reveals that the two are very similar, with the computed regeneration air temperature being only 1.2 ^{o}C above the recorded air temperature. This ind icates that the computer model is simulating closely the peak summertime performance of the plant.

5.0 SOLAR COOLING STUDY

Once it had been established that the desiccant model gave results similar to those achieved by the Lincoln desiccant system, a computer-based study was designed to establish potential energy savings that could be achieved through utilising solar energy. The study used historical meteorological and insolation data for a site in the east midlands of England. The aim of the study wa s 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 4 was created and then modelled for a location in Finningley in South Yorkshire, which was chosen because of its proximity to Lincoln. The parameters used in the study are presented in Table 1.

	SUMMER MODE	WINTER MODE
Room dry bulb temperature	23.0^{o}C	21.0^{o}C
Room wet bulb temperature	14.9^{o}C	14.9^{o}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^{o}C	21.0^{o}C
Plant start time	07.00 hours	07.00 hours
Plant stop time	18.00 hours	18.00 hours

Table 1: Study parameters

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).

		15th January 1991				29th July 1991		
Time (Hours)	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	-1.9	2.9	-2.0	39.1	14.3	11.8	13.7	46.8
02.00	-1.4	2.3	-1.6	39.0	13.5	12.3	12.7	46.7
03.00	-1.7	-3.5	-2.2	39.0	13.3	12.3	12.6	46.7
04.00	-1.6	-3.0	-2.0	38.9	12.9	12.0	12.3	46.6
05.00	-1.9	-2.9	-2.1	38.8	13.4	12.6	12.9	46.6
06.00	-3.2	-4.5	-3.5	38.8	14.2	13.7	13.8	46.5
07.00	-3.0	-5.0	-3.5	38.7	15.1	14.0	14.4	46.5
08.00	-2.2	-3.7	-2.6	38.7	17.1	15.4	16.0	46.4
09.00	-3.6	-5.4	-4.0	38.6	20.3	15.8	17.4	43.5
10.00	-3.1	-4.8	-3.5	38.5	23.3	16.1	18.5	44.4
11.00	-0.9	-3.1	-1.6	36.3	26.2	14.5	18.6	48.0
12.00	1.3	-1.3	-0.4	36.9	27.0	13.2	18.2	52.5
13.00	2.7	-0.3	1.6	38.6	27.7	12.5	18.1	56.2
14.00	3.9	-0.2	2.5	40.2	28.0	12.3	18.1	59.7
15.00	4.0	-1.5	2.0	40.8	27.5	12.0	17.8	62.5
16.00	3.3	-0.5	1.9	40.6	26.6	12.0	17.6	62.9
17.00	1.3	-1.3	0.4	40.6	25.7	13.0	17.7	61.0
18.00	0.2	-2.5	-0.7	40.5	24.2	13.6	17.5	56.9
19.00	-1.0	-2.6	-1.5	40.4	22.1	15.4	17.7	50.8
20.00	-1.4	-3.4	-2.0	40.4	19.7	14.7	16.5	50.8
21.00	-1.2	-3.8	-2.0	40.3	17.8	14.3	15.5	50.7
22.00	-2.3	-4.2	-2.8	40.2	16.6	14.2	15.1	50.7
23.00	-2.6	-4.6	-3.1	40.2	16.4	14.4	15.1	50.6
24.00	-2.5	-4.1	-2.9	40.1	16.3	14.5	15.1	50.5

Table 2: Finningley meteorological data

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.

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
CO2 coefficient for gas (kg/kWh)	=	0.21
CO2 coefficient for electricity (kg/kWh)	=	0.68

Table 3: Energy cost and efficiency data

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

	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^2K	35.0 W/m^2K
Surface area of coils	0.060 m^2/m^2	0.060 m^2/m^2

Table 4: Solar heating coil specification

6.0 THE RESULTS

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

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	15th January Standard System	15th January System with Solar Coils	29th July Standard System	29th July System with Solar Coils
Delivered Gas (kWh/m^2)	0.1617	0.0000	0.8065	0.4431
Delivered Electric (kWh/m^2)	0.0000	0.0000	0.0015	0.0015
Energy Cost per Day (p/m^2)	0.2426	0.0000	1.2171	0.6721
Primary Energy (kWh/m^2)	0.1617	0.0000	0.8107	0.4474
CO_2 Produced (kg/m^2)	0.0340	0.0000	0.1704	0.0941

Table 5: Results for Finningley daily energy analysis

From the results presented in Tables 5 the following observations can be made:

- It can be seen that considerably more energy is consumed by the desiccant system in summer than in winter;
- The summertime supply air temperature of 23°C is achieved mostly by consuming heat energy and there is very little need to use the supplementary cooling coil;
- The contribution made by the solar heating coils in summertime is substantial, with a 45% gas energy saving being achieved;
- The contribution made by the solar heating coils in wintertime is so great that no additional gas energy is required.

7.0 YEAR LONG STUDY

In order to confirm the results of the sample day study presented in Tables 5, a further yearlong analysis was undertaken for Finningley using hourly meteorological data for 1994. In this study it was assumed that the desiccant system switched from summer mode to winter mode when the outside air dry bulb temperature fell below 17°C. The results of this additional study are presented in Table 6.

	Standard System	System with Solar Coils

Delivered Gas (kWh/m^2)	144.948	43.379
Delivered Electric (kWh/m^2)	0.120	0.120
Energy Cost per Year (p/m^2)	218.020	65.666
Primary Energy (kWh/m^2)	145.290	43.721
CO_2 Produced (kg/m^2)	30.520	9.191

Table 6: Results for Finningley yearly energy analysis

The yearly analysis results, Table 6, clearly demonstrate the large contribution made by solar energy over the 12 month period. A 70 % annual reduction in gas consumption is achieved purely by utilising solar energy.

8.0 CONCLUSIONS

The results of the studies described above clearly demonstrate that there is great potential in the UK for using solar energy to drive desiccant cooling systems. The results also confirm the findings of earlier theoretical studies (2,3). Solar powered desiccant cooling is an environmentally friendly technology, which is viable in a UK context.

Acknowledgement:

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