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Research Article

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TRNSYS simulation of desiccant integrated hybrid cooling and dehumidification system

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Abstract
The traditional air conditioners suffer from performance degradation especially in humid conditions. This is due to fact that the excess moisture level in ventilation air considerably increases latent cooling load of the space to be conditioned. The use of desiccant integrated sensible cooling system can alleviate this problem by controlling the temperature and humidity separately. It also reduces energy consumption for obtaining desired thermal comfort. In the present study, TRNSYS simulation studio project has been developed to perform the simulations of the desiccant dehumidifier coupled HVAC system for different configurations in summer cooling season. Measurements are also carried out to observe the influence of operating parameters on system performance. The obtained results show that the proposed system has ensured a substantial reduction in process air humidity at dehumidifier exit while maintaining the conditioned room comfort.

Introduction

Research conducted by most of the researchers in the field of air conditioning led to the conclusion that the proportion of energy used by the air-conditioning systems in the household and commercial buildings now accounts for nearly 45%. Air-conditioning systems today account for almost 15% of the total energy consumption of the world. Rising standards of living, technological advancement and increasing population have led to a significant increase in per capita energy demand and thus total energy consumption in the last few decades. Even though human beings have made much progress in almost every field, but still, we rely on fossil fuels as the primary source of energy to meet our demands [1-3].

Air conditioning systems are often used to provide comfortable indoor air conditions in general. Removing latent and sensible loads from outside air is usually required during summer to provide the desired indoor air conditions. Especially moisture removal accounts for peak loads of conventional air conditioning systems since it requires cooling process air below dew point temperature. Cooling and dehumidification are coupled necessarily due to the process itself. Required cooling capacities are often provided by electrical driven vapor compression cycles. In contrast, removal of sensible and latent loads is separated within a desiccant assisted air conditioning process. A desiccant material is used to remove latent loads from the process air stream. Thus, required cooling capacities are reduced, especially at high outside air humidity ratios. Shallow geothermal energy can be utilized to remove sensible loads from the process air stream. Utilizing the soil for cooling, an equalized energy balance of the soil is essential regarding long-term efficiency of the geothermal system. This can be improved by using a ground-coupled heat pump for heat supply during winter.

Increasing the moisture level of supply air is a sensitive but often little noticed comfort aspect during winter. Dry indoor air conditions can adversely affect occupants' comfort, especially in modern buildings relying on mechanical ventilation without additional humidification systems during winter. Conventional air conditioning systems require additional components to achieve sufficient supply air humidity ratios. This is an advantage of desiccant assisted systems, because moisture recovery by means of the existing hygroscopic material is possible. A further hygienic advantage of desiccant assisted moisture recovery against conventional air conditioning relying on adiabatic or isothermal air humidification is the fact that no liquid or vaporous water is sprayed into the process air stream [4].

Nowadays, most of the conventional air-conditioning (AC) systems are based on the traditionally used mechanical vapor-compression cooling technology which is driven by an electrical energy. Since the major part of the global electricity comes from fossil fuels, it causes the rising awareness of environmental and sustainability issues. One of the alternatives to the mechanical vapor- compression systems is the desiccant assisted cooling

(DAC) process, based on the dehumidification of moist air in present of solid or liquid desiccant material. This result into substantial energy saving for conditioning-built environment as shown in Fig. 1 [5-6].

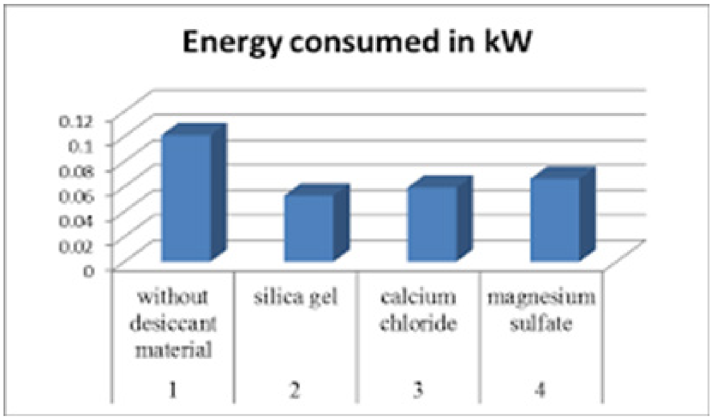

Figure 1: Comparison of energy consumption of various solid desiccant materials.

Research conducted by International Institute of Refrigeration in Paris led to the conclusion that the proportion of energy used by the air-conditioning systems in the household and commercial buildings now accounts for nearly 47%. Air-conditioning systems today account for almost 21% of the total energy consumption of the India as shown in Fig. 2. Rising standards of living, technological advancement and increasing population have led to a significant increase in per capita energy demand and thus total energy consumption in the last few decades. Even though human beings have made much progress in almost every field, but still, we rely on fossil fuels as the primary source of energy to meet our demands.

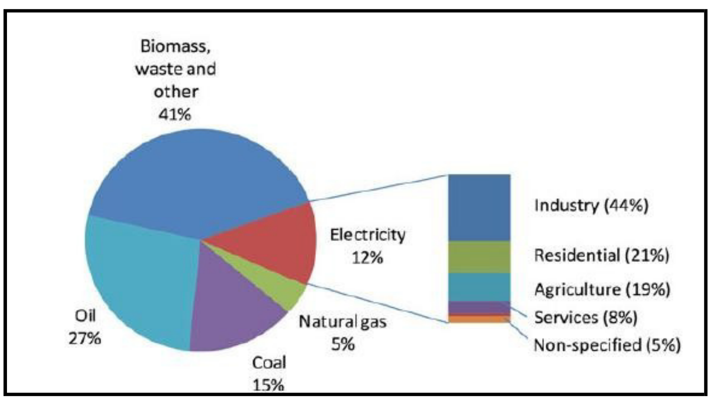

Figure 2: Total energy consumption of India from various energy resources.

Moisture content or latent heat of air can be controlled either by condensing the water vapour or by using suitable absorbents as used in desiccant cooling systems. While conventional vapor compression systems (VCSs) simultaneously cool and dehumidify the air, a desiccant system only dehumidifies it. Moreover, a desiccant system can be used in combination with evaporative cooling system to maintain the temperature and moisture of incoming air. Earlier, desiccant systems were used for industrial and agricultural sector like textile mills, post-harvest crop storage units for humidity control and drying. However, energy crisis and necessity to develop more eco-friendly systems have led to the introduction of desiccant cooling systems as an effective method to control humidity [7-8].

Desiccant systems can use solid desiccants or liquid desiccants. Some commonly used solid desiccants include activated silica gel, titanium silicates, alumina, Zeolite (natural and synthetic), molecular sieves, etc. whereas liquid desiccants comprise lithium chloride, lithium bromide, tri- ethylene glycol, calcium chloride and potassium-format. Apart from aforementioned desiccants, there are organic-based desiccants, polymeric desiccants, compound desiccants and composite desiccants. Desiccant systems include rotating desiccant wheel, solid packed tower, liquid spray tower, falling film and multiple vertical bed.

Desiccant systems can be categorized based on the type of desiccant used:

1. Liquid desiccant systems,

2. Solid desiccant systems,

3. Advanced desiccants which include polymeric desiccant, composite desiccant, bio-desiccant.

Desiccant cooling systems are becoming popular in the coming days as they have an efficient method of controlling the moisture content in the humid climate while carrying out air conditioning. They do not use any ozone-depleting coolants and consume less energy as compared with the vapour compression systems. The desiccant cooling system consists of basic components such as dehumidifier, regenerator, desiccant material and cooling coil. In addition, integration of desiccant cooling with sensible cooling technologies can result into efficient cooling economy. Moreover, solid and other advanced desiccants can take part in the economic evaluation of desiccant cooling systems in the forth coming years in the HVAC business all over the world [9-10].

Description of system

In ventilation mode of solar assisted solid desiccant cooling system outdoor air enters into the desiccant wheel at point 1 (Figure: 3).

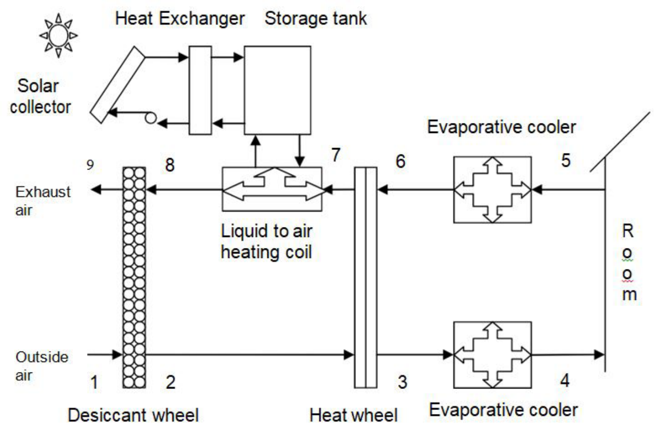

Figure 3: Desiccant assisted HVAC system

After dehumidification, temperature of process air increases due to adsorption. Process air is sensibly cooled between state point 2 and 3 in heat recovery wheel. It is further cooled between state point 3 and 4 by evaporative cooler before entering to the room. After leaving the room, return air passes through evaporative cooler and heat recovery wheel before heating in water to air heating coil at 7-8. Between points 8 to 9, regeneration air removes moisture from dehumidifier by desorption process before leaving to atmosphere. Figure: 4 shows the simulation studio modeling of the solar assisted solid desiccant cooling system using TRNSYS 16 in ventilation mode. TRNSYS is a transient system simulation programmed developed at the University of Wisconsin, to assess the performance of thermal energy systems. In the present simulation studio project rotary desiccant dehumidifier is modelled as type 683, type 760b is heat wheel, type 506c is supply air evaporative cooler, type 506c- 2 is regeneration air evaporative cooler, type 690 is room, type 3b is pump, type 73 is flat plate collector, type 652 is heat exchanger, type 109-TMY2 is weather data file for Delhi, type 33e is psychometrics, type 65d is plotter and type 4a is stratified tank.

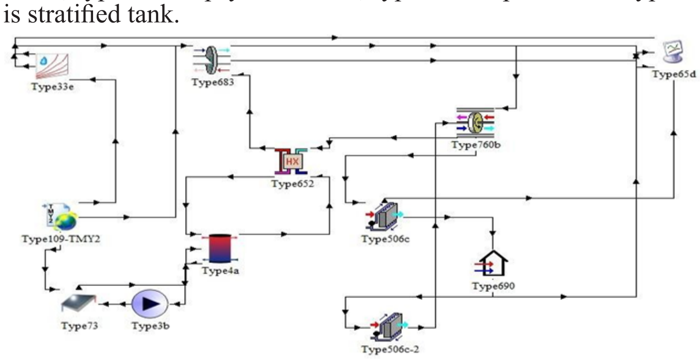

Figure 4: TRNSYS simulation studio project of desiccant assisted HVAC system.

Simulation and result discussion

A lecture hall having sitting capacity of 100 persons has been selected. The cooling load is estimated as 30 kW out of which sensible cooling load is 24 kW and latent cooling load is 6 kW. The inside room conditions are assumed as 50% RH and 250C DBT. Outdoor conditions for the present case 350C DBT and 85% RH. The mass flow rates of process and regeneration air is 2.5 kg/s. Effectiveness of desiccant wheel and heat wheel are assumed as 70% and 80% respectively. Saturation efficiency of evaporative cooling is 0.85 while effectiveness of process and regeneration air heat exchanger is assumed 1 [11-13]. Simulation models for ventilation modes give following results for temperature and specific humidity for calculation of enthalpy of the required state points and COP as given in Table 1.

Table 1. Conditions at main state point in ventilation mode.

Temperature (0C)	Sp. Humidity (kg/kg)	Enthalpy (kJ/kg)	COP
T_4=18	0.01003	43.44	
T_5=25	0.01110	53.16	0.494
T_7=63	0.01473	102.62	
T_8=82	0.01473	122.26	

Figure 5, shows simulations results for variation of temperatures in ventilation mode of desiccant assisted HVAC system. It is observed that the required regeneration temperature for ventilation mode is 820C. So, lower energy needed in heater to obtain the required regeneration air temperature for desorption of desiccant wheel in low ambient humidity condition. Variations in ambient temperature, Supply air temperature, process air outlet temperature and room temperature also shown in the same figure.

Variations in the humidity ratio of ambient air, process air at outlet of desiccant wheel, room air and supply air are shown in Fig. 6 for ventilation mode. Humidity ratio is the main parameter indicating the removal of moisture from room in terms of latent heat to obtain desired comfort conditions inside the room.

Temperature and specific humidity variations at important state point of a desiccant assisted HVAC system are studied for ventilation mode using TRNSYS 16 simulation software. It is observed that COP for system depends main on requirement of reactivation temperature for efficient desorption of dehumidifier which is ultimately governed by existing ambient conditions in terms of its ambient humidity and temperature [14-15].

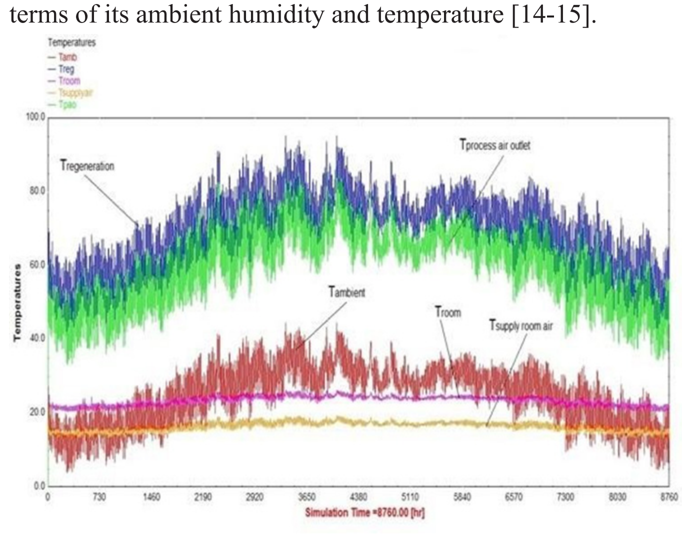

Figure 5: Temperature at important state points during simulation

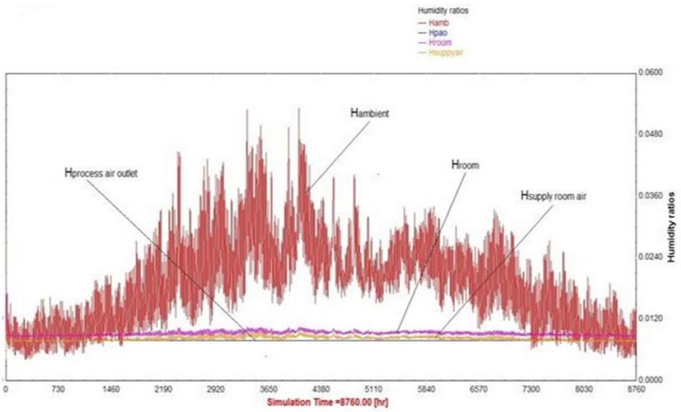

Figure 6: Humidity ratio at important state point during simulation.

Conclusion

The simulation results obtained by use of TRNSYS for solid desiccant assisted HVAC system highlights good performance in hot humid climates and justifies its use. The moisture level of process air was substantially lowered by use of solid desiccant based rotary dehumidifier. The simulation results mainly give the output parameters or the system performance varying over the selected time period. One needs to fix-up the time for getting the output or performance at that instant. The use of TRNSYS can best be exploited by the design engineers by considering the extreme range of parameters in their design. Also, the performance can be predicted for such extreme conditions. Solid desiccant cooling systems are found reliable in performance, environmentally friendly and capable of improving indoor air quality at a reasonable cost. Because of the high accuracy and short computing time, this methodology can be very useful to simulate the performance of desiccant assisted HVAC systems at different operating conditions. The performance of the solid desiccant assisted HVAC system may be augmented by integrating it with the use of advance desiccant materials which can regeneration approximately at ambient conditions can save lot of primary heat for the desorption of rotary dehumidifier.

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