Low Energy 100%-Outside-Air Dryer

for temperature sensitive materials and aqueous coatings

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Most drying air needs are met by simply heating ambient air to a high temperature. However, drying systems for heat sensitive, hygroscopic chemicals and tablet coatings such as gelatin and sugar require air at dew points lower than ambient. Whether by refrigeration or absorption, the energy cost of removing moisture from air is high. This article describes an energy efficient method.

The article compares various processes and methods of air dehumidification and their energy costs.

Background

Refrigerated dehumidifiers can dry air to a dew point of about 40°F in an air-conditioned space. Lower dew points down to −100°F can be achieved only by using desiccants. In both cases, if ambient air is used, it must be pre-cooled. Hybrid systems that use refrigeration for pre- and post cooling and a desiccant for absorbing the remaining moisture are now in vogue. Even so, the energy cost of this process is quite high.

Table 1 compares the energy costs of drying 1625 CFM of air by various methods from ambient conditions (113 °F dry bulb, 83 °F wet bulb), to a dew point of 40 °F, which must then be re-heated to 104° F dry bulb temperature.

We will examine the first three conventional systems, then consider the possible improvements and discuss the last two systems that incorporate our recommended changes. Lastly in the epilogue, we will compare the estimated energy consumption figures with results from an actual installation. All data presented here has been taken from the Bock compressor catalogue and other standard manufacturer's catalogues. The cooling load tonnage has been calculated using standard formulae.

SystemNo.	Type of System	Electrical energy required in kilowatts	
		Electric Reheat	Waste Heat Reheat
1	Single Stage - DX	67	36
2	Two Stage - Chilled water + Brine	65	38
3	Two Stage with Desiccant and Chilled Water 1st stage	58	16
4	Unit described in Fig. 4.1 of this article	-	20
5	-- Do --, but with attachment of Fig. 5.1	-	15

Table 1 : Comparison of energy consumption for drying air by various methods

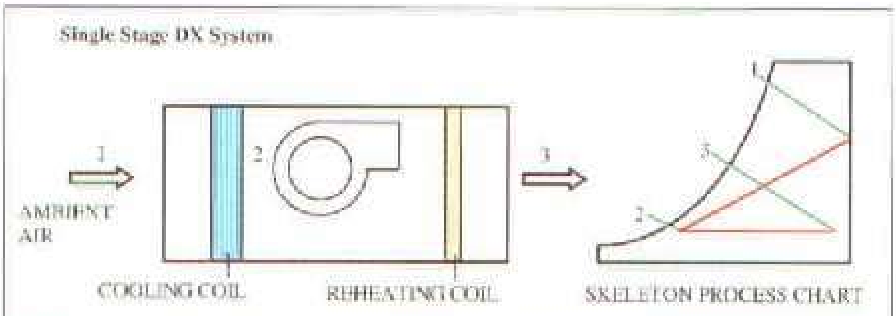

Figure 1.1 : Schematic diagram of single stage DX system with electric reheating

About the Authors

Surendra Shah is a Mechanical engineer from Clemson University, USA and has 40 years of varied experience in the HVACR field. In the 70s he started his own manufacturing company and has developed many innovative energy saving products, six of which have been patented. He is a member of ISHRAE.

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In a Single Stage DX- system ambient air is cooled by a single stage cooling coil working at a lower temperature. After cooling, reheating is provided by electric heaters. See Figure 1.1. Psychrometric values of the process points are given in Table 1.1 and an analysis of power consumption is given in Table 1.2.

Figure 2.1 shows the schematic diagram of a two stage cooling system using chilled water in the first stage and brine in the second stage. Ambient air is first cooled by the chilled water coil and then by the brine cooling coil. After cooling, it is reheated to the desired temperature by electic heaters.

Point	Description	DB °F	WB °F	DP °F	Enthalpy BTU/pound
1	Ambient air conditions	110	83	74.5	45.89
2	DX coil leaving conditions	44	42	40	16.14
3	Reheating air leaving conditions	104	66	40	30.85

Table 1.1 : Psychrometric properties

	Cooling load for 1625 CFM TR	Comp. kW	Evap. Fan Motor kW	Cond. Fan Motor kW	Heater Power kW	Total Power kW
Single Stage DX System working at 41°F evap. and 122°F cond.	18.73	28.7†	4	3	30.84	66.54*

Table 1.2 : Power consumption analysis

* If waste heat is available for reheat, then total power will reduce to 37.5 kW

† Compressor power consumption is high because of low evaporating temperature

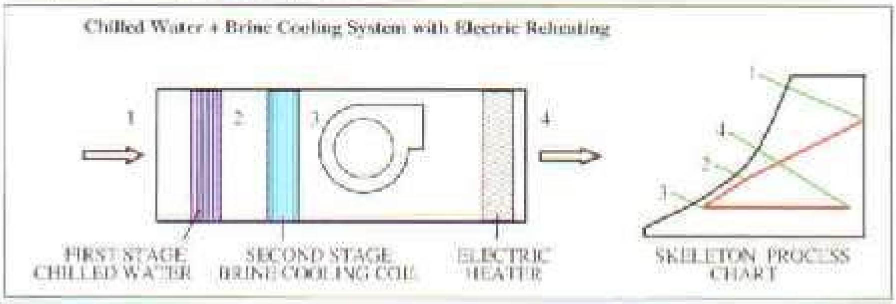


Figure 2.1 : Schematic diagram of chilled water + brine cooling system with electric reheating

Point	Description	DB °F	WB °F	DP °F	Enthalpy BTU/pound
1	Ambient air conditions	110	83	74.5	46.89
2	CHW coil leaving conditions	62	60	58.5	26.4
3	Brine coil leaving conditions	44	42	40	16.14
4	Reheating coil leaving conditions	104	66	40	30.85

Table 2.1 : Psychrometric properties

	Cooling load for 1625 CFM TR	Comp. kW	Evap. Fan Motor kW	Water Pump & CT Fan kW	Heater Power kW	Total Power kW
1st Stage chiller comp. working at 41°F evap. & 122°F cond.	12.49	12.7	3‡	3	30.84	66.94*
2nd Stage brine plant†comp. working at 5°F evap & 122°F cond.	6.25	12.4		3		

Table 2.2 : Power consumption analysis

‡ Common for both stages

* If waste heat is available for reheat, then total power will reduce to 34.1 kW

† Chilled water alone cannot achieve a dew point of 40°F, hence brine stage has been added. Note that this combination leads to a slightly higher power consumption than the DX system

In Figure 3.1 ambient air is first cooled in the precooling stage by a chilled water coil. The desired dew point is attained by passing the air through a silica gel drier. The silica gel drier provides dehumidification and heating. Any extra reheating required after the dehumidifier can be provided by external heaters. In any case, reactivation requires heated air that needs electric or waste reheat as the energy source.

Maximizing Energy Saving by Improving Energy Efficiency (Systems 4 & 5)

The following design concept suggests the energy saving processes that provide integrated low energy, low dew point, dry air supply. This is achieved by improving every step of the process. Some of the measures seem quite radical, but they have been field-tested and they work.

Step 1 : Pre-cooling Stage

In Figure 4.1, ambient air enters at point 1. The lower portion of the Heat Bypass Coil absorbs a part of the incoming air heat and passes it on to its upper portion, where it is transferred to the cold air leaving the second stage. See page 33 for further explanation. The action is similar to a heat pipe, but not quite. This provides free pre-cooling and free re-heating, which is

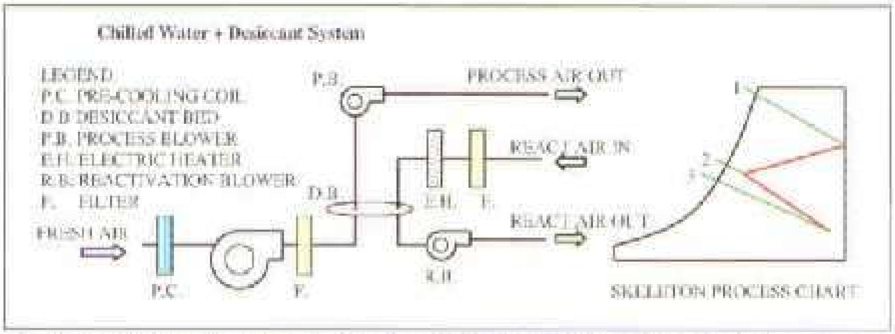


Figure 3.1 : Schematic diagram of desiccant type dehumidifier with chilled water cooling

Point	Description	DB °F	WB °F	DP °F	Enthalpy BTU/pound
1	Ambient air conditions	110	83	74.5	46.89
2	CHW coil leaving conditions	68	66	65	30.76
3	Dessicant dehumidifier leaving conditions	104	66	40	30.85

Table 3.1 : Psychrometric properties

	Cooling load for 1625 CFM TR	Comp. kW	Evap. Fan Motor kW	Cond. Fan Motor kW	Heater Power kW	Total Power kW
1st Stage chilled water comp. working at 41°F evap. and 122°F cond.	9.82	10.1	3	3	42.1	58.2*

Table 3.2 : Power consumption analysis

* If waste heat is available at 250°F or above, then the power will reduce to 16.1 kW. Note that the adiabatic dehumidification process through silica gel is exothermic and adds heat to the dehumidified air.

the first energy saving feature of this design. The Heat Bypass Coil, along with the 1st stage Cooling Coil and associated connections form the dual pressure evaporator which is a patented device.

Step 2 : First & Second Cooling Stages

The pre-cooled air at 2 enters the first- stage cooling coil that cools it to an accurately controlled intermediate temperature by its own refrigeration system. Since this system operates at a high evaporating temperature, its EER is about 12.5. This advantage is neutralized when the air travels through the second stage cooling system that has to operate at sub-zero evaporating temperature, the EER being 7.5. (See page 33 for more information re. "The Importance of Precise Temperature Control.") Thus the average EER is 10, which is much better than having a single stage system operating at an EER of 7.5. So the two- stage operation is the second energy saving feature.

Step 3 : The Fan

The third energy saver is the Single Inlet Single Width non-overloading backward inclined fan specially designed for high efficiency. The impeller is directly mounted on the shaft of a flanged TEFC motor fitted outside the air stream. This arrangement is very compact, has no belt loss or alignment problems and the motor heat is kept out. It also eliminates complex ducting and canvass connections, which is important as the fan static pressure can be as high as 6" WG.

Step 4 : Re-heating

After leaving the second stage coil that cools it to a dew point of about 40° F, the air passes the upper portion of the Heat Bypass Coil at point 5 and picks up the free re- heat collected at point 2. The air then gets the balance re- heat from the hot gas coil, which is the condenser of the second stage compressor. Controls, not shown, regulate the precise amount of heat being supplied, so as to maintain the desired output temperature at point 6. Another patented precision controller holds the intermediate temperature at point 3 within ± 2 °F.

This hot gas reheating eliminates electric, steam or hot water heat and is the fourth and the largest energy saver.

Step 5 : Indirect Pre-cooling of the Entering Air (for hot regions)

See Figure 5.1. This operation is carried out before air enters the main unit of Fig. 4.1. Two ambient air streams 1 and 2 enter a multi- element metal plate type heat exchanger. Only one element 3 of the exchanger is shown for clarity. Water is sprayed only on the outside surface of the elements. The evaporative cooling of the plate extracts heat from the inside air stream 2, without adding moisture to it. The spray also cools the outside air stream 1 by evaporation. At point 1A it is much cooler than ambient even after picking up the heat from air stream 2. This air is then supplied to the condenser of stage 1 of the main cooling unit. Obviously, there is a substantial increase in its efficiency. This stage provides two energy savers at once. Thus only 19 kW of energy is needed instead of 69 kW.

In the Figure 4.1 system ambient air is first passed through a two row pre-cooling coil and then through the first stage cooling coil, which is working at high evaporation temperature. Air leaving the first

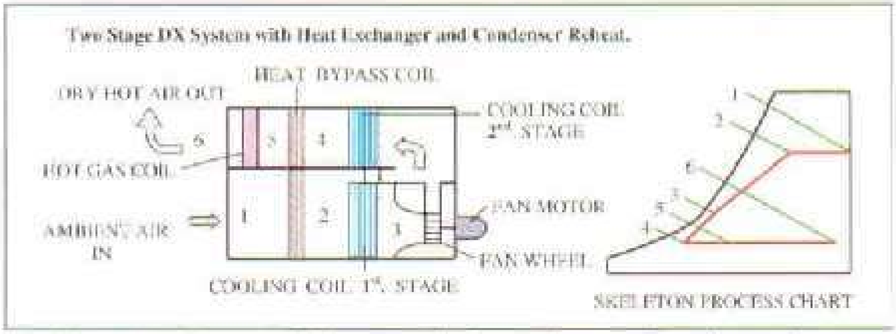


Figure 4.1 : Two stage DX system with heat exchanger and condenser reheat

Point	Description	DB °F	WB °F	DP °F	Enthalpy BTU/pound
1	Ambient air conditions	110	83	74.5	46.89
2	Precooling coil leaving air conditions	90	78.43	74.5	41.91
3	DX - Stage I leaving conditions	61	58.9	57.6	25.66
4	DX - Stage II leaving conditions	44	42	40	16.14
5	Reheat coil leaving conditions	64	51.3	40	21.01
6	Extra reheat coil leaving conditions	104	66	40	30.65

Table 4.1 : Psychrometric properties

	Cooling load for 1625 CFM TR	Compr. kW	Evap. Fan Motor kW	Cond. Fan Motor kW	Heater Power kW	Total Power kW
1st Stage DX system working at 50°F evap. & 122°F cond. temperature	9.9	8.8	3‡	1	Nil (reheat supplied by 2nd Stage condenser)	19.2
2nd Stage DX system working at 23°F evap. & 86°F cond. temperature	5.6	5.4		1		

Table 4.2 : Power consumption analysis

‡ Common for both stages

stage cooling coil then enters second stage cooling coil, which is working at low evaporation and high condensation temperature. Major benefit of the combination of the two stages is that the EER ratio remains the same as a single stage system working at higher evaporation temperature. Reheating is provided by the second stage condenser.

In the Figure 5.1 system ambient air is first cooled in the indirect evaporative precooler and then enters the two-stage cooling unit. The rest of the circuit is the same as shown in Fig. 4.1. In this system to the condenser of the first stage, which results in greater efficiency of the system.

Applications

The epilogue gives data and analysis of an actual installation where these units are providing dried and reheated air to the coating pans. Here various coatings cover sugar candy pellets. Both the absolute humidity and the temperature are critical and must be controlled within narrow limits. The energy saving figures give a competitive advantage to this high volume product.

Fluid bed dryers are second cousins benefits.

The pharmaceutical industry uses both coaters and dryers. They must also maintain positive pressure in clean room passages to prevent cross contamination. Dried air, reheated only up to room conditions, can leak into the production areas without affecting the room conditions. A combination of a chilled water first stage and a DX booster as a second stage would eliminate brine and hot water systems altogether. Chilled water temperature need not be low, so the entire chilling plant can work at a higher efficiency.

An important application would be the air-handling units for th operation theatres of hospitals which require 50% to 100% outside air. Currently, chilled water and electric heaters are used. Energy bills are high and the humidity control is not very effective, particularly in the monsoon season.

In the plastics industry, many high production machines have chilled water-cooled moulds. When the room dew point is high, as in the monsoon season, moisture deposits on the mould surface, cause surface defects in the products. The moulding zone is usually covered and pressurized with dry but cool air.

In hotels, the guest rooms have to be supplied with a fixed quantity of fresh air through a separate 24-hour system. Here also, the chilled water plus DX booster could supply cold air that would keep the rooms dry enough to prevent mold growth, thus avoiding a dank smell.

Conclusion

Energy efficiency is paramount for remaining competitive in a liberalized market. It is established that the system described above will substantially reduce the running cost of 100% fresh air systems supplying reheated air at a low dew point. The authors invite comments and

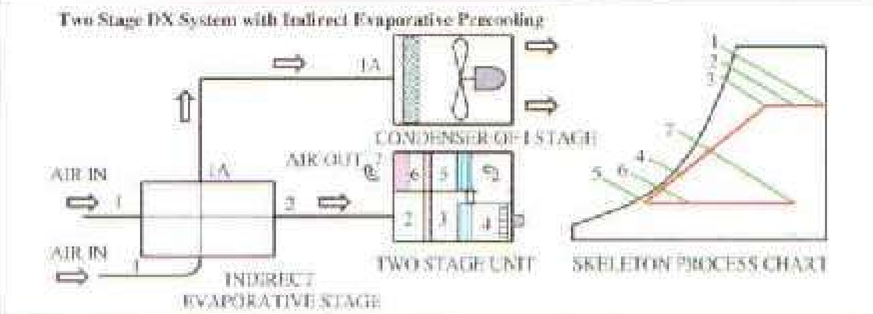


Figure 5.1 : Schematic diagram of two stage DX system with indirect evaporation precooling

Point	Description	DB °F	WB °F	DP °F	Enthalpy BTU/pound
1	Ambient air conditions	110	83	74.5	46.89
2	Evap. Stage leaving conditions	100	80.77	74.5	44.39
3	Precooling coil leaving conditions	80	75.96	74.5	39.43
4	DX Stage - I leaving conditions	58	55.3	53.4	23.34
5	DX Stage - II leaving conditions	44	42	40	16.14
6	Reheat coil leaving conditions	64	51.2	40	21.01
7	Extra reheat coil leaving conditions	104	66	40	30.85

Table 5.1 : Psychrometric properties

	Cooling load for 1625 CFM TR	Comp. kW	Evap. Fan Motor kW	Cond. Fan Motor kW	Heater Power kW	Total Power kW
1st Stage DX system working at 50°F evap. & 86° cond.	9.8	5.1	3‡	1	Nil (reheat supplied by 2nd Stage condenser)	15.0
2nd Stage DX system working at 23°F evap. & 86°F cond.	4.38	4.9	3	1		

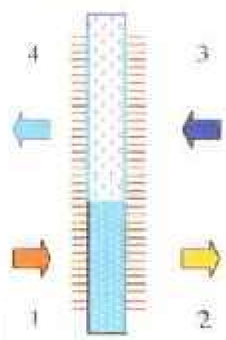
Table 5.2 : Power consumption analysis

‡ Common for both stages

Functioning of the Heat Bypass Coil

The heat bypass coil or reflux boiler is a vertical finned tube that is partially filled with a liquid whose vapour fills the upper portion.

Both the liquid and its vapour are at equilibrium at starting conditions.



Warm air from the room enters at 1 and heats the liquid which boils and generates vapour, absorbing heat from the air in the process and cooling it as it leaves at 2.

Cold air from the cooling coil enters the upper portion at 3 and condenses this vapour, absorbs its heat of condensation and warms up, leaving at 4.

The liquid runs down by gravity and the cycle continues. Heat absorbed between 1 & 2 is given up from 3 to 4.

The Importance Of Precise Temperature Control

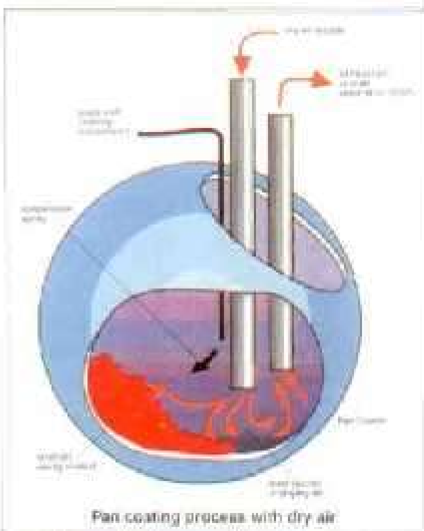
The output temperature of the second stage cooling coil must be controlled within a narrow band, as near the freezing point as possible. By precisely controlling the inlet air temperature, we can provide a steady load to the coil. Then the output temperature will remain stable.

This means, of course, that the output temperature of the first stage must remain steady under varying inlet conditions. If the first stage has a chilled water coil, then a close controlled mixing/diverting valve would do the job. Care must be taken to avoid channeling or unstable operation at low loads.

If the first stage is DX, then an electronic expansion valve or its equivalent control must be used. A proprietary device available in India allows an ordinary expansion valve to achieve the same result. Cycling the compressor is not an option.

Epilogue

The following data was obtained from an actual system installed for a multinational company at Chennai. Dry air is required at this plant to feed a battery of coating pans in which sugar pellets are coated with several layers of liquid containing ingredients and flavors to impart a unique taste to the finished product which is a chewy candy or toffee. The pellets are being constantly rotated in the 'coater' and the introduction of dry air speeds up the drying. See photo of coating pans and the schematic diagram explaining the coating process.



Schematic diagram of coating process

Total Ambient Air Requirement
= 11000 m³/hr. (6500 CFM)

Ambient Conditions
= 110 °F DB, 86 °F WB

Desired Supply Air Conditions
= 104 °F DB, 57 °F Dew Point

The above requirement was filled by four 15 TR capacity units. Each unit is designed to provide 1625 CFM of ambient air at 104 °F DB and 57 °F dew point. The units are working on R- 134a refrigerant, which is less efficient than R -22. Even so, the energy saving is substantial, as shown in the results tabulated in Tables E1 & E2. Indirect evaporative pre-cooling is not provided here due to

A battery of coating pans. *Photo courtesy of Gansons Ltd.*

Parameters	System I	System II	System III	System IV
1. Supply air quantity (CFM)	1625	1625	1625	1625
2. Supply air Dry Bulb Temperature (°F)	106	104	105	105
3. Supply air Dew Point Temperature (°F)	56	55	57	56
4. Power Consumption (kW)	19	18	18	17.6
5. Total Measured Power Consumption (kW)	72.6kW			

Table E1 : Data collected from an actual installation at Chennai

Conventional System & Calculated Power (ref. Table 1)	kW	Measured Power (Each Unit) kW	Saving Per Unit kW	Saving for Four Units kW	Saving for 300 days and 16 Hrs kWh	Savings in Rs/Year
1. Single Stage – DX (electric reheat)	67	(for units working at Chennai) 19 (as per Table E1)	48	192	9,21,600	55,29,600
2. Single Stage – DX (condenser reheat)	36		17	68	3,26,400	19,58,400
3. Two Stage - chilled water + brine (electric reheat)	65		46	184	8,83,200	52,99,200
4. Two Stage – chilled water + brine (condenser reheat)	38		19	76	3,64,800	21,88,800
5. Single Stage dessicant + chilled water 1st Stage	57		38	152	7,29,600	43,77,600

Table E2 : Savings obtained as compared to conventional systems described in Table 1

Thus, the saving range from Rs. 20 lakhs to Rs. 55 lakhs/year. As the initial cost of the system is less than Rs. 40 lakhs, the payback period is