Desiccants: Benefits for the Second Century of Air-Conditioning

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ABSTRACT

Desiccant technology now stands where mechanical cooling stood in the 1930's. Desiccant systems have been used by industrial engineers to achieve productivity and energy benefits which far outweigh their installed cost. Now, with lower cost desiccant components, commercial buildings are using desiccant systems because they provide benefits beyond those of air cooling technology alone.

In many ways, the rise of desiccant systems is parallel to the 80-year-old transition from fan-only cooling to mechanical cooling. Mechanical cooling did not reduce the need for fans and blowers. Likewise, desiccant technology may not reduce the need for mechanical cooling. And just as mechanical cooling adds cost to a fan-only system, desiccant equipment can sometimes cost more than mechanical cooling. But just as cooling coils add functionality to a ventilation system, desiccant systems provide benefits which are beyond the reach of mechanical cooling systems. Specifically, desiccant systems can provide:

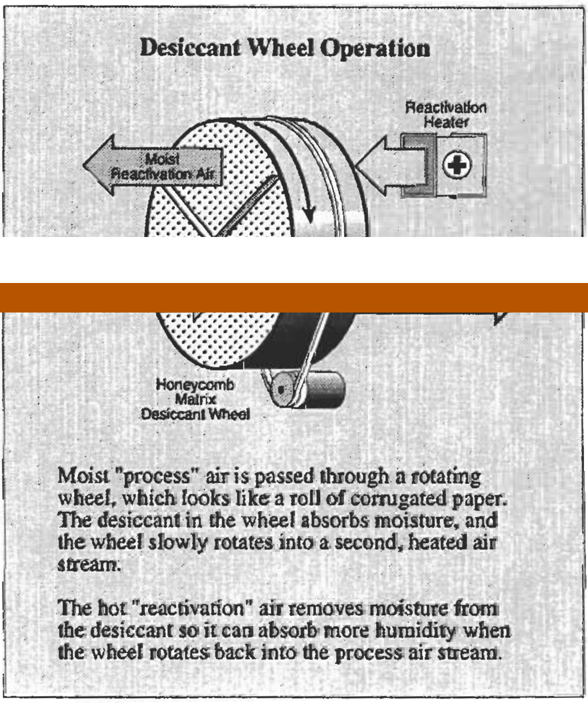
- Total control of humidity, independent of [illegible]
- Dew points below the practical limits of cooling technology.
- Humidity control in cold environments and cold air streams.
- Lower operating cost
- Lower peak electrical demand.
- Ability to use low-cost thermal energy to control both humidity and temperature.
- Dry duct systems in accordance with ASHRAE Standard 62, avoiding microbial and fungal growth associated with sick building syndrome.

HOW DESICCANTS WORK

Desiccants remove water vapor by chemical attraction caused by differences in vapor pressure. When air is humid, it has a high water vapor pressure. In contrast, there are very few water molecules on a dry desiccant surface, so the water vapor pressure at the desiccant surface is very low. Water molecules move from the humid air to the dry desiccant in order to equalize this pressure differential.

With desiccants, moisture removal occurs in the vapor phase. Consequently, desiccant dehumidification can continue even when the dew point of the air is below freezing. This is different from cooling-based dehumidification, in which the removed moisture freezes and halts the process if any part of the coil surface is below 32°F.

Desiccants can be either liquids or solids, and there are many different materials of both types. The principles described here apply to both liquid as well as solid systems. However, the great majority of systems built for commercial buildings use dry desiccants.



Moist "process" air is passed through a rotating wheel, which looks like a roll of corrugated paper. The desiccant in the wheel absorbs moisture, and the wheel slowly rotates into a second, heated air stream.

The hot "reactivation" air removes moisture from the desiccant so it can absorb more humidity when the wheel rotates back into the process air stream.

Figure 1: Desiccant wheel operating principle.

Figure 1 shows the basic desiccant component—the wheel. The desiccant material, usually a silica gel or some type of zeolite, is impregnated into a support structure. This looks like an honeycomb which is open on both ends. Air passes through the honeycomb passages, giving up it's moisture to the desiccant contained in the walls of the honeycomb cells. The desiccant structure is formed into the shape of a wheel. The wheel constantly rotates through two separate air streams. The first air stream, called the process air, is dried by the desiccant. The second air stream, called reactivation or regeneration air, is heated. It dries the desiccant.

One aspect of desiccant wheel behavior can be confusing to the first-time user of the technology; air leaves a desiccant wheel dry, but warmer than when it entered the wheel. For example, if air enters a desiccant wheel at 70°F and 50% rh, it will leave the wheel at about 100°F and 4% rh.

This non-intuitive behavior becomes easier to understand as the reverse of evaporative cooling. When water is sprayed into air, it evaporates by using part of the sensible heat in the air—so the dry bulb temperature falls as water vapor is added to the air. That process is intuitive to children running through sprinklers in summertime.

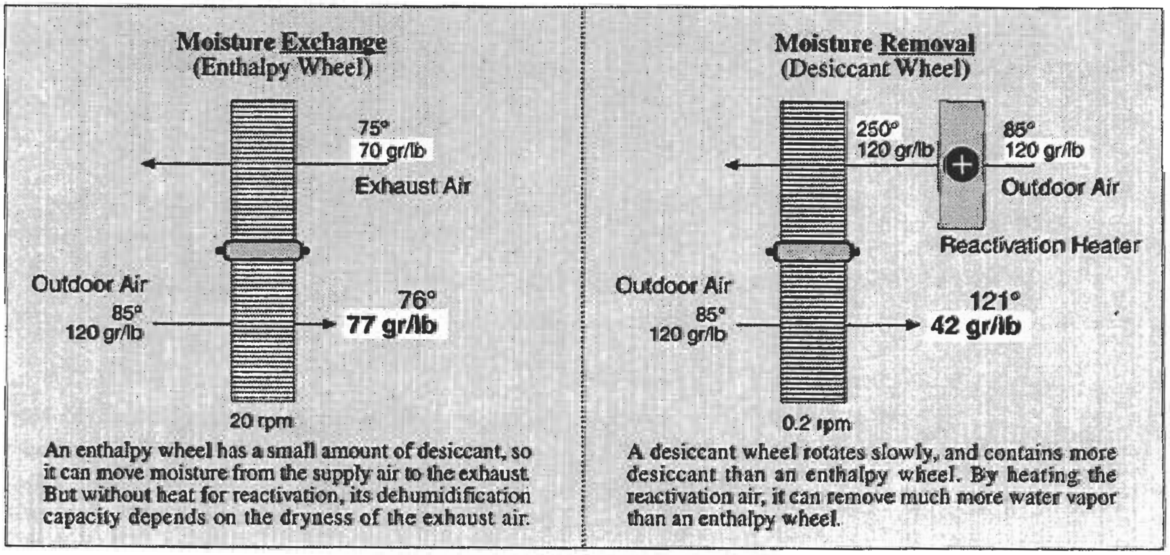
Desiccants produce the opposite phenomenon. As water vapor is removed from air, the dry bulb temperature of the air rises. The amount of temperature rise depends on the amount of water removed. More water removal produces a greater temperature rise. The initial user naturally asks: how can desiccant systems save cooling energy if dehumidification adds sensible heat to the air? Part of the answer is that some heat is moved to reactivation by a heat exchanger. The rest of the answer depends on the application.

For example, if air is dry, it may not be necessary to cool it if the space is already overcooled—as in a supermarket, where display cases cool the aisles as well as the product. Alternatively, dry air can be cooled using low-cost indirect evaporative cooling such as cooling towers, or with highly efficient vapor compression systems operating at high evaporator temperatures. In such cases, desiccants can save energy and energy cost. However, the temperature rise issue also shows that desiccant systems have fewer advantages if inexpensive post-cooling is not available.

ENTHALPY VS. DESICCANT WHEELS

Desiccant wheels are often confused with enthalpy heat recovery wheels. The confusion is understandable. Both devices look nearly the same, because modern enthalpy wheels and all desiccant wheels are constructed with honeycomb media. Also, enthalpy wheels contain desiccant; and sensible heat wheels are sometimes used as post-coolers in desiccant systems. But there are important functional differences between these devices which appear so similar.

Heat wheels are optimized to transfer heat between two air streams, while desiccant wheels are optimized to remove moisture. These different purposes lead to differences in materials and in wheel rotation speed. A heat wheel rotates at a comparatively high speed (20 rpm), to maximize the heat transfer between air streams. A desiccant wheel rotates 60 times more slowly (10 to 20 rph). The slow rotation speed allows the desiccant to adsorb more moisture, and it minimizes the amount of heat carried over from the



An enthalpy wheel has a small amount of desiccant, so it can move moisture from the supply air to the exhaust. But without heat for reactivation, its dehumidification capacity depends on the dryness of the exhaust air.

A desiccant wheel rotates slowly, and contains more desiccant than an enthalpy wheel. By heating the reactivation air, it can remove much more water vapor than an enthalpy wheel.

Figure 2: Desiccant wheels compared to enthalpy wheels.

hot reactivation air into the cooler process air.

If the exhaust air is dry, an enthalpy wheel can transfer some moisture out of the incoming air. But enthalpy wheels contain less desiccant than true desiccant wheels. Also, the honeycomb material, air seals and support structure of an enthalpy wheel are not designed to endure the high temperature and moisture differences encountered in desiccant wheel operation. Figure 2 shows how these differences affect the moisture removal performance of enthalpy wheels and desiccant wheels.

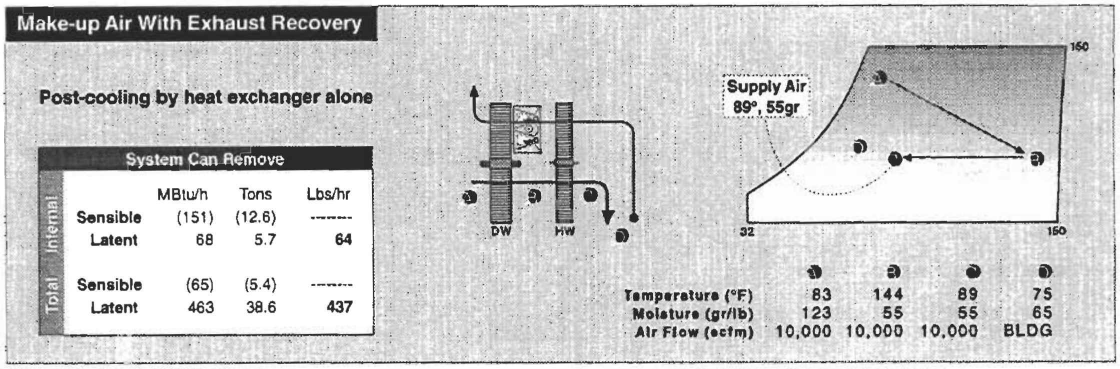
EXHAUST RECOVERY

System 1 and 2 differ in only one respect: system 1 uses building exhaust air to cool the process air after the desiccant wheel, and system 2 uses outside air for post-cooling.

In all other respects, the systems are the same. They process 10,000 cfm of fresh air and deliver it dry, for subsequent cooling by other systems down steam. Both systems can remove 438 lbs of moisture per hour from the fresh air. Consequently, that air is so dry that it can remove 71 lbs per hour from the building, when the desired control level is 75°, 50% rh. So both systems have ample moisture removal capacity, and it is very unlikely that any cooling coil downstream of the desiccant system will have to remove any moisture at all.

Because the cooling air comes from different places, the two systems do different amounts of work. System 1 does more work, delivering air at 89°F. System 2 delivers air at 95°. This is because, on the cooling side of the heat exchanger, system 1 uses 75° air from the building, where system 2 uses air from the outside at 83°. In almost all cases, the lower temperature is more desirable because it reduces cooling requirements in the rest of the HVAC system.

However, in some buildings, it may not be practical to bring the exhaust air back to the same location as the fresh air inlet duct work. For example, in a light industrial building with many internal fire walls and a dozen different process exhaust points, the return duct work may be more costly than the small additional cost to add capacity to the other rooftop air conditioning units. Or in cases where a very small amount of fresh air is needed, rather than 10,000 cfm, the additional sensible cooling capacity may already be available in other parts of the system at no additional cost, compared with a high cost for return duct work.

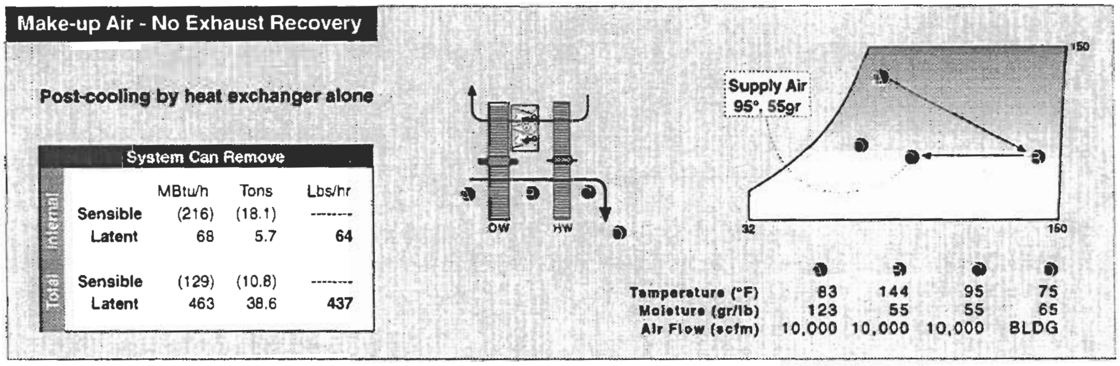


System Can Remove

		MBtu/h	Tons	Lbs/hr
Internal	Sensible	(151)	(12.6)	-------
	Latent	68	5.7	64
Total	Sensible	(65)	(5.4)	-------
	Latent	463	38.6	437

	●	●	●	●
Temperature (°F)	83	144	89	75
Moisture (gr/lb)	123	55	55	65
Air Flow (scfm)	10,000	10,000	10,000	BLDG

Figure 3: System 1, 100% outside air with exhaust air used for post cooling.



System Can Remove

		MBtu/h	Tons	Lbs/hr
Internal	Sensible	(216)	(18.1)	-------
	Latent	68	5.7	64
Total	Sensible	(129)	(10.8)	-------
	Latent	463	38.6	437

	●	●	●	●
Temperature (°F)	83	144	95	75
Moisture (gr/lb)	123	55	55	65
Air Flow (scfm)	10,000	10,000	10,000	BLDG

Figure 4: System 2, 100% outside air with outside air used for post cooling.

But in most cases, and in particular those cases where as much as 10,000 cfm of fresh air is needed, the use of return air for post-cooling should quickly pay off any small cost of a return duct system to bring the exhaust air back to the unit before it leaves the building.

INDIRECT EVAPORATIVE COOLING

Systems 3 and 4 are very similar to systems 1 and 2, the difference being that 3 and 4 use indirect evaporative post cooling.

This feature adds slightly to the purchase cost of the equipment, but saves on downstream cooling capacity in the rest of the HVAC system.

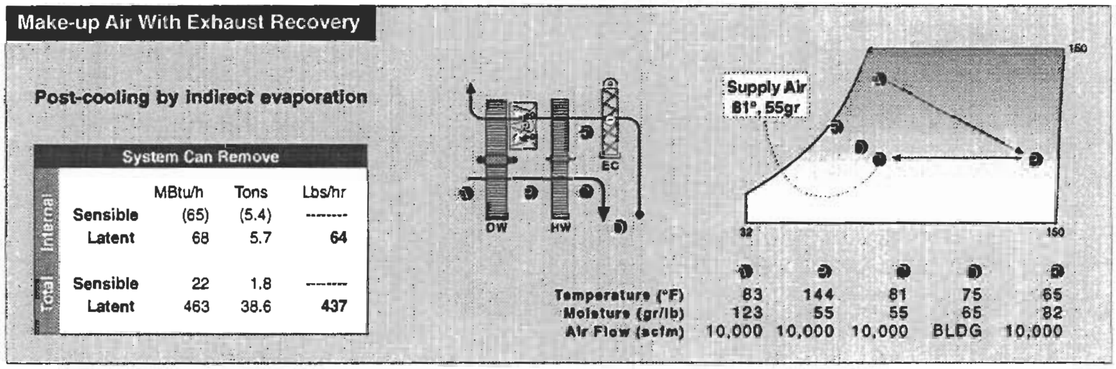
For example, note that the supply air temperature for system 3 is 8 degrees lower than what system 1 can provide (81° compared to 89°). On 10,000 cfm, that allows the system 3 configuration to save 7 tons of cooling capacity. As with the previous systems, system 3 outperforms system 4, because the exhaust air can cool the supply air more deeply than can the outside air.

The major advantage to indirect evaporative cooling is its very low operational cost. The only cost to cool the air evaporatively is the cost of the water, and the modest cost to overcome the additional air flow resistance of the evaporative pad (less than 0.25"WC). That is usually less than 1/10th the cost of running an equivalent vapor compression cooling system.

Of course, these benefits do not come without some cost. For example, the evaporative cooling system will require some additional maintenance beyond the maintenance of the desiccant wheel and the heat exchanger. Also, saving 7 tons on 10,000 cfm may not justify the increased purchase cost and maintenance cost if there are 7 extra tons of cooling capacity downstream of the desiccant system.

These facts imply that indirect evaporative post-cooling is likely to yield the best cost-benefit ratio when:

- The system is large enough so the net cooling savings and peak electrical demand reduction is large in absolute terms.
- The building is large enough to have a maintenance staff which will already be familiar with service requirements of simple evaporative coolers or cooling towers.
- The exhaust can be returned to the same place as the supply, so the extra cooling effect of the dry

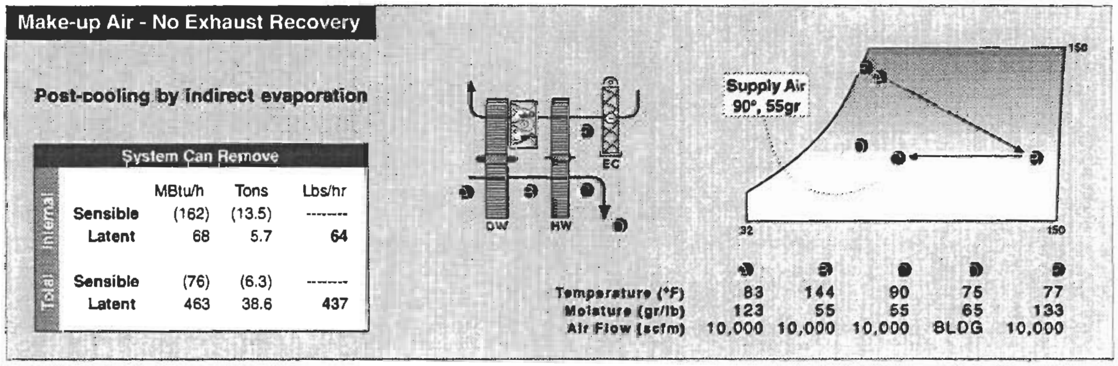


System Can Remove

		MBtu/h	Tons	Lbs/hr
Internal	Sensible	(65)	(5.4)	--------
	Latent	68	5.7	64
Total	Sensible	22	1.8	-------
	Latent	463	38.6	437

	①	②	③	④	⑤
Temperature (°F)	83	144	81	75	65
Moisture (gr/lb)	123	55	55	65	82
Air Flow (scfm)	10,000	10,000	10,000	BLDG	10,000

Figure 5: System 3, 100% outside air, exhaust heat recovery and indirect evaporative cooling



System Can Remove

		MBtu/h	Tons	Lbs/hr
Internal	Sensible	(162)	(13.5)	--------
	Latent	68	5.7	64
Total	Sensible	(76)	(6.3)	-------
	Latent	463	38.6	437

	①	②	③	④	⑤
Temperature (°F)	83	144	90	75	77
Moisture (gr/lb)	123	55	55	65	133
Air Flow (scfm)	10,000	10,000	10,000	BLDG	10,000

Figure 6: System 4, 100% outside air, outside air indirect evaporative cooling.

exhaust air can maximize the cooling savings.

HYBRID SYSTEMS WITH AND WITHOUT EXHAUST RECOVERY

Systems 5 and 6 are hybrid desiccant systems. In other words, they use conventional or gas cooling coils after the heat exchanger so the system can deliver air to the building at the 55° temperature which is typical of AC systems.

That conventional assist allows these system to remove 71 lbs of water vapor and 216,000 Btu/h from inside the building, in addition to removing all the temperature and moisture loads from the incoming fresh air.

To do that, they use 30 and 36 tons respectively of conventional equipment, which is mounted after the heat exchanger. System 5 uses less conventional cooling, because it makes use of recovered cooling by using building exhaust air on the cooling side of the heat exchanger. System 6 has no energy recovery, so it must use an additional 6 tons of conventional cooling to achieve the same 55° supply air temperature. Each of these alternatives has its own advantages compared to the other, and both have significant differences from systems 1 through 4.

Systems 5 & 6 vs. Systems 1-4

- 5&6 remove 18 tons of sensible load from the building, 1-4 add sensible heat load to the building.
- 5&6 use more electrical power
- 5&6 cost more to purchase

System 5 advantages over 6

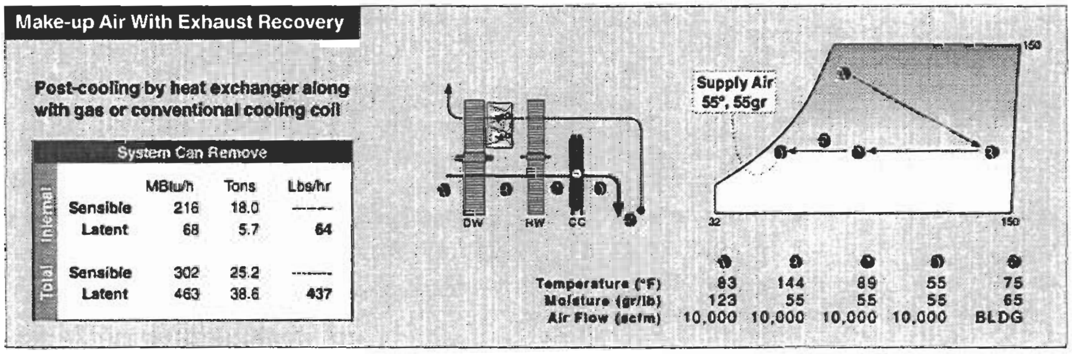
- Uses less electrical power for the same cooling work
- Reduces winter heating costs
- Reduces annual operating costs

With these advantages, system 5 is especially useful for buildings which have return air duct work, and for mid-continent and northern climates where the cost of heating make up air in the winter can be reduced by the exhaust recovery.

System 6 advantages over 5

- Lower installed cost by avoiding return air duct work
- Allows multiple, independent exhaust points

System 6 is advantageous where first cost is more of a concern than operating cost, and where there are a reduced benefit to winter heat recovery; such as in hot and humid climates. Eliminating a central, combined exhaust makes this system useful in applications where air must be exhausted from a building at many different points.



Make-up Air With Exhaust Recovery

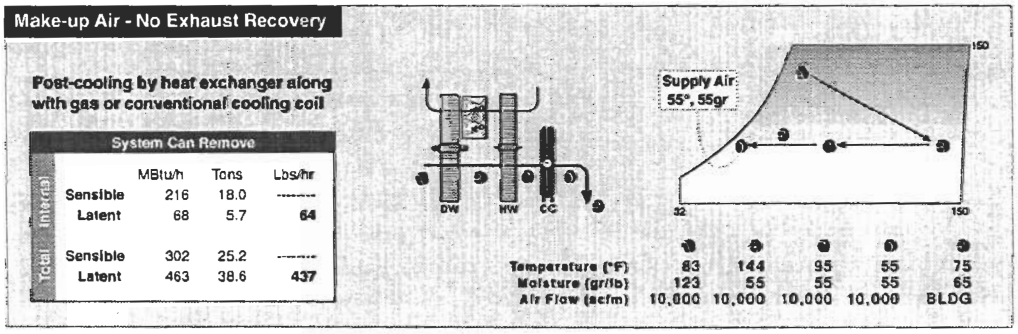
Post-cooling by heat exchanger along with gas or conventional cooling coil

System Can Remove

		MBtu/h	Tons	Lbs/hr
Internal	Sensible	216	18.0	------
	Latent	68	5.7	64
Total	Sensible	302	25.2	-------
	Latent	463	38.6	437

Temperature (°F)	83	144	89	55	75
Moisture (gr/lb)	123	55	55	55	65
Air Flow (scfm)	10,000	10,000	10,000	10,000	BLDG

Figure 8: System 5, 100% outside air, exhaust heat recovery and assisted by a cooling coil.



Make-up Air - No Exhaust Recovery

Post-cooling by heat exchanger along with gas or conventional cooling coil

System Can Remove

		MBtu/h	Tons	Lbs/hr
Internal	Sensible	216	18.0	--------
	Latent	68	5.7	64
Total	Sensible	302	25.2	--------
	Latent	463	38.6	437

Temperature (°F)	83	144	95	55	75
Moisture (gr/lb)	123	55	55	55	65
Air Flow (scfm)	10,000	10,000	10,000	10,000	BLDG

Figure 7: System 6, 100% outside air, no heat recovery and assisted by a cooling coil.

HYBRID SYSTEMS WITH AND WITHOUT EVAPORATIVE COOLING

System 7 includes all the components and same flow schematic as system 6, but also includes an evaporative pad to boost the cooling effect of the heat exchanger.

This allows system 7 to cool the air leaving the desiccant wheel to 90°, which in turn reduces the amount of conventional cooling capacity needed to lower the supply air temperature to 55°. System 7 needs 32 tons of conventional cooling, compared to 36 tons in system 6. That 4 tons of capacity is not really a significant saving at installation time, but it saves a considerable amount of money over a year's operation. As the temperature and moisture outside decreases, the evaporative cooling effect increases. Then the conventional equipment to be shut off entirely for thousands of hours of the year, when the temperature and humidity outside is reduced. For example, during spring, and fall, and during evenings and mornings in the summer.

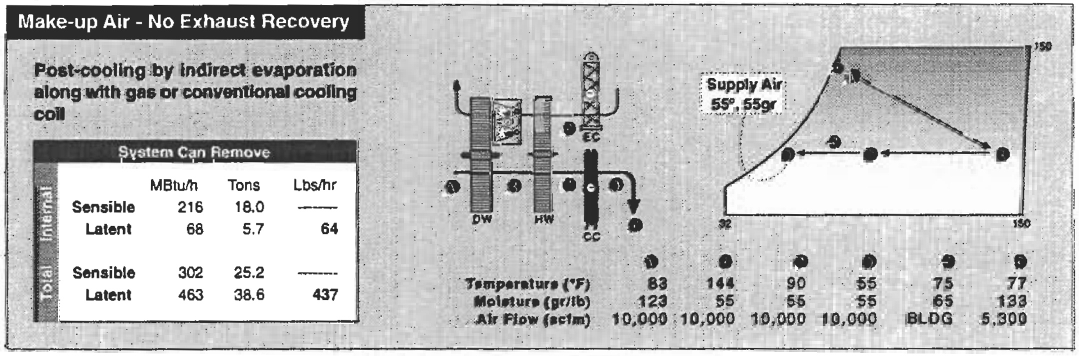
System 8 is the ultimate makeup air dehumidification system. Unlike all the other systems, it uses an enthalpy heat exchanger in front of the desiccant wheel to pre-cool and pre-dehumidify the air before the desiccant process. This allows the desiccant wheel to deliver the process air at 31 gr/lb instead of 55 gr/lb. Consequently, the system can remove more than 3 times as much moisture load from the building as any of the other designs (226 lbs/hr vs. 71 lbs/hr). On the other hand, because system 8 removes so much moisture from the incoming air, and because it does not use a heat exchanger for post-cooling, the system needs 56 tons of conventional assist to cool air to 55°F.

Such a system would be especially useful for buildings which need a lower humidity control level than 50%. The system's immense dehumidification capacity allows a building to be kept at 40 or 45% rh, useful for such buildings as pharmaceutical production areas or research labs. Also, such a system is useful in buildings like theatres and food processing areas, where either people or wash-down cycles generate a great deal more moisture than sensible heat.

COMPARING OUTSIDE AIR ALTERNATIVES

Figure 11 compares all of the makeup air systems according to four characteristics:

- Loads they remove from the building (or add to it)
- Loads they remove or add to the incoming fresh


Make-up Air - No Exhaust Recovery

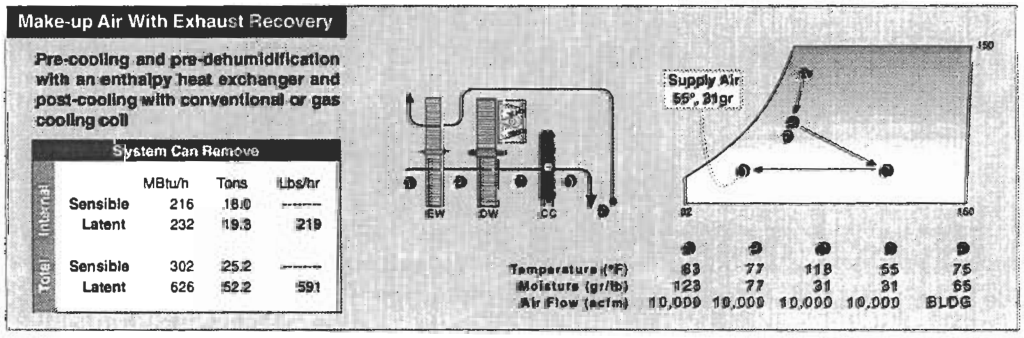
Post-cooling by indirect evaporation along with gas or conventional cooling coil

System Can Remove

		MBtu/h	Tons	Lbs/hr
Internal	Sensible	216	18.0	------
	Latent	68	5.7	64
Total	Sensible	302	25.2	-------
	Latent	463	38.6	437

Temperature (°F)	83	144	90	55	75	77
Moisture (gr/lb)	123	55	55	55	65	133
Air Flow (acfm)	10,000	10,000	10,000	10,000	BLDG	5,300

Figure 10: System 7, 100% outside air, indirect evaporative cooing, assisted by a cooling coil.


Make-up Air With Exhaust Recovery

Pre-cooling and pre-dehumidification with an enthalpy heat exchanger and post-cooling with conventional or gas cooling coil

System Can Remove

		MBtu/h	Tons	Lbs/hr
Internal	Sensible	216	18.0	------
	Latent	232	19.3	219
Total	Sensible	302	25.2	------
	Latent	626	52.2	591

Temperature (°F)	83	77	118	55	75
Moisture (gr/lb)	123	77	31	31	65
Air Flow (acfm)	10,000	10,000	10,000	10,000	BLDG

Figure 9: System 8, 100% outside air, enthalpy wheel pre cooling and and pre dehumidification, and assisted by a cooling coil.

air

- Thermal energy they need to operate at the design condition
- Supplemental cooling needed to bring the supply air to a building-neutral temperature of 75° (or to 55° in systems 5-8).

The figure divides the systems into two groups. Systems 1 through 4 are considered all-desiccant systems, because they do not contain cooling components. Systems 5 through 8 are hybrid systems, because they combine desiccants with conventional cooling.

COMMON CHARACTERISTICS

Each approach has advantages and limitations, but all eight systems share some common characteristics:

Dry & Fungus-Free Duct Work

Every alternative shown here delivers dry air to the building. The warning in ASHRAE Standard 62 against saturated air in duct systems can be satisfied by any of these alternatives. The low humidity also allows all internal cooling coils to run dry, reducing the hazard of microbial growth in drain pans and insulation.

Internal Latent Loads Removed By Makeup Air

All of these alternatives remove so much moisture from the makeup air, that any internal cooling coils can be designed to operate at a higher evaporator temperature, which can reduce their power consumption.

Rock-Solid Humidity Control

The moisture removal capacity of all these systems allows very stable humidity levels inside the building

Improved Temperature Control

Without the moisture load to remove, the internal cooling system can control temperature much more evenly, because there is no need to over-cool and reheat the air as incoming ventilation air changes in temperature and moisture content.

Reduced Peak Power Demand

All these systems remove moisture through thermal energy rather than by using electric power. Part of the sensible load created by dehumidification is removed by a heat exchanger, so the net peak power demand is reduced.

CHARACTERISTICS OF SYSTEMS 1 - 4

These are all-desiccant system, in that they contain no supplemental conventional cooling. In addition, they share these characteristics:

Lowest first cost

The all-desiccant systems are less costly than the hybrid systems, because they contain fewer components.

Remove moisture, but add heat

The post-cooling heat exchanger, even when assisted by the evaporative cooler, does not have enough capacity to remove all the sensible heat produced by dehumidification, so these systems remove the latent load from both the incoming air and from the building itself, but they deliver air which must be slightly cooled by other systems inside the building.

Exhaust recovery improves winter economics

In the summer months, exhaust recover reduces post-cooling expense, but not by much. For example, system 1 uses exhaust recovery and system 2 does not. System 1 has only saved 5.3 tons of post-cooling. But during winter months, the value of waste heat recovery can be very great, perhaps reducing makeup air heating costs by 60% or more.

Cost advantage for buildings with high internal sensible load

If extra sensible capacity already exists inside the building for other reasons, the small additional sensible load from the all-desiccant makeup air system may be inconsequential. This would keep costs down by avoiding the need for a supplemental cooling system on the makeup air.

CHARACTERISTICS OF SYSTEMS 5-8

These systems all include extra cooling capacity to deliver air at 55°, so they can all remove not only moisture, but also remove some of the heat from inside the building. In addition, they share these characteristics:

They do more work, so they cost more

Systems 5-8 all include supplemental cooling coils, so they cost more than systems 1-4. But the hybrid systems also do much more work than the all-desiccant systems, delivering air at 55° to the building instead of 78 or 90°.

Cost advantage for buildings with low internal sensible load

If the makeup air represents not only 80% of the moisture load on the building, but also a high percentage of the total sensible load, then all the internal loads may be removed by cooling the required makeup air. That way, there may be very little need for internal cooling systems, which would lower the overall installation costs for the building.

System 8 ideal for low humidity control levels

Because the makeup air is so deeply dried by system 8, it can be used to control humidity at levels as low as 40% rh inside the building. In electronic manufacturing and pharmaceutical processing, this can save both installed cost and operating costs over conventional alternatives.

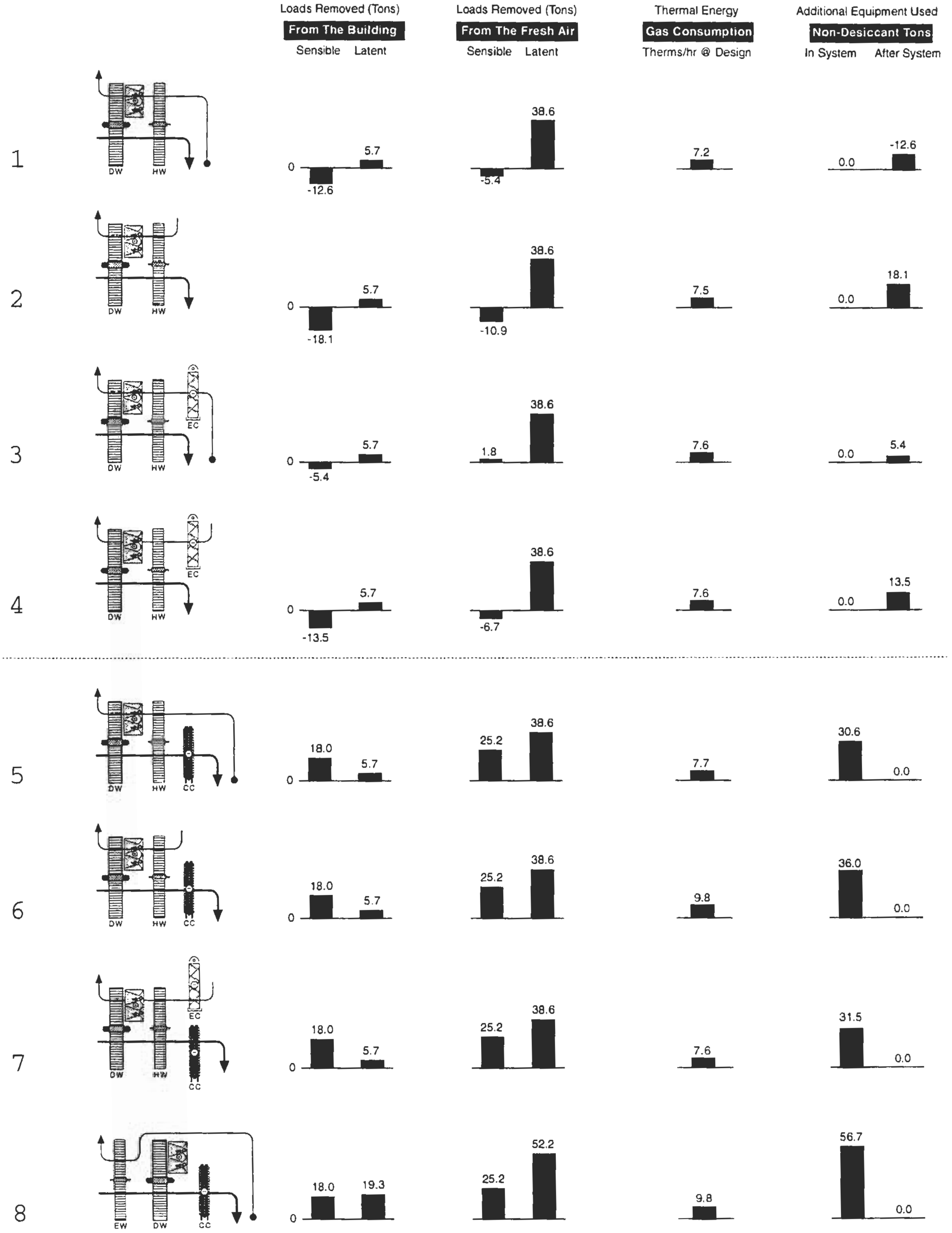


Figure 11: Capacity comparisons of all 100% outside air systems.