

## **What Would Comprise an Ultimate Outside Air Dehumidifier?**

- (1) A machine that used resources already available at the HVAC setting. These include waste heat from an air cooled condenser, outside air, exhaust air from the building, plus sufficient electricity to operate pumps and fans
- (2) The condenser energy from each ton of a rooftop DX providing an extra ton of cooling / dehumidification by the ancillary equipment
- (3) Where over 70% of this capacity went for moisture removal
- (4) An EER of over 50 at ARI-A
- (5) An independently tested 95% removal of virus, mold, bacteria, and particles
- (6) Energy savings of 75% or more in cases where reheat had been previously employed
- (7) A payback of 2.5 years in humid areas such as the Southeast.

## **Product Operational Background**

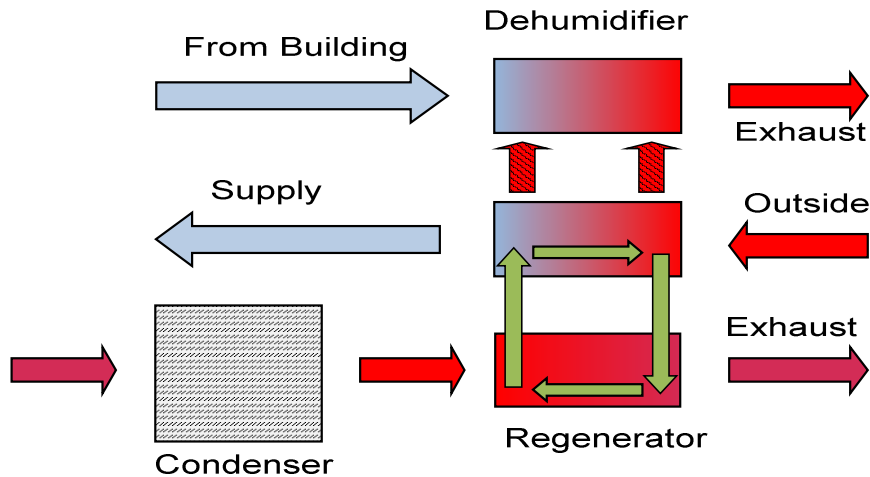
Compressor-based rooftop air conditioners exhaust air from their air cooled condensers at approximately 20°F above outside ambient temperatures. This small change can have substantial effects on the relative humidity of air. For instance, at an American test condition (ARI-A, which is much like Houston in the summer) temperatures are established at 95°F dry bulb (normal temperature reading) and 75°F wet bulb (achieved by placing a wet sock around the thermometer and moving it briskly to cause maximum evaporation) resulting in a relative humidity of 40%. By increasing the dry bulb temperature to 115°F, when using heat generated by an air cooled compressor, a lowering of relative humidity to 22 percent is achieved, a reduction of 45 percent. Removing moisture from the air using a liquid desiccant causes the air to rise in temperature. This is because the exchange is adiabatic meaning there is no change in the air stream energy. At 27% relative humidity, for example, the temperature would be 103°F. To be effective, this temperature needs to be reduced using a heat sink. This heat sink can be supplied by using air exhausted from the building, which is nearly the same flow rate as the outside air brought into the building. Again at ARI-A the return air is specified at 80°F and 50% relative humidity. Saturating this air reduces its temperature to 67°F wet bulb. Exchanging heat from the outside air with this saturated cooler air can significantly reduce its temperature.

In addition to temperature, air also contains a mass component that is measured as moisture contained within the air. This is usually expressed as pounds of water per pound of air, a pound of air being the volume of a cube measuring approximately 2.5 feet per side. At the maximum conditions expressed above, air would contain 0.014 pounds of water per pound of air. A cube 10 feet on a side would contain one pound of water. The heat (temperature) and the moisture content (mass) make up in general terms the energy contained in the air. In the imperial system this is expressed as British Thermal Units or Btu. At the outside ARI-A conditions this is 38.4 Btu per pound of air. 12,000 Btu are the same as one ton of air conditioning.

## **Product Operational Structure**

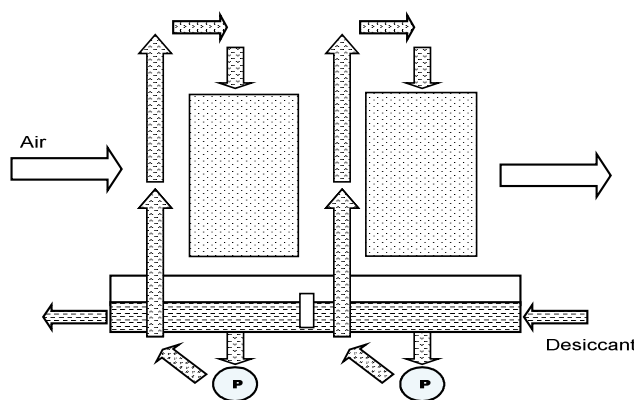
In summary, operations involve dehumidification of an outside air stream by employing a liquid desiccant that has been concentrated by exposure to heated air from a conventional air conditioner while concurrently cooling this air stream by means of heat exchange with building air that is being exhausted and that is maintained saturated throughout the process.

A schematic of the process is presented following.



Given the low temperature spreads available, care must be given to maintaining the integrity of each air flow. Of central importance is employment of stages. The heat and mass of each air stream should not be mixed during passage through the device. If mixed, when in heat exchange with another air stream for instance, the driving force or temperature differential between air streams would be significantly reduced. As an example, an air stream with entering temperatures of 90 degrees F and transferring heat providing an exit air temperatures of 70 degrees F would have an average temperature of 80 degrees F. Were two stages employed, the average of the uppermost stage would be approximately 85 degrees F and the lower stage 75 degrees F thus providing both higher and lower temperature heat exchange possibilities. Without staging, the moisture content of an air stream would be blended thus averaging relative humidity of an air stream as well as its temperature.

Diagram of Stages

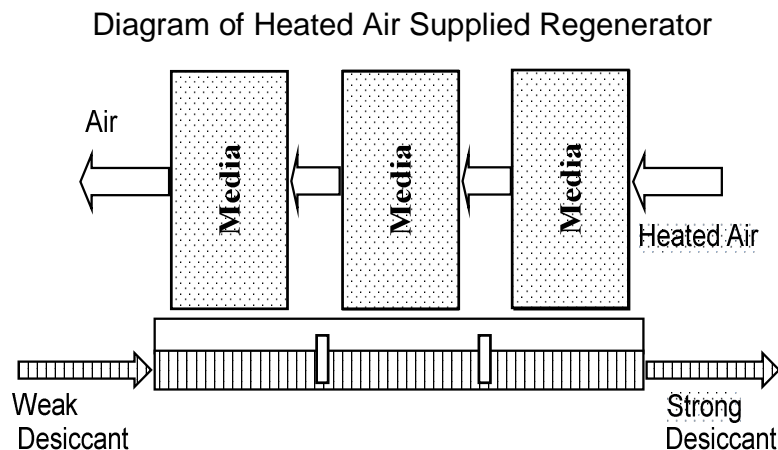


This mixing is largely prevented by the development of stages, each with unique properties of heat and mass. As seen in the following diagram, each stage contains a basin that is connected to a pump. Liquids are distributed upon media such as that

found in evaporative coolers or in small cooling towers where the liquids are in contact with an air flow before falling into the basin thereby providing contact between the liquid and the air stream.

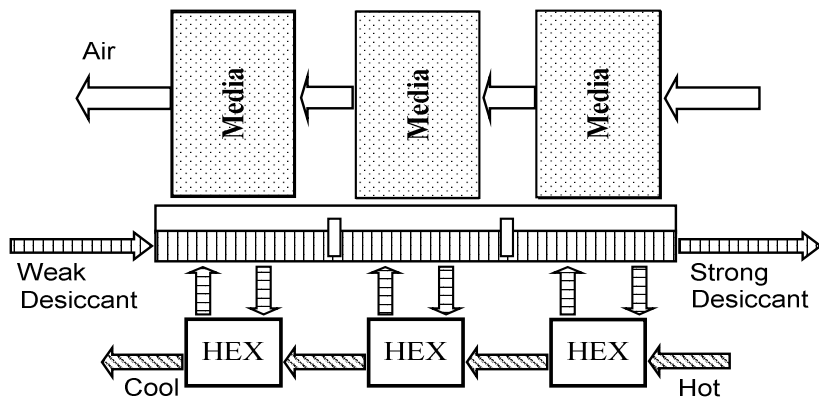
Operation is carried out through utilization of three air streams. The first ambient air flow is augmented in temperature by a low temperature waste heat source. In many cases this air exits from an air conditioner condenser if the condenser is air cooled or air in heat exchange between the liquid desiccant and the hot water source by means of liquid-to-liquid heat exchangers if the condenser is cooled with water. The amount of heat rejected to the condenser is equal to the cooling capacity of the air conditioner plus the heat generated by the inefficiency of the compressor system, an amount equal to at least 10 percent of the cooling capacity. This heated air can evaporate water from a liquid desiccant owing to its reduced relative humidity.

This heated regenerative air stream is segregated into stages in order that each stage can maintain its own temperature and relative humidity composition. In the same manner as in the supply air stream, a small flow of desiccant is allowed to course counter-currently to the air stream with the air stream being first in contact with the coolest and highest relative humidity air progressively flowing to contact the highest temperature of the air stream that has the lower relative humidity. This regeneration air stream is exhausted to the environment at the same energy content as at its entrance but with at a lower temperature and with a higher moisture level. Diagram of a hot air supplied regenerator is first shown.



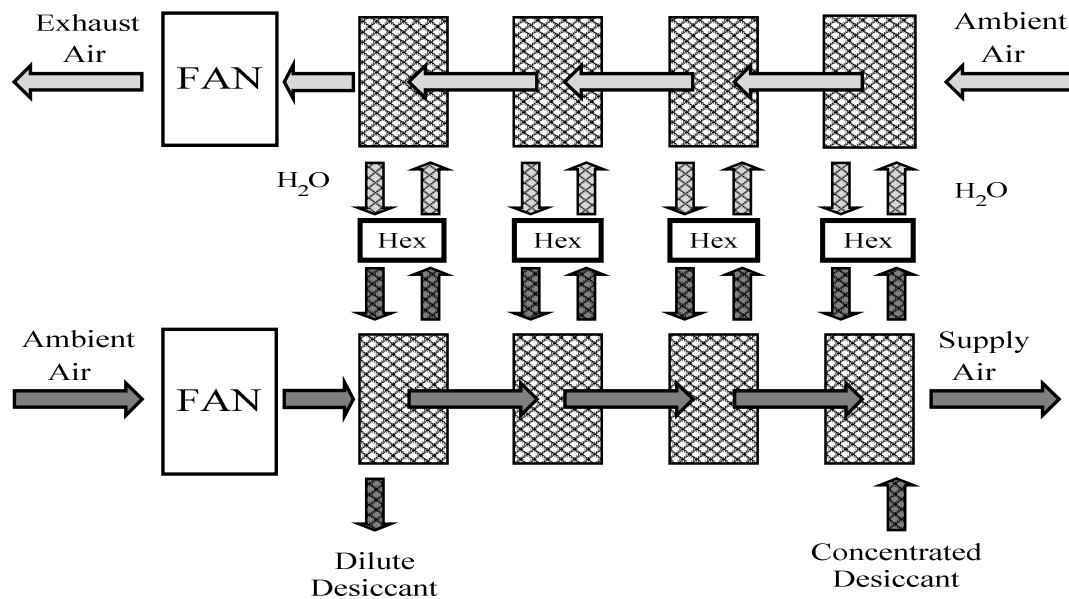
The second means of temperature enrichment is by using warmed water from a water cooled air conditioner system. The hot water is heat exchanged with the liquid desiccant by means of liquid-to-liquid heat exchangers.

Diagram of Hot Water Supplied Regenerator



The liquid desiccant then contacts a separate ambient air stream, known as the supply air stream, and after removing moisture from this air stream is returned for regeneration. The energy content of this air stream remains the same. As the desiccant removes moisture from this supply air stream the energy is balanced by energy related to its rise in temperature. The effect of this temperature increase of this supply air is mitigated by utilization of a third air stream. This air stream is maintained in a near saturated condition causing this air stream to reduce in temperature with the energy balanced by substituting moisture for heat. The two air streams pass counter-currently in a staged manner. The water, cooled by water evaporation into the air stream, is in liquid-to-liquid heat exchange with the warmer liquid desiccant, removing heat from the desiccant. Reduction of heat from the air stream is caused by exchange with the liquid desiccant owing to direct contact. In this manner, heat of dehydration of the supply air is mostly transferred to this saturated air stream and depending on its wet bulb temperature most likely will reduce temperature of the supply air to less than ambient air conditions. This temperature reduction causes the relative humidity of the supply air to increase thereby increasing the effectiveness of moisture removal by the liquid desiccant. As seen in the following diagram, pumped basin liquid from a supply air stage is directed through a liquid-to-liquid heat exchanger that exchanges heat with a correspondent liquid from a saturated air stage. After passage through the liquid-to-liquid heat exchanger caused by a dedicated pump, a small stream of liquid is allowed to flow between stages of the supply air stream before its return to contact the regenerative air stream.

Diagram and Picture of the Dehumidifier / Air Cooler



### Detailed Operational Example

The advantage of employing stages in order to obtain close proximity of air temperatures and improved management of air relative humidity can be shown by presenting a calculated example, employing the ambient conditions previously presented. Employing an air cooled condenser and a rise above ambient temperature of 20°F, air conditions would be 115°F dry bulb, 80°F wet bulb with a moisture loading of 0.014 pounds of moisture per pound of air, energy of 43.3 Btu per pound of air, and a relative humidity of 22%. Assuming a compressor-based air conditioner of one ton (12,000 Btu) output, heat available to the regenerator would be 13,200 Btu, given compressor inefficiencies. With the 20°F temperature rise, air needed to remove heat from the condenser would be the difference between the exhausting air of 43.3 Btu per pound of air and the entering outside air at 38.4 or 4.9 Btu per pound – which when divided into 13,200 Btu yields 2,694 pounds of air per hour. Assuming air exiting the regenerator at 35% relative humidity in its sixth stage, water removed by evaporation per pound of air would be 0.017 less 0.0141 or 0.0029 pounds of water per pound of air. At 2,694 pounds air per hour, the water removal would be 7.8 pounds.

Looking to the six stage air dehumidification and air cooling module, air delivery temperature of 80°F is obtainable given heat exchange with the exhaust air having an ambient wet bulb of 67°F. Relative humidity can be reduced to 33% resulting in a moisture decrease from 0.0141 to 0.0070 or a reduction of 0.0071 pounds of moisture per pound of air. Delivery air conditions would be 80°F dry bulb, 61.1°F wet bulb, 0.0071

pounds moisture per pound of air, 27.1 Btu per pound of air, and a relative humidity of 33%. Regenerator removal of 7.8 pounds moisture divided by 0.0071 pounds allows an air flow of 1,116 pounds of air per hour or 255 cubic feet per minute through the dehumidification and cooling module. Energy reduction is 38.4 less 27.1 or 11.3 Btu per pound of air that when multiplied by 1,116 pounds of air per hour gives 12,600 Btu of energy reduction, an amount doubling the original compressor-driven cooling capacity of 12,000 Btu per hour.

In many locations, moisture removal would exceed the importance of the capacity increase. As is well known, a coil based conventional air conditioner is limited to about 25% of its capacity relegated to moisture removal. Indeed, the ARI-A test limits outside air to 15% of the total air flow in order to remain within this limitation. This amount of outside air is insufficient in many applications. In perspective, a one ton conventional produces 12,000 Btu of cooling. Moisture removal is one-fourth of this, or 3,000 Btu. To condense one pound of water requires 1,000 Btu so removal is three pounds of water. Reviewing *GENIUS* operation, moisture removal amounted to 0.0071 pounds per pound of air that when multiplied by the 1,116 pounds of air per hour equals 7.9 pounds. When added to removal by the conventional air conditioner, the total is 10.9 pounds per hour.

### Energy Efficiency

Electrical usage consists of pumps and fans. The four positive displacement pumps utilized for each tier of a previously constructed 2,700 CFM dehumidifier required 300 watts. For six pumps the total would increase to 450 watts. In the *GENIUS* machine there two tiers in each the dehumidifier and regenerator giving a total of 1,800 watts. As regards to air movement, the extent of augmentation needed beyond that available by the conventional air conditioner will vary. For calculations it is assumed that fans providing a boost of 0.25 water column would be required for all air streams. A 2,800 CFM blower mates with a quarter HP motor (186 watts). If both the chambers required the fan addition the electrical consumption would be 372 watts, A 7,000 CFM fan for the regenerator requires 466 watts. In total, electrical usage could increase to 2,638 watts. The 2,700 CFM capacity dehumidifier when divided by 255 CFM per ton gives a tonnage of 10.6. The 2,638 watts divided by 10.6 yields 249 watts per ton. Cooling of 3,603 watts divided by 249 gives a COP of 14.5 and an EER of 51

### Water Usage

The *GENIUS* air conditioner evaporates water in the second chamber of the dehumidifier that discharges air from the building space. The amount of water evaporated is equal to the heat removed from the delivery air (in this case 38.4 Btu per pound of air entering less 27.1 Btu per pound at delivery. Air conditions at exhaust from

the chamber are the entering air from the building of 32.2 Btu per pound of air plus 11.3 or 43.6 Btu. As the air is saturated its moisture content has increased from 0.011 to 0.022, a gain of 0.11 pounds of moisture per pound of air. This gain times the air flow per ton (1,116 pounds per hour) amounts to 12.2 pounds of water (1.5 gallon) evaporated per hour. A 12 EER rated compressor uses 1 kW per hour. A report by NREL, "Consumptive Water Use for U.S. Power Production", 2003, page 4, states that average consumption of water equals 2 US gallons per kWh or 16.7 pounds. Offsetting this is the electrical usage of the waste heat unit of 300 watts or 5.0 pounds water at the generation level. The balance is total water related to the waste heat unit of 17.2 pounds versus the usage of 16.7 pounds by a compressor system. Water usage is viewed to be neutral.

### Desiccant Carryover

All salt-based desiccants such as lithium chloride or lithium bromide are corrosive. Carryover occurs when a passing air stream impinges desiccant droplets or causes desiccant to release from falling film surfaces. The National Renewable Energy Laboratories (NREL) has worked years solving this problem by using a low flow of desiccant per plate surface area and affixing a wicking surface to these vertical plates that allows for uniform desiccant films. The *GENIUS*® approach moves several steps further. The wicking surface is replaced by media that actually absorbs the desiccant thus the air stream contacts the surface of the media, not a desiccant film. Secondly, the media is a honey-combed structure any continuous desiccant stream from developing.

### **Other Climatic Conditions – Summary Tables of Performance**

In the following analysis, the energy supply to the waste heat using air conditioner (trademarked "*GENIUS*®") is from a one ton (12,000 Btu) air cooled compressor system. The heated condenser air supplies the thermal input to the unit. Design points in the table below again include an American test condition known as ARI-A, the high humidity design condition of Miami, the hot and dry climate of Phoenix, and the more moderate temperature but extremely high moisture content conditions of a Singapore design point. The following tables summarize characteristics. Details of each condition are presented subsequently.

#### **Operating Parameters of Waste Heat Using Air Conditioner (Connected to One Ton Conventional Air Conditioner)**

Design Point	Outside Air RH	Capacity (Btu)	Latent Load	EER
ARI-A Houston	40%	12,600	63%	51

Miami	54%	11,600	69%	44
Phoenix	14%	13,100	33%	49
Singapore	86%	10,300	76%	35

### Moisture Removal per Ton of Air Conditioning (in Pounds)

Design Point	Conventional	Waste Heat	Combined	Times Increase
ARI-A Houston	3	7.9	10.9	3.6
Miami	3	8.0	11.0	3.7
Phoenix	3	4.3	7.3	2.4
Singapore	3	7.8	10.8	3.6

### Air Flow Requirements for One Ton Output of Waste Heat Using Air Conditioner

Design Point	Tons	Dehumidifier CFM	Regenerator CFM
ARI-A Houston	1.05	243	620
Miami	0.97	272	684
Phoenix	1.09	268	597
Singapore	0.86	301	755

### Independent Tests

A standard test in the United States is by the American Refrigeration Institute (ARI-A) which takes a condition similar to Houston in the summer and reduces this temperature to 55 degrees with 100% relative. The *GENIUS*® system attached to a high temperature regenerator has been successfully tested and approved by laboratories in the United Kingdom and China. It is interesting to note that the ARI-A test limits the amount of outside air to 15% as that is the maximum that a compressor-based system can accommodate (25% latent (moisture) removal while *GENIUS*® passed the test using 100% fresh air. Independent tests by Winton laboratories and the China CDC have confirmed 95% removal of virus, bacteria, molds, as well as particulates. Winton also verified the carryover of the desiccant in the delivery air stream. Carryover was slightly higher than the background air (all air has lithium when measured in parts per billion) thus the delivery air was qualified as very safe.

### Operating Cost Savings

Target markets are selected to be “big box” stores such as Walmart or Target or franchised restaurants (McDonalds, Burger King, etc.). These targets have a significant mandated need for significant amounts of outside air as well as long operating hours (3,600 per year) when outside air must be treated. Blended peak and non-peak

electrical rates have been established by DOE and reported by EIA and amount to \$0.153 per kilowatt hour.

An efficient compressor based air conditioner uses one kilowatt hour per one ton (12,000 Btu) of cooling. At 3,600 hours per year the cost would be \$545. A one ton *GENIUS*<sup>®</sup> unit would consume 249 watts per hour which amounts to electrical charges of \$136 per year. The savings is \$409 per year representing savings of 75%.

### **Payback Scenario**

Prices for the conventional compressor (DX) system have been based upon products made by the major manufacturers such as Carrier, Trane, or York. Their models are priced at about \$600 per ton but cannot effectively remove humidity. For indoor humidity removal applications, the humidity removal limitation of conventional DX compressor systems employing standard air rates results in oversized equipment which may cause, for example, many hotel lobbies to feel too cool. The alternative is to employ a reduced air rate or utilize other technologies.

There are other systems, primarily solid desiccant wheels that can remove moisture at higher costs and significantly increased energy usage. Prices for the reduced air delivery systems with heat recovery wheels, which increase outside air dehumidification, are more expensive. One quoted price for the AAON RK-16 (16 ton) compressor-based system that processes 3,200 CFM is \$20,000 plus \$4,500 for controls or \$1,531 per ton.

Desiccant wheel products have end user prices that vary with the size and complexity of the unit and range from \$6 to \$10 per CFM of delivery air. In the 4000 Series air delivery range, the Munters' model HR20N with heat recovery wheel and evaporative cooler is priced at \$24,000 which equates to \$8 per CFM of processed air. As Munters attempts to compete more on its engineering assistance than on price, the comparisons have been based upon a desiccant wheel system selling for \$7 per CFM.

In contrast to the other devices, construction of the stages found in the *GENIUS*<sup>®</sup> dehumidifier and the regenerator are identical. This includes the media, liquid distribution systems, basins, pumps, and pathways for the migration of the desiccant. In dimension, the two units are the same height, both are of two chambers: in the dehumidifier the upper chamber contains water while the lower chamber is for desiccant. In the regenerator, two identical chambers are stacked owing to the greater air flow required. Comparison of these systems is found in the following table. Also

included is an approximate energy use factor using the *GENIUS*® machine as a basis. Energy usage of the competing systems is many times higher thus the *GENIUS*® waste heat system is the only system qualifying for rebates bringing its average price to \$1,050 per ton. The savings of \$409 per year indicate a payback of 2.5 years. In moderate climates with shorter summers and lower humidity the operating hours could reduce to 2,500 per year offering a payback of 3.5 years.

#### Product Comparisons

COMPANY	PRODUCT	PRICE PER TON	X ENERGY USE
<b>Kathabar</b>	<b>Industrial</b>	<b>Made to Order</b>	<b>6</b>
<b>AAONI</b>	<b>Commercial</b>	<b>\$1,500 \$1,800</b>	<b>5</b>
<b>Munters</b>	<b>Commercial</b>	<b>\$1,700 \$2,200</b>	<b>7</b>
<b>GENIUS</b>	<b>Commercial</b>	<b>\$1,100 \$1,300</b>	<b>1</b>

## TECHNICAL DETAIL ON WASTE HOT AIR PERFORMANCE

### United States Standard Test Condition (ARI-A)

#### Heat Removal Requirements of a One Ton Conventional A/C

The amount of air required by the condenser is the dissipation of heat removed by the compressor from the building plus the inefficiencies attributed to this removal.

Computation involves examination of the energy contained in entering ambient air compared with the energy of the air discharged from the condenser.

Outside Air Condition is 95° / 75° (dry bulb and dry bulb temperatures), 0.0142 lb/lb (pounds of water per pound of air), 38.4 Btu/lb (energy per pound of air), 40% RH (relative humidity)

Air Exiting A/C Air Cooled Condenser is 115° / 80°, 0.0142 lb/lb, 43.3 Btu/lb, 22% RH

Per ton A/C heat removal equals 100% of 12,000 Btu (13,200 Btu/hr of waste heat)

Pounds of air required is 43.3 less 38.4 or 4.9 Btu removed per pound of air

Pounds of air then equals 13,200 Btu divided by 4.9 or 2,694 pounds of air per hour

Per minute is 2,694 divided by 60 equals 44.9 pounds or 665 CFM per Ton A/C at 14.8 cubic feet of air per pound

#### GENIUS Regenerator

The regenerator would consist of a four sector device accepting 674 CFM of hot air discharged by the conventional air cooled air conditioner. There would be no heat added to the air in its passage through the regenerator thus no need for heat exchangers. The activity would be completely adiabatic meaning that the air exchanges heat for moisture while the air maintains a consistent energy level.

Air Entering Regenerator 115° / 80°, 0.014 lb/lb 43.3 Btu per pound of air, 22% RH

Air Exiting Regenerator 102.5°, 0.0170 lb/lb, 43.3/lb Btu, 38% RH

Air Volume Exiting the Regenerator is 14.5 CFM per pound of air times 44.9 pounds or 651 CFM

Water removed per pound of air is 0.0170 less 0.0141 or 0.0029 pound water / pound of air

Water removed per hour is 2,694 pounds of air from the A/C times 0.0029 or 7.8 pounds

Equilibrium value of desiccant exiting regenerator is equal to an air stream of 28% RH based upon prior tests.

#### GENIUS Performance with Heat Supplied from a One Ton Conventional A/C

The dehumidifier consists of two chambers, each with four sectors. Desiccant flows counter-currently to an air stream in one chamber while the other chamber receives this heat of dehumidification by heat exchange with an air stream flowing in the opposite direction (discharge from the building space) and then reduced to its wet bulb condition by continual saturation.

Return Air from Building is 80° / 67° 0.011 lb/lb, 31.2 Btu/lb, 50% RH (ARI-A test conditions)

Air Delivery Temperature 80° / 61.1° 0.0071 lb/lb, 27.1 Btu/lb, 33% RH

Moisture Removal .0142 lb/lb outside air condition less 0.0071 lb/lb yields 0.0071 pound of water per pound of air reduction.

Regenerator removal capacity of 7.8 pounds of water divided by the 0.0071 reduction gives an air flow of 1,116 pounds per hour, or 18.6 pounds per minute. CFM Flow based on 13.7 cubic feet per pound of air gives 255 CFM. Energy Removal is outdoor air enthalpy of 38.4/lb less delivered air enthalpy of 27.1 or 11.3 Btu per pound of air. Enthalpy Reduction equals 1,116 pounds of air times 11.3 or 12,600 Btu (1.05 ton) per hour or 3,603 watt hours. Moisture Removal is 0.0071 lb/lb times 1,116 pounds of air or 7.91 pounds. At 1,000 Btu per pound this is equal to 7,910 Btu. Water removal is then 63% of the cooling capacity. Air Flow per Ton is 268 divided by 1.05 tons or 255 CFM Total Cooling and Dehumidification combination with a one ton conventional air conditioner increases performance to slightly over 2 ton.

### Energy Efficiency of GENIUS

Parasitic electrical usage consists of pumps and fans. The 4 pumps for each tier of the 2,700 CFM dehumidifier required 300 watts. For six pumps the total is 450 watts. There are two tiers in each the dehumidifier and regenerator giving a total of 1,800 watts. The extent of augmentation needed beyond that available by the conventional air conditioner. It is assumed that a boost of 0.25 water column would prove sufficient. A 2,800 CFM blower mates with a quarter HP motor (186 watts). If both the chambers required the fan addition the electrical consumption would be 372 watts, A 7,000 CFM fan for the regenerator requires 466 watts. In total, electrical usage could increase to 2,638 watts. The 2,700 capacity dehumidifier when divided by 255 CFM per ton gives a tonnage of 10.6. The 2,638 watts divided by 10.6 yields 249 watts per ton. Cooling of 3,603 watts divided by 249 gives a COP of 14.5 and an EER of 51

### Water Usage

The waste heat air conditioner evaporates water in the second chamber that is discharging air from the building space. The amount of water evaporated is equal to the heat removed from the delivery air (in this case 38.4 Btu/lb entering less 27.1 Btu/lb at delivery. Air conditions at exhaust from the chamber are the entering air of 32.2 Btu/lb plus 11.3 or 43.6 Btu. As the air is saturated its moisture content has increased from 0.011 to 0.022, a gain of 0.11. This gain times the air flow per ton (1,063 pounds per hour) amounts to 11.7 pounds of water (1.4 gallon) evaporated per hour. A 12 EER rated compressor uses 1 kW per hour. A report by NREL, "Consumptive Water Use for U.S. Power Production", 2003, page 4, states that average consumption of water equals 2 US gallons per kWh or 16.7 pounds. Offsetting this is the electrical usage of the waste heat unit of 300 watts or 5.0 pounds water at the generation level. The balance is total water related to the waste heat unit of 16.6 pounds versus the usage of 16.7 pounds by a compressor system. Water usage is viewed to be neutral.

### **Miami Design Conditions**

#### Heat Removal Requirements of a One Ton Conventional A/C

Outside Air Condition is 91° / 77°, 0.0167 lb/lb, 4 0.4 Btu/lb, 54% RH

Air Exiting A/C Air Cooled Condenser is 111°/ 81.7 °, 0.0167 lb/lb, 45.2 Btu/lb, 29% RH  
Per ton A/C heat removal equals 100% of 12,000 Btu (13,200 Btu/hr waste heat)  
Pounds of air required is 45.2 less 40.4 or 4.8 Btu removed per pound of air  
Pounds of air then equals 13,200 Btu divided by 4.8 or 2,750 pounds of air per hour  
Per minute is 2,750 divided by 60 equals 45.8 pounds or 687 CFM per Ton A/C

### GENIUS Regenerator

Air Entering Regenerator is 111°/ 81.7°, 0.0167 lb /lb, 45.2 Btu/lb, 29% RH  
Air Exiting Regenerator is 98°, .0196 lb/lb, 45.2 B tu/lb, 50% RH  
Air Volume Exiting the Regenerator is 45.8 pounds times 14.5 or 664 CFM  
Water removed per pound of air is 0.0196 less 0.0167 or 0.0029 pound water per pound of air  
Water removed per hour is 2,750 pounds of air from the A/C times 0.0029 or 8 pounds  
Equilibrium value of desiccant exiting regenerator is equal to an air stream of 34% RH.

### GENIUS Performance with Heat Supplied from a One Ton Conventional A/C

Return Air from Building is 80°/ 67° 0.011 lb/lb, 31.2 Btu/lb, 50% RH  
Air Delivery Temperature is 80°/ 63.1° 0.0085 lb/l b, 28.5 Btu/lb, 39% RH  
Moisture Removal is 0.0167 lb/lb outside air condition less 0.0085 lb/lb yields 0.0082 pound of water per pound of air reduction.  
Regenerator removal capacity of 8 pounds of water divided by 0.0082 lb/lb reduction gives an air flow of 976 pounds per hour, or 16.3 pounds per minute.  
CFM Flow based on 13.9 cubic feet per pound of air gives 246 CFM.  
Energy Removal is outdoor air enthalpy of 40.4 less delivered air enthalpy of 28.5 or 11.9 Btu per pound of air.  
Enthalpy Reduction equals 976 pounds of air times 11.9 or 11,614 Btu (0.97 ton) per hour or 3,318 watt hours.  
Moisture Removal is 0.0082 lb/lb times 976 pounds of air or 8 pounds. At 1,000 Btu per pound this is equal to 8,000 Btu. Water removal is then 69% of total cooling capacity.  
Total Cooling and Dehumidification combination with a one ton conventional air conditioner increases performance to about 2 tons.

### Energy Efficiency of GENIUS

Electrical usage has been developed at 2,638 watts. As the air flow is higher in Miami, the capacity is reduced to 10 tons or 264 watts per ton. With a cooling capacity of 3,318 watt hours the COP is 12.6 or an EER of 44.

### **Phoenix 1% Design Condition**

#### Heat Removal Requirements of a One Ton Conventional A/C

Outside Air 108°/ 70°, 0.0071 lb/lb, 33.7 Btu/lb, 13.6% RH  
Air Exiting A/C Air Cooled Condenser 128°/ 75.3°, 0.0071 lb/lb, 38.7 Btu, 7.8% RH  
Per ton A/C heat removal equals 100% of 12,000 Btu (13,200 Btu/hr waste heat)  
Pounds of air required is 38.7 less 33.7 or 5.0 Btu/lb removed per pound of air  
Pounds of air then equals 13,200 Btu divided by 5.0 or 2,640 pounds of air per hour

Per minute is 2,640 divided by 60 equals 44 pounds or 656 CFM per Ton A/C at 14.9 CFM per pound of air

#### GENIUS Regenerator

Air Entering Regenerator 128°/ 75.3°, 0.0071 lb/lb , 38.7 Btu/lb, 7.8% RH

Air Exiting Regenerator 121°, 0.0087 lb/lb, 38.7 Btu/lb, 11.6% RH

Air Volume Exiting the Regenerator is 14.8 times 44 pounds or 651 CFM

Water removed per pound of air is 0.0087 less 0.0071 or 0.0026 pound water / pound of air

Water removed per hour is 2,640 pounds of air from the A/C times 0.0026 or 4.2 pounds

Equilibrium value of desiccant exiting regenerator is equal to an air stream of 12.8% RH.

#### GENIUS Performance with Heat Supplied from a One Ton Conventional A/C

Return Air from Building is 80°, 67° 0.011 lb/lb, 31.2 Btu/lb, 50% RH

Air Delivery Temperature 80°/55.4° 0.0038 lb/lb, 23.4 Btu/lb, 17.8% RH

Moisture Removal 0.0071 lb/lb outside air condition less 0.0038 lb/lb yields 0.0033 pound of water per pound of air.

Regenerator removal capacity of 4.2 pounds of water divided by 0.0033 reduction gives an air flow of 1,272 pounds per hour, or 21.2 pounds per minute.

CFM Flow based on 13.8 cubic feet per pound of air gives 292 CFM.

Energy Removal is outdoor air enthalpy of 33.7 less delivered air enthalpy of 23.4 or 10.3 Btu per pound of air.

Enthalpy Reduction equals 1,292 pounds of air times 10.3 or 13,102 Btu (1.09 ton) per hour or 3,743 watt hours.

Moisture Removal is 0.0033 lb/lb times 1,292 pounds of air or 4.3 pounds. At 1,000 Btu per pound this is equal to 4,300 Btu. Water removal is then 33% of total cooling capacity.

Air Flow per Ton equals 268 CFM per ton.

Total Cooling and Dehumidification combination with a one ton conventional air conditioner increases performance to 2 ton.

#### Energy Efficiency of GENIUS

Electrical usage has been developed at 2,638 watts. As the air flow is higher in Phoenix than at ARI-A conditions, the capacity is reduced to 10.1 tons at 268 watts per ton. With a cooling capacity of 3,743 watt hours divided by 268 the COP is 14 or an EER of 44.