

GENIUS AIR CONDITIONERS

ENERGY UTILIZATION COMPARISONS

BACKGROUND

As the *GENIUS* air conditioners utilize 100% outside air in their operation, calculation of energies contained in this air and other air streams is required. It is equally important to examine conventional compressor or chiller based air conditioners in terms of air energies. Thus, a review of psychrometrics with emphasis on energy calculation is central to understanding the *GENIUS* systems. These include:

ENTHALPY

Enthalpy is defined as energy per unit mass and is commonly used to define the internal energy of moist air. On the psychrometric chart, enthalpy is expressed in terms of energy per weight of dry air. Enthalpy is presented in United States based psychrometric charts employing British thermal units (Btu's) per pound of dry air plus associated moisture (I-P units). One thousand Btu's, for example, are required to evaporate one pound of water. The energy content of air is based upon a number of factors.

Density of air is the total mass of a sample to the total volume of this sample. For moist air, water vapor and air are included in the totals. The number of cubic feet of air per pound varies with its temperature and its moisture content (which may be expressed in terms of relative humidity or the ratio of mole fraction of water vapor in a given sample to the mole fraction in a saturated air sample at the same temperature and pressure). For instance, 70°F and 50% relative humidity air has the same density as 65°F, 100% relative humidity air, that being a specific volume of 13.5 cubic feet per pound. At higher temperatures the density is less, and more air is required, for example, 15 cubic feet weigh a pound at 110°F and 50% relative humidity.

The energy held in air is dependent upon its temperature and its moisture content. The temperature is expressed in degrees F while the moisture content is given as pounds of moisture per pound of air. In common psychrometric charts used in the United States, (for example ASHRAE Chart No.1) air temperature is found along the horizontal base line while moisture content is given (to three decimal places) on the right hand vertical. This may be measured either in pounds of moisture per pound of air or in grains of moisture per pound of air. (7 grains = .001 lb) This presentation uses pounds per pound (lb/lb). Knowing the moisture content allows determination of the relative humidity of the air. For example, if the moisture content is 0.0142 pounds of moisture per pound of air (lb/lb air) and the temperature is 95°F, the relative humidity (RH) is found by moving left on the 0.0142 line until it intersects the vertical 95°F temperature line which occurs at 40% RH (the curved lines in the table). More commonly the temperature and the RH are known, for example, 80°F, 50%. Finding this point on the chart and moving horizontally to the right will give the moisture content, in this case 0.01097 lb/lb air. Another conventional method of presenting data is stating the dry-bulb (DB) and wet-bulb (WB) temperatures. Dry-bulb temperature of air can be read on a standard thermometer thereby obtaining its thermal state while wet-bulb temperature is the equilibrium temperature reached as water evaporates from a

thoroughly wetted thermometer wick into an air stream. The 80°F, 50% example above can be expressed as 80°F DB and 66.7°F WB. The WB is the saturation temperature of the air (100% relative humidity). The relative humidity of 80°F DB, 66.7°F WB would be found by locating 66.7°F saturated along the left curved portion of the chart and following it on the sloping straight lines (equal enthalpy or energy) until it intersects with the vertical 80°F DB temperature line.

Enthalpy of the air is determined from the sloping straight line (or broken straight lines on some charts) on the left side of the chart. Energy in the 80°F, 50% RH air example would be the same anywhere along the sloping straight line (including 66.7°F web bulb). Extending this line further left gives an enthalpy measurement of 31.23 Btu's per pound of air. In the other example, 95°F, 40% RH air would be the same as listing 95°F DB, 75°F WB, and looking further left of the WB location would designate an enthalpy of 38.46 Btu/lb air.

While air temperature and air energy are generally associated, in working with a psychrometric chart, it becomes evident that a change in moisture content has a very significant impact. As presented earlier, 95°F, 40% RH air (0.0142 lb moisture per lb air) has an energy content of 38.46 Btu/lb air. Holding moisture content the same, this air at 85°F contains energy of 36.0 Btu/lb air, a reduction of 2.46 Btu per pound of air. Conversely, reducing the water content by only 0.002 lb/lb air has the same effect on energy content.

GROSS AND NET COOLING CAPACITY

Gross cooling capacity relates to the difference between the energy contained in outdoor air and the energy contained in air delivered to the interior space. Net cooling capacity is the difference in the energy content of recycled building (return) air and that of delivery air.

CALCULATION ASSUMPTIONS

The assumptions made are that the amount of outside air needed is 20 cubic feet per minute (cfm) per person (ASHRAE Standard 62-89) and a density of 7 people per 1,000 square feet of usable floor area for an office building. In an educational setting, the assumption is 30 persons per 1,000 square foot classroom. The total air flows per square foot of net building area are assumed to average 1 cfm per square foot (0.75 cfm for interior and 1.25 cfm along the building perimeter). For presentation purposes, density of air is assumed constant at the ARI-A indoor air conditions, or 13.89 cubic feet per pound.

DELIVERY TEMPERATURES

Compressor based or combination chiller / air handler systems are assumed to deliver air at 55°F 100% RH (air having energy content of 23.2 Btu/lb air and 0.00923 lb moisture per pound of air. In contrast, the *GENIUS* thermal based air conditioners (those using natural gas, hot water, etc. to remove water from the desiccant) supplies air at 22.6 Btu/lb air with 0.0044 lb moisture per pound of air. With no moisture added the supply air, it equates to 74°F at 25% RH, or depending upon the RH of the interior space, the delivery air may have moisture added to saturation at approximately

54°F. The *GENIUS* hybrid unit (combination compressor / desiccant) supplies air at 0.0083 lb/lb air at 62°F and 70% RH.

MOISTURE REMOVAL

The conventional system can remove 0.00497 lb/lb air (0.0142 to 0.00923) from the outdoor environment while the *GENIUS* thermal-based unit has the capability of 0.0098 lb/lb air (0.0142 to 0.0044). The *GENIUS* hybrid system can reduce an air stream to 0.0083 lb/lb air or 0.0059 lb/lb air reduction.

When reviewing the American Refrigeration Institute (ARI-A) test conditions, the indoor air has a moisture content of 0.011 lb/lb air (actually 0.01097) while indoor delivery using conventional systems contains a moisture content of 0.00923 lb/lb air. The difference is only 0.00174 lb/lb air. At an air flow of 1 cfm per net square foot of space, this equals the removal of 0.0075 pounds per square foot per hour (a number equal to 0.12 ounces, or 3.4 grams). In many cases, for example caused by air infiltration in a hot and humid climate, this is inadequate. As conventional units remove moisture by its condensation from air as it passes over refrigerated coils, the resultant air is already saturated. Providing a margin of safety is thus difficult for design engineers. They can do nothing in which case the building interior can become too humid or they can oversize equipment in which case the building may operate at too cold a temperature. More sophisticated options such as super-cooling and then reheating the air are often rejected by building owners because of capital and operating costs.

In contrast, the *GENIUS* thermal-based equipment allows a reduction from indoor conditions (0.011 lb/lb air) to 0.0044 lb/lb air. This reduction amounts to 0.0066 lb/lb air or about four times greater than a compressor system operating at the ARI-A test condition. The *GENIUS* hybrid compressor / desiccant unit reduces the moisture content by 0.0027 lb/lb air (0.011 to 0.0083) or an amount 55% greater than a compressor system operating at the ARI-A standard.

COMPARISON OF CONVENTIONAL TO *GENIUS* HYBRID SYSTEM AT ARI-A

The American Refrigeration Institute (ARI-A) test standard utilizes 95°F, 40% RH for its outdoor condition and 80°F, 50% RH for the indoor space. The comparison that follows relates to chiller, or compressor energy usage. Excluded from the calculations are air movement devices (both within the building and without) and liquid movement associated with the *GENIUS*® units and with the chillers. Conventional systems typically use the same power as *GENIUS*® for inside air movement and more for external air movement than *GENIUS*® uses for liquid movement.

Office Building

Working with an office building of 100,000 square feet, the above assumptions require 100,000 cfm with 14,000 cfm of outside air (700 persons times 20 cfm).

The conventional system would circulate 86,000 cfm. This cfm divided by 13.89 cubic feet of air per pound times 60 minutes per hour gives 371,500 pounds of air per hour. This poundage times 31.23 less 23.2 or 8.03 Btu/lb air energy change yields 2,983,100 Btu/hr. Supply of outside air would amount to 14,000 cfm divided by 13.89 cubic feet per pound times 60 or 60,500 lb/hr air. The energy differential is 38.46 less 23.2 or 15.26 Btu/lb, which, times the pounds of air per hour, is 923,200 Btu/hr. Employing a chiller with a coefficient of performance (COP) of 4.5, the energy required for the circulated air would be 662,900 Btu/hr and 205,200 for conditioning outside air. In total, this amounts to 868,199 Btu/hr or 254 kW with 60 kW related to outside air treatment and 194 kW demanded for circulated air.

Conventional systems supplying 86,000 cfm circulated air at 194 kW plus employment of 5 *GENIUS* units (2,750 cfm each using compressor energy of 7.2 kW) or 36 kW would present a circulated and outside air total energy usage of 230 kW. As the outside air component represents 26% of the chiller load, the chilled water supply loop along with the chiller and cooling tower size could be substantially reduced.

In summary, total energies are 254 kW for the conventional system and 230 kW for the combination system, thus the conventional system consumes 10% more energy than does the *GENIUS*®/conventional system combination. In comparing energy used only for fresh air supply, the conventional system required 60 kW while the combination utilized 38 kW. *The conventional system thus demanded 58% more energy.*

It should be noted that the conventional system circulating 100% of building air would consume 221 kW (432,000 lb/air/hr times 8.03 Btu/lb energy differential)) compared with 230 kW for the combination conventional / *GENIUS*® system. *When incorporating GENIUS® air conditioners, the fresh air supply can be supplied at only a 4% operating cost penalty.*

Classroom Facility

Examining a school building of 30 class rooms or 30,000 square feet of net classroom area, an air volume of 30,000 cfm provided with 18,000 cfm of outside air (30 classrooms times 30 occupants or 900 persons times 20 cfm each) would be necessary.

A conventional system would circulate 12,000 cfm divided by 13.89 cubic feet per pound times 60 minutes or 51,800 pounds of air per hour. Air energy reduction would equate to 31.23 less 23.2 or 8.03 Btu/lb energy change yielding 416,000 Btu/hr. Supply of outside air would be 18,000 cfm divided by 13.89 cubic feet per pound times 60 or 77,800 lb air per hour. Given an energy differential of 38.46 less 23.2 or 15.26 Btu/lb totals 1,186,500 Btu/hr. Employing compressors with a COP of 3.5, energy required to treat circulated air would be 118,900 Btu/hr or 35 kW and 339,000 Btu/hr related to outside air treatment. Total energy input would be 134 kW.

Given the energy demanded to treat the outside air, a heat exchange device might be specified. The temperatures entering each side of this device would be 95°F and 80°F. At 65% efficiency, the device would reduce supply air temperature by 9°F to 86°F however the air would continue to contain 0.0142 lb moisture per lb of air. From the psychrometric chart, its energy content is 36.2 Btu per pound of air. Energy treatment of outside air now becomes 36.2 less 23.2 or 13 Btu/lb air. Given the 18,000 cfm outside air requirement (77,800 lb/hr air), energy used would be 1,014,400

Btu/hr. With a compressor efficiency of 3.5, energy utilized would be 289,800 Btu/hr or 85 kW. The reduced total, including recycled air, would be 120 kW.

A system using conventional equipment for the recycled air (plus *GENIUS*® for outside air) would have the same energy requirements for recycled air (35 kW). The outside air treated would be 18,000 cfm. Aggregate compressor electrical usage plus liquid pumping requirements (no chiller liquid pumping offset is involved) for *GENIUS*® units would be 57 kW yielding a total of 92 kW including the recycled air component.

In comparison, total energies are 120 kW for the conventional system with a heat recovery device and 92 kW for the combination system. *The conventional system consumes 30% more energy than does the GENIUS®/conventional system combination.*

Since outside air supply represents two thirds of the energy consumed by the combination system, total utilization of GENIUS® units might be preferred owing to installation simplicity. In treating the total 30,000 cfm with outside air, the electrical usage would be 95 kW.

COMPARISON AT ELEVATED OUTDOOR TEMPERATURE AND HUMIDITY (CONVENTIONAL TO *GENIUS* HYBRID SYSTEM)

The following evaluations utilize 95°F DB, 83.3°F WB, having a moisture content of 0.022 pounds of moisture and an enthalpy of 47.3 Btu's per pound of air. Indoor conditions remain at 80°F, 50% RH. The office building and classroom facility have the same cooling and outside air requirements.

Office Building

Employing the chiller with a COP of 4.5, energy required for recirculated air remains at 662,900 Btu/hr. Supply of outside air would continue at 60,500 lb/hr air. The new outside air energy differential is 47.8 less 23.2 or 24.6 Btu/lb, or a total of 1,488,300 Btu/hr. Employing the chiller, energy required for conditioning outside air would be 330,700 Btu/hr. The total air conditioning requirement would be 993,600 Btu/hr or 291 kWh with 97 kWh related to outside air treatment

Conventional systems supplying 86,000 cfm circulated air at 194 kWh plus employment of 5 *GENIUS* units (2,750 cfm each using compressor energy of 8.6 kWh) or 43 kWh would present a circulated and outside air energy usage of 237 kWh. As the outside air component represents 33% of the chiller load, the chilled water supply loop along with the chiller and cooling tower size could be substantially reduced.

In summary, total energies would be 291 kWh for the conventional system and 238 kWh for the combination system, thus the conventional system consumes 22% more energy than does the *GENIUS*/conventional system combination. In comparing energy used only for fresh air supply, the conventional system required 97 kWh while the combination utilized 43 kWh. *The conventional system demanded over twice the energy consumption of the GENIUS system for treating the outside air component.*

Classroom Facility

Employing compressors with a COP of 3.5, energy required to treat circulated air would remain at 35 kW. Supply of outside air would stay at 18,000 cfm or 77,800 lb air per hour. Outside air energy reduction would be 47.3 Btu/lb to 23.2 or a reduction of 24 Btu/lb times 77,000 or 1,848,000 Btu/hr. At a compressor COP of 3.5 the energy required would be 528,000 Btu/hr or 155 kW. Total energy input would be 190 kW.

A heat exchange device might be specified to reduce supply air temperature to 86°F thereby providing an energy content of 44.8 Btu's per pound of air. Energy treatment of outside air now becomes 44.8 less 23.2 or 21.6 Btu/lb air. Given the 18,000 cfm outside air requirement, energy needed would be 1,663,200 Btu/hr. With a compressor efficiency of 3.5, energy utilized would be 475,200 Btu/hr or 139 kW. The reduced total, including recycled air, would be 174 kW.

Treatment of outside air (18,000 cfm) by the *GENIUS*® hybrid units would necessitate electrical usage (compressors plus pumps) of 66 kW yielding a total of 101 kW including the recycled air component.

In comparison, total energies would be 174 kW for the conventional system with a heat recovery device and 101 kW for the combination system. *The conventional system consumes 72% more energy than does the GENIUS®/conventional system combination.*

Total utilization of GENIUS® units might be preferred owing to installation simplicity. In treating the total 30,000 cfm with outside air, the electrical usage would be 110 kW.

COMPARISON AT REDUCED SEASONAL OUTDOOR HUMIDITY CONDITIONS (CONVENTIONAL TO GENIUS HYBRID SYSTEM)

In many ambient outside air conditions, the *GENIUS*® hybrid air conditioner provides cooling without activation of its compressor system. This would be in contrast to conventional air conditioning systems where compressor activation is generally needed whenever cooling is required.

The hybrid air conditioner is produced in two configurations. These include operation as an air conditioner and dehumidifier in climates having conventional to high humidity characteristics, and as an air conditioner operating in climates that, for a significant portion of the cooling season, do not have a significant humidity issue. The difference in the two products is the manner of supply air treatment.

When servicing locations having relatively high seasonal moisture content in the outside air, the *GENIUS*® hybrid air conditioners employ an energy exchange media to exchange outside air heat and humidity with air exiting the indoor space. The efficiency of this energy exchange ranges from 60% to 65% based upon the energy difference in the outside and return air streams. In areas having only limited periods of high humidity, the *GENIUS*® hybrid air conditioners utilize a staged evaporative cooling device that is capable of reducing the outdoor air temperature to within 2 °F of its dew point. Without the compressor system operating, the absolute humidity of this air is not altered. When needed, the combination compressor /desiccant system operates as described above.

Selection of the *GENIUS*® hybrid air conditioner with the staged indirect evaporation device depends upon a seasonal analysis of the cooling season and determining the portion that has acceptable moisture content in the outside air. For illustration purposes, the level is assumed to be that obtained with a conventional air conditioner delivery condition of 55°F saturated or 0.0092 pounds moisture per pound of air. At a temperature at 2°F above the dew point, the hybrid supply air would be 57°F, 0.0092 moisture or 23.7 Btu's per pound of air. The outside air enthalpy at this moisture content would be 30.5 Btu's per pound of air at 85°F DB, 31.7 at 90°F DB, and 32.9 at 95° DB. The cooling obtained for the office building and the classroom facility is presented in the following table.

Application	Outside DB 85°F	Outside DB 90°F	Outside DB 95°F
Office Building	411,400 Btu/hr	484,000 Btu/hr	556,600 Btu/hr
Classroom Facility	529,000 Btu/hr	622,400 Btu/hr	715,800 Btu/hr
Classroom (All Cooling)	882,000 Btu/hr	1,038,000 Btu/hr	1,192,200 Btu/hr

As the *GENIUS*® hybrid would not consume compressor energy during these periods, hourly energy savings compared with a conventional air conditioning system are presented below. In line with the above examples, the office building is assumed to contain a chiller having a COP of 4.5 while the classroom facility is deemed to be cooled by an air-cooled compressor system with a COP of 3.5.

Application	Outside DB 85°F	Outside DB 90°F	Outside DB 95°F
Office Building	27 kW	32 kW	36kW
Classroom Facility	44 kW	52 kW	60 kW
Classroom (All Cooling)	74 kW	87 kW	100 kW

COMPARISON (CONVENTIONAL TO *GENIUS*® THERMAL-BASED SYSTEMS)

AIR CONDITIONING OPERATION

Energy Usage

Usage of thermal energy is directed toward removal of moisture absorbed by the desiccant as it passes through the dehumidifier. The water load varies considerably and is directly related to outdoor conditions. For instance, the ARI-A condition of 95°F, 40% RH contains moisture of 0.0142 lb/lb air, an outside condition of 90°F, 60% RH has a moisture content of 0.01835 lb/lb air, while a moderate condition of 85°F, 45% RH contains only 0.01162 lb/lb air. Were the thermal systems to reduce the air delivery condition to that provided by conventional systems (0.00923 pounds moisture per pound of air), the removal respectively be 0.00497, 0.0912, and 0.00239 pounds per pound of air. In actuality, the thermal based systems can deliver air to 0.0044 which allows removal of 0.0098, 0.0141, and 0.0074 pounds moisture per pound of air.

Electrical energy utilization is directed to powering blowers (outside and return air), and pumps in the air conditioner and in the regenerator. For the air conditioner portion, usage totals 3.6 kW when processing 2,750 CFM and 5.2 kW for air conditioners supplying 4,000 cfm. The electrical requirements for the thermal regenerator are 0.9 kW.

Regenerator Efficiencies

GENIUS® desiccant regenerators vary in efficiency in direct relationship to the thermal temperature provided by the fuel. The multi-effect units requiring high grade input such as natural gas or propane have an overall usage of 680 Btu's per pound of moisture removed from the desiccant. Regenerators provided with maximum temperatures of 190°F, such as from a gas turbine coolant or hot water supply, require 1,150 Btu's to evaporate one pound of water from desiccant. Lower temperature supply, such as maximum 165°F coolant from a Stirling engine would need 1,400 Btu's to evaporate one pound of water.

Office Building Comparison

As shown above, the conventional air conditioner (chiller) utilized 205,200 Btu's per hour for treatment of the fresh air portion of the building load at the ARI-A condition. The *GENIUS*® regenerator would need to remove 301 pounds of water per hour (60,500 pounds of air times 0.00497) to equal the removal rate provided by conventional air conditioners. This would require 204,700 Btu's of natural gas (approximately 2 therms), or 346,200 Btu's of low temperature heat. At actual delivery conditions of 0.0044 pounds of moisture per pound of air, natural gas usage would be 4.1 therms, or the low grade heat requirement would be 696,800 Btu's per hour.

Class Room Facility Comparison

The 30 classrooms needed 273,400 Btu's per hour to supply the fresh air requirement (energy exchange device coupled with a compressor having a COP of 3.5). Water removal by a *GENIUS*® regenerator would total 387 pounds per hour (77,800 pound of air per hour times 0.00497 lb/lb air) in order to match conventional equipment removal rates. Energy would be 263,160 Btu's of natural gas or 445,000 Btu's of low grade heat. At actual *GENIUS*® delivery conditions of 0.0044 pounds of moisture per pound of air, natural gas usage would be 5.3 therms, or low grade heat usage of 891,200 Btu's per hour would be required

Energy Cost Comparisons

Comparisons to the *GENIUS*® thermal based units are complex owing to a lack of standards when contrasting all electric units to systems that also employ natural gas, hot water, or low grade heat available from CHP or other heat systems. One common denominator would be price. Using this comparison, natural gas is generally priced at one-fourth that of electricity on a thermal basis. At the other extreme, waste energy from a gas-driven engine would have no value. An aggregate macro approach is to place the comparison on an electricity equivalent basis. In the United States the general assumption is that 30% of the energy actually consumed by an electrical generation facility is available to the end user (a factor of 3.3). In analyzing utility rates from a number of locals, the operational cost savings are generally 50% or higher not including demand charges faced by many commercial customers at spot conditions utilized in this paper. As the boiler demand is directly related to the moisture absorbed by the desiccant, seasonal thermal usage will be significantly reduced.

VENTILATION OPERATION

The thermal-based air conditioner is equipped with an indirect evaporative cooler and variable saturator. Without operating the desiccant dehumidifier, the indirect cooler is capable of reducing the temperature of the outside air by 75% of the difference between the outside air dry bulb temperature and the wet bulb temperature of the return air from the building. In the example used herein, were the outside air 95°F DB and the return air 67°F WB (80°F and 50% RH), the temperature depression would be 21°F, thus reducing the outside temperature to 74°F.

Energy Usage

Electrical energy utilization is directed to powering blowers (outside and return air), and pumps in the air conditioner and in the regenerator. For the air conditioner portion, usage totals 2.3 kW when processing 2,750 cfm and 3.2 kW for air conditioners supplying 4,000 cfm (including air movement and pumps utilized in the indirect evaporative cooler).

Performance

Using the 95°F outside temperature as a basis, the following results can be tabulated:

Outside Air Moisture (lb/lb air)	Outside Air Enthalpy (Btu/lb air)	Supply Air 75% Sat. (°F)	Supply Air Moisture (lb/lb air)	Supply Air Enthalpy (Btu/lb air)
0.007	30.5	63	0.0092	25.4
0.008	31.6	65	0.0099	26.5
0.009	32.7	67	0.010	27.6

As the *GENIUS*® desiccant system would not need to be utilized during these periods, the energy savings compared with a conventional air conditioning system are presented below. In line with the above examples, the office building is assumed to contain a chiller having a COP of 4.5 while the classroom facility is deemed to be cooled by an air-cooled compressor system with a COP of 3.5.

Application	Air Flow (lb/hr)	Energy Saving
Office Building (Outside Air)	60,600	20 kW
Classroom Facility	88,800	33 kW
Classroom (All Cooling)	129,600	50 kW

Specifications and operational data pertaining to the *GENIUS* air conditioners are constantly being refined and may be altered at any time without notice.

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