I&I FINAL REPORT
TO THE U.S. DEPARTMENT OF ENERGY

Project Title: **High-Efficiency Variable Dehumidification for Air Conditioners: ClimaStat™**

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Executive Summary

The results of this project would absolutely have been impossible without DOE funding, and the technical and marketing assistance from the U.S. DOE personnel listed on the title page of this report. Because of air-conditioning manufacturer's primary focus on cost control and production volume, any new air-conditioning technology must be well developed and proven to even be considered. R&D and testing resources within individual air-conditioning technology and manufacturing companies have been spread thin for several years, making outside funding crucial.

The project goal was to produce a production prototype of a highly marketable energy efficient dehumidification technology applicable to standard air conditioning equipment. The small-to-medium sized HVAC market (less than 50-tons) is driven almost entirely by first cost; this is a major barrier to adoption of many new air conditioning technologies. High indoor humidity is unacceptable because it interferes with manufacturing such as paper and pharmaceuticals, and leads to mold growth, poor indoor air quality, and material damages. Forty-six percent of buyers indicate that low energy costs is their most important factor in choosing new air-conditioning equipment. Forty-one percent indicate that better humidity control is the characteristic in their systems most in need of improvement.

An engineering prototype was refined, and a production prototype was constructed based on a *Centurion* roof top package unit provided by Carrier Corporation, Syracuse NY. The *Carrier* prototype was operated under a wide range of psychrometric conditions. Test data was analyzed to identify refinements, which were implemented to further improve performance in an iterative procedure that resulted in a fully optimized technology. The latest results show an increase in dehumidification capacity of 56% with ClimaStat™ in full dehumidify mode vs. with ClimaStat™ off. Dehumidification improved by a factor of 1.7 to 1.9 @500 cfm/ton – meaning that the unit can provide nearly twice the water removal per unit of sensible cooling load. Performance testing results have been consistent, verifiable and repeatable.

Advantek has successfully developed the first low-cost technology offering significant improvement in both Seasonal Energy Efficiency (SEER) and comfort & humidity control. ClimaStat™ cost-effectively controls humidity on-demand and improves indoor air quality while reducing annual energy costs. Test data clearly shows that ClimaStat™ costs 20% to 60% less to operate than reheat – hot-gas reheat is the most common and least energy efficient type of dehumidification. ClimaStat™ is ready for market.

Project Description

1. Goals & Objectives

The project goal is to produce a light-commercial air conditioner production prototype that will lead to a highly marketable product offering significant improvement in energy efficiency and dehumidification performance for unitary air-conditioning. Because of air-conditioning manufacturer's primary focus on cost control, new air-conditioning technology must be well developed and proven to be of interest to their customers. The project is designed to take the articulated concept and mature it into a tenable engineering prototype ready for commercialization, with an emphasis and clear focus on marketing strategy and manufacturing costs. The project directly addresses cost effectively controlling humidity on-demand and improving indoor air quality while reducing seasonal energy use. Original objectives are as follows:

1. Refine and test the engineering prototype
2. Develop, test, and refine a production prototype
3. Demonstrate performance by field-testing
4. License the developed and proven technology

Compared with the original objectives, considerably more time and effort was put into testing and refining the production prototype, and towards commercialization via licensing the proven technology to a manufacturer(s). At the suggestion of DOE, the project team expended significant effort to test and integrate a variable speed motor controller (another I&I project) into our ClimaStat™ technology. As such, field-testing efforts are still underway at the time of this report.

2. Work Performed

Work completed included making needed improvements to the prototypes, performing a more detailed energy and economic analysis, and a good deal of testing to prove the viability of a pre-production prototype over the engineering prototype. Performance testing under standardized laboratory conditions confirmed advantages and facilitated comparison with competing technologies. Technical details were optimized based on test results. An overall production strategy with cost estimates and a description of potential manufacturing methods and licensing strategies was developed. Comments from owners, occupants, service technicians and other representatives of the target market were solicited. Critical field maintenance and support needs were identified and addressed.

An engineering prototype was refined, and a production prototype was constructed based on a *Carrier Centurion* roof top package unit. The *Carrier* prototype was operated under a wide range of psychrometric conditions. Test data was analyzed to identify refinements, which were implemented to further improve performance in an iterative procedure that resulted in a fully optimized technology. The production prototype was developed and constructed using readily available, standard air-conditioning components and parts.

All test results were analyzed in detail to confirm performance and advantages over competing technologies. Test data was used to calibrate a computer model of the technology, which was then used to (a) determine the effect on cooling capacity, sensible heat ratio, and energy efficiency, including a propagation of error/accuracy of results analysis, and (b) identify potential and/or needed improvements, and possible problems that needed to be overcome. Several significant additional improvements were made to the prototype before final lab testing. Testing

and refinement of the control hardware and sequence of operation for suitability for field installation was addressed. Improvements focused on further development of the control sequences and hardware in the *Carrier* production prototype, with iterative testing & data collection to optimize performance. The system includes temperature and damper position relays, a motor speed controller, and an electro-magnetic latch for the barometric damper.

Laboratory performance tests at Standard ARI conditions were performed on the production prototype. This work included numerous subtasks such as installation/calibration of instrumentation, apparatus verification and calibration, test runs, and data logging/conversion. Testing was performed with clean new filters, and then again with fully loaded filters, to assess the effect of filter pressure drop and the resulting reduction in airflow on performance of the ClimaStat™ technology. Test data was compared with published *Carrier* OEM performance data. The results verify performance as good as, or in some cases better than expected. The results were presented to product development and marketing teams at Carrier on March 28, 2007 and was very well received.

TEST MATRIX

#	Description	Desuperheater	Subcooler	Bypass Damper	R22 Solenoid	Hot Gas Bypass
1	Baseline	OFF	OFF	CLOSED	OPEN	OFF
2	Tests Desuperheater (DSH)	ON	OFF	CLOSED	OPEN	OFF
3	DSH + Subcooler (SBC)	ON	ON	CLOSED	OPEN	OFF
4	DSH + SBC + Bypass	ON	ON	OPEN	OPEN	OFF
5	DSH + SPC + Solenoid (SL)	ON	ON	CLOSED	CLOSED	OFF
6	DSH + SPC + SL + Hot Gas	ON	ON	CLOSED	CLOSED	ON

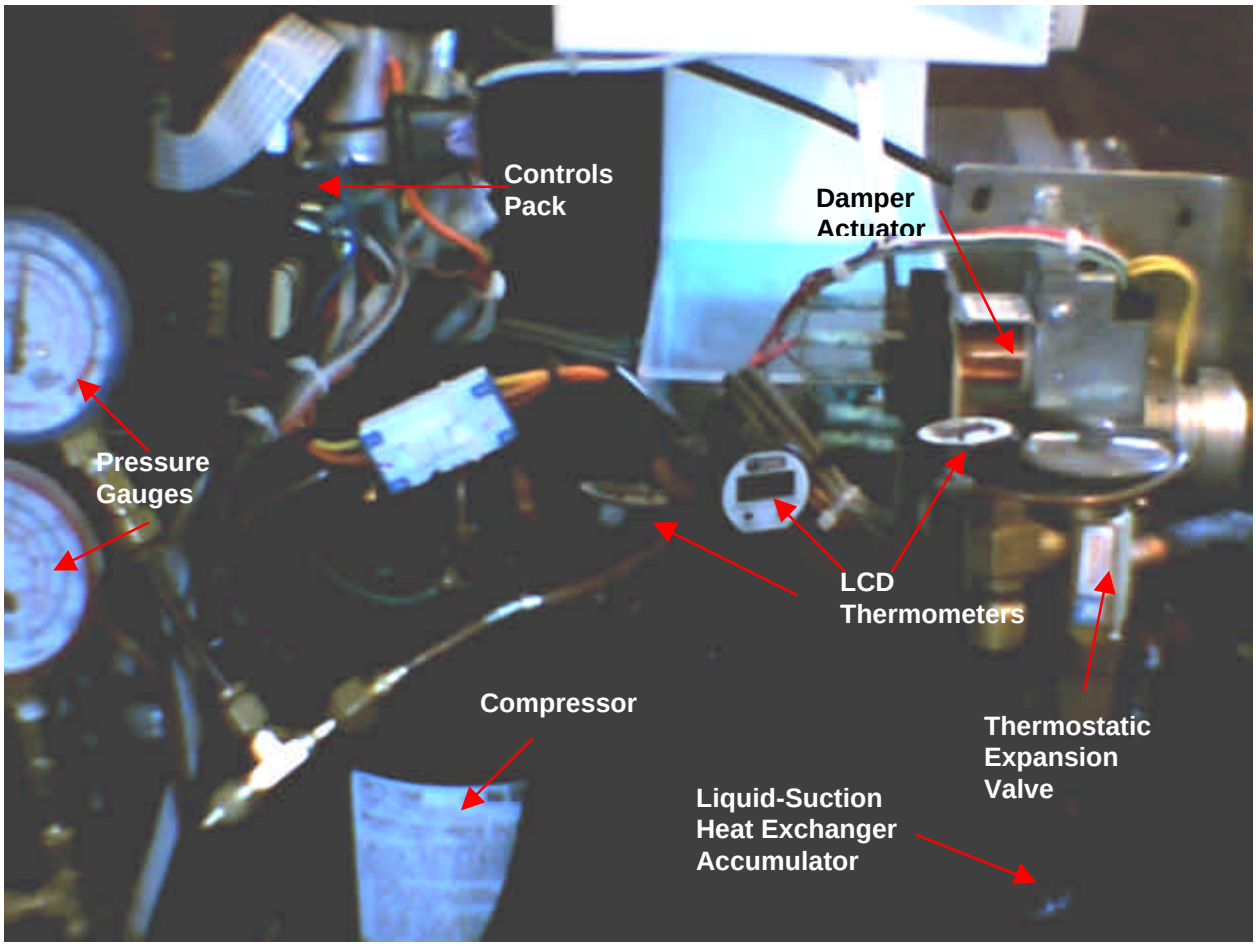
Potential manufacturing methods and marketing/licensing approaches were developed. A production concept with cost estimates was developed. Potential manufacturing methods and licensing strategies was addressed. Using OEM specifications for existing products, proposed production configurations were developed using standard line components to minimize incremental costs. Reliability, preventative maintenance and service issues were addressed.

Three suitable, representative, accessible, and challenging candidate commercial sector field sites were identified, surveyed, and prepared: a small 2-story office building, an ice-cream shop, and a café. Work included survey existing rooftop air conditioning units, cooling load analysis, ducting layouts, and cost estimates. The ice-cream shop has demanding air-conditioning loads due to large numbers of customers during rush periods from 2:00 to 4:00 pm and 7:00 to 9:00 pm each day, when as many as 60 customers occupy the 2,200 square foot store. Because chocolate is actually made on-site in the customer area, and stored on shelves and display cases, the relative humidity must be maintained below 55% to ensure product quality. In addition, the store displays ice cream in refrigerated cases that have issues with frost build up that could be mitigated with improved humidity control.

We began coordinating with Carrier's Control Applications Group regarding using the on-board *Carrier* control sensors and web interface with real-time monitoring for the field test. We have asked that *Carrier* provide this hardware and software to the project in exchange for first-look at the resulting data. Further progress on data collection from the field installation is pending their consideration of this request.

Dissemination of project results and promotion of technology implementation and commercialization was done at ASHRAE (American Society of Heating Refrigerating, and Air-Conditioning Engineers) Annual Meetings, at an NREL Industry Growth Forum, and at meetings and presentations at manufacturer's facilities. A product fact sheet and presentation slide sets

were developed. A tabletop demonstration unit was constructed for these events, to give a "show and tell" on the technology. The demo unit is portable and fully instrumented with meters for electric power, space and supply air temperature and humidity, refrigerant high-side and low-side pressures, and refrigerant temperatures at four key locations, and all components are visible (see photo) to provide a fully functional demonstration.



3. Hurdles Overcome

Testing, troubleshooting, and refinement of the prototype continued throughout the project. Numerous tests were run at a wide range of ambient temperatures, logging the following data: return air temperature & humidity, supply air temperature & humidity, mixed air temperature, cooling water entering and leaving temperatures, HCFC-22 liquid entering and leaving temperatures, system power draw (Watts), system airflow, coil airflow, and high and low side refrigerant pressures.

Using data from these tests, we identified the cause of every problem and corrected each one-by-one. First, we found that the bypass damper actuator linkage prevented the damper from sealing fully closed. Due to the significant pressure differential across the damper (0.40-in wg), even the very small (about 0.05-inches) gap allowed significant air bypass, which resulted in skewed baseline data. We also found a problem with the evaporator coil solenoid valve that would not close fully. Most likely, because we installed the valve just downstream of the capillary tube, jetting of the liquid-vapor mixture held the valve partially open. We adjusted the

closing pressure and remedied the problem. Next, data showed that the compressor suction pressure fell dangerously low during low-ambient tests with the solenoid valve closed and the bypass damper open. We installed a low-pressure cutout bypass switch and investigated further. After considerable analysis, we installed an adiabatic modulator proportioning refrigeration controller de-superheater, which remedied this problem.

Then, the prototype electronic controller unit (built by AED Electronics, Inc.) crashed whenever a relay or solenoid de-energized. We first replaced the 24-V transformer, which helped, but the problem continued. After numerous consultations with AED engineers, we removed the unit along with the relay pack and shipped the entire system, exactly as wired in the prototype, to AED so they could reproduce the problem in their lab. By adding MOV's (metal-oxide varistors, similar to those used in surge suppressers) across the controller outputs the problem was solved. Finally, the prototype was functioning as it should and the performance met or exceeded expectations.

Much time and effort was invested in analyzing, diagnosing, and retesting the *Opto Generic Devices* (OGD) motor speed controller. Use of the OGD controller with our ClimaStat™ technology was encouraged by DOE, as *Opto Generic Devices* (www.ogd3.com) is also and I&I grant recipient and has worked with *Carrier* in the past. After analysis of test data, and in agreement with engineers at OGD, we finally succumbed to the conclusion that the OGD Unit A1 motor speed controller is not compatible with the Carrier factory blower motor and have abandoned its use in the prototype. Although speed control is not required for the ClimaStat™ technology, it would provide optional features and meshes well with the design intent. We are currently working with another speed control unit, the Nimbus controller by *Control Resource Inc.* of Littleton, MA. Speed control is a desirable but certainly not a required upgrade for the ClimaStat™ technology. Technology details are available on their website at www.controlres.com/nimbus.htm

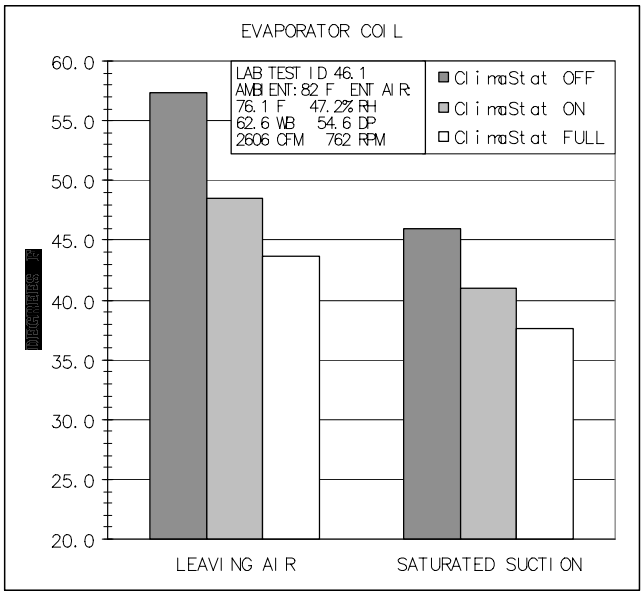
Three manufacturers appear to be using the ClimaStat™ technology without a license agreement. Discussions between company officials and Advantek's patent counsel are underway. It was learned that one manufacturer is claiming to be using the technology under their patent, which was applied for after the issuance of, and is a reference for our patent (US 6,427,454).

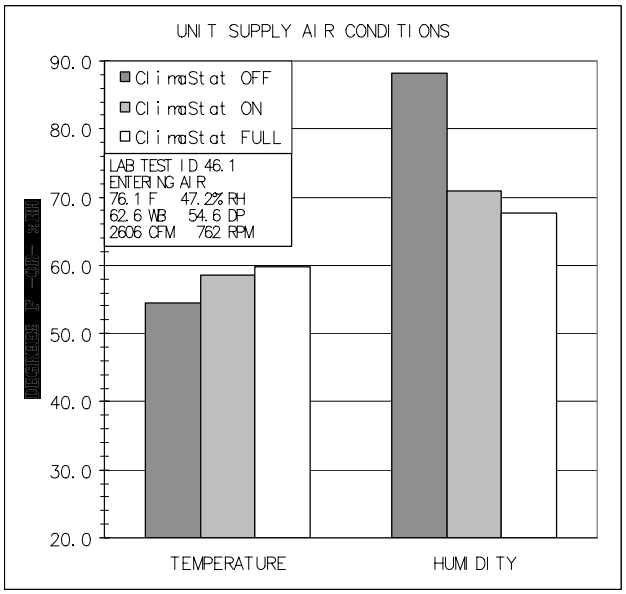
4. Results

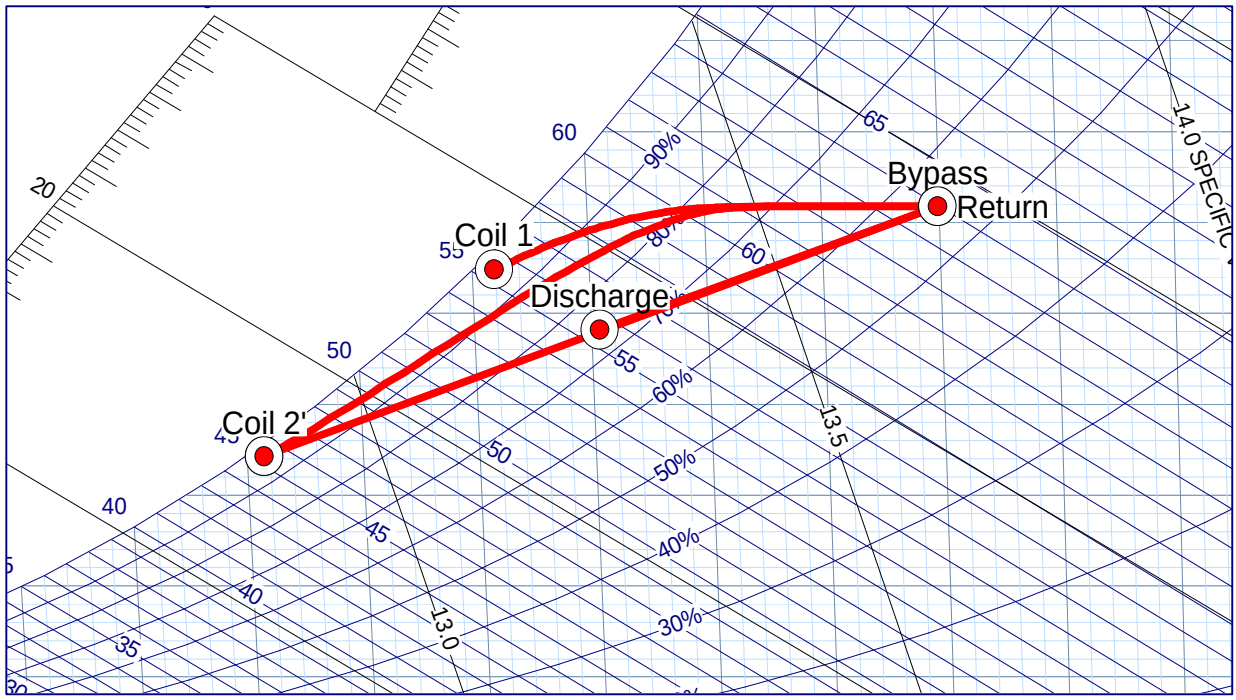
An interesting and somewhat unexpected finding is that even the "Normal" mode of the ClimaStat™ modified unit is providing more dehumidification than a factory *Carrier* unit. This effect is likely a result of the refrigerant circuit improvements that are part of the ClimaStat™ technology, and are not turned "off" in normal mode, specifically, the liquid-suction heat-exchanger accumulator and adjustable thermostatic expansion valve. The reduction in leaving coil air temperature averaged 8.3 to 16.0 degrees F, and evaporator spread was reduced from 10.5 / 11.3 F to just 9.4 / 2.5 F, indicating much greater heat exchanger effectiveness as the filters become loaded.

The latest test data shows an increase in dehumidification capacity of 56% with the ClimaStat™ in full dehumidify mode vs. with the ClimaStat™ off. Test data shows the system is capable of maintaining the coil in the region of the freezing point (32F) without runaway coil icing, and provide an average coil leaving air temperature as low as 29F. Dehumidification capacity increase factor improved from 1.7 to 1.9 @500 cfm/ton – meaning that the unit can provide nearly twice the water removal per unit of sensible cooling load in RH mode versus off.

We have successfully developed the first highly marketable low-cost technology offering significant improvement in both Seasonal Energy Efficiency (SEER) and comfort & humidity control. ClimaStat™ cost-effectively controls humidity on-demand and improves indoor air quality while reducing annual energy costs. Test data clearly shows that ClimaStat™ costs 20% to 60% less to operate than reheat – hot-gas reheat is the most common and least energy efficient type currently used by Lennox and York. **ClimaStat™ is ready for market.**







Appendix A. Final Task Schedule

Project Schedule by Task (revised Janary 2, 2007) as of December 30, 2006
DE-FG36-03GO13003
Inventions and Innvoations Program: "**High-Efficiency Variable Dehumidification for Air Conditioners**"
Advantek Consulting, Inc. PI: Michael K. West, Ph.D., P.E. (321) 733-1426 x31 mwest@advantekinc.com

Task Number	*Description*	*Task Completion Dates*					Progress Notes
		Original Planned	*Revised Planned*	*Extended Planned*	*Actual*	*Percent Complete*	
	Engineering Development						
1	Refine/Construct Prototype	3/1/03	8/4/03	9/12/04	2/11/05	100%	complete
2	Standard Lab Testing	5/1/03	10/21/03	3/30/06	9/30/06	100%	complete
3	Test Data Analysis	6/1/03	1/6/04	4/30/06	10/30/06	100%	complete
4	Improvements & Final Testing	9/1/03	3/10/04	3/1/06	9/30/06	100%	complete
5	Manufacturing Methods	9/1/03	5/8/04	5/30/06	10/30/06	100%	complete
	Demonstration						
6	Field Site Prepearation	10/1/03	5/30/04	4/30/06	*	90%	*continuing beyond grant
7	Prototype Field Installation	11/1/03	8/24/04	5/30/06	**	90%	**continuing beyond grant
8	Data Collection	8/1/04	10/13/04	9/30/06	12/30/06	100%	complete
9	Data Analysis	8/1/04	12/28/04	10/30/06	12/30/06	100%	complete
10	Dissemination of Results	9/30/04	4/21/05	12/30/06	12/30/06	100%	continuing beyond grant

Appendix B. Final Spending Schedule

Final Spending Schedule
DE-FG36- DE-FG36-03GO13003
Inventions and Innvoations Program: "High-Efficiency Variable Dehumidification for Air Conditioners"
Project Period: 9/4/2003 to 12/9/2006

Task		Approved Budget	Final Project Expenditures
Task 1	Refine/Construct Prototype	32,800	34,481
Task 2	Standard Lab Testing	30,900	45,423
Task 3	Test Data Analysis	21,300	17,532
Task 4	Improvements & Final Testing	34,100	59,038
Task 5	Manufacturing Methods	15,900	30,619
Task 6	Field Site Prepearation	11,300	7,643
Task 7	Prototype Field Installation	30,600	3,454
Task 8	Data Collection	17,900	11,465
Task 9	Data Analysis	21,300	28,004
Task 10	Dissemination of Results	33,900	30,695
Total		250,000	268,355
	DOE Share	200,000	$200,000
	Cost Share	25.5%	$68,355

C. Cost Share

Final Cost Share Contributions

Funding Source	Approved Cost Share		Final Contributions	
	Cash	In-Kind	Cash	In-Kind
Advantek Consulting, Inc.	50,000		50,000	
Engineered Systems and Services, Inc.				5,250
Carrier Corporation				10,000
Pawlik Air Conditioning, Inc.				3,105
Total	50,000	0	50,000	18,355
Cumulative Cost Share Contributions				68,355

Appendix D. Energy Savings Metrics

Current energy use for air conditioners in the target market for the innovation is estimated to be 3 Quads. The energy consumption for the proposed unit is 200 million Btu/year/unit. The energy consumption for the comparable competing unit is 342 million Btu/unit/year. The energy consumption of the innovation is 42% less to deliver the same 20,000 ton-hours of latent cooling capacity over the course of one cooling season. The savings calculation is based on a typical cooling load profile: total seasonal cooling load of 67,370 ton-hours of which 70% is sensible load and 30% is latent load. To meet the sensible load, annual operating hours is 2846 hours for the innovation unit and 3480 hours for the reheat unit; more operating hours because the reheat unit supplies warmer & more humid air so it must run longer. The energy efficiency ratio (EER) is 14.3 Btuh per Watt (0.84 kW/ton) for the innovation unit and 9.9 Btuh per Watt (1.2 kW/ton) for the reheat unit.

Once fully commercialized, total energy savings by 2010 is projected to be 23 trillion Btu per year, by 2020 the projection is 124 trillion Btu per year, and by 2030 the energy savings is projected to be 885 trillion Btu per year. At an energy rate of $24 per million Btu saved (at $0.047 per kWh and $9.78 per kW demand), the proposed technology would save $520 million in energy per year within 5 years of production.

ClimaStat web page: http://www.advantekinc.com/atdevelopment.html