Emerging Energy-Saving HVAC Technologies and Practices for the Buildings Sector (2009)

December 2009 (additional note May 2011
re: Advanced Northern Heat Pumps)

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RESULTS OF THE 2008–2009 EMERGING HVAC TECHNOLOGIES STUDY

Introduction

This note summarizes the results of the 2008–2009 ACEEE review of emerging building sector heating, ventilating, and air-conditioning (HVAC) technologies. ACEEE'S work on emerging technologies in the buildings sector began with a broad-based review in 1993, followed by publications in 1998 and 2004 that were similar in scope.[1] Since then, ACEEE has concentrated on more narrowly focused annual or biennial efforts. The present HVAC review is the first of an anticipated five-part cycle of Web-based reports. The next "volume" will address water heating, to be followed in later years by lighting and building-scale onsite power generation (CHP), appliances (including electronic equipment) and motors, and whole-building measures (shell and energy management).

The methods used in this study are adapted from Chapter 3 of Sachs and others (2004).[2] In this series, we have expanded our treatment of technologies from one-page synopses to brief essays that can serve as introductions to the technologies. Our reported metrics remain the same, but we place less emphasis on likelihood of success and priority than in earlier studies across broader ranges of technologies.

Energy Savings Potential and Economics

Table 1 summarizes the savings from the measures studied, all converted to source energy saved in 2025. The first observation is that there is still a lot of energy to be saved. The 15-year cumulative source energy sum is 4.4 Quads in 2025, which is just under 10% of projected base case buildings sector energy use for 2025.[3] As an alternative perspective, full adoption of these 15 emerging technologies alone would reduce projected U.S. energy consumption by 0.5–1%/year.

Second, the potential savings from these measures vary enormously, from about 1.4 Quads/year at negative cost (commercial ground source heat pump systems) to measures like hot-dry climate residential air conditioners that might save < 2% as much energy. Still, some of the measures with relatively small energy savings are extremely important, because they can greatly reduce energy demand at peak times. This would include hot-dry climate air conditioners, ventilation and energy recovery, and numerous others. Estimated demand savings for each technology are given for each technology treated.

In general, the measures studied in this round are highly cost-effective. In several cases, the cost of saved energy is *negative.* This means that the technology studied should have lower first cost than the present method to which it was compared. One example is the advanced, single-pipe commercial ground-source heat pump system, when compared with current variable air volume (VAV) norms. Ground-coupled (ground-source) systems show $3 per square foot lower first cost (including the ground loop, where conditions are favorable). The operating savings (>8 kWh/yr) are partly attributable to use of the ground as heat source and sink. However, they also follow from the use of water as the principal medium for carrying energy in the building, while the VAV system distributes energy in the air, which has much lower heat capacity.[4] This also helps explain the benefits of chilled beams with dedicated outdoor air systems (DOAS). Like ground source systems, these also use water to carry as much of the energy distribution load as possible. Indeed, we expect that ground source and chilled beams will find synergies in medium-sized office building applications.

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[1] Respectively ACEEE Publications A931, A984, and A042. See aceee.org/emertech/buildings.htm.

[2] Sachs, H., S. Nadel, J. Amann, M. Tuazon, E. Mendelsohn, L. Rainer, G. Todesco, D. Shipley, and M. Adelaar. 2004. *Emerging Energy-Saving Technologies and Practices for the Buildings Sector as of 2004.* aceee.org/pubs/a042.htm. Washington D.C.: American Council for an Energy-Efficient Economy.

[3] U.S. Energy Information Agency. *Updated Annual Energy Outlook 2009 Reference Case Service Report,* Figure 36. http://www.eia.doe.gov/oiaf/aeo/demand.html.

[4] Kavanaugh, S. and H. Sachs. 2007. "Water-Based Energy Distribution & Integrated Design for 50% Demand and Energy Savings." ASHRAE Winter Meeting, Seminar 32: Achieving 50% and Beyond Approach to Net-Zero-Energy Use in Buildings, Part 2.

Table 1. *Per*-Technology Energy Savings in 2025

Technology	Priority	Sector	Fuel	2010-2025 cum. TBtu	CSE, $/kWh	CSE, $/MMBtu
Commercial Ground-Source Heat Pumps	Medium	Commercial	Elec.	1415	$ (0.07)	
Advanced Modulating HVAC Compressors	Medium	Residential and Commercial	Elec.	615	$ 0.01	
Robust Central Air Conditioners	Medium	Residential	Elec.	380	$ 0.13	
Advanced All-Climate Heat Pump	High	Residential	Elec.	300	$ 0.07	
Residential Boiler Controls	Special	Residential	NG	262		$ 4.86
Active Chilled Beam Cooling w. DOAS	high	Commercial	Elec.	260	$ (0.16)	
Liquid Desiccant Hybrid AC	Medium	Commercial	All	210	$ 0.02	
Optimized Residential Duct Work	High	Residential	Elec.	200	$ 0.03	
HVAC System Prognostics & Diagnostics	Medium	Commercial	Elec.	130	$ (0.03)	
Air-Side Economizers	Special	Commercial	Elec.	115	$ 0.08	
High-Efficiency Gas-Fired Rooftop Units	Special	Residential	NG	85		$ 7.18
Hot-Humid RTU with Dual Enthalpy	Special	Commercial	Elec.	65	$ 0.01	
Advanced Rooftop Packaged AC	High	Commercial	Elec.	35	$ 0.11	
Residential Hot-Dry Air Conditioners	Medium	Residential	Elec.	25	$ 0.07	
Ventilation and energy recovery	High	Commercial	Elec.	25	$ 0.06	

As part of this project, we have also developed separate economic cases for 12 of these 15 technologies with high potential in Canada. These include all items in the list above, *except* three that are particularly well-adapted for hot-dry or hot-humid climates: liquid desiccant hybrid air conditioning, hot-humid roof-top units with dual enthalpy, and residential hot-dry air conditioners. For the others we have used the conversion of $US 1.00 = $CAN 0.94,[5] and converted source Btu to gigajoules, to conform with Canadian practice.

Finally, we were unable to get timely completion of one other high-priority technology from a cooperating institution, and thus have been unable to compare ductless split systems with air-based applied air conditioners and heat pumps.

Although the universe of technologies and practices studies has changed over time (Table 2), it is interesting to compare the average *per measure* savings from this HVAC study with estimates from our 1998 and 2004 broad-span studies that looked at HVAC, shell, lighting, and many other measures. In the 1998 study, the average savings estimate was >1000 TBtu/measure, which dropped to about 325/measure in 2004.

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[5] http://www.xe.com/, October 27, 2009

Table 2. Numbers of Measures Studied in 1998 and 2004, by Technology Group[6]

Measures Group	1998	2004	2008
appliances	8	2	
motors and drives	6	4	
HVAC	**19**	**23**	**15**
lighting	15	14	
power	5	4	
practices	2	7	
refrigeration	1	3	
shell	5	10	
water heating	7	4	
laundry	3	0	
miscellaneous, other	1	2	

Savings in this study average about 310 TBtu/measure, which is not considered to be a real decrease from 2004. The savings found in this study compare well with those from the most recent comparable ACEEE work, our 2004 review across a broad range of technologies and practices.[7] Table 3 gives some relevant comparisons for the HVAC measures included.[8]

Table 3. Average Cost of Saved Energy and Cumulative Savings from the 2004 HVAC Measures and the Present Study

	CSE, $/kWh	CSE, $/MMBtu	Savings, TBtu
2004 HVAC average	$ .05	$ 6.10	131
2008 average	$ .04	$ 2.32	181

Note: the cumulative savings are based on 2005–2020 for the 2004 study, and on 2010–2025 for this study.

We infer that the tree of low-hanging energy efficiency fruit is still productive.

Lessons Learned and Implications of the Study

Perhaps the most important finding of this study is that the “well” of emerging technologies and practices has not been drawn down: it continues to yield many promising measures with high energy savings potential (as noted above, average per measure cumulative savings are about 300 TBtu). Of course, the supply is changing, as older emerging technologies become mainstream (or fail to compete successfully), and newer opportunities emerge.

Although we work carefully, there are large inherent uncertainties in estimating the costs of emerging technologies as mature products that have significant market share at some time in the future. This is also true for estimating the energy savings that can be attributed to them. As an example, consider the Smart Premium (Robust) Central Air Conditioner. We illustrate the points by varying the estimated incremental cost and incremental savings, in Table 4.

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[6] See Footnote 2, Table 4-6.

[7] See Footnote 2.

[8] We delete the 2004 measure H6, ultraviolet germicidal radiation, since it is not primarily an efficiency measure, and has very high costs when considered only on the basis of energy savings (from estimated air handler fan power savings).

Table 4. Effects of Changing Cost and Savings Estimates on the Computed Cost of Saved Energy for the Smart Premium (Robust) Air Conditioner

Savings, KWh/yr	Incremental Cost, $	Cost of Saved Energy, $/kWh
700	$1320	$0.13
1000	$1320	$0.09
700	$1000	$0.10
1000	$1000	$0.07

First, even under the most optimistic assumptions used in Table 4 (1000 kWh/yr savings; $1000 incremental cost), the Smart Premium AC is one of the less cost-effective emerging technology we studied in this project. Second, the results are very sensitive to our starting assumptions on costs and savings. If both are off by 30%, the CSE is slightly over half as high as with our base assumptions of 700 kWh/yr and $1320 cost. Finally, this is an important case in which the "non-energy benefits" to the consumer may be larger than the value of the energy savings, but these benefits are omitted from our calculations entirely. The Smart Premium AC incremental cost includes the ECM fan motor, which gives quiet soft starts and can modulate to match output and control humidity, as well as giving large energy savings. It includes diagnostics that remind owners of required maintenance (e.g., air filter changes) and will probably avoid service calls from failures. Again, these benefits are not included in the savings calculations, but would be important parts of a "value package" marketed to consumers.

There is also a huge range among these technologies in their readiness for the next step, from niche emerging technologies to market transformation programs. At one extreme, the design parameters for high-efficiency gas-fired rooftop units (RTUs) are still very uncertain. Many advocates urge adoption of condensing gas furnace sections, while manufacturers note that more fan power would be needed to overcome the pressure drop of the secondary heat exchanger, and they stress the difficulties of condensate control and disposal for weatherized equipment. Our report stresses the poorly-understood issues with off-cycle losses and the role of enhanced cabinet insulation, proper dampers between the RTU and the building per se, etc. Thus, further work is required to estimate the annual savings potential of optimum design approaches. Even then, present metrics used in standards are unlikely to capture the off-cycle benefits of advanced units, so prescriptive requirements may be needed to accelerate movement into the market. At the other extreme of feasibility, all residential boilers will include outdoor reset or the equivalent controls in manufactured after September 12, 2012.[9] Other technologies lie between these extremes.

As noted above, commercial ground source heat pumps are close to a "home-run" opportunity, where applicable. They are not the lowest cost HVAC (generally cost more than RTUs), but they are lower cost than options with comparable amenity.[10] These systems offer an estimated 1.4 Quads of savings in 15 years, at a negative cost of saved energy ($0.07/kWh). "Unpacking" this number suggests that it is not unreasonable: HVAC site energy use in education facilities was about 0.5 Q per year in 2003, slightly less than office building HVAC energy use.[11] Thus, we are unlikely to run out of buildings (school, office, and other) for which the system is applicable and cost-effective, since the 1.4 Quad figure is a fifteen year cumulative number. The greatest challenge to the acceptance of ground-coupled systems is information-related: few designers have the experience required to do a low-cost, low-risk system, and designers new to the field tend to insist on "bells and whistles" that raise costs and degrade performance. In most areas, there are too few contractors who are experienced at ground loop installation plus too little information about ground conditions to get competitive bids with low risk of failure. Finally, all aspects of

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[9] *Per* Section 303 of the Energy Independence and Security Act (2001). This provision overturned a DOE ruling to implement a consensus agreement between manufacturers and advocates.

[10] Ground-source economics depend on two factors: local conditions (geology, drilling costs, and market maturity) and selection of a design engineer who understands how to design robust systems without bells and whistles.

[11] EIA CBECS Table E1a. http://www.eia.doe.gov/emeu/cbecs/cbecs2003/detailed_tables_2003/detailed_tables_2003.html#enduse03.

the system are simply unfamiliar to the decision-makers involved. Unfortunately, the buildings industry defines “early adopters” as those who want to be second—no one wants the risks of being first.

Active chilled beam cooling for office buildings offers even greater cost-effectiveness than ground-coupled systems, but smaller potential savings because the stock of larger commercial buildings is relatively small. One reason that chilled beam approaches are interesting is their similarities to ground-source systems. Both represent a huge change from conventional practice in using hydronics (water) to distribute most of the energy to zones. Both work best with a separate dedicated outdoor air system that delivers relatively dry tempered air to each zone, thereby avoiding dealing with condensate and drains in the zones. Thus, both have large “learning curves” for the designers, owners, and builders. Chilled beams will penetrate the market because they will cost less than VAV, take less of the building’s volume for energy distribution (freeing more space for productive use), and are actually simpler to control and operate. That they save energy is a side benefit.

Other aspects of market transformation are illustrated by comparing the likely paths of all-climate heat pumps with advanced modulating compressors. Modulating compressors for air conditioners and heat pumps are much more likely to become pervasive than cold climate heat pumps. To start with, modulating (“inverter drive”) compressors are ubiquitous in multi-split systems, and are entering the forced air market now as premium products. Competitive pressures will force U.S. compressor manufacturers to respond with more cost-effective modulating compressors (and design tools for them), or risk losing their customers, the manufacturers, to off-shore vendors. And, the modulating compressor air conditioner is part of a product that will be made by major manufacturers with substantial marketing muscle. In contrast, the all climate or cold climate heat pump is a specialty product, not a national one. More importantly, its performance is highly dependent on the caliber of the local contractor’s installation (e.g., sealing duct leaks, insulating ducts), factors that are outside the control of the manufacturers. If a higher-cost modulating compressor heat pump fails to deliver on all of its comfort promises, the customer may be disappointed. On the other hand, if the cold climate heat pump fails to deliver (while continuing to operate), the customer will face extraordinary bills for resistive back-up. It will have a harder time living up to expectations. Finally, until the niche manufacturers establish a large enough market to interest the major firms, the cold climate heat pump will have a harder time being visible to contractors and purchasers.

At first glance, advanced liquid desiccant air conditioners would seem to face similar problems to those confronting the cold climate heat pump, but there are enough differences to be illustrative. The liquid desiccant hybrid is a ten ton commercial roof-top unit targeted specifically to installations requiring substantial dehumidification work, such as supermarkets in the Southeast. This market is characterized by national and regional chain decision-making, with decent engineering, reasonable mechanical contractors, and management that can show interest in new approaches. The liquid desiccant approaches may come from small firms, but they enter a market that recognizes the value of specialized approaches in HVAC and refrigeration. In contrast, the all-climate heat pump will compete in the residential market, where the manufacturer will have to invest heavily in training contractors and supporting them with marketing information that provides assurance to risk-averse customers without the costs of building a national brand.

To summarize the key lessons of this review, new technologies continue to emerge that have huge potential for energy savings.

To some extent, the newer opportunities are more specialized, by region or building type, but this is a characteristic to be expected of high performance buildings, as of high performance vehicles: they are much more closely designed to specific operating conditions.

Finally, the likelihood of market success depends not only on the virtues of the technology, but also about the niche it would enter and its characteristics.

Emerging Technologies Report

Advanced Rooftop Packaged Air Conditioners

August, 2009

Definition	Rooftop packaged air conditioners incorporating advanced features				
Base Case	5-ton rooftop unit				
New Measure:	Incorporation of features such as improved fans and economizers, diagnostics	Percent savings	2025 Savings TBtu (Source)	Cost of Saved Energy, $/kWh	Success Rating (1-5)
		17%	34	0.11	4

Summary

Advanced roof-top units (RTUs) with higher efficiency and additional features designed to save energy off-peak and improve reliability. Features could include improved fans and economizers; better controls of the fan, refrigerant cycle, and economizer; and advanced monitoring and diagnostics. Projected package costs are relatively high, but should come down with greater acceptance of the feature set.

Background and Description

Rooftop packaged air conditioners are commodity air cooling and handling equipment, often including gas fired or electric air heating equipment. They account for about 0.74 quads of energy annually, or around 54% of commercial building cooling primary energy consumption, and are used to cool about half of all commercial space.[12] These products are often selected based on their initial cost, as most buyers are builders and developers who are more interested in minimum purchase price, rather than the occupants who have to pay the operating costs.[13]

EER, or energy efficiency ratio, is a measure of the cooling efficiency of the equipment at full load (measured at 95^{o}F dry-bulb). As the EER can only reflect the efficiency of the equipment when it is running at full load, it may not be a very accurate reflection of the equipment's energy efficiency when it is run at part load. Also, EER does not fully reflect the potential energy efficiency benefits that can be achieved by advanced rooftop packaged air conditioners through part-load measures such as effective economizers and dampers, demand controlled ventilation, variable speed fans, ventilation lockout during the startup, and evaporative pre-cooling of the condenser unit.

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[12] AD Little. 2001. "Energy Consumption Characteristics of Commercial Building HVAC Systems—Volume 1: Chillers, Refrigerant Compressors, and Heating Systems."

[13] DOE. 2000. "Technology Fact Sheet—High-performance Commercial Rooftop Air Conditioners."

Data Summary

Market Sector	Market Application	End Use	Fuel Type
Commercial	New/Replace on Burnout	Cooling	Electricity
Current Status	**Date of Com**	**Product Life (years)**	**Source**
Prototype	2010	15	Pier (CA work is being done on the adoption of a scorecard

Base Case Energy Use		Units	Notes, Explanation	Source
Efficiency	10.0	EER	Federal mandated energy efficiency, from 2010	
Electricity Use	9,000	kWh/year	Using FEMP energy cost calculator.	
Summer Peak Demand	6	kW	5 ton, 10 EER (5 tons*12,000 Btu/ton/10,420 Btu/kWh)	
Winter Peak Demand		kW		
Fuel Use	0	MMBtu/year		
New Measure Energy Use				
Efficiency	10.8	EER	Draft minimum energy efficiency requirement in ARTU scorecard, CEE Tier 2 minimum	CEE
Electricity Use	7,500	kWh/year	Using FEMP energy cost calculator, and assuming 10% further reduction (see assumptions)	
Summer Peak Demand	5.6	kW	5 ton, 10.8 EER [(5 tons)*(12,000 Btu/ton)/(10.8 Btu/kWh)]	
Winter Peak Demand	0	kW		
Fuel Use	0	MMBtu/year		
Savings				
Electricity Savings	1,500	kWh/year		
Summer Peak Demand Svgs	0.4	kW		
Winter Peak Demand Svgs	N/A	kW		
Fuel Savings	0.0	MMBtu/year		
Percent Savings	17%			
Percent Feasible	16%		30% (cost effective fraction) of packaged units * (54% of total commercial cooling load)	
Industrial Savings > 25%?	No			
Costs				
Incremental Cost	$4100	2007 $		Sachs, this study
Other Costs (Savings)	-300	$/ year		
Ranking Metrics				
2025 Savings Potential	3,200	GWh		
2025 Savings Potential	34	TBtu		
Cost of Saved Energy	0.11	$/kWh		
Cost of Saved Energy		$/MMBtu		

Unusual Market Barriers	**Non-Energy Benefits**	**Current Activity**	**Next Steps**
- Very high upfront costs - Concerns about the reliability and robustness of new features - Need for building operation changes	-Improved maintenance and serviceability - Early detection of faults through self-diagnosis and monitoring	analysis only	Research & Development Test Procedure Field Testing
Likelihood of Success	4	(1-5)	
Priority	High	Low, Med, High	
Data Quality Assessment	B	(A-D)	
Principal Contacts			
Mark Cherniak, New Buildings Institute			
Afroz Khan, CEE			
Written by: Wilson Lin, with Harvey Sachs			

Current Status of Measure

Over the years, the efficiency of rooftop packaged air conditioners has steadily improved. Models with advanced features include:

Carrier Centurion:
http://www.commercial.carrier.com/commercial/hvac/product_physical_data/0,3060,CLI1_DIV12_ETI440_PRD1171,00.html
Lennox Strategos:
http://www.lennoxcommercial.com/pdfs/datatables/30W83_strategos_data_54496_0608.pdf
Aaon:
http://www.aaon.com/product.aspx?id=1

Manufacturers are continuing to develop advanced rooftop packaged air conditioners, with improved energy efficiency and incorporating new features like economizers and advanced sensors. As part of the California Energy Commission's Public Interest Energy Research (PIER) program, Architectural Energy Corporation (AEC) has prepared a document describing the features that should be incorporated into an advanced rooftop packaged air conditioner.[14] These features include:

- Economizer improvements;
- Fan improvements
- Unit efficiency;
- Refrigeration cycle;
- Fan control;
- Refrigerant control;
- Thermostat capability;
- Sensors;
- Installation and check-out capabilities;
- Advanced monitoring; and
- Advanced diagnostics

The Consortium for Energy Efficiency is currently exploring the possible development of a program framework for a voluntary initiative to promote consumer awareness of advanced rooftop packaged air conditioner features, based on the specifications in the PIER program. This would be accomplished through utility-run consumer education and incentive programs.

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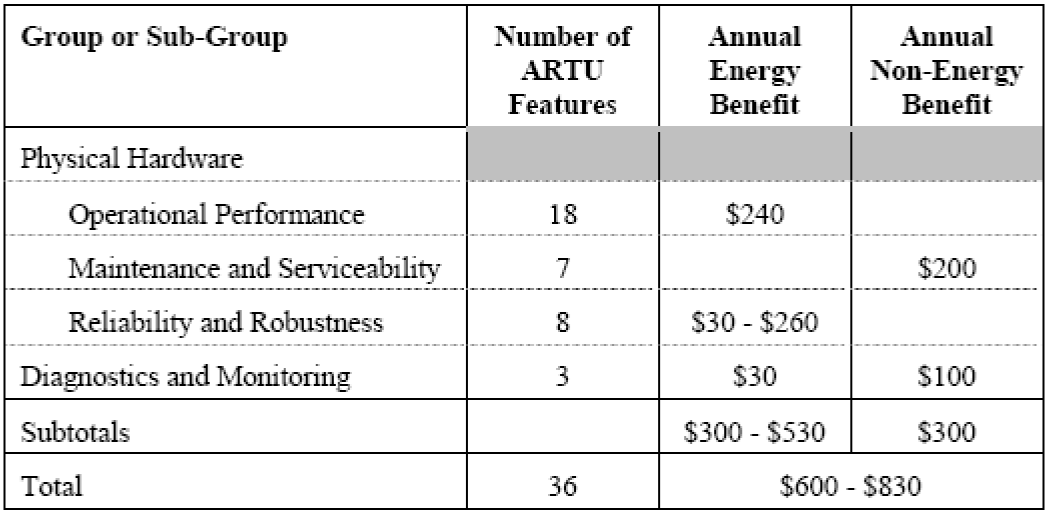
[14] http://www.archenergy.com/pier-fdd/packaged_rtu/Proj4_Deliverables/D4.3c_FinalARTUProductDefnRpt_091205.pdf

Savings Potential and Cost-Effectiveness

A cost-benefit assessment was conducted by AEC as part of the PIER project.[15] It was estimated that a 5-ton advanced rooftop unit incorporating the 36 features identified (see *Features List Appendix*, below) would have an installed cost of about $9800, about 72% more than the estimated installed cost of a baseline unit ($5700). The report also estimates that the features would result in annual energy savings of between $300 and $530, based on conditions in several California cities, as well as non-energy benefits of around $300 yearly. This results in a simple payback period of 5-7 years for the advanced rooftop unit features.



Group or Sub-Group	Number of ARTU Features	Annual Energy Benefit	Annual Non-Energy Benefit
Physical Hardware			
Operational Performance	18	$240	
Maintenance and Serviceability	7		$200
Reliability and Robustness	8	$30 - $260	
Diagnostics and Monitoring	3	$30	$100
Subtotals		$300 - $530	$300
Total	36	$600 - $830	

Source: http://www.sabreargentina.com/downloads/ARTU_Cost-BenefitAnalysis.pdf

Market Barriers

The cost premium for an advanced rooftop air conditioner is very high. In the 5-ton example, the installed cost was 72% higher for the advanced unit. This can be overcome with incentives, and may be attractive to ESCOs and similar programs in areas with high utility costs, including high demand charges.

However, widespread adoption of the advanced RTU is most likely where owners, contractors and other service vendors are receptive to new business models. Currently, RTU service is based on a scheduled check-up basis (change filters and check units twice yearly, for example). Advanced units with on-board diagnostics will allow an as-needed service model, in which technicians are dispatched when the unit sends notice that it requires service, whether more or less frequently than would have been scheduled. Adopting such a model will involve risk.

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[15] Architectural Energy Corporation. 2008. “Advanced Automated HVAC Fault Detection and Diagnostics Commercialization Program Draft Final Report”, 65-68.

Key Assumption Used in Analysis

Average Price of Electricity	\$0.1032/kWh[16]
Average Price of Natural Gas	\$10.97/MMBtu[17]
Projected 2025 End Use Electricity Consumption[18]	0.39 quads
Real Discount Rate	4.53%
Projected 2025 End Use Gas Consumption[19]	1.25 quads
Heat Rate	10.48 kBtu/kWh

Based on a review of field studies on commercial rooftop units in the Pacific Northwest and California, it was found that:

- An average of 46% of the units tested had a refrigerant charge that deviated by more than 5% from the specifications. Correcting the refrigerant charge is estimated to result in 5-11% savings in the cooling energy; and
- An average of 64% of the units tested had economizers that required adjustment, or had failed. Repairing a failed economizer is estimated to result in 15-40% savings in cooling energy.

Taking the lower end of the estimated energy savings and considering the average failure rate of units, it is estimated that features that help correct refrigerant charge and economizer errors would result in at least 10% energy savings on average.

Next Steps

Now that a coherent and realistic specification is on hand or close, the next steps are raising visibility, which is being undertaken by the Western Cooling Energy Center. When national account-scale enterprises understand the benefits of the RTU, they will be ready for trials. Success will open opportunities for coordinated rebates for standard products, such a Consortium for Energy Efficiency program.

Features List Appendix

No.	Description
ECONOMIZER	
1	Factory installation
2	Direct drive / permanent lubrication
3	Differential dry-bulb or enthalpy control, or dewpoint control
4	Demand controlled ventilation capability
5	Compressor lockout on low outdoor air temperature
6	Economizer modulation on low outdoor air temperature
7	Dead band to be 2 °F or less
8	2 to 5 years factory warranty on economizer parts and labor
9	Low leakage return air damper (@ 2%)
FANS / FAN CONTROL	
1	Power limitation per ASHRAE 90.1
2	Continuous supply fan operation during occupied hours

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[16] EIA, “Electric Power Monthly—Feb 2009”, (YTD-Nov08, Commercial Price)
[17] http://tonto.eia.doe.gov/dnav/ng/ng_sum_lsum_dcu_nus_m.htm
[18] EIA. 2009. *Annual Energy Outlook 2009 with Projections to 2030.* Tables 4 and 5.
[19] Ibid.

UNIT EFFICIENCY	
1	Rated efficiency per CEE's "Tier 2"
REFRIGERATION	
1	High efficiency HFC with no ozone depletion potential used (Such as R410A)
2	Improved-efficiency condenser fan motor
3	Thermostatic expansion valve, or electronic expansion valve, or other adjustable expansion control device used
THERMOSTATS	
1	Commercial grade
2	Dual set-point, min. 5°F deadband, continuous fan operation, time-of-day/weekend/holiday programming, temporary override
3	Integrated economizer capability
4	Occupancy sensor interface
SENSORS	
1	Accuracy requirements +/- 1°F
2	Solid-state electronic humidity elements
3	Connections design to prevent misconnections
4	CO_2 sensor supplied by control manufacturer
INSTALLATION AND CHECK-OUT CAPABILITY	
1	Refrigerant line labels if there are multiple circuits
2	High pressure liquid line port, low pressure suction port
3	Ports accessible without removing panels
4	Minimum outside air adjustments accessible without removing panels
ADVANCED MONITORING	
1	Permanent sensors, readings displayed at controller
2	Controller indicated enabled operating mode, including economizer
3	Ability to initiate tests of operating modes
ADVANCED DIAGNOSTICS	
1	8-bit minimum digital resolution
2	Detect faulty sensors and send notification signals
3	Detect faulty economizer and send notification
4	Detect and signal evaporator air temperature difference out of range
5	Detect and signal refrigerant charge out of range
6	Other faults

Emerging Technologies Report

Advanced "Gas-Pack" Rooftop Packaged Air-Conditioner

August, 2009

Definition	Packaged roof-top units with higher efficiency gas furnace sections				
Base Case	AFUE 80				
New Measure:	Condensing, with internal condensate drain; better insulation; duct dampers to reduce thermal bypasses	Percent savings	2025 Savings TBtu (Source)	Cost of Saved Energy, $/MMBtu	Success Rating (1-5)
		18%	85	$7.18	2

Summary

The principal market for packaged roof-top air conditioners is light commercial buildings, such as individual store bays in strip malls, and lower quality schoolroom service. In some regions, there is also an emerging residential market, typically for light frame multifamily townhouses. In these situations, the rooftop mounting reduces ground level noise (from the condensing unit) and frees space that would otherwise be occupied by split system condensing units outside, and the furnace-air handler-air conditioner evaporator inside.

For both technical and market reasons, there has been little interest in higher efficiency roof-top units (RTUs) until recently. As use of small RTUs becomes more popular in residential applications and others where heating loads may be high, interest in improved performance increases. This scan examines paths for delivering greater heating efficiency. Options might include (a) condensing units that drain to the interior of the building, (b) much better unit (and duct) insulation, to eliminate the possibility of freeze damage (at least in most climates), and (c) duct dampers to prevent off-cycle convective loops from stealing heat from the building.

Background and Description

Packaged air conditioners are the most prevalent commercial cooling technology.[20] However, commercial buildings use many heating sources, and packaged equipment accounts for only about one-quarter of the heated buildings, or their floor space.[21] Thus, we expect a minority of the roughly 1.1 million small packaged roof top units to include gas heating sections, perhaps 200,000/yr.[22] We assume 15-year expected life.[23]

Packaged units with gas furnace heating are called "gas-packs." By definition, roof-top units are weatherized air-conditioners/furnaces, and thus must be able to survive freezing temperatures without any damage to components, performance degradation, or hazard from frozen condensate. Thus, condensing gas-packs (AFUE ≥90 ≤ Et) are essentially unavailable:[24] they would be susceptible to freeze issues. In addition, RTUs have two other major efficiency issues that are not measured by the rating

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[20] 85% of non-mall cooled commercial buildings, and over 50% of cooled floor space. tables B-40 and B-41 in http://www.eia.doe.gov/emeu/cbecs/cbecs2003/detailed_tables_2003/detailed_tables_2003.html

[21] Tables B-38 and B-39, op. cit.

[22] Inferred from EIA data and shipment data from http://ahrinet.org/Content/CentralAirConditionersandAirSourceHeatPumps_604.aspx.

[23] Derived from ASHRAE, used by DOE, slide 49 in http://www1.eere.energy.gov/buildings/appliance_standards/commercial/pdfs/comm_ac_lcc.pdf.

[24] August 12, 2009: The AHRI directory of certified products lists 55 of 4520 weatherized furnaces as condensing. http://www.ahridirectory.org/ahridirectory/pages/home.aspx. We were unable to find the relevant product listings on the manufacturers' Web sites for the corresponding products, and assume that these represent listing errors. That is, we assume there are no certified, weatherized, condensing units on the market today.

method: (1) Cabinet insulation is poor, typically about R-3.[25] During winter, heat will be lost to the outdoors. (2) The air handler and heat exchangers are above the heated space of the building, connected by large vertical ducts. During the off cycle, these can host convective loops that bring heated air up to the RTU, where it convectively cools and drops back into the living space. Thus, the losses caused by poor insulation continue during the entire heating season, whether the unit is running or not.

In this context, an advanced roof-top gas-pack would include the following attributes:

- Well-insulated cabinet with low leakage to the outside. Engineering analysis will be required to determine minimum levels; we provisionally note that some of today's units are rated at R-7. One manufacturer is moving its product line to two inches of foam insulation.[26]
- Condensing furnace section (Et[27] and AFUE ≥ 90), with interior condensate drain and appropriate controls.
- Insulated, low-bypass duct dampers for both the supply and return ducts, to prevent development of off-cycle convective loops.

Our principal concern is that the sales of small gas-pack RTUS into the residential sector could increase dramatically if builders begin to recognize their perceived noise and space advantages, as noted above. This could lead to the substitution of 80 AFUE products with expected high off-cycle losses for the 90-AFUE and better gas non-weatherized furnaces (with split system air conditioners) often installed in northern climates. If the assumptions we make on losses are reasonable, much better roof-top units are necessary.

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[25] Inferred from http://www.aaon.com/Documents/Sales/HB_Sales_070621.pdf. August 12, 2009.
[26] M. Fly, Aaon, personal communication, August 2009
[27] Thermal efficiency

Data Summary

Market Sector	**Market Application**		**End Use**	**Fuel Type**
Residential	New/Replace on Burnout Long Life		Heating	Natural Gas
Current Status	**Date of Com**		**Product Life (years)**	**Source**
Field Test	2010		15	ASHRAE
Base Case Energy Use		**Units**	**Notes, Explanation**	**Source**
Efficiency	69%	Field AFUE	Conventional, non-condensing	
Electricity Use	500	kWh/year	PSC motor, draft inducer, etc.	
Summer Peak Demand	0	kW		
Winter Peak Demand	0	kW		
Fuel Use	63.2	MMBtu/year	Average of Midwest and NE residential	Databook, Table 2.1.11
New Measure Energy Use				
Efficiency	87%	Field AFUE	Minimum condensing	
Electricity Use	600	kWh/year	Increment allowed for secondary HX	
Summer Peak Demand	0	kW		
Winter Peak Demand	0	kW		
Fuel Use	50.1	MMBtu/year		
Savings				
Electricity Savings	-100	kWh/year		
Summer Peak Demand Svgs	0	kW		
Winter Peak Demand Svgs	0.00	kW		
Fuel Savings	13	MMBtu/year	Based on effective or field AFUE	text table
Percent Savings	18%			
Percent Feasible	40%		Mostly for colder climates, as analyzed	
Industrial Savings > 25%?	No			
Costs				
Incremental Cost	$925	2007 $		Sachs, this study
Other Costs (Savings)	0	$/ year		
Ranking Metrics				
2025 Savings Potential	-	GWh		
2025 Savings Potential	85	TBtu		
Cost of Saved Energy	$ -	$/kWh		
Cost of Saved Energy	$ 7.18	$/MMBtu		
Unusual Market Barriers	**Non-Energy Benefits**		**Current Activity**	**Next Steps**
No availability, at least for small sizes Cost-sensitive customers	None		analysis only	Research & Development Test Procedure Field Testing
Likelihood of Success	2	(1-5)		
Priority	Special	Low, Med, High		
Data Quality Assessment	C	(A-D)		
Principal Contacts				
Harvey Sachs, ACEEE				
Martin Thomas, NRCan				

Current Status of Measure

Various manufacturers have built large condensing commercial roof-top gas packs on a custom basis, and at least one manufacturer has literature on a variable speed condensing product in sizes from 100 MBtu and larger. This product is not yet listed on the Web site.[28] The technical requirements seem straightforward: condensing section, excellent insulation and infiltration control on the cabinet, condensate drains to the building interior, through the mounting curb, and probably provisions to prevent freezing or freezing damage when the building is not in use. The challenge is establishing customer value, which will depend on both efficiency and perceived reliability.

Otherwise, there is no known product availability.

Savings Potential and Cost-Effectiveness

Savings potential is difficult to estimate because we have found no research on off-cycle losses of roof-top gas-packs. However, the losses of these units can be estimated from other studies.

Thomas reports that the steady-state efficiency of gas-packs studied in the field is several Et points lower than their ratings would suggest.[29] His measurements were based on flue gas analysis, and he did not investigate off-cycle losses. In one egregious case, the difference was 9 points (9%). Partly in response, Thomas has proposed performance degradation factors for weatherized furnaces installed outdoors in Canada.[30] These would reduce Et values by about 3.5%. This *may* serve as a lower bound for off-cycle losses, because it does not include the potential losses attributable to convective loops in the supply and return ducts. Still, it brings up a key point: If the efficiency metric is steady-state efficiency (during the on cycle), then design improvements that reduce off-cycle losses may not be credited in the market that only judges performance by Et.

Turning to another class of equipment, the seasonal efficiency of gravity-vented unit heaters is estimated at 62–64%, while that of power-vented units is estimated about 80–83%.[31] Gravity unit heaters have an open draft diverter below the vent, which serves as a hole in the roof of equivalent cross section, so these are expected to have very high off-cycle losses.[32] The 20-point difference in estimated seasonal efficiency is at least an upper bound on the degradation from off-cycle losses expected from roof-top gas pack furnaces.

We can extrapolate from Thomas's findings and the unit heater study to compare current units with a hypothetical high-efficiency RTU. In doing this, the most important assumption we make is that dampers that isolate the supply and return ducts from the RTU during the off cycle will all but eliminate the convective losses hypothesized for present units (line 4 *v* line 8, below).[33]

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[28] www.engineeredair.com/index.html. August 13, 2009

[29] Martin Thomas, "Summary of Test Results" unpublished, received August , 2009

[30] Canadian Standards Association Standard p.8, Annex C (Informative).

[31] Krauss, W.E., M.J. Hewett, and M.S. Lobenstein. 1992. *Commercial Gas Space Heating Equipment: Opportunities to Increase Energy Efficiency.* Minneapolis, Minn.: Center for Energy and the Urban Environment.

[32] Sachs, H. M. 2003. *Unit Heaters Deserve Attention for Commercial Programs.* ACEEE Report A031.

[33] Occasionally, code requirements lead to smoke dampers being installed between the building and RTI, so this is considered feasible.

Line	Present Situation for Gas-Packs	
1	0.8	rated steady-state efficiency
2	0.03	degradation, high fire, from Thomas data
3	0.77	net steady state
4	0.08	estimated seasonal convective column loss
5	0.69	estimated seasonal efficiency (AFUE-like)
	Advanced Unit	
6	0.9	lowest condensing
7	0.02	estimated jacket loss
8	0.01	convective loss w. duct dampers
9	0.87	estimated seasonal efficiency (AFUE-like)

With substantial uncertainty, we estimate the retail price of the improvements as:

Estimated Retail Price Increase for Advanced RTU	
$325	Condensing furnace upcharge (TSD)[34]
$300	Estimate for improved cabinet
$300	Estimate for dampers/controls
$0	Condensate drain (included for AC section)
$925	total

All numbers *except* the $325 condensing furnace upcharge (computed from the referenced table) are ACEEE estimates.

Market Barriers

1. Roof-top units have been dominated by lowest-price commodity products, largely because specifiers typically work for owners, while tenants pay the utility bills. Beyond that, the market for the smallest products, now beginning to be used in multi-story vertical applications, has been small.
2. The test methods are executed in laboratory conditions that do not include the off-cycle losses expected for roof-top units. They overestimate annual efficiency, and thus discourage innovation to improve efficiency.
3. Residential builders of relatively high density housing that would adopt roof-top units are not driven by efficiency, but by maximizing "sellable" floor space (putting the HVAC outside, on the roof), by the amenity value of removing the condensing unit from proximity to living area windows, and by cost considerations. They have not been good candidates for high efficiency solutions with premium prices.

Next Steps

1. The critical path is testing the field performance of small roof top gas pack units, to validate or refute the assumptions of this scan. If performance is much lower than would be estimated from Et and AFUE ratings, additional work is called for.
2. In parallel, it would be worthwhile to develop a model of a RTU gas-pack that is realistic enough to account for its insulation, infiltration, coupling to the building, the effects of duct insulation, and off-cycle performance, including possible development of convective loops between the living space and the roof-top unit.
3. Based on the outcomes of the field and/or simulation studies, prototype advanced RTUs should be constructed and tested.

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[34] 2006 (Residential Furnaces) Technical Support Document, Table E.1.1. http://www1.eere.energy.gov/buildings/appliance_standards/residential/pdfs/furnaces_boilers/fb_tsd_appendixe_0906.pdf

4. If these work as prescribed, the fastest way to bring units to market is likely to be a market aggregation program, such as a mass buy.

Key Assumptions Used in Analysis

Average Price of Electricity	\$0.1032/kWh[35]
Average Price of Natural Gas	\$10.97/MMBtu[36]
Projected 2025 End Use Electricity Consumption[37]	0.39 quads
Real Discount Rate	4.53%
Projected 2025 End Use Gas Consumption[38]	1.25 quads
Heat Rate	10.48 kBtu/kWh

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[35] EIA, “Electric Power Monthly—Feb 2009”, (YTD-Nov08, Commercial Price)

[36] http://tonto.eia.doe.gov/dnav/ng/ng_sum_lsum_dcu_nus_m.htm

[37] EIA 2009. “Annual Energy Outlook 2009 with Projections to 2030”. Tables 4 and 5.

[38] Ibid.

Emerging Technologies Report

Commercial Energy Recovery Ventilation Systems

March, 2009

Definition	Energy recovery ventilation systems for commercial applications				
Base Case	6600 sf, 561 cfm office building (used in ASHRAE 1254-RP), 8.5 tons RTU				
New Measure:	Add ventilation energy recovery and downsize equipment	Percent savings	2025 Savings TBtu (Source)	Cost of Saved Energy	Success Rating (1-5)
		10%	23	$0.06/kWh	4

Summary

Codes require the introduction of outdoor air for mechanically-ventilated commercial buildings, to help assure that pollutants and bio-effluents introduced into the indoor air will be diluted and flushed out. When the outdoor air is very humid, hot, or cold, substantial energy is required to temper the outdoor air. Energy recovery ventilation (ERV) systems exchange heat (often both sensible heat and water vapor) between the outgoing exhaust air and the ventilation air being brought in. Under appropriate conditions, this allows reducing the capacity of the HVAC system and saves energy. Heat and energy recovery wheels are the most commonly applied ERV systems, and they are rapidly increasing their market share.

Background and Description

Heating, Ventilation, and Air Conditioning (HVAC) systems control temperature, humidity, and other conditions of the air in a building.[39] In 2006, commercial buildings used about 2.8 quads of energy for space heating, ventilation, and space cooling. This is about 34% of the total energy consumption by the US commercial sector.[40] Of this, 2.5 quads were consumed for space heating and cooling.

Pre-conditioning the (outdoor) ventilation air can achieve significant reductions in the space heating and cooling loads. Ventilation systems can be fitted with heat/energy recovery devices to transfer energy between the supply air and the exhaust air to pre-condition the intake air.

Exhaust energy recovery technologies include energy recovery loops, heat pipes, plate exchangers, and rotating wheel air-to-air heat exchangers. Heat recovery devices transfer sensible heat between the supply and exhaust airstreams by making use of the temperature difference between the two airstreams. In contrast, energy recovery devices transfer both sensible and latent heat (also known as heat of vaporization) by exploiting both the temperature difference and the difference in humidity levels between the two airstreams. Where there are large humidity loads, energy recovery devices can recover more energy than heat recovery devices. A brief description of the heat/energy recovery devices is in the Appendix**,** together with a tabular comparison of the technologies.

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[39] Howell, R., Sauer, H., and Coad, W. 2005. “Principles of Heating, Ventilating, and Air Conditioning.”

[40] DOE, 2008 Buildings Energy Data Book, http://buildingsdatabook.eren.doe.gov/TableView.aspx?table=3.1.4

Data Summary

Market Sector(s)	**Application(s)**	**End Use(s)**	**Fuel Type(s)**
Commercial	New/Replace on Burnout; Long Life	Cooling	Electricity
Current Status	**Date of Commercialization**		***Notes***
Commercialized			
Life			
15			

Basecase Energy Use		**Units**	**Notes, Explanation**	**Source**
Efficiency		EER		
Electricity Use	13,532	kWh/year	1592 kWh/ton * 8.5 ton	St Louis Case in ASHRAE 1254-RP
Summer Peak Demand		kW		
Winter Peak Demand		kW		
Fuel Use	46.2	MMBtu/year	1796 kWh/ton * 8.5 ton / 293.07 MMBtu/kWh	
New Measure Energy Use				
Efficiency				
Electricity Use	12,121	kWh/year	1426 kWh/ton * 8.5 ton	
Summer Peak Demand		kW		
Winter Peak Demand	0.0	kW		
Fuel Use	41.4	MMBtu/year	1178 kWh/ton * 8.5 ton / 293.07 MMBtu/kWh	
Savings				
Electricity Savings	1,411	kWh/year		
Summer Peak Demand Svgs	N/A	kW		
Winter Peak Demand Svgs	N/A	kW		
Fuel Savings	4.8	MMBtu/year		
Percent Savings	10%			
Percent Feasible	12%		Buildings types with high outdoor air requirements, southern region only.	DEG
Industrial Savings > 25%?	Yes			
Costs				
Incremental Cost	$ 1,150	2009 $	$5 per cfm, subtracting saved "first cost" for RTU	TIAX DOE Report (worst case listed)
Other Costs (Savings)	0	$/ year		
Ranking Metrics				
2025 Savings Potential	2182	GWh		
2025 Savings Potential	23	TBtu		
Cost of Saved Energy	0.06	$/kWh		
Cost of Saved Energy	$ 5.48	$/MMBtu		

<table>
<tr><th>Unusual Market Barriers</th><th colspan="2">Non-Energy Benefits</th><th>Current Activity</th><th>Next Steps</th></tr>
<tr><td>Limited market (hot-humid only)</td><td colspan="2">Improved comfort</td><td>limited</td><td>Education</td></tr>
<tr><td>Likelihood of Success</td><td>4</td><td>(1-5)</td><td colspan="2" rowspan="3"></td></tr>
<tr><td>Priority</td><td>High</td><td>Low, Med, High</td></tr>
<tr><td>Data Quality Assessment</td><td>B</td><td>(A-D)</td></tr>
<tr><td colspan="5">Principal Contacts</td></tr>
<tr><td colspan="5">Drake Erbe, Airxchange</td></tr>
<tr><td colspan="5">Prepared by Wilson Lin, with Harvey Sachs</td></tr>
</table>

Current Status of Measure

The North American Energy Recovery Ventilation market is estimated to have earned revenues of $324.6 million in 2006, which is expected to grow to $778.7 million in 2012.[41] Early manufacturers faced a lack of understanding by HVAC practitioners, credibility, and maintenance issues.[42] Manufacturers have since improved the technology, addressing many reliability and maintenance issues. AHRI has also implemented Standard 1060 for rating device effectiveness, increasing confidence in them.

Driving Factors

Besides the energy efficiency benefits of commercial energy recovery ventilation systems, there are also significant non-energy benefits that help to drive the development of the market.

Growing Concern about Indoor Environmental Quality. According to the US EPA, “a growing body of scientific evidence has indicated that the air within homes and other buildings can be more seriously polluted than the outdoor air in even the largest and most industrialized cities."[43] These pollutants can pose serious health hazards to occupants. Increasing ventilation is a recognized way to improve indoor environmental quality. However, there are many cases where the outside air needs to be conditioned prior to circulation, leading to increased energy consumption. The use of energy recovery ventilation systems can help to increase ventilation rates while mitigating the increase in energy consumption.

Load Reduction. Energy recovery ventilation systems introduce pre-tempered air to the main air-conditioning units. This reduces the capacity required. Smaller units generally cost less, and thus heat/energy recovery devices may result in “first cost” savings. For example, reducing the capacity of a single zone roof top air conditioner from 20 tons to 18 tons is estimated to reduce the cost by about US$4700, which is about 23% of the installed price.[44] This can offset the additional costs of energy recovery ventilation components.

Standards and Recommendations. Government and non-government organizations promote adoption. ASHRAE’s 90.1 standard prescribes the use of energy recovery ventilation systems with at least 50% recovery effectiveness for individual fan systems designed with fan capacities of 5000 cfm or greater and a minimum outdoor air supply of at least 70%. The federal government mandates energy recovery ventilation systems in federal buildings[45] and recommends that schools[46] and small businesses consider the use of energy recovery ventilation.[47] Several utilities have implemented incentive program to promote

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[41] Internet Article: Energy Recovery Ventilation Systems Growing in Importance, quoting Frost and Sullivan report, http://www.enn.com/green_building/article/28780

[42] “EVR Comes of Age for DX Systems”, *The ACHR News*, March 19, 2007

[43] USEPA and US CPSC. *The Inside Story: A Guide to Indoor Air Quality.* http://www.epa.gov/iaq/pubs/insidest.html#Intro1

[44] Estimates from RS Means Building Construction Cost Data 2009 67th Annual Edition by RS Means Company

[45] US GSA, *Facilities Standards for the Public Building Service*, March 2005

[46] http://www.epa.gov/iaq/schooldesign/hvac.html#Energy%20Recovery%20Ventilation

[47] http://www.business.gov/guides/environment/energy-efficiency/upgrades/hvac.html

these devices.[48] They include Florida's Progress Energy, Texas' Austin Energy, Vermont Gas, and Wisconsin's Focus on Energy.

Newer buildings generally have more efficient envelopes. This reduces the sensible heat load relative to the latent heat load that results from internal sources and ventilation air. But single-stage unitary equipment deals particularly poorly with high humidity loads at low sensible loads (typically when outdoor temperatures are mild).[49] This can result in a loss of humidity control, which may in turn lead to issues for occupants, and even damage the structure. Energy recovery ventilation systems can help stabilize humidity levels.

Limiting Factors

Of course, energy recovery devices use energy themselves, at least to overcome the air pressure drop across the devices. The value of the recovered energy must offset the parasitic losses of the fans that overcome the pressure drops. Energy recovery ventilation systems are least effective when the temperature and humidity of the outside air are similar to that of the circulating air, and where the ventilation load is relatively small (in which case economizers and natural ventilation may be more appropriate). Conversely, they are most effective at peak demand times, when energy may be most highly valued and tightly constrained. The US EPA has prepared an application map showing areas where schools could potentially benefit from the use of energy recovery ventilation systems.[50]

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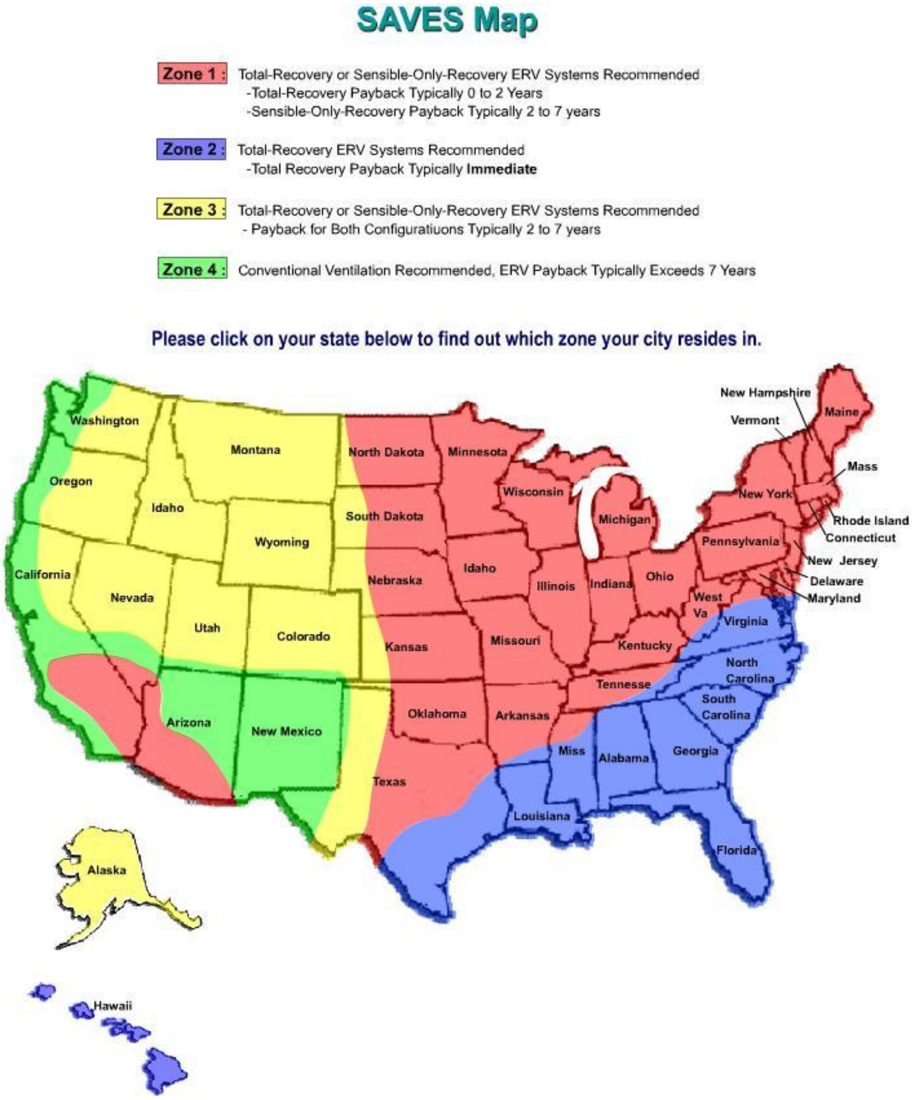
[48] http://www.dsireusa.org

[49] ASHRAE Journal August 2008 "Improving Humidity Control with Energy Recovery Ventilation", pg 38-45

[50] http://www.epa.gov/iaq/schooldesign/saves.html#ERV_System_Application_Map



Notes:
Zone 1 Total Recovery or Sensible-only, comprises the Eastern half of the US, except the humid Zone 2 (see below). Also includes hot-dry parts of SE California and Southern Arizona.
Zone 2 Total Recovery, includes all of Florida, Georgia, South Carolina, North Carolina, Louisiana, and Alabama. It also includes all but NW Mississippi, all but the northernmost part of Virginia, SE Tennessee, SE Arkansas, and SE Texas.
Zone 3 Total Recovery or Sensible-only. West, except SW and Pacific Coastal regions.
Zone 4 Lower climate intensity, energy recovery pays back slowly.

Barriers

Energy recovery devices can save money by reducing equipment loads. However, at the design phase, they may suffer from being viewed as “additional” equipment that would add to the cost of the HVAC system. Many HVAC designers don't understand the potential first cost savings that arise from being able to reduce the capacity of the air handling equipment. Thus, the decision to use energy recovery ventilation systems should also be made early in the design process, as their use could have significant impacts on sizing and design of other HVAC equipment. For example, when an economizer is used together with an energy recovery ventilator, the ventilator must be controlled together with the economizer and the operation adjusted to provide for the economizer. If no economizer is used, the operation of the energy recovery device needs to be controlled to prevent over-warming the air, and air bypasses may be useful.[51]

Even where apparently cost-effective, energy recovery devices may also not be appropriate for some applications. For example, they are hard to apply if the supply and exhaust airflow ducts are widely separated for some reason (such as central supply but distributed exhaust). Tools such as design guidance need to be prepared to help HVAC designers evaluate the possibility of using energy recovery ventilation systems as well as to give designers more confidence when recommending their use.

In addition, there are few detailed case studies of commercial applications of energy recovery ventilation systems in the public domain. A compilation of these case studies would help encourage HVAC designers to consider recommending energy recovery ventilation systems in commercial applications.

Energy Savings and Costs

The table below summarizes information on energy savings and cost from case studies.

Some Attributes from Case Studies on Energy Recovery Ventilation

Project	Size	Type of ERV	Cost of ERV	Benefit	Comments
Whitehead Biomedical Research Facility[52]	325,000 gross sf	Enthalpy Wheels	$450,000	$136,028 annual savings	-
Process and Environmental Technology Laboratory at Sandia National Laboratories[53]	151,435 gross sf	Heat Pipes	$329,600	$31,800 annual energy savings 249,400 kWh of electricity and 90,400 therms of natural gas saved annually	Does not include savings due to the “significant” reduced heating and cooling requirements
Nidus Center for Scientific Enterprise[54]	22,554 gross sf	Enthalpy Wheels	—	—	More than $210,000 in “first cost” saved as smaller air handling systems could be used due to the wheels
Fox Chase Cancer Center[55]	120,000 sf	Heat Pipes	$300,000	$72,510 anticipated energy cost savings	
Doherty Memorial High School	38,250 cfm	Enthalpy Wheels	Less than capital equipment savings (smaller boiler, less expensive fan coil units)	$31,277 annual operating savings estimated	Estimated avoided boiler cost is $52,800

Of course, energy recovery ventilators are part of the HVAC systems. There are complex interactions among all the HVAC system components, which can affect the efficiency of the system as a whole. The exact climate conditions in the location are also crucial to determining if energy recovery ventilators are economically viable. A systems approach that incorporates energy recovery ventilators into the HVAC system design is needed.

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[51] ASHRAE, et al. “Advanced Energy Design Guide for Small Office Buildings”, 2008, pg 83
[52] http://labs21.lbl.gov/DPM/Assets/cs_emory_508.pdf
[53] http://labs21.lbl.gov/DPM/Assets/cs_petl_508.pdf
[54] http://labs21.lbl.gov/DPM/Assets/cs_nidus_508.pdf
[55] http://www.ashraeno.com/Delta%20Digest%20Archive/20081001_vangeet_web.pdf

Key Assumptions Used in Analysis

Average Price of Electricity	\$0.1032/kWh[56]
Average Price of Natural Gas	\$10.97/MMBtu[57]
Real Discount Rate	4.53%
Heat Rate	10.48 kBtu/kWh

Recommended Next Steps

Tools such as design guidance need to be prepared to help HVAC designers evaluate energy recovery ventilation systems, and to give designers more confidence when recommending their use. As far as possible, the tools should take a system approach to take into account cross effects due to interactions among various HVAC system components (e.g., the installation of energy recovery ventilators could allow smaller capacity chillers).

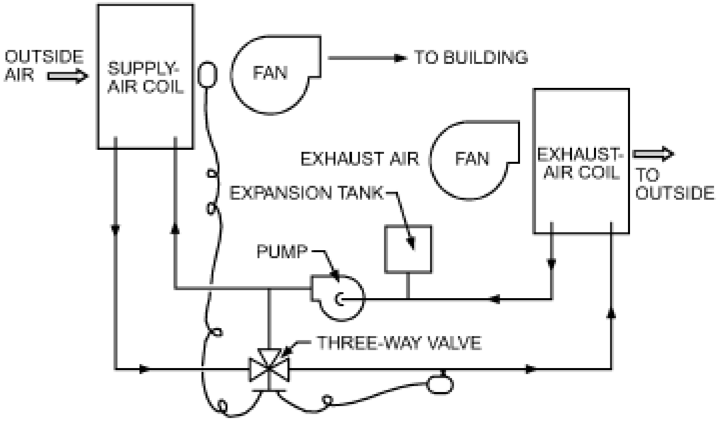
Detailed case studies of commercial applications of energy recovery ventilation systems are also somewhat lacking in the public domain. A compilation of these case studies would help encourage HVAC designers to consider recommending energy recovery ventilation systems in commercial applications.

Appendix

Energy Recovery Loops

Coil energy recovery loops, also known as runaround loops, utilize a fluid medium (usually water) to transfer energy from the warmer airstream to the cooler airstream (see figure below). The fluid is contained within a separate pipe system and is exposed to the airstreams by a series of coils across which the airstreams flow. Heat is transferred between the fluid and the airstreams through these coils. It is also possible to remove the circulating pump and utilize gravity instead to circulate the fluid; such coil energy recovery loops are called thermosiphon loops.

Coil Energy Recovery Loop



Source: 2008 ASHRAE Handbook—HVAC Systems and Equipment

Coil energy recovery loops do not require the exhaust and supply air ducts to be co-located. There is no cross contamination of the supply air by the exhaust air, and they can be used even when the pressure difference between the supply and exhaust air is significant. However, these systems tend to be costly

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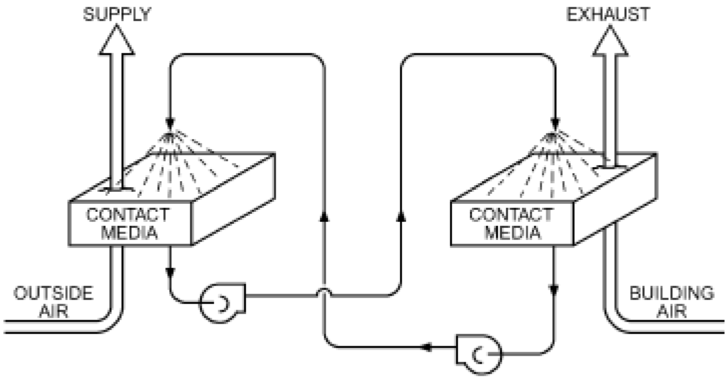
[56] EIA, “Electric Power Monthly—Feb 2009”, (YTD-Nov08, Commercial Price)
[57] http://tonto.eia.doe.gov/dnav/ng/ng_sum_lsum_dcu_nus_m.htm

due to limited suppliers and high installation costs. Additional energy and equipment are also needed to circulate the fluid in the coil.[58] As there is a risk that the fluid in the coil could become frozen, antifreeze and other treatments may need to be added.

A similar technology to the coil energy recovery loop is the twin-tower enthalpy recovery loop (see the figure on the next page). Contactor towers are set up through which a sorbent liquid (usually a halogen salt solution) is circulated. The sorbent liquid absorbs both humidity and heat and transfers them between the airstreams. Twin-tower enthalpy recovery loop systems are thus energy recovery devices.

Twin-Tower Enthalpy Recovery Loop



Source: 2008 ASHRAE Handbook—HVAC Systems and Equipment

Twin-tower enthalpy recovery loop systems are usually used in systems where there is a need to clean bacteria from the airstreams, such as industrial processes and some hospital applications.[59] Their application in commercial HVAC systems is limited due to the large size, the lack of published performance data, and the possibility of the sorbent liquid being transported along with the airstream.[60]

There is ongoing research to develop a runaround energy recovery system known as a runabout membrane energy exchanger (RAMEE).[61] Much like the twin-tower enthalpy recovery loop system, RAMEE uses semi-permeable membranes to allow the desiccant to absorb heat and moisture from the airstreams while keeping the desiccant from being transported away in the airstreams. RAMEE systems are currently at the prototype stage.

Heat Pipe Exchangers

Heat pipes differ from "runaround" loops because they are two-phase systems in which the heat exchange fluid is evaporated on the hot side and condensed on the cold side (see the next two figures). In the evaporation section of the heat pipe, the fluid medium absorbs heat and evaporates. The vapor then travels to the condensation section of the pipe, where it condenses and releases heat to the airstream. In many cases, the fluid is transferred from the condensation section to the evaporation section via capillary action through a wicking material in the pipe. It is also possible to utilize gravity to circulate the fluid medium — such heat pipes are known as thermosiphon tubes.

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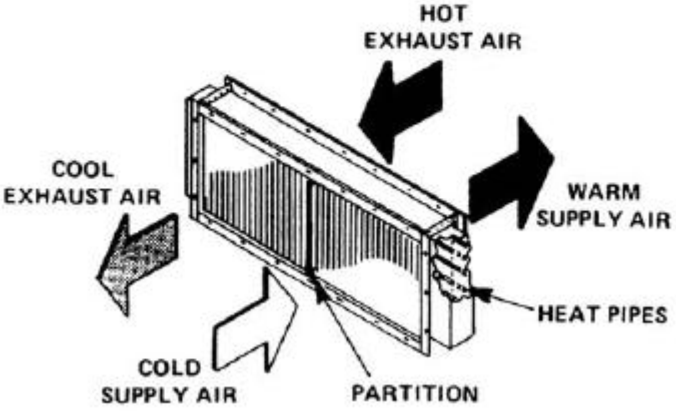
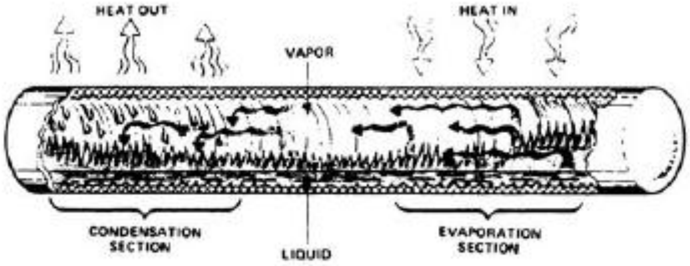
[58] http://www.lowex.net/guidebook/concepts_and_technologies/a11.pdf
[59] http://www.lowex.net/guidebook/concepts_and_technologies/a11.pdf
[60] http://library2.usask.ca/theses/available/etd-11102008-132017/unrestricted/SeyedAhmadiMehran,M.Sc.Thesis,SubmittedtoCGSR.pdf; pg 6
[61] http://library2.usask.ca/theses/available/etd-11102008-132017/unrestricted/SeyedAhmadiMehran,M.Sc.Thesis,SubmittedtoCGSR.pdf

Heat Pipe Exchanger



Source: 2008 ASHRAE Handbook—HVAC Systems and Equipment

Heat Pipe



Source: 2008 ASHRAE Handbook—HVAC Systems and Equipment

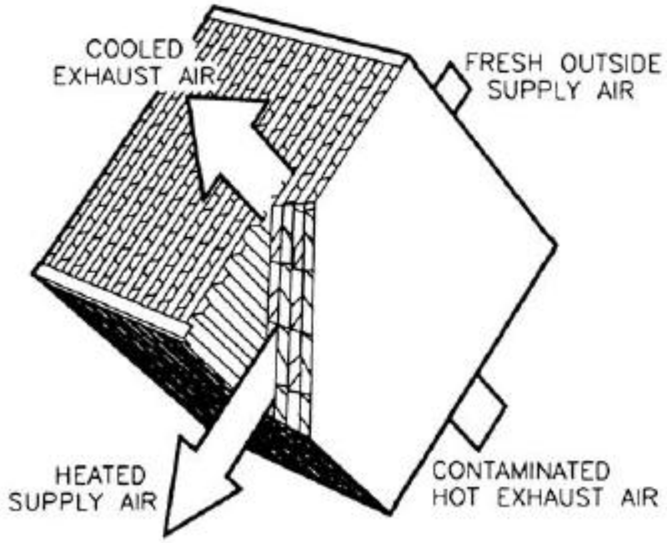
These systems have no moving parts, can be used even when there is a significant pressure difference between the supply and exhaust airstreams, and would not cause cross-contamination of the airstreams. However, they require the supply and exhaust airstreams to be co-located. The systems are also limited by their relatively high cost and pressure drop. There may also be a need for condensate drains and frost prevention methods such as reducing intake flow, bypass, and preheating.

Plate Exchangers

Fixed plate sensible heat exchangers use a multiplate exchanger core (see the figure on the next page). The supply and exhaust airstreams are passed through the core in close proximity, allowing sensible heat to be transferred.

The core of fixed plate exchangers can be made from permeable membranes that allow moisture to be transferred between airstreams but minimizes air transfer. Such membrane plate exchangers, typically based on paper-like or polymer materials, allow both sensible and latent heat to be transferred.

Plate Exchanger



Source: 2008 ASHRAE Handbook—HVAC Systems and Equipment

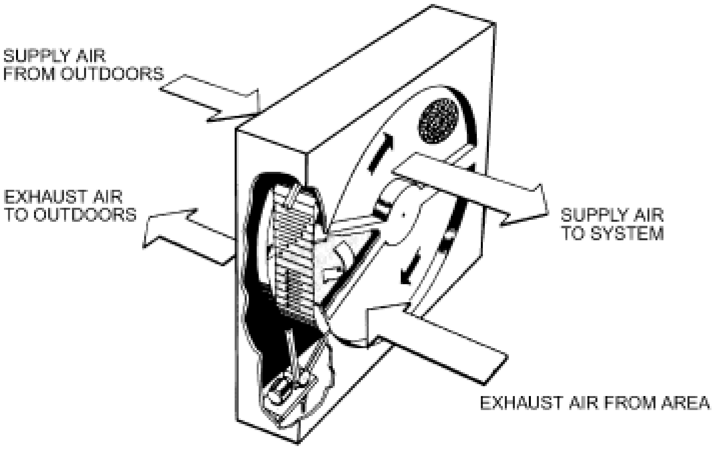
Plate exchanger systems have no moving parts (except fans in some designs), and cross-contamination of the airstreams is not generally an issue. However, the supply and exhaust airstreams need to be co-located and the size of the exchanger can be rather large for systems that handle high flow rates. There may also be a need for condensate drains and frost prevention methods such as reducing intake flow, bypass, and preheating.

Rotary Air-to-Air Energy Exchangers

Rotary (or "wheel") air-to-air energy exchangers are revolving cylinders made of materials that transfer energy between adjacent but separated incoming and outgoing airstreams (see the figure on the next page). The revolution of the cylinders exposes the cylinders’ surface to the supply and exhaust airstreams sequentially, causing the surface to absorb heat from the warmer airstream and release that heat into the cooler airstream. These devices are commonly called heat wheels.

Latent heat can be transferred by coating the surface of the exchangers with desiccant materials that absorb or adsorb moisture from the more humid airstream and release that moisture to the less humid airstream. Heat wheels with desiccant materials are commonly referred to as energy or enthalpy wheels.

Rotary Air-to-Air Energy Exchanger



Source: 2008 ASHRAE Handbook—HVAC Systems and Equipment

Rotary air-to-air energy exchangers are relatively compact and operate with fairly low pressure drops. However, the supply and exhaust airstreams need to be co-located and there is possible cross contamination of the airstreams, which may necessitate purging air near the wheel to limit cross contamination. There may also be a need for condensate drains and frost prevention methods such as reducing intake flow, bypass, and preheating.

Altering Heat Exchanger

Altering heat exchangers make use of banks of aluminum plates to store and release heat. A damper is used to divert the supply air to one set of aluminum plates while the exhaust air is diverted to the other set. The plates absorb heat from the warmer airstream. After a set period of time, the damper is activated and the airflows are exchanged so that the supply air now flows over the set of aluminum plates that the exhaust air had previously flown over and vice versa. The plates that had previously been warmed now release heat to the cooler airstream, while the other set of plates now begin to absorb heat. It is also possible for desiccant material to be used so that latent heat can also be transferred.[62]

As there is mixing of the supply and exhaust air when the damper is activated, cross-contamination of the air would occur. The supply and exhaust airstreams must be co-located. There is also a need to address the possible freezing of moisture on the aluminum plates.

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[62] http://www.lowex.net/guidebook/concepts_and_technologies/a14.pdf

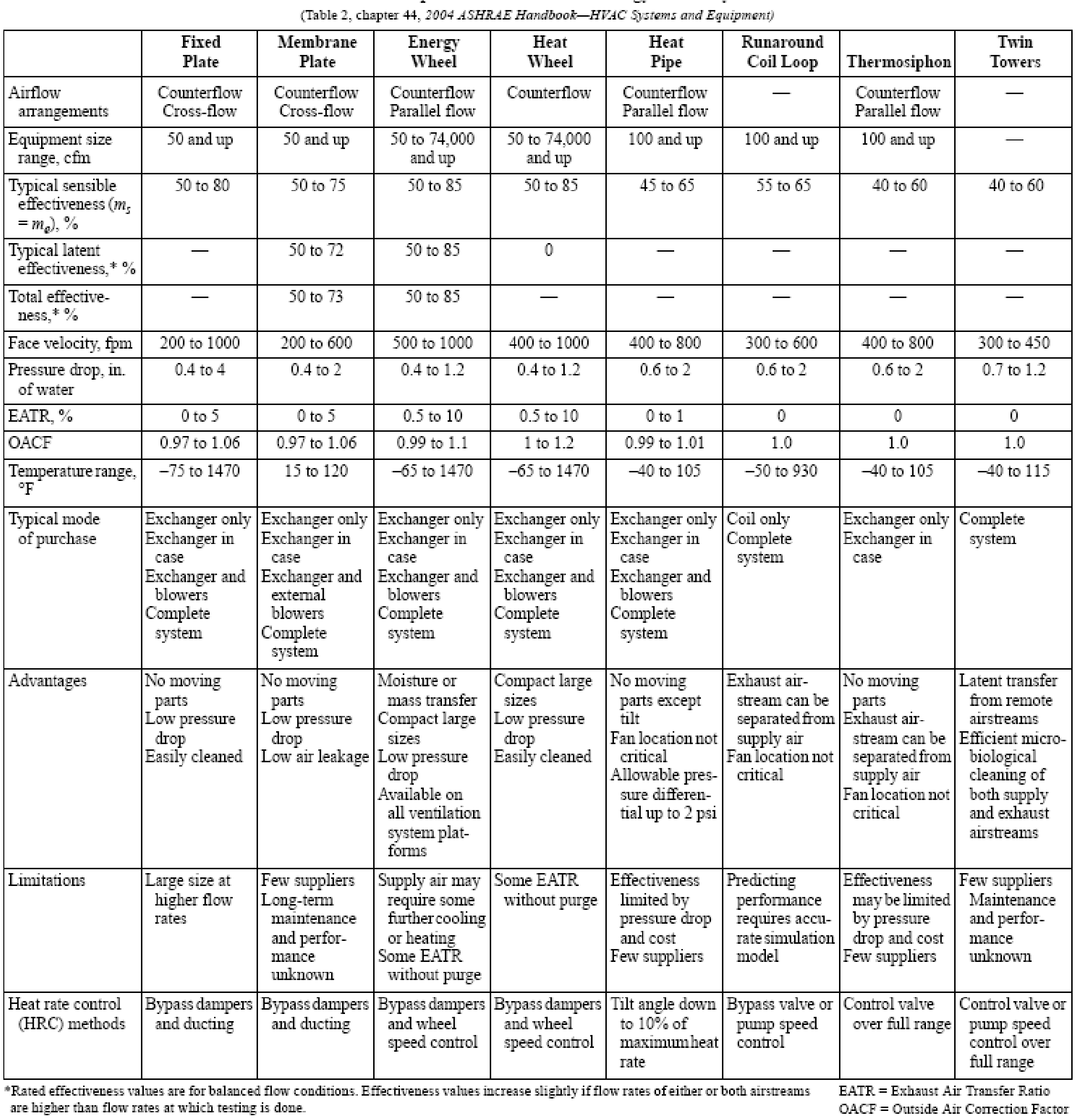
Comparison of Heat/Energy Recovery Devices

	ENERGY RECOVERY LOOPS		**HEAT PIPE EXCHANGERS**	**PLATE EXCHANGERS**		**ROTARY AIR-TO-AIR EXCHANGERS**	
	Runaround Coil Loop	**Twin Tower Loop**		**Fixed Plate**	**Membrane Plate**	**Heat Wheel**	**Energy Wheel**
Capacity (cfm)	100 and up	-	100 and up	50 and up	50 and up	50 to 74000 and up	50 to 74000 and up
Typical sensible effectiveness $(m_s = m_e)$, %	55 to 65	40 to 60	45 to 65	50 to 80	50 to 75	50 to 85	50 to 85
Typical latent effectiveness,* %	-	-	-	-	50 to 72	0	50 to 85
Total effectiveness,*, %	-	-	-	-	50 to 73	-	50 to 85
Face velocity, fpm	300 to 600	300 to 450	400 to 800	200 to 1000	200 to 600	400 to 1000	500 to 1000
Pressure drop, in. of water	0.6 to 2	0.7 to 1.2	0.6 to 2	0.4 to 4	0.4 to 2	0.4 to 1.2	0.4 to 1.2
Temperature range, ^{o}F	-50 to 930	-40 to 115	-40 to 105	-75 to 1470	15 to 120	-65 to 1470	-65 to 1470
Advantages	Exhaust air-stream can be remote from supply air Fan location not critical	Latent transfer from remote airstreams Efficient micro-biological cleaning of both supply and exhaust airstreams	No moving parts except tilt Fan location not critical Allowable pressure differential up to 2 psi	No moving parts Low pressure drop Easily cleaned	No moving parts Low pressure drop Low air leakage	Compact large sizes Low pressure drop Easily cleaned	Moisture or mass transfer Compact large sizes Low pressure drop Available on all ventilation system platforms
Limitations	Predicting performance requires accurate simulation model	Few suppliers Maintenance and performance unknown	Effectiveness limited by pressure drop and cost Few suppliers	Large size at higher flow rates	Few suppliers Long-term maintenance and performance unknown	Leakage between exhaust and supply airstreams	Leakage between exhaust and supply airstreams Supply air may require some further cooling or heating

* Rated effectiveness values are for balanced flow conditions. Effectiveness values increase slightly if flow rates of either or both airstreams are higher than the flow rates at which testing is done.

Source: Adapted from Table 2, Chapter 25, 2008 ASHRAE Handbook—HVAC Systems and Equipment

Comparison of Air-to-Air Energy Recovery Devices



(Table 2, chapter 44, *2004 ASHRAE Handbook—HVAC Systems and Equipment*)

	Fixed Plate	**Membrane Plate**	**Energy Wheel**	**Heat Wheel**	**Heat Pipe**	**Runaround Coil Loop**	**Thermosiphon**	**Twin Towers**
Airflow arrangements	Counterflow Cross-flow	Counterflow Cross-flow	Counterflow Parallel flow	Counterflow	Counterflow Parallel flow	—	Counterflow Parallel flow	—
Equipment size range, cfm	50 and up	50 and up	50 to 74,000 and up	50 to 74,000 and up	100 and up	100 and up	100 and up	—
Typical sensible effectiveness ($m_s = m_e$), %	50 to 80	50 to 75	50 to 85	50 to 85	45 to 65	55 to 65	40 to 60	40 to 60
Typical latent effectiveness,* %	—	50 to 72	50 to 85	0	—	—	—	—
Total effectiveness,* %	—	50 to 73	50 to 85	—	—	—	—	—
Face velocity, fpm	200 to 1000	200 to 600	500 to 1000	400 to 1000	400 to 800	300 to 600	400 to 800	300 to 450
Pressure drop, in. of water	0.4 to 4	0.4 to 2	0.4 to 1.2	0.4 to 1.2	0.6 to 2	0.6 to 2	0.6 to 2	0.7 to 1.2
EATR, %	0 to 5	0 to 5	0.5 to 10	0.5 to 10	0 to 1	0	0	0
OACF	0.97 to 1.06	0.97 to 1.06	0.99 to 1.1	1 to 1.2	0.99 to 1.01	1.0	1.0	1.0
Temperature range, °F	–75 to 1470	15 to 120	–65 to 1470	–65 to 1470	–40 to 105	–50 to 930	–40 to 105	–40 to 115
Typical mode of purchase	Exchanger only Exchanger in case Exchanger and blowers Complete system	Exchanger only Exchanger in case Exchanger and external blowers Complete system	Exchanger only Exchanger in case Exchanger and blowers Complete system	Exchanger only Exchanger in case Exchanger and blowers Complete system	Exchanger only Exchanger in case Exchanger and blowers Complete system	Coil only Complete system	Exchanger only Exchanger in case	Complete system
Advantages	No moving parts Low pressure drop Easily cleaned	No moving parts Low pressure drop Low air leakage	Moisture or mass transfer Compact large sizes Low pressure drop Available on all ventilation system platforms	Compact large sizes Low pressure drop Easily cleaned	No moving parts except tilt Fan location not critical Allowable pressure differential up to 2 psi	Exhaust airstream can be separated from supply air Fan location not critical	No moving parts Exhaust airstream can be separated from supply air Fan location not critical	Latent transfer from remote airstreams Efficient microbiological cleaning of both supply and exhaust airstreams
Limitations	Large size at higher flow rates	Few suppliers Long-term maintenance and performance unknown	Supply air may require some further cooling or heating Some EATR without purge	Some EATR without purge	Effectiveness limited by pressure drop and cost Few suppliers	Predicting performance requires accurate simulation model	Effectiveness may be limited by pressure drop and cost Few suppliers	Few suppliers Maintenance and performance unknown
Heat rate control (HRC) methods	Bypass dampers and ducting	Bypass dampers and ducting	Bypass dampers and wheel speed control	Bypass dampers and wheel speed control	Tilt angle down to 10% of maximum heat rate	Bypass valve or pump speed control	Control valve over full range	Control valve or pump speed control over full range

*Rated effectiveness values are for balanced flow conditions. Effectiveness values increase slightly if flow rates of either or both airstreams are higher than flow rates at which testing is done.

EATR = Exhaust Air Transfer Ratio
OACF = Outside Air Correction Factor

Source: 2008 ASHRAE Handbook—HVAC Systems and Equipment

Emerging Technologies Report

Residential Hot-Dry Air Conditioners

April, 2009

Definition	A hot-dry air conditioner is designed to meet the high sensitive heat ratio requirements of hot-dry climates.				
Base Case	A 3-ton residential central air conditioner with furnace				
New Measure:	A low-latent fraction air conditioner	Percent Savings	2025 Savings TBtu (Source)	Cost of Saved Energy	Success Rating (1-5)
		20%	26	7.01 $/MMBtu	4

Summary

Conventional residential central air conditioners are designed for "average" climates represented by the federal test conditions. To assure adequate dehumidification in most climates, the evaporator provides rather deep cooling of the air. In hot-dry climates, this is not required, and wastes energy. A climate-optimized central air conditioner for the Southwest should save about 20% of air conditioning energy.

Background and Description

Federal regulations require HVAC equipment to meet performance standards based on nationally-averaged weather conditions. HVAC manufacturers have thus designed and packaged most refrigeration components to meet these requirements. This results in equipment designs that achieve sensible heat ratios (SHR) of about 0.75 to 0.80 at standard conditions. SHR will rise when the return air is dryer, but the evaporators of conventional units waste energy by overcooling in dry climates. The ideal hot-dry climate vapor compression equipment should have SHRs of 0.90 or higher at rated conditions to achieve optimal efficiency. A redesign of refrigeration and fan systems to meet the specific needs of the hot-dry climate zones such as that in California and the Southwestern United States is thus needed.

Data Summary

Market Sector	**Market Application**	**End Use**	**Fuel Type**
Residential	New/Replace on Burnout Long Life	Cooling	Electricity
Current Status	**Date of Com**	**Product Life (years)**	**Source**
Research	2010	18	Lennox Case Study

Basecase Energy Use		**Units**	**Notes, Explanation**	**Source**
Efficiency	13.0	SEER	Yuba field test	PG&E 2008 report
Electricity Use	1,387	kWh/year	Yuba field test	PG&E 2008 report
Summer Peak Demand	1.914	kW	Yuba field test, 3–4pm coincident peak demand	PG&E 2008 report
Winter Peak Demand	0.0	kW		
Fuel Use	0.0	MMBtu/year		
New Measure Energy Use				
Efficiency	14.2	SEER	Yuba field test	PG&E 2008 report
Electricity Use	1,111	kWh/year	Yuba field test	PG&E 2008 report
Summer Peak Demand	1.3	kW	Yuba field test, 3-4pm coincident peak demand	PG&E 2008[63]
Winter Peak Demand	0.0	kW		
Fuel Use	0.0	MMBtu/year		
Savings				
Electricity Savings	276	kWh/year		PIER
Summer Peak Demand Svgs	0.6	kW		PIER
Winter Peak Demand Svgs	0.0	kW		
Fuel Savings	0.0	MMBtu/year		
Percent Savings	20%			
Percent Feasible	11%		Sum of population of California, Nevada, Arizona, and New Mexico	US Census, DOE
Industrial Savings > 25%?	No			
Costs				
Incremental Cost	$ 246	2009 $		PIER
Other Costs (Savings)	0	$/ year		
Ranking Metrics				
2025 Savings Potential	2498	GWh		
2025 Savings Potential	26	TBtu		
Cost of Saved Energy	0.07	$/kWh		
Cost of Saved Energy	7.01	$/MMBtu		

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[63] Hot Dry Climate Air Conditioner Pilot Field Test, Phase II http://wcec.ucdavis.edu/images/stories/technologies/pg%26e%202008%20pilot%20field%20test%20report.pdf

<table>
<tr><th>Unusual Market Barriers</th><th colspan="2">Non-Energy Benefits</th><th>Current Activity</th><th>Next Steps</th></tr>
<tr><td>More precise specs for installation required</td><td colspan="2">Higher Airflow</td><td rowspan="3">WCEC will be supporting utility HDAC pilot programs</td><td>Research & Development</td></tr>
<tr><td>AC Rating methods do not reflect efficiency gains</td><td colspan="2">Improved comfort</td><td>Incentives</td></tr>
<tr><td></td><td colspan="2"></td><td>Standards & Codes</td></tr>
<tr><td>Likelihood of Success</td><td>4</td><td>(1-5)</td><td colspan="2" rowspan="3"></td></tr>
<tr><td>Priority</td><td>Medium</td><td>Low, Med, High</td></tr>
<tr><td>Data Quality Assessment</td><td>C</td><td>(A-D)</td></tr>
<tr><td colspan="5">Principal Contacts</td></tr>
<tr><td colspan="5">Chris Scruton, CEC</td></tr>
<tr><td colspan="5">Marshall Hunt, WCEC</td></tr>
<tr><td colspan="5">Steve Dunn, SWEEP</td></tr>
<tr><td colspan="5">Mark Cherniak, NBI</td></tr>
<tr><td colspan="5">By: Amanda Korane, Wilson Lin, Harvey Sachs</td></tr>
</table>

Current Status of Measure

The CEC PIER project commissioned a study of optimized hot-dry air conditioners (HDAC) in 2004, with the participation of Southern California Edison, Proctor Engineering, and Bevilacqua-Knight.[64] This study resulted in an optimized HDAC design, along with market data and recommended measures. In addition, the 2007 Energy Policy Act instructed DOE to investigate regional standards for residential central air conditioners, which could include standards for hot-dry conditions. This work is underway.

The Western Cooling Efficiency Center is currently holding the Western Cooling Challenge, which is aimed at encouraging the development of new commercial rooftop unit concepts that are optimized for the western states (dry climate). Twelve companies have committed to participating in the challenge, whose goal is to have the products in the market by Jan 2011.[65]

Energy Savings and Costs

The PIER study[66] found several design changes that improved the efficiency in hot-dry regions. These included: a plastic fan housing, which increased the EER by 2.7% and the sensible EER by 7%; a clamshell style heat exchanger, which increased the EER by 0.7% and the sensible EER by 1.5%; and a ½ HP ECM motor (as opposed to 1/3 HP), which improved the EER by 15%. In sum this resulted in a 9.8% higher EER, and an 11.8% higher sensible EER. The incremental cost over a SEER 13 baseline is $246 and has a lifetime cost savings of $319–509.[67] These HDAC systems should prove cost-effective if they are not marked up as premium products.

Field tests for hot-dry air conditioners were conducted by Proctor Engineering Group in three California locations.[68] The report concluded that existing single speed air conditioners selected specifically for hot-dry climates can reduce peak electricity demand and give annual cooling savings of 20%, and that control modifications to the fan timing can further reduce annual electricity and peak consumption by 9 to 17%.

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[64] Chris Buntine, Southern California Edison; John Proctor, Proctor Engineering, Ltd., Robert Knight, Bevilacqua-Knight, Inc., Mark Cherniack, New Buildings Institute, 2007 Energy Performance of Hot Dry Air Conditioning Systems. California Energy Commission, PIER Building End-Use Energy Efficiency Program. CEC-500-2008-056.

[65] http://wcec.ucdavis.edu/content/view/92/110/

[66] Buntine et al.

[67] Ibid.

[68] "Hot Dry Climate Air Conditioner Pilot Field Test Phase 2", Pacific Gas and Electric Company Emerging Technologies Program, Proctor Engineering Group, 2008.

Key Assumptions Used in Analysis

The Yuba City field test by PG&E was selected as a representative case. The unit used in this field test has the highest sensible heat ratio of 0.79 amongst the field tests. The Yuba City site is also fairly representative, being a 1600 sf house built in 1991. The Yuba City site was also one of the field tests for the PIER study mentioned above, and the energy and peak consumption savings from both sets of tests are fairly consistent.

Recommended Next Steps

The principal barrier to market introduction of hot-dry air conditioners is that the current rating method, focused on SEER, does not provide manufacturers with a way to capture the benefits of regionally optimized equipment designs. Given the incremental cost of the hot-dry air conditioners over standard air conditioners, there is a need to clearly communicate the energy efficiency benefits of the hot-dry air conditioner to contractors and consumers in order to promote adoption. The inclusion of a hot and dry climate condition test point in performance rating tests such as SEER would help provide consumers with that information. These performance rating tests can also form the basis for utility incentive programs to incentivize the adoption of energy-efficient equipment and reduce energy consumption.

Incentive programs using criteria like the Western Cooling Challenge could provide an early market for residential HDAC, and encourage manufacturers to address this huge niche. In this context, one market barrier must be addressed: FTC regulations prevent manufacturers from making efficiency claims other than SEER,[69] for which the rating method is legally prescribed by DOE. Thus, manufacturers are limited in the claims they can make for better units.

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[69] In addition, EER may be presented in literature for contractors. Federal Trade Commission, letter of May 22, 2003, from Hampton Newsome to Stephen Yurek, ARI.

Emerging Technologies Report

Smart Premium (Robust) Residential Air Conditioners[70]

August, 2009

Definition	Residential central air conditioners incorporating auto-diagnostics and design features to assure long-term operating performance				
Base Case	SEER 13, EER 11, 3-tons, QI but no ECM				
New Measure	Incorporation of features such as improve fans and economizers, diagnostics	Percent savings	2025 Savings TBtu (Source)	Cost of Saved Energy	Success Rating (1-5)
		24%	376	$0.13	3

Summary

The efficiency of residential central air conditioners (CAC) and heat pumps (HP) has roughly doubled in the last two decades, as measured by federal metrics. Another doubling in rated efficiency of these forced air units is unlikely, for thermodynamic, manufacturing, and economic reasons. However, there are still several approaches for large improvements in long-term *field performance,* which is not closely modeled by the conventional metrics. One approach, the "Smart Premium" air conditioner, focuses on cost-effective improvements that would provide maximum assurance to the customer that the purchased efficiency is likely to be maintained over the life of the product. Conservative simulations indicate that a Smart Premium Air Conditioner would save about 10%, or more than the rated difference between SEER 14 and SEER 15.[71] A Smart Premium "label" would give manufacturers independent validation for their efforts to market products differentiated by energy efficiency and reliability, core elements of value. The proposed is a premium unit, meeting or exceeding ENERGY STAR performance specifications. Relative to base products, it should save at least 20%. Half the savings are from the ENERGY STAR performance, and half the savings are from the Smart Premium features.

Background and Description

Depending on the economic cycle, five to eight million central air conditioners and heat pumps smaller than five tons capacity are sold annually in the US.[72] The expected median life is 18.4 years.[73] These units generally do not achieve efficiency in the field implied by their SEER ratings.[74] Shortfalls arise from deficiencies in the national rating method, and from poor installation and maintenance. For 2006 and more recent equipment, these factors include incorrect air flow, leaky ducts, and oversizing.[75] Slow refrigerant leaks are thought to be reasonably common, and would degrade performance by leading to refrigerant charge levels lower than could be compensated by the thermostatic expansion valves (TXVs) that are almost ubiquitous in SEER 13 and higher equipment. “Smart Premium” units could largely compensate for charge losses (20% degradation in SEER) and low airflow (25% cumulative). With auto-diagnostic signals, they would also signal for maintenance required to protect performance, including both user actions (e.g., filter loaded) and service needs (e.g., hard start, low refrigerant levels, high head pressure).

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[70] This concept was formerly referred to as the “Robust” residential air conditioner. A reviewer suggested that “Smart Premium” better captures the value proposition proposed, so we have changed the term.

[71] Sachs, H.M, H. Henderson, D. Shirey, and W. DeForest, 2008. *A Smart Premium Feature Set for Residential Air Conditioners.* ACEEE Report A081, ACEEE, Washington DC.

[72] http://ahrinet.org/Content/CentralAirConditionersandAirSourceHeatPumps_604.aspx

[73] DOE, 2001. "Central Air Conditioners and Heat Pumps Energy Conservation Standards; Final Rule." *Federal Register* / Vol. 66, No. 14 / Monday, January 22, 2001 / Rules and Regulations, 7169 - 7200

[74] Neal, C.L. 1998. “Field Adjusted SEER [SEERFA] Residential Buildings: Technologies, Design, and Performance Analysis.” In *Proceedings of the ACEEE 1998 Summer Study on Energy Efficiency in Buildings,* 1.197. Washington, D.C.: American Council for an Energy-Efficient Economy.

[75] Equipment manufactured before the 2006 transition to minimum 13 SEER generally used orifice-type metering devices that were much more sensitive to refrigerant charge anomalies.

The Smart Premium air conditioner specification addresses issues over which manufacturers have full or partial control. *Each of these features is individually available today, but there is no program to recognize the cumulative value.* Note that the feature set does not require a modulating compressor. The required features include the following:

- *Minimum energy efficiency* SEER ≥14.5 and EER ≥12.[76]
- *Adaptive response* to incorrect charge. This simply requires a TXV or electronic control valve. These are essentially universal at this efficiency level and higher.
- *Airflow management. With appropriate controls*, this function can be met with widely available permanent magnet fan motors, such as the GE-Regal Beloit "ECM."
- *Sealed cabinet,* with minimum leakage rate to be determined.[77]
- *System integration:* condensing unit, evaporating unit, and controls from the same source. These controls are to include diagnostic signals at the thermostat, so action can be taken. The thermostat must be a 2-way communicating type, capable of receiving utility price or demand reduction signals, and of transmitting demand response to the utility, and diagnostic signals to the contractor (or other service provider).[78]

The "Smart Premium" feature suite is suitable for incorporation into efficient product recognition and incentive programs, including ENERGY STAR and CEE[79] utility incentive programs, since it encourages including advanced features that both save energy and establish the value of a suite of premium features. This feature set would be difficult to capture in standards, not least because standards only try to measure the performance of new equipment. Consumers who purchase a Smart Premium system with Quality Installation (QI)[80] would have the greatest possible assurance of realizing the efficiency they purchase, over the lifetime of the equipment and system.[81]

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[76] These are the 2009 ENERGY STAR specifications for split systems.

[77] Conforming to (draft) ASHRAE SPC 193P, "Method of Test for Determining the Air-Leakage Rate of HVAC Equipment"

[78] The homeowner must be able to decline activation of utility or contractor control, and the controller should indicate control features that are enabled, and those that are active.

[79] Consortium for Energy Efficiency, Boston. cee1.org

[80] *ANSI / ACCA 5 QI 2007 HVAC Quality Installation Specification,* https://www.acca.org/Files/?id=116

[81] The extent to which some kind of routine Quality Maintenance program would still be required remains uninvestigated. With appropriate diagnostics and homeowner filter replacement, could the service plan built around annual or semi-annual house visits be replaced by as-needed visits? (ANSI/ACCA 4, 2009. Maintenance of Residential HVAC Systems.)

Data Summary

Market Sector	Market Application	End Use	Fuel Type
Residential	New/Replace on Burnout Short Life	Heating & Cooling	Electricity
Current Status	**Date of Com**	**Product Life (years)**	**Source**
Research	2010	18.4	Sachs & others 2008

Basecase Energy Use		**Units**	**Notes, Explanation**	**Source**
Efficiency	11.7	SEERFA[82]	field-adjusted SEER, with QI, but 10% reduction from SEER 13	
Electricity Use	2,200	kWh/year	Updated with ratio of SEER 13/10 to bring forward from RECS	RECS 2001,[83] ACEEE, Measure H7[84]
Summer Peak Demand	2.9	kW	Estimated as 10% better than SEER 10 unit	RECS 2001[85], ACEEE Measure H7[86]
Winter Peak Demand	0.0	kW		
Fuel Use	0.0	MMBtu/year		
New Measure Energy Use				
Efficiency	14.5	SEERFA	field-adjusted SEER, with QI	
Electricity Use	1,800	kWh/year		As above
Summer Peak Demand	2.7	kW		
Winter Peak Demand	0.0	kW		
Fuel Use	1.9	MMBtu/year	extra heating season gas due to less resistance heating by better fan motor	
Savings				
Electricity Savings, Annual	700	kWh/year	Includes fan savings of 300 kWh in winter	Sachs & Smith[87]
Summer Peak Demand Svgs	0.2	kW		
Winter Peak Demand Svgs	0.0	kW		
Fuel Savings	-1.9	MMBtu/year		
Percent Savings	24%			
Percent Feasible	85%		Central AC portion of residential AC use	RECS[88]
Industrial Savings > 25%?	No			

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[82] Neal, 1998, Field Adjusted SEER [SEERFA]. Residential Buildings: Technologies, Design, and Performance Analysis. In *Proceedings of ACEEE's 1998 Summer Study on Energy Efficiency in Buildings,* 1.197 –1.209. ACEEE, Washington, DC.

[83] Residential Energy Consumption Survey 2001. http://www.eia.doe.gov/emeu/recs/recs2001/detailcetbls.html

[84] Sachs, H. S. Nadel, J. Amann, M. Tuazon, E. Mendelsohn, L. Rainer, G. Todesco, D. Shipley, and M. Adelaar 2004. *Emerging Energy-saving Technologies and Practices for the Buildings Sector as of 2004.* ACEEE Report A042. American Council for an Energy-Efficient Economy, Washington DC. http://www.aceee.org/pubs/a042.htm.

[85] Residential Energy Consumption Survey 2001. http://www.eia.doe.gov/emeu/recs/recs2001/detailcetbls.html

[86] Sachs, H. S. Nadel, J. Amann, M. Tuazon, E. Mendelsohn, L. Rainer, G. Todesco, D. Shipley, and M. Adelaar 2004. *Emerging Energy-Saving Technologies and Practices for the Buildings Sector as of 2004.* American Council for an Energy-Efficient Economy, Washington DC. www.aceee.org/pubs/a042.htm.

[87] Sachs, H. and S. Smith 2003. *Saving Energy with Efficient Residential Furnace Air Handlers: A Status Report and Program Recommendations*. ACEEE Report A033. American Council for an Energy-Efficient Economy, Washington, DC.

[88] Residential Energy Consumption Survey 2001. http://www.eia.doe.gov/emeu/recs/recs2001/detailcetbls.html

Costs				
Incremental Cost	$ 1,320	2004 $	estimate for ECM, diagnostics, etc.	
Other Costs (Savings)	($23.75)	$/ year	@ $12.50/MMBtu	
Ranking Metrics				
2025 Savings Potential	35,890	GWh		
2025 Savings Potential	376	TBtu		
Cost of Saved Energy	$ 0.13	$/kWh		
Cost of Saved Energy	$ 12.66	$/MMBtu		
Unusual Market Barriers	**Non-Energy Benefits**	**Current Activity**	**Next Steps**	
No marketing strategy	More even cooling	Research only	Field Testing	
Lack of education			Test Procedure	
Likelihood of Success	3	(1-5)		
Priority	Medium	Low, Med, High		
Data Quality Assessment	B	(A-D)		
Principal Contacts				
Harvey Sachs, ACEEE				

Current Status of Measure

Each of the features required for the Smart Premium air conditioners is available today in a reasonable number of premium models. Over 100,000 combinations (indoor and outdoor units) meet the SEER ≥14.5 and EER ≥12 specification for ENERGY STAR listing.[89] At this performance level, TXV or better feedback metering devices are ubiquitous. Airflow management can be done with a well-controlled feedback-enabled motor such as the GE-Regal Beloit "ECM," which is relatively common in premium equipment, and qualifies for current federal tax credit.[90] One key element is a control architecture that prevents the fan from responding to excess ESP by using more power than a PSC motor would. This requirement could be met with an alarm/diagnostic that lets the installer know that the blower cannot meet the airflow requirements of the system without duct modification.[91] The *sealed cabinet* provision responds to a relatively new concern: Although residential air handler leakage areas are small, the pressure differentials are large, so the air handler can comprise a substantial fraction of total system leakage,[92] which is critical for equipment installed in attics, garages, or other areas outside the thermal envelope. We also recommend that qualifying equipment include an air-tight filter rack. The cabinet leakage can account for 1% to 3% of system energy use. This feature was not modeled by Sachs and others.

The requirement for *System Integration* is novel and requires additional comment. It has two parts. First, the condensing unit, evaporating unit, and controls must be "bundled" or integrated by a single supplier. This could be an original equipment manufacturer (OEM) such as Carrier, Trane, or Goodman. Or, it could be any other firm (utility, ESCO) that would certify the performance of the complete system and its compliance with the Smart Premium feature set. Because the Smart Premium unit has advanced controls, we believe that this level of integration is required to assure that contractors and consumers are not trapped in finger-pointing exercises among piece-part suppliers if a system does not work properly.[93] It may also be seen in the market as a quality indicator.

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[89] http://www.ahridirectory.org/ceedirectory/pages/ac/cee/defaultSearch.aspx, August 11, 2009.

[90] http://energytaxincentives.org/consumers/heating-cooling.php#fans, August 11, 2009

[91] In operation, this should also alert the occupants of out-of-range conditions, such as would be encountered with excess filter loading, crushing or blocking a duct, etc. This alternative suggested by a reviewer.

[92] Withers, C.R. and J.B. Cumings. 2006. "Air Handlers: An Appliance of Airtight Defiance?" P. 1-348–1-359 in *Proceedings of the ACEEE Summer Study on Buildings*. American Council for an Energy-Efficient Economy, Washington.

[93] In the short run, this requirement also addresses concerns about delivered performance of some third-party (Independent Coil Manufacturer, or ICM) indoor coils that have been certified by simulation. In response to AHRI certification concerns, by the July 15 deadline, approximately 50,000–75,000 coil combinations were voluntarily de-rated or removed by individual OEMs. And another

The consumer view of the stipulated "controls" is a high-capability programmable thermostat, with additional features and capabilities: (1) Diagnostic/alarm signals, including air filter loaded, and "alarm: call for service" when performance is outside the manufacturer's specified parameters. The technician would "see" three other attributes. (2) Two-way communicating capability. This means that the controller can receive utility signals, such as critical peak periods that require deactivating[94] the air conditioner. It might also receive test signals from a remote technician, for supplemental fault analysis before arriving on site. Two-way communicating thermostats were not adopted for new residential construction in California's Title 24 in 2008, but they may be considered again in the 2011 cycle.[95] (3) Fault and diagnostic code display, on the equipment or the thermostat. The goal is to notify the owner when capacity or performance degrade by some fraction, such as 10%. *The* necessary *"intelligence"* can be implemented in multiple *ways,* including using feedback from the compressor,[96] and/or with supplemental sensors on refrigerant lines and other components. These technologies are available on some premium products today. (4) Easy connection of thermostat to equipment. This can be achieved with (encrypted) wireless, or with pre-made wire sets with standard connectors, so that they can be pulled and connected very quickly, and cannot be connected incorrectly.

Multiple manufacturers have expressed some interest in this premium product offering.

Note that the *Smart Premium* air conditioner is not inherently more efficient under *laboratory test* conditions than a conventional product, but is expected to maintain its performance better than conventional equipment, thereby offering long-term efficiency gains. Simulations reported in Sachs and others[97] strongly suggest savings in the range of 10% for *Smart Premium* equipment, and that these savings are maintained over the life of the equipment. There has not been field validation of these savings estimates. Indeed, there is relatively little information on performance degradation of a large population of split systems in the field.

Savings Potential and Cost-Effectiveness

As noted above, the *Smart Premium* unit should save at least 20% of the energy required by the equivalent SEER/EER equipment with Quality Installation. Roughly half the savings are from increased SEER (14.5 vs. 13), and half from the *Smart Premium* features themselves.

Market Barriers

1. *Smart Premium* is a novel concept. Market actors are (at best) accustomed to associating efficiency with performance revealed by federal ratings. *Smart Premium* implicitly asserts that the efficiency (and value) "bundle" has many additional dimensions, factors that are required to achieve long-term, sustainable savings. The concept is easier to symbolize than explain (and even its name may need to be supplanted by one that resonates better with consumers).
2. *"Show me"* prevails in the world. *Smart Premium* capabilities have been simulated, but there is little in field experience or measurements to document field performance degradation over time due to the factors addressed by *Smart Premium.*
3. *High first costs. Smart Premium* describes a premium product that both manufacturers and dealers will be tempted to include with their "best" offerings (in a "good-better-best" sales strategy). Although the technologies required are not necessarily high-cost, the equipment will be relatively high-priced.

20,000 coil combinations were de-listed by AHRI and are no longer available in the AHRI database, as a result of concerns that the simulation results used to rate mix-match combinations may not be reliable. "ACCA Alert," 7/24/2009.

[94] Some utilities may accept *unloading* of modulating equipment at peak times. That is, running the equipment at low capacity. Presumably, this would not apply to *critical peak intervals.*

[95] C. Scruton, CEC, personal communication, August 2009

[96] The Emerson *Comfort Alert,* http://www.emersonclimate.com/contractor/products/ultratech/comfort-alert-diagnostics.shtm, might be a prototype for such capabilities.

[97] Sachs, H.M, H. Henderson, D. Shirey III, and W. DeForest 2008. A Robust Feature Set for Residential Air Conditioners. Report #A081, American Council for an Energy-Efficient Economy, Washington, DC.

Key Assumptions Used in Analysis

Average Price of Electricity	$0.1032/kWh[98]
Average Price of Natural Gas	$10.97/MMBtu[99]
Projected 2025 End Use Electricity Consumption[100]	0.39 quads
Real Discount Rate	4.53%
Projected 2025 End Use Gas Consumption[101]	1.25 quads
Heat Rate	10.48 kBtu/kWh

Next Steps

1. Get feedback on the concept of a *Smart Premium* air conditioner as a premium "brand" that offers improved efficiency and reliability over the life of the product.
2. Measure performance of units in the field, to form better understanding of field performance degradation.
3. Consider adopting the *Smart Premium* specification as a component of ENERGY STAR and utility programs.

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[98] EIA, “Electric Power Monthly—Feb 2009”, (YTD-Nov08, Commercial Price)
[99] http://tonto.eia.doe.gov/dnav/ng/ng_sum_lsum_dcu_nus_m.htm
[100] EIA 2009. “Annual Energy Outlook 2009 with Projections to 2030”. Tables 4 and 5.
[101] Ibid.

Emerging Technologies Report

Advanced Northern Heat Pumps[102]

August, 2009

Definition	More sophisticated, multi-stage air source heat pump				
Base Case	Normal air-source heat pump, SEER 13, EER 10, HSPF 7.7				
New Measure:	HP, SEER 16, EER 12, HSPF 9.6, multi-stage compressor, large HX, and optimized controls	Percent savings	2025 Savings TBtu (Source)	Cost of Saved Energy	Success Rating (1-5)
		26%	299	$0.07/kWh	4

Summary

Conventional heat pumps do poorly in colder climates. As temperatures drop below freezing, both capacity and efficiency drop, and large amounts of back-up resistive heat is required. Emerging "northern," "cold climate," or "all climate" heat pumps use more sophisticated designs to capture heat better. They are expected to improve performance and climate range when compared with conventional air source heat pumps. Costs will be lower than for residential ground source (GSHP, geothermal, or geoexchange) heat pumps, but performance is not expected to be as good as GSHPs in very cold regions. This report is restricted to ducted equipment, and excludes ductless mini-splits and multi-splits.

Background & Description

In the North American context, a heat pump is basically a residential air-to-air central air conditioner with a reversing valve and other design modifications. These allow it to pump heat from the outside air into the house (winter), as well as from the inside to the outside (summer). In winter, the evaporator (indoor coil) becomes the condenser, and the condenser (outdoor coil) serves as the evaporator. Heat pumps have been available for several decades, but acceptance has been largely limited to Southern climates by operational limitations of conventional approaches. First, the performance of any heat pump decreases when the required "lift" (difference between outdoor and indoor temperature) increases. This reduces both capacity (Btuh) and efficiency (COP). Typical units work little better than resistance electricity (COP = 1) at temperatures < 32ºF, with performance systematically declining below that temperature. As the (outdoor) evaporator coil temperature drops, frost formation is likely. To prevent this, periodic cycle reversal to heat the coil and defrost it is required. This uses heat from the inside, and results in a short "cold-blow" that consumers do not like. This can be reduced with adaptive controls, or additional energy (resistance heat) can be employed to neutralize the cooling effect on the occupants. Electric heat (or occasionally a gas furnace in series with the heat pump) also makes up the difference between the unit's capacity at a given temperature and the load of the building.

Advanced northern-climate heat pumps are designed to operate without resistance heating back-up, even in cold climates. Resistance heating is very expensive, and can impose large peak demand loads on utilities. Heat pumps that largely avoid supplemental heat have enormous potential benefits to the homeowner and the grid, by reducing winter peak loads. For the homeowner, it would reduce operating costs, and avoid the complexity of a dual-fuel system that would use supplemental natural gas or propane burned in a furnace section when the output of the heat pump is inadequate. For the grid, there have been major problems, particularly early on winter mornings, with simultaneous calls for resistance heat from large numbers of customers' heat pumps. This peak load is expensive to meet with generation, and

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[102] This discussion is limited to *air-source* heat pumps. Ground-source units optimized for cold climates are also available, such as the Econar line, http://www.econar.com/index.htm. Ground-source systems are typically substantially more expensive than air-source systems, due to the smaller market, the premium nature of the product, and the cost of installing a ground loop.

many utilities (particularly those serving rural customers) are challenged to meet the load with cost-effective distribution systems.

The need for and potential of specialized cold climate heat pumps has been recognized by special provisions for rating two-stage cold climate heat pumps in the federal air conditioner and heat pump rating method.[103] Available specialty products use two-stage compressors plus an auxiliary compressor; major firm offerings seem to be limited to two-stage compressors.

Data Summary Table

Market Sector	**Market Application**		**End Use**	**Fuel Type**
Residential	New		Heating & Cooling	Electricity
Current Status	**Date of Com**		**Product Life (years)**	**Source**
Commercialized			18.4	DOE TSD
Basecase Energy Use		**Units**	**Notes, Explanation**	**Source**
Efficiency	7.7	HSPF	2006 federal minimum	
Electricity Use	13,353	kWh/year	Spokane, WA	E* calculator
Summer Peak Demand	3.24	kW	0.9 coincidence even for cold region	
Winter Peak Demand	8.35	kW	Peak demand conversion taken from COP@17 assumed 1.2	ACEEE 2004,[104] Measure H9
Fuel Use	0	MMBtu/year		
New Measure Energy Use				
Efficiency	8.6	HSPF, Zone 5.	Region V, part-season field-based	Russ Johnson
Electricity Use	9,895	kWh/year		EnergyStar calculator[105]
Summer Peak Demand	2.7		0.9 coincidence even for cold region	
Winter Peak Demand	3.71	kW	0.9 coincidence from COP at 17 F=2.45	
Fuel Use	0	MMBtu/year		
Savings				
Electricity Savings	3458	kWh/year	Energy Star Calculator, Calc_ASHP	
Summer Peak Demand Svgs	0.54	kW		
Winter Peak Demand Svgs	4.64	kW	Consistent with estimate by BPA[106] of diversified peak reduction on very cold days	
Fuel Savings	0	MMBtu/year		
Percent Savings	26%			
Percent Feasible	29%		Electric heat, cold regions taken as climate regions 1-5+, estimated as 50% of population	
Industrial Savings > 25%?	No			
Costs				
Incremental Cost	$ 3,000	2004 $	WSU[107] lower bound, above BPA estimate	
Other Costs/ (Savings)	$ -	$/ year		

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[103] " 1.46 Two-capacity, northern heat pump Means a Heat Pump that Has a Factory or field-Selectable Lock-Out Feature to Prevent Space Cooling at High-Capacity. P. 59139 in *Federal Register* / Vol. 70, No. 195 / Tuesday, October 11, 2005 / Rules and Regulations, 10 CFR Part 430.

[104] Sachs, H. S. Nadel, J. Amann, M. Tuazon, E. Mendelsohn, L. Rainer, G. Todesco, D. Shipley, and M. Adelaar 2004. *Emerging Energy-saving Technologies and Practices for the Buildings Sector as of 2004.* ACEEE Report A042. American Council for an Energy-Efficient Economy, Washington DC. www.aceee.org/pubs/a042.htm.

[105] http://www.energystar.gov/index.cfm?c=cac.pr_central_ac

[106] Bonneville Power Administration (undated). Energy Efficiency New Technology. BPA began a Cold Climate Heat Pump (CCHP™) Performance Pilot Project in November 2004.

[107] http://www.energyideas.org/documents/Factsheets/PTR/AcadiaHeatPump.pdf

Ranking Metrics			
2025 Savings Potential	28,543	GWh	
2025 Savings Potential	299	TBtu	
Cost of Saved Energy	$ 0.07	$/kWh	
Cost of Saved Energy	$ 6.73	$/MMBtu	
Unusual Market Barriers	**Non-Energy Benefits**	**Current Activity**	**Next Steps**
Market confidence Niche manufacturer only	Less mechanical shock Longer mechanical life	NRECA field testing, Hallowell; sales through distributors	Field Testing Demonstrations Incentives
Likelihood of Success	4	(1-5)	
Priority	High	Low, Med, High	
Data Quality Assessment	B	(A-D)	
Principal Contacts			
Duane Hallowell, Hallowell International, 1-877-322-2342			
Russ Johnson, Johnson Research LLC; johnson.research@att.net			
By Harvey Sachs, with Russ Johnson			

Current Status of Measure

In 2009, the Acadia "All Climate Heat Pump" is available from Hallowell International.[108] As of early 2011, it appears that Hollowell International has ceased or suspended operations. [109] The predecessor system from Nyle, the "Cold Climate Heat Pump," is no longer mentioned on the manufacturer's web site. [110] The Nyle product was originally sold under contract with the inventor, David Shaw. Shaw terminated his contract with Nyle (in ~2005?) and formed Hallowell International to develop and market the current product. Several thousand Hallowell units have been sold and installed, and performance of a number has been monitored in the field.[111] Earlier in the decade, Oak Ridge National Laboratory worked on a heat pump that used resistance heat applied to the accumulator liquid, in an effort to eliminate defrost and "cold blow" during the defrost cycle. It did not extend the temperature range of the unit to colder regimes.[112]

Savings Potential and Cost-Effectiveness

Early models showed field performance lower than predicted from the ratings, which is characteristic of air-source heat pumps. However, it is also noteworthy that the U.S. rating method, HSPF, does not consider any temperatures <17ºF. The principal advantage of the Northern heat pump is its ability to maintain capacity and efficiency at colder temperatures. BPA estimates a diversified load reduction of about 5 kW on cold days. Current field tests suggest that this expectation is reasonable for nominal 3-ton systems, at outdoor temperatures as low as -10°F.

Cost estimates vary, and will depend strongly on production volume and contractor experience. Washington State University estimated incremental cost of $3000–4000, while BPA estimated about $2000. The Hallowell unit is marketed through distributors, like most other HVAC equipment, with mark-ups set by the distributor and contractor.

Savings estimates are based on the ENERGY STAR air-source heat pump calculator, and give nearly identical results for two cities with different cold climates, Spokane, WA and Chicago, Il. Results are presented for Spokane. They are considered very conservative, because the ENERGY STAR calculator

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[108] http://www.gotohallowell.com/
[109] http://new.bangordailynews.com/2011/03/29/business/what%E2%80%99s-going-on-with-hallowell-international/
[110] http://www.nyle.com/
[111] According to Mr. Russ Johnson, Johnson Research, LLC, who follows this segment closely.
[112] Richard Murphy, ORNL, personal communication July 7, 2009

will not capture low winter temperature savings when the Northern heat pump is using the refrigeration cycle instead of resistance heat (down to less than 0°F).

Market Barriers

1) First cost premiums are always a barrier. First cost for the Northern climate air-source heat pump will remain higher than conventional heat pumps because the technology is more complex. It begins with a two-stage compressor, and adds a second compressor and heat exchanger, which is likely to more than double the compressor cost for a conventional unit. It also requires a more complex thermostat and a large outdoor coil. At any production volume, there will remain a cost premium. Today, few contractors have experience with the units; risk averse contractors will be expected to charge a premium to recover training and possible call-back costs.

2) Published ratings impede meaningful comparisons. The federal rating method requires calculations in all climate zones, but manufacturers do not have to publish data other than for Climate Zone IV (moderate). Without Zone V (cold) for comparison, it is difficult to establish demand and energy savings for cold regions. In addition, the rating method does not include temperatures below 17°F, where much of the value of the specialized Northern heat pump lies.

3) Finally, consumers have not traditionally regarded heat pumps as desirable systems, because of high bills associated with resistive backup, and past experience with low supply-air delivery temperatures. Utilities have been concerned about peak demands due to resistive back-up, and have often required "dual fuel" capabilities for all heat pump installations. In these systems, the resistance section is replaced with a fossil-fuel furnace section, generally operated with propane during very cold weather.

Manufacturers of northern heat pumps have to overcome all of these barriers.

Key Assumptions Used in Analysis

Average Price of Electricity	$0.1032/kWh[113]
Average Price of Natural Gas	$10.97/MMBtu[114]
Projected 2025 End Use Electricity Consumption[115]	0.39 quads
Real Discount Rate	4.53%
Projected 2025 End Use Gas Consumption[116]	1.25 quads
Heat Rate	10.48 kBtu/kWh

Recommended Next Steps

Field study data are essential for establishing the actual operating cost differences between Northern heat pumps and conventional units. Such data and case studies are required so manufacturers can justify marketing statements.[117] Field data are also essential as a basis for utility incentive programs to promote the products. For these programs, winter demand savings are likely to be as important as energy savings, in some cases.

Rating method changes based on these findings are desirable, but likely to take many years to work their way through ASHRAE, AHRI, and DOE processes. However, the case study information itself could justify changes in the ENERGY STAR calculator.[118]

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[113] EIA, "Electric Power Monthly – Feb 2009", (YTD-Nov08, Commercial Price)
[114] http://tonto.eia.doe.gov/dnav/ng/ng_sum_lsum_dcu_nus_m.htm
[115] EIA 2009. "Annual Energy Outlook 2009 with Projections to 2030". Tables 4 and 5.
[116] Ibid.
[117] FTC requirements limit efficiency claims that manufacturers can make beyond the values for the federal rating method.
[118] Reached from http://www.energystar.gov/index.cfm?c=airsrc_heat.pr_as_heat_pumps.

Because Northern climate heat pumps will remain more expensive than the conventional alternative, it is essential to develop the value proposition by showing economic (and installation) advantages relative to the two alternatives likely to appeal to consumers. These are dual fuel air-source heat pumps, and ground-source (geothermal) heat pumps. The All Climate Heat Pump (ACHP) occupies a niche between conventional air-source heat pumps and geothermal heat pumps. Field testing and life-cycle cost analysis will be required to demonstrate whether the ACHP has a more favorable life-cycle cost than its competition.

Emerging Technologies Report

Commercial Ground-Source Heat Pumps: One-Pipe Loops

August, 2009

<table>
<tr><td>Definition</td><td colspan="5">Commercial (~50–200 ton) ground-source heat pumps with advanced distribution architecture</td></tr>
<tr><td>Base Case</td><td colspan="5">Air-source heat pump RTUs</td></tr>
<tr><td rowspan="2">New Measure:</td><td rowspan="2">One-pipe primary distribution architecture, each heat pump has individual circulator as mini-secondary loop, circulator replaces motorized valves, balancers, etc.</td><td>Percent savings</td><td>2025 Savings TBtu (Source)</td><td>Cost of Saved Energy</td><td>Success Rating (1-5)</td></tr>
<tr><td>60%</td><td>1,651</td><td>$0.07</td><td>4</td></tr>
</table>

Summary

Ground-source heat pumps (GSHP), commonly referred to as geothermal systems, have been available as very efficient niche products for decades. With growing experience, designers of school and other systems for commercial buildings are developing highly disciplined approaches, such as the one-pipe loop discussed here. For schools, and potentially for office and similar buildings, one-pipe loops can decrease total system first costs by almost half relative to some alternative GSHP designs, and by about 15% when compared with VAV system offering comparable amenity. They are close to the cost of roof-top unitary equipment approaches. The single pipe design is also simpler to design, install, and commission.

Background and Description

Ground-coupled heat pump systems (also called ground-source heat pumps or GeoExchange) consist of a water loop for exchanging thermal energy between soil or groundwater, and heat pumps that provide space heating, cooling, and/or water heating to the conditioned space. In most applications this hydronic loop is a closed loop transferring heat with tubing located in the ground. Ground loops are typically vertical boreholes (~200–300 foot depth per ton of capacity) with U-tubes providing a flow path through the grouted borehole. Alternative approaches include horizontal closed loops (typically for small, residential-scale installations) and open loop systems that withdraw water from underground, pass it through a heat exchanger, and return the warmed/cooled water to the aquifer.

Almost all GSHP systems use packaged unitary heat pumps for heating and cooling each zone, such as a classroom. Unit capacity is typically is 1–10 tons. Units are rated by steady-state measures for cooling (EER) and heating (COP), unlike other small equipment (central air and heat pumps). In buildings with ground-source heat pumps, ventilation air for commercial buildings may be treated by the local zone heat pumps, or provided by a separate outdoor air system.

Because the outdoor heat exchanger is the earth, with relatively moderate temperature swings, ground-coupled systems can achieve higher operating efficiencies than typical air-source heat pump equipment. Several key advantages of ground-coupled technology derive from the single-package design, which eliminates the outdoor heat exchanger. Due to the short refrigeration path within the indoor unit, the refrigerant charge is lower and can be accurately measured at the factory. The lack of outdoor components increases expected equipment life. In general, ground-source heat pump technology is mature. Manufacturers report that early installations of each type have operated successfully for decades.

Data Summary

Market Sector	Market Application	End Use	Fuel Type
Residential	New/Replace on Burnout Long Life	Heating, Cooling & WH	Electricity
Current Status	**Date of Com**	**Product Life (years)**	**Source**
Commercialized		18.4	DOE TSD[119]

Basecase Energy Use		**Units**	**Notes, Explanation**	**Source**
Efficiency	11, 3.3	(system) EER, COP		
Electricity Use	13.9	kWh/sf (site)	Schools Heating & Cooling Energy, 100,000 sf school	BEDB, 2008[120],
Summer Peak Demand	153	kW	0.7 assumed if school in session	
Winter Peak Demand	164	kW (thermal load)	0.9 assumed when school is in session	
Fuel Use	0	MMBtu/year		
New Measure Energy Use				
Efficiency	16, 3.0	(system) EER, COP		
Electricity Use	5.6	kWh/sf-year	weighted .8 htg, 0.2 cooling	
Summer Peak Demand	105	kW	0.7 assumed if school in session	
Winter Peak Demand	55	kW	0.9 assumed for warm-up when school is in session	
Fuel Use	0	MMBtu/year		
Savings				
Electricity Savings	8.3	kWh/year		
Summer Peak Demand Svgs	48	kW		
Winter Peak Demand Svgs	109	kW	If load on peak had been met with resistance heating (ASPF off)	
Fuel Savings	0	MMBtu/year		
Percent Savings	60%			
Percent Feasible	50%		Assume 50% GSHP, 50% condensing boilers	
Industrial Savings > 25%?	No			
Costs				
Incremental Cost	(3.00)	2008 $, per sf	relative to VAV system	
Other Costs/ (Savings)	(0.50)	2008 $, per sf	no routine maintenance except filter changes	
Ranking Metrics				
2025 Savings Potential	157,536	GWh		
2025 Savings Potential	1651	TBtu		
Cost of Saved Energy	$(0.070)	$/kWh		
Cost of Saved Energy	$ (6.67)	$/MMBtu		

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[119] Used service life for residential central air conditioners as best analogue, from DOE, "Technical Support Document: Energy Efficiency Standards for Consumer Products: Residential Central Air Conditioners and Heat Pumps: Including: Regulatory Impact Analysis". May 2002

[120] Tables 3.1.9+3.1.13: http://buildingsdatabook.eren.doe.gov/docs/DataBooks/2008_BEDB_Updated.xls

Unusual Market Barriers	Non-Energy Benefits		Current Activity	Next Steps
Weak design & installation infrastructure in most regions	Greater comfort Low maintenance effort and skills needed		Evangelical designers are selling to customers Incentives in some states	Education Incentives
Likelihood of Success	4	(1-5)		
Priority	Medium	Low, Med, High		
Data Quality Assessment	C	(A-D)		
Principal Contacts				
Mr. Kirk Mescher, CM Engineering, Columbia, MO				
Kavanaugh, S.P and K. Rafferty 1997. *Ground-Source Heat Pumps - Design of Geothermal Systems for Commercial and Institutional Buildings*. 167 pp. ASHRAE, Atlanta GA				
ASHRAE Technical Committee 6.8				
by Harvey Sachs				

The typical school or office system uses vertical closed-loop heat exchangers (“boreholes”). Where the annual heat rejection from cooling dominates over the heat extracted in winter, an auxiliary closed circuit cooling tower may be employed to reject the extra heat at lower cost. Conversely, designers occasionally specify auxiliary boilers to assure sufficient heating capacity, or to handle ventilation and service hot water needs.

The typical school or office system today employs a primary-only, two-pipe distribution architecture within the building. Each heat pump is effectively a diverter between a supply line and a return pipe. Frequently, designers specify a *reverse return* architecture as a relatively simple way to roughly balance pressure drops. Two pipe circulation loops work well, but require two-way valves at each heat pump, and various auxiliaries[121] to balance the systems. The two-way valves prevent water flow through a heat pump when it is not operating. In turn, this changes the pressure in the loop. When a heat pump stops (starts), the pressure change signals a variable speed circulating pump to reduce (increase) flow, to minimize energy use for pumping.

In contrast, a one-pipe loop is best considered as a “primary— distributed secondary” circulation architecture.[122] A small integral horsepower central pump (typically a pair of 2 hp pumps, for peak and redundancy) drives primary loop circulation in the ground loop and around the building. Each heat pump has an independent secondary loop, which has its own small wet-rotor circulating pump that draws water from the primary loop and returns it downstream. Control logic assures that the pump must be on for the heat pump compressor to operate. This eliminates the two-way valves.[123] Even though the small circulators cumulatively may draw about as much current as the primary, Mescher shows that the total single-pipe system requires about 80% as much power at high loads, dropping to 60–70% at more typical part loads. However, considering *system efficiency* (including the heat pumps and water circulation, a two-pipe system will be slightly more efficient at loads >60%,[124] showing about 6% higher EER. However, more than 78% of the annual operating hours are at less than 60% load for schools.

Current Status of Measure

Ground-coupled technology was aggressively promoted by DOE and EPA in residential and commercial applications during the 1990s. Although data are limited, the commercial market, particularly for school installations, appears to be growing well.[125] Significant school market penetration has been achieved in

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[121] flow control valves, strainers, inverters etc.

[122] Mescher, K. *in press. "*Ground Coupled Heat Pump One Pipe Systems." *ASHRAE Journal*.

[123] In practice, each heat pump will also have a pair of disconnect valves so it can be removed from the system for service. These can be low pressure-drop globe valves or the equivalent; they are not motorized and they do not get actuated often.

[124] Mescher, in press, Figure 10a.

[125] About 240,000 water-source heat pumps were shipped in 2007, the most recent census data. This includes both commercial and residential equipment, and both ground-source and “boiler-tower” commercial water-source systems. *Current Industrial Reports,*

regions where severe climates and low electric rates (such as the South and Midwest), or the absence of competitively priced heating fuel(s), favor ground-coupled systems.[126] Economics will favor expansion as designers and contractors gain experience and customers gain awareness.

Savings Potential and Cost-Effectiveness

According to Mescher,[127] in the upper Midwest, well-designed, disciplined, conventional two-pipe ground-source heat pump systems have installed costs about $16 per square foot served. A 50–200 ton single-pipe system will save between $0.50 to $1.50 per sq. ft. when compared with the two-pipe alternative. Savings are attributed to design simplicity and installation efficiency: There are very few pipe size reductions, no flow control valves, and low water balance requirements for the loop. Simpler piping means simpler and less expensive pipe and valve insulation, too.

For context, upper Midwest alternative systems would include two-pipe fan-coil systems, which might be installed for as little as $14/s.f.[128] New approaches save heating energy and have faster cut-over times than traditional two-pipe systems.[129] However, two-pipe systems cannot simultaneously support heating and cooling of different zones, which is inherent in GSHP systems. The more common system with equivalent amenity to the ground-source system would be variable air volume (VAV), quoted at $18–20/sf. We believe the two-pipe alternative would be more likely to be considered for retrofits, and VAV would more likely to compete for new construction. Mescher finds that ground-source systems are readily retrofitted into schools. Our economic analysis compares heat pump roof top units with ground-source heat pumps for ease of comparing energy use.

Ground-source systems show good energy performance and low maintenance costs. In a study of nine commercial systems, the average GSHP system used 14.4 kWh/ft^2-year, vs. 22.7 for the alternatives considered for those buildings. Peak demand was also significantly lower: 4.7 W/ft^2 instead of 7.2 for the conventional systems modeled. For these buildings, the average return on investment was 19%, or a simple payback of 5.9 years.[130]

Mescher (in press, figure 11) presents energy use data for four schools. On average, the peak month used one-quarter as much energy as pre-retrofit; annual savings are smaller but still quite large: School year use was 46% of the pre-retrofit consumption (apparently on whole-school, all uses basis). The schools improved from being much worse than the Illinois schools average to much better. Mescher also quotes enthusiastic facility managers who report ENERGY STAR ratings of at least 90 in five of six recently retrofitted schools.[131] Routine maintenance is limited to air filter changes that can be handled by custodial staff.

As shown by the Data Summary Table above, the one-pipe ground-source implementation has great potential. It could cumulatively save almost 2 Quads (1,700 TBtu), at a *lower* first cost than comparable systems.[132] This means that it has a *negative cost of saved energy* (-$0.07/kWh). In this case, spending less on first cost saves money from day one.

MA333M—Refrigeration, Air Conditioning, and Warm Air Heating Equipment. http://www.census.gov/manufacturing/cir/historical_data/ma333m/index.html

[126] Dinse (personal communication, ~2008) reports more than 100 Tennessee school installations, and Mescher (personal communication 2009) reports substantial activity in the upper Midwest.

[127] Mescher, K. 2009. "Simplified GCHP System." *ASHRAE Journal,* v. 51, 24–40, and personal communication, August 20, 2009.

[128] We have not confirmed that this includes chilled water system cost.

[129] Durkin, T. H. 2006. Boiler System Efficiency. *ASHRAE Journal*, July, 51–57.

[130] ASHRAE, 1998. *Operating Experiences with Commercial Ground-Source Heat Pump Systems*. Special Publication. ASHRAE, Atlanta, GA.

[131] Mescher, in press. 75 points qualifies for ENERGY STAR, which is principally based on energy use relative to comparable buildings.

[132] Ultimate savings would strictly depend on finding ground loop installation costs comparable to those in Mescher's region.

Market Barriers

To date, the best markets for commercial scale ground-source heat pump systems have been the public sector, particularly schools. Increasingly, other government buildings are selecting these systems, driven by mandates to reduce energy use or get USGBC LEED certification. In one review of 100 very high performance buildings, 20% used GSHP systems.[133] Secondary markets seem to include owner-occupied free-standing office and retail establishments.

The first barrier to expansion is lack of awareness and comfort among building owners, the clients. The second, highly important barrier, is that too few design consulting engineers are comfortable with the systems, have experience with them, and know how to do disciplined, low-cost, low-maintenance systems. Too often, they load their designs with "bells and whistles" to protect themselves — or raise the price estimates and make the choice less desirable for their clients. In addition, many regions do not have experienced drilling contractors (or suitable geology), which can double installation prices for the borehole heat exchanger. Finally, good GSHP systems are elegant because they are simple. This means that they achieve good economic performance by leaving out many features dear to owners and designers, such as over-elaborated energy management systems and their interfaces.

Key Assumptions Used in Analysis

Average Price of Electricity	$0.1032/kWh[134]
Average Price of Natural Gas	$10.97/MMBtu[135]
Projected 2025 End Use Electricity Consumption[136] (EIA 2006)	0.39 quads
Real Discount Rate	4.53%
Projected 2025 End Use Gas Consumption[137] (EIA 2006)	1.25 quads
Heat Rate	10.48 kBtu/kWh

Next Steps

The government market is expected to continue growing at a healthy pace, driven by mandates to reduce energy use and a long-term investment perspective. Uptake could be accelerated by utility incentives for the private sector. Better infrastructure, including a public database of location, geologic substrate, drilling conditions, and thermal conductivity, would gradually reduce risks and thus costs.

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[133] M. Frankel, *undated.* Aggressive Building Energy Performance: Getting to 50 and beyond. Slide 17 in http://www.newbuildings.org/downloads/presentations/GT50-presentation.pdf

[134] EIA, "Electric Power Monthly—Feb 2009", (YTD-Nov08, Commercial Price)

[135] http://tonto.eia.doe.gov/dnav/ng/ng_sum_lsum_dcu_nus_m.htm

[136] EIA 2009. "Annual Energy Outlook 2009 with Projections to 2030". Tables 4 and 5.

[137] Ibid.

Emerging Technologies Report

Residential Ductwork Optimization

March, 2009

Definition	More energy-efficient residential ductwork designs				
Base Case	Traditional residential ductwork designs				
New Measure	Phenolic duct board, EDPM-sealed metal ductwork, etc.	Percent savings	2025 Savings TBtu (Source)	Cost of Saved Energy	Success Rating (1-5)
		9%	200	$0.03	3

Summary

Space conditioning energy distribution in U.S. residential applications is dominated by forced-air systems that use ductwork to move air from the prime mover (furnace, central air conditioner) to the various rooms, and bring return air back. In general, the ducts are undersized, leaky, and inappropriately insulated. Optimized ductwork should save 20% of space conditioning energy use. Unfortunately, this measure is predominantly applicable to new construction, as complete replacement of duct systems in existing buildings is rarely possible.

Background and Description

The majority of residential housing units in the U.S. utilize central warm-air furnaces (61%) and central air conditioning systems (59%) to meet their space heating and cooling needs.[138] These systems use a fan-forced air supply and return ducts to distribute conditioned air from the central unit to the serviced spaces and to bring return air back to the central unit. Beyond the efficiency of the furnace and air conditioner, the energy efficiency of the residential HVAC system depends on the ductwork. Residential ducts typically leak at least 20% of the air they convey.[139] Besides reducing energy loss, reducing the air leakage in the ductwork can also mean that smaller capacity furnaces, air conditioners, and blower fans can be installed to meet air conditioning requirements, reducing first costs. Builders and consumers are generally unaware of the significant savings that they can make by optimizing residential ductwork.

Residential ductwork typically runs through unconditioned spaces, such as the attic.[140] Particularly in two-story houses, ducts often run in exterior wall stud spaces, displacing insulation, because supply registers are conventionally sited under windows to prevent winter condensation and offset loads from infiltration and conduction.

Optimizing Ductwork

Installing all ductwork in conditioned spaces (i.e., within the insulated building envelope) substantially eliminates air and energy losses to the outside. This can allow smaller heating and cooling systems to be used, resulting in first cost savings.[141] Interior ducts are also subjected to less severe conditions, which may prolong the life of sealants (such as mastic) used to reduce leakage. However, even duct leaks to the inside can affect air and energy distribution, leading to cold rooms with inadequate air supply in winter. If there are space or aesthetic issues with running the ducts through conditioned space, additional insulation can be installed to convert the space around the ducts into conditioned space. Strategies to place ducts in conditioned space include:[142]

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[138] EIA, *2005 Residential Energy Consumption Survey*, Tables HC2.4 and HC2.6
[139] ASHRAE, *2004 ASHRAE Handbook—HVAC Systems and Equipment*, page 9.3
[140] ASHRAE, *2004 ASHRAE Handbook—HVAC Systems and Equipment,* page 9.7
[141] http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/27630.pdf
[142] http://resourcecenter.pnl.gov/cocoon/morf/ResourceCenter/article/1404

- Placing ducts in a chase that runs through a central corridor below the attic or on top of the ceiling through the attic. If the chase runs through the attic, it must be fitted within the roof truss and properly insulated;
- If ducts are in an attic, insulating and sealing the underside of the roof sheathing, and properly converting the attic to a conditioned space;
- If ducts are in a crawlspace, insulating and sealing the external crawlspace walls; and
- If ducts are in a basement, converting the basement into a conditioned space and installing basement wall insulation to minimize heat loss

If the building envelope performs well, with high thermal integrity and very good glazing, simpler duct architectures can be employed. In particular, all supply and return ducts can be on interior walls, minimizing insulation problems. Good thermal integrity means lower losses, so smaller ducts may deliver enough air. This may give greater design freedom. These strategies can reduce the duct surface area by 50% or more,[143] as well as reduce the leakage of conditioned air to the outdoors as compared to traditional designs. This also can result in lower installation costs.

The duct system needs to be designed and installed to reduce friction and turbulence. Quality materials should be used for ducts. Undersized ducts require higher air velocities to deliver enough energy, increasing friction and turbulence. Higher airflow can also increase noise.

All ducts need to be sealed properly to minimize energy and conditioned air losses. All connections should be sealed with approved mastic, metal tape, or an aerosol-based sealant.[144] Ironically, duct tape is never appropriate; it quickly degrades in duct sealing surface. Ducts in uninsulated spaces should have insulation of R-value 8 or higher.[145] There are also some emerging new sheet metal and other duct systems with self-sealing connectors, generally using O-ring type construction.[146] Some manufacturers are introducing safety-listed polypropylene or other fittings that are designed to improve sealing and reduce installation time.[147] Some do not require mastic, but are self-sealing.

An optimized duct system has appropriately sized ducts, short runs, the smoothest interior surfaces possible, and the fewest, most gradual direction and size changes possible.[148] Some general rules on duct design include:[149]

- Providing both supply and return systems that are large enough to carry the full amount of air needed. Return duct systems must be complete and sealed; it is not appropriate to use "panned in joists," stud spaces, and other shortcuts.
- Keeping the main ducts as straight as possible.
- Streamlining transitions.
- Designing elbow points with an inside radius of more than one-third the duct width where possible; include turning vanes if not.
- Sealing ducts to limit air leakage (see section above).
- Insulating and/or lining ducts, where necessary, to conserve energy and limit noise.
- Locating branch duct takeoffs at least 4 feet downstream from a fan or transition, if possible.
- Isolating air-moving equipment from the duct by using flexible connectors to isolate noise.

These considerations lead some to question the future role of the predominant duct materials used today. Sheet metal and rigid fibreglass "ductboard" are typically used for major trunks. Both have high friction losses and are challenging to seal, and to install with leak-proof transitions to terminal ducts. Terminal

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[143] ASHRAE, *2004 ASHRAE Handbook—HVAC Systems and Equipment*, page 9.7

[144] US EPA, "Duct Sealing" Brochure, http://www.energystar.gov/ia/products/heat_cool/ducts/DuctSealingBrochure04.pdf

[145] CA title 24 requires R8 for supply or return located outdoors, in a space between roof and insulated ceiling, in space directly under a roof with fixed vents or openings to outside or unconditioned spaces, in unconditioned crawlspace, or any other unconditioned space. Else, min is R4.2 or enclosed in directly conditioned space.

[146] These systems are often derived from high-end European commercial products, which are now being adapted for the U.S. market. For example, http://www.lindab.com/usa/web_LINDAB/home.htm.

[147] For example, http://www.toolbase.org/Technology-Inventory/HVAC/self-sealing-ducts

[148] ASHRAE, *2004 ASHRAE Handbook—HVAC Systems and Equipment*, page 9.8

[149] ASHRAE, *2004 ASHRAE Handbook—HVAC Systems and Equipment*, page 9.9

ducts (and, frequently, trunks) are often "flex-duct," which is insulated plastic film ductwork with a wire helix to give form. This has very high friction losses, particularly when not stretched tightly but left with excess length as loops.

An ideal duct system would be inexpensive, have smooth joints and transitions, assemble quickly and easily, and be virtually impossible to assemble with leaky joints. It might look like a fire-retardant version of today's plastic drainpipe. Drainpipe uses slip-joints (one female end on each pipe section, inexpensive couplers) that give some length and alignment "slip," but that are nearly leakproof at low pressure, even without glue. It is very difficult to build a leaky, site-constructed fitting, but easy and inexpensive to use factory fittings. The material is lightweight and easily cut to length. Available low-cost drainpipe probably could not be certified to today's fire and smoke codes, but other materials are considered feasible, or code revisions may be appropriate (as for supply ducts laid in the subslab space).[150]

Data Summary

Basecase: Representative single-family residential new construction in the Northwest[151]
New Measure: New construction with optimized ductwork

Market Sector	**Market Application**		**End Use**	**Fuel Type**
Residential	New		Cooling	Electricity
Current Status	**Date of Commercialization**		**Product Life (years)**	**Source**
Commercialized			30	phenolic duct board
Basecase Energy Use	**Units**		**Notes, Explanation**	**Source**
Efficiency	13.0	SEER	national minimum	
Electricity Use	2,427	kWh/year	single-family houses, CAC, national average	RECS 2005, AC2
Summer Peak Demand	2.5	kW	90% undiversified, SEER 13	
Winter Peak Demand				
Fuel Use	52	MMBtu/year	single-family houses, national	RECS 2005 SH8
New Measure Energy Use				
Efficiency	13.0	SEER	Yuba field test	PG&E 2008 report
Electricity Use	2,206	kWh/year	Ratio from Yuba field test	PG&E 2008 report
Summer Peak Demand	2.3	kW		PG&E 2008 report
Winter Peak Demand		kW		
Fuel Use	47	MMBtu/year	Ratio from Yuba field test	PG&E 2008 report
Savings				
Electricity Savings	221	kWh/year		
Summer Peak Demand Svgs	0.22	kW		
Winter Peak Demand Svgs	N/A	kW		
Fuel Savings	4.7	MMBtu/year		
Percent Savings	9%			
Percent Feasible	72%		Based on the number of housing units served by central warm air heaters vs. total using heating equipment; Assume 100% feasible as the advanced ductboard share similar constraints with existing ductwork.	RECS 2005

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[150] D'Lane Wisner, consultant to Plastic Pipe Council, personal communication.

[151] Based on the report "Single-Family Residential New Construction Characteristics and Practices Study" by RLW Analytics for the Northwest Energy Efficiency Alliance, March 27 2007

Industrial Savings > 25%?	No			
Costs				
Incremental Cost	$300	2004 $	Cost is lower than sheet metal, but higher than fibreglass ductwork. Labor cost savings could mitigate material cost; Assume cost competitive	
Other Costs/ (Savings)	0	$/ year		
Ranking Metrics				
2025 Savings Potential	19,098	GWh		
2025 Savings Potential	200	TBtu		
Cost of Saved Energy	0.03	$/kWh		
Cost of Saved Energy	$2.62	$/MMBtu		
Unusual Market Barriers	**Non-Energy Benefits**		**Current Activity**	**Next Steps**
Unfamiliarity with the materials	tighter ductwork may reduce differential infiltration, reducing dust levels in some cases		Initial sales, principally into commercial applications	
Likelihood of Success	3	(1-5)		
Priority	High	Low, Med, High		
Data Quality Assessment	B	(A-D)		
Principal Contacts				
Harvey Sachs, ACEEE				

Current Status of Measure

Early ductboards were made of uncoated, rigid boards of fibreglass insulation. There were concerns that ductboards were prone to collecting water and supported the growth of mold, as well as the erosion of the fibreglass by air.[152]

Advanced ductboards have been introduced. Typically these are made of rigid fire-resistant foam, coated on both surfaces, and edge jointing systems that help improve the air seal for joints. Other approaches are in development. One is to use formed plastic ductwork with slip joints, which offer low installation costs, tight joints, and smooth interiors and transitions. Conventional materials such as PVC have had flame/smoke issues, but the value of the approach was demonstrated in a Building America project by Stephen A. Winter Associates. For that project, they used rated laboratory exhaust duct components, which would be far too expensive for routine residential application. Proctor Engineering has developed proprietary sealed joint for round sheet metal ductwork, which may be commercialized. This is one critical junction, but leaves out others that may require different solutions. One example is a round take-off from a rectangular plenum, or a smaller round take-off from a round plenum.

Ultimately, it is likely to be found that it is easier to move ductwork inside the thermal envelope than to insist on leak-proof ductwork, but this remains to be seen.

Savings Potential and Cost-Effectiveness

Based on a study of residential new construction characteristics and practices in the Northwest states, the typical duct leakage to outside the thermal envelope of a home there is about 21% of the total measured airflow.[153] This suggests that about 21% of the conditioned air is "wasted."

Tests were conducted on a 5.346m long duct with internal dimensions of 600 x 600mm. It is estimated that the flow rate in the duct can be reduced by 9.0–16.5% with an advanced ductboard design as

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[152] http://www.ibacos.com/pubs/DuctBoard.pdf

[153] *Single-Family Residential New Construction Characteristics and Practices Study*, by RLW Analytics for the Northwest Energy Efficiency Alliance, March 27, 2007.

compared to steel ductwork due to the reduction in air leakage.[154] This not only improves energy efficiency by reducing the loss of conditioned air and by reducing the fan power needed, it also allows for first cost savings since a smaller capacity (and generally cheaper) fan can be installed.

Due to their low friction, airflow through the ducts can be minimized with advanced ductboard, as well as other approaches. Advanced ducts will occupy less space than steel ductwork with insulation, which not only saves space, but can also mean that ductwork can be installed in places where steel ductwork cannot be installed. Advanced systems such as foam ductboard will be easier to handle, and will be easier and faster to install.
Based on RS Means 2009, the estimated total cost for a rectangular steel duct ranges from $4.20/sf to $10.61/sf[155] of floor space served. The corresponding labor cost ranges from $3.36/sf to $6.32/sf. The estimated total cost for a fibreglass ductboard is $3.75/sf, with the corresponding labor cost estimated at $3.02/sf.

Market Barriers

Ductwork is the Rodney Dangerfield of residential construction: "Ducts don't get no respect." In general, HVAC for its own sake is low on the priority list for home buyers.

Key Assumptions Used in Analysis

As tests conducted on an advanced ductboard suggest that the flow rate can be reduced by 9–15%, it is estimated that the use of the advanced ductboard can reduce energy consumed and peak demand by 9%. Given that the measured averaged airflow loss to unconditioned space is 21% in the Northwest states, the estimate of 9% reduction in energy consumption and peak demand seems reasonable.

Average Price of Electricity	$0.11/kWh
Average Price of Natural Gas	$11/MMBtu
Projected 2025 End Use Electricity Consumption[156]	0.39 quads
Real Discount Rate	4.53%
Projected 2025 End Use Gas Consumption[157]	1.25 quads
Heat Rate	10.48 kBtu/kWh

Next Steps

Field experiments by third parties would greatly accelerate acceptance by market transformation programs and builders, leading to Code performance requirements based on the improved performance.

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[154] http://www.koolduct.kingspan.com/koolduct/pdf/koolduct_white_paper_energy.pdf

[155] Assuming 26 gage thick steel, based on *2004 ASHRAE Handbook—HVAC Systems and Equipment*, 16.3

[156] EIA 2009. “Annual Energy Outlook 2009 with Projections to 2030”. Tables 4 and 5.

[157] Ibid.

Emerging Technologies Report

Active Chilled Beam Cooling with DOAS

August, 2009

Definition	Commercial building HVAC systems that combine high efficiency and high amenity levels by using radiant-convective active chilled beams as the terminal units. These mix tempered ventilation air with recirculated room air.
Base Case	Standard variable air volume (VAV) system with centrifugal chiller.

New Measure	Percent Savings	2025 Savings GWh (TBtu)	Cost per kWh (MMBtu) Saved	Success Rating (1-5)
Chilled beam system with DOAS (dedicated outdoor air system)	20%	25,041 (262)	negative	4

Summary

Conventional variable air volume (VAV) systems for large commercial buildings use a large fraction of their energy just to distribute energy in air; pumping air is much less efficient than pumping water. One alternative is the "chilled beam" system, in which small amounts of outdoor air are entrained into a larger supply of recirculated air, and passed across a radiant-convective "chilled beam" fixture. One benefit is that the chiller energy is delivered efficiently to the zone by being carried in water. Also, to prevent condensation, much warmer water is used, which helps reduces energy consumption. These systems can be quieter, and can allow smaller floor-to-floor heights, reducing construction costs. At least 20% energy savings of and costs competitive with VAV systems should be feasible when more experience is gained.

Description

In North America, large, air-conditioning dominated, commercial buildings typically use "built-up" or "engineered" HVAC systems designed for the specific application. The standard practice for new buildings may be taken as "VAV" (variable air volume) systems that supply varying amounts of tempered air to each zone, depending on its load. These are integrated ventilation and thermal comfort systems that carry space-conditioning energy in air. An alternative approach, dedicated outdoor air systems (DOAS), separates the tasks of ventilation and humidity control from the sensible heat load. The alternative "Chilled beams" approach was introduced in Scandinavia in the 1980s. The application is beginning to be seen in North America. In our context chilled beams are generally not "beams," but integrated fixtures which combine (1) Lighting, (2) water-cooled convective[158] heat exchange surfaces, and (3) ventilation. Fresh, tempered, air blows across the cooled surfaces, and mixes with entrained room air (see the figure below).

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[158] While *passive* radiant ceilings have been used, we refer here to *active* chilled beams that cool air that is drawn across the surfaces.

Data Summary

<table>
<tr><th>Market Sector</th><th colspan="2">Market Application</th><th>End Use</th><th>Fuel Type</th></tr>
<tr><td>Commercial</td><td colspan="2">New</td><td>Cooling</td><td>Electricity</td></tr>
<tr><td>Current Status</td><td colspan="2">Date of Commercialization</td><td>Product Life (years)</td><td>Source</td></tr>
<tr><td>Commercialized</td><td colspan="2"></td><td>15</td><td></td></tr>
<tr><td colspan="2">Basecase Energy Use</td><td>Units</td><td>Notes, Explanation</td><td>Source</td></tr>
<tr><td>System Efficiency</td><td>8.50</td><td>EER</td><td>=1.41 kW/ton</td><td>Kavanaugh & Sachs 2007 (ASHRAE)[159]</td></tr>
<tr><td>Electricity Use</td><td>2,000,000</td><td>kWh/year</td><td>100,000 sf building with chiller.</td><td>CBECS 2003 C21</td></tr>
<tr><td>Summer Peak Demand</td><td>201</td><td>kW</td><td>Based on assumption of efficient building @ 700 sf/ton, and peak beyond design load.</td><td>calculations on scratch sheet</td></tr>
<tr><td>Winter Peak Demand</td><td>50</td><td>kW</td><td>Assumed 25% of full load, ~ turn-down limit</td><td></td></tr>
<tr><td>Fuel Use</td><td>0</td><td>MMBtu/year</td><td></td><td></td></tr>
<tr><td colspan="5">New Measure Energy Use</td></tr>
<tr><td>Efficiency</td><td>10.20</td><td>Btu/kWh</td><td>20% better than VAV system, = 1.18 kW/ton</td><td>kW/ton=12/EER</td></tr>
<tr><td>Electricity Use</td><td>1,600,000</td><td>kWh/year</td><td></td><td></td></tr>
<tr><td>Summer Peak Demand</td><td>161</td><td>kW</td><td>20% better than VAV system</td><td></td></tr>
<tr><td>Winter Peak Demand</td><td>50</td><td>kW</td><td>assume no further turn-down</td><td></td></tr>
<tr><td>Fuel Use</td><td>0.0</td><td>MMBtu/year</td><td></td><td></td></tr>
<tr><td colspan="5">Savings</td></tr>
<tr><td>Electricity Savings</td><td>400,000</td><td>kWh/year</td><td></td><td></td></tr>
<tr><td>Summer Peak Demand Svgs</td><td>40</td><td>kW</td><td></td><td></td></tr>
<tr><td>Winter Peak Demand Svgs</td><td>0.00</td><td>kW</td><td></td><td></td></tr>
<tr><td>Fuel Savings</td><td>0.0</td><td>MMBtu/year</td><td></td><td></td></tr>
<tr><td>Percent Savings</td><td>20%</td><td></td><td></td><td></td></tr>
<tr><td>Percent Feasible</td><td>70%</td><td></td><td>of commercial buildings >50,000 sf</td><td></td></tr>
<tr><td>Industrial Savings > 25%?</td><td>No</td><td></td><td></td><td></td></tr>
<tr><td colspan="5">Costs</td></tr>
<tr><td>Incremental Cost</td><td>$(100,000)</td><td>2004 $</td><td>5% saving today from assumed $20/sf for VAV HVAC</td><td>derived from R.S. Means 2005[160]</td></tr>
<tr><td>Other Costs/ (Savings)</td><td>-75000</td><td>$/ year</td><td>$0.75/yr maintenance savings</td><td></td></tr>
<tr><td colspan="5">Ranking Metrics</td></tr>
<tr><td>2025 Savings Potential</td><td>25,041</td><td>GWh</td><td colspan="2"></td></tr>
<tr><td>2025 Savings Potential</td><td>262</td><td>TBtu</td><td colspan="2"></td></tr>
<tr><td>Cost of Saved Energy</td><td>negative</td><td>$/kWh</td><td colspan="2"></td></tr>
<tr><td>Cost of Saved Energy</td><td>negative</td><td>$/MMBtu</td><td colspan="2"></td></tr>
</table>

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[159] Water-Based Energy Distribution: Integrated Design for 50% Demand and Energy Savings. S. Kavanaugh and H. Sachs. *In* Achieving 50% and Beyond Approach to Net-Zero-Energy Use in Buildings, Part 2. ASHRAE Seminar 32, Dallas, 2007.

[160] R.S. Means, 2005. Mechanical Cost Data. 28th Edition.

<table>
<tr><th>Unusual Market Barriers</th><th colspan="2">Non-Energy Benefits</th><th>Current Activity</th><th>Next Steps</th></tr>
<tr><td>simulation programs treatment</td><td colspan="2">reduced maintenance
reduced noise</td><td>early US installations</td><td>Demonstrations
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<tr><td>Likelihood of Success</td><td>4</td><td>(1-5)</td><td colspan="2" rowspan="3"></td></tr>
<tr><td>Priority</td><td>high</td><td>Low, Med, High</td></tr>
<tr><td>Data Quality Assessment</td><td>C</td><td>(A-D)</td></tr>
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<tr><td colspan="5">HVAC calculations: S. Kavanaugh</td></tr>
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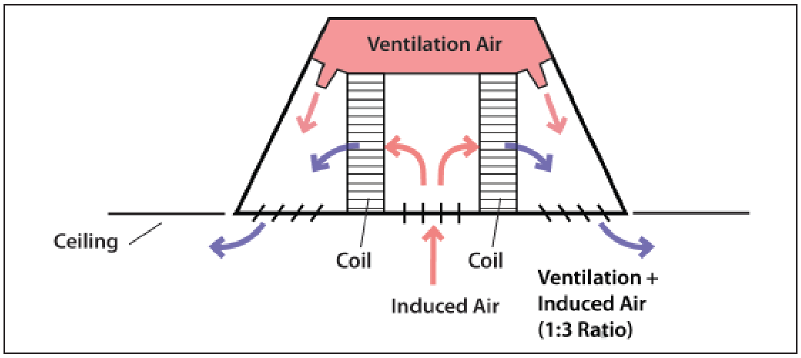
</table>

Schematic Cross Section of Chilled Beam Unit



Figures credit: Rumsey Engineers Inc.

Note: Length and width in standard sizes for drop-in ceilings or other configurations. This schematic does not show lamps, which are generally included in the fixture (Roth et al. 2007).

How Chilled Beams Save Energy

Chilled beam systems save energy by replacing fan energy with pump energy. They use pumped chilled water instead of blown cold air. Water has much higher heat capacity, both by mass and volume. In typical pump and fan arrangements, this translates into a reduction in fan energy by a factor of seven[161].

Chilled beams save energy by moving much less air (only the "primary" or ventilation air is brought to the zone, where it mixes with recirculated room air). VAV systems are typically designed with very high duct resistance, typically in the range of 6 inches water gauge (iwg). Instead, most energy for chilled beam systems is distributed by chilled (or heated) water carried to the beams. The ventilation air requires no more than 1 iwg in most designs, so there is a large difference in fan energy. In retrofitting a 215,000 s.f. office structure in Chicago, combined fan and pump energy dropped from 190 kW at design and 114 kW at 70% load for the VAV base case, to 34 kW for the chilled beam system (250 S. Wacker example in table below).

Second, chilled beams generally require a *minimum* supply water temperature >57F, to avoid condensation forming on the beam surface. Cooling the supply water less saves energy.[162] Indeed, in addition, for roughly the northern half of the US and all of Canada, where groundwater is available, the groundwater temperature is <55F, so direct cooling with groundwater would suffice for radiant beams.

The warmer supply water also minimizes or eliminates terminal reheat that may account for 20% of energy consumption in complex VAV installations such as laboratories[163] and large office buildings: too

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[161] Rumsey & Weale 2007
[162] Katsnelson 2007
[163] Rumsey & Weale 2007

many lightly-loaded zones require that the chilled air, typically 55F, be reheated before being distributed. Finally, chilled beam systems reduce the mean radiant temperature (MRT) of a space by 2–4°F. This saves energy because the space can be kept at a higher dry-bulb (sensible) temperature.[164]

Other Benefits

- Chilled beams reduce the floor-to-floor height required, because less space is required for ductwork. Thus, they may become a preferred design for buildings where this is important, by. For new construction, this might allow five stories at the height usually needed for four,[165] which would offer substantial construction economies. For retrofits, it may allow higher ceilings.
- Chilled beams reduce first costs by eliminating up to 50% of ductwork required.[166]
- Chilled beam systems don't require equipment rooms on each floor. This may increase rentable floor area, perhaps as much as 2%.[167]
- Commissioning time and cost may decrease because the beams are more nearly ‘plug and play’.[168]
- Maintenance is simpler, less frequent, and less expensive. Chilled beams do not have fans or filters. Because the surface temperature must be held above the dew point, they have no condensate lines or traps. We estimate savings at roughly $0.75/sf-yr.[169]
- Finally, chilled beam systems have low air flow velocities, which reduce drafts. Low pressures and remote fans also lead to relatively quiet work zones.

Current Status of the Measure

BSRIA, a British consultancy, estimates that the market for chilled beams grew by 33% in 2006 compared with 2005 and predicted further growth of 40% for 2007. US designers are beginning to use the technology in two principal applications: laboratories and large office retrofits. Laboratories are attractive because their ventilation requirements are high. In large office retrofits, there can be several advantages, starting with the relatively small amount of space (and headroom) required for installing a premium system.[170] We expect fairly rapid growth relative to the office building market as a whole, because of the combination of energy efficiency, relatively easy design, reduced maintenance requirements, and perceived amenities (quiet, comfortable, etc).

Factors that May Affect Growth Rate

Chilled beam approaches cannot handle super-high internal loads, so they are more-or-less constrained to situations with cooling demand < 80W/m2 (maybe peak at 120 W/m^2); and heating loads <40 W/m^2 (Rehva 2008). Chilled beam systems also require good humidity control. The dew point of the air in the space must remain above the temperature of the beams. This requires that the ventilation air must be dried to relatively low humidity, and internal moisture loads must be reasonable and understood.

Barriers include the following:[171]

- Lack of familiarity with the technology. Better design tools are needed. It would help to have a DOAS system design tool consisting of reliable design data, verified simulation models, and more systematic design guidance.

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[164] Jeong & Mumma 2006
[165] Farthing 2007
[166] Katsnelson 2007
[167] Fruehling 2007
[168] Farthing 2007
[169] Geraghty 2008
[170] Examples include 250 Wacker Street (215,000 s.f.), Chicago; and the Constitution Center (1.3 million s.f.), Washington, DC.
[171] Jeong & Mumma 2006

- Chilled beams require a low-infiltration building shell, for two reasons; (1) Only the ventilation air is filtered so if the system is bringing in dust by ventilation, or if it has large internal sources, it will get dirt-streaking (2) High infiltration guarantees that you will lose control of humidity.[172]
- It is important to insulate pipes that might be at temperature less than dew point.[173]

Energy Savings and Costs

North American chilled beam applications are not yet well-documented. Further, energy savings and incremental cost estimates vary considerably, and are generally estimates from designs. However, when chilled-beam systems reach market maturity, they are likely to have *lower* first costs than systems that offer comparable levels of amenity (4-pipe fan-coil or VAV with low noise levels). The table presents information from recent studies

Some Attributes of Four Recent Chilled Beam Installations

Project	Bldg Type	Size, sf.	Incremental Cost	Energy Use
Tahoe Center	Lab	10,000	-3%	-57%
Constitution Center	Office	1,300,000	+10% to 15%	-10% - 12%
250 S. Wacker	Office	215,000	Savings inferred	70% - 80% distribution
Genomics, UNC (MGMA 2008)	Lab	210,000	n/a	-20% estimated
Sandhill, Clemson U (Barista 2005)	Lab	25,000	-16%	-20% to -50%

The Constitution Square project manager expects to recoup his cost in 2.5 years by saving 10 to 12 percent on energy costs.[174]

Today, the table above suggests that costs are in the same ball-park as those for VAV or other comparable, high-amenity systems. For the Clemson laboratory, calculated HVAC costs dropped 16% from $37.23/ft2 to $31.28/sf (based on comparing VAV benchmark with active beams without lighting fixtures).

Key Assumptions Used in Analysis

- We assume 5% first cost savings today, and 12% at maturity. Since some design teams calculate larger savings today, this is conservative.
- We assume office building HVAC costs of $20/ft^2 for VAV systems, based on R.S. Means Library HVAC[175] and chilled beam case studies.[176]
- We assume 20% operating cost savings, and national average office building energy consumption and costs. For a base of about 20 kWh/ft^2-yr,[177] is a saving of 20%*20 kWh/ft^2-yr= 4 kWh/ft^2-yr. This is valued at $0.32/kWh/ft^2-yr, against a base of about $1.60/kWh.[178]
- For feasibility, we assume that chilled beams are only appropriate for "built-up" (chiller-based) central systems, roughly corresponding to buildings of at least 50,000 sf. We assume applicability only for new construction and major retrofits. 27% of office space is in such buildings; we ignore other building types.[179]

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[172] From Robert Fagg talk to ASHRAE NCC.
[173] Geraghty 2008
[174] Fruehling 2007
[175] R.S. Means 2005
[176] Derived by ACEEE. We infer that the low values given for 5–10 story office buildings are not VAV.
[177] EIA 2003a
[178] EIA 2003b
[179] EIA 2003c

Recommended Next Steps

- Detailed case studies are perhaps the most effective way to address lack of familiarity with the technology. Utilities that provide incentives to designers for highly efficient buildings should consider also paying for exemplary, case studies with performance data.
- Better design tools would help. Proprietary tools (Carrier HAP, Trane TRACE, etc) are unlikely to provide assistance until the respective equipment makers sell the chilled beam terminal units. Groups such as ASHRAE and CEE could encourage the development of chilled beam (and DOAS) modules in other design tools, such as Energy Plus (DOE).
- Utilities and other program providers who are serious about efficiency for large office and laboratory buildings should consider a "design assistance" program. This responds to an owner's request for assistance by paying an experienced chilled beam design engineer to assist the local designer of record. The cost is moderate, and this "mentoring" has produced good results for ground source heat pump systems—when care is taken to assure that the consulting designer is not a potential competitor of the designer of record.
- To avoid negative results (with all high performance systems), program operators should investigate ways to improve envelope integrity and decrease inadvertent ventilation in new construction. Failure to control infiltration can lead to unsustainable moisture loads.

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Emerging Technologies Report

Advanced (Commercial AC) Modulating HVAC Compressors

August, 2009

Definition	Advanced HVAC compressors with modulating capabilities				
Base Case	5-ton rooftop unit with hot gas bypass				
New Measure:	5-ton rooftop unit with modulating compressors	Percent savings	2025 Savings TBtu (Source)	Cost of Saved Energy	Success Rating (1-5)
		21%	615	$0.01	4

Summary

Conventional air conditioners have only one "speed:" Either they are running, or they are idle. Because full capacity is rarely needed (only on peak days, if then), the units run intermittently to reduce their output to meet part-load conditions such as mild days. Cycling is less efficient (in most cases), and it is associated with discomfort from temperature swings. As critically, short cycles do not quickly cool the evaporator coil to its operating temperature, which leads to reduced condensation of water vapor. In turn, this leads to poor humidity control, which leads to "cold, clammy" conditions and may contribute to development of mold where the building has cool surfaces on which nearly saturated air can condense.

Modulating compressor systems can vary their output, in steps or continuously, to better match load. Running the compressor at part load while the heat exchanger size remains constant yields higher part-load efficiency (but may reduce latent capacity). Together with variable speed air handlers, modulation can also give enhanced humidity control at low loads, where single-speed systems struggle. Modulating systems generally are sold as premium products, with incremental prices greater than inferred incremental costs. However, more technology alternatives are entering the market, which will increase competition and reduce consumer prices for these more efficient units.

Background and Description

Compressors are the "engines" of vapor compression air conditioning systems, the most commonly used systems. The compressor is the main power consumer in roof-top units, accounting for about 55-83% of total energy use[180]. Variable capacity compressors represent a major opportunity in terms of efficiency improvements[181].

In most residential and commercial applications, the heating or cooling load is lower than the maximum capacity during almost all operating hours, because outdoor conditions are more moderate than the design condition.. With a single-speed compressor, this results in on-off cycling of the unit to reduce the *average* output. Modulating compressors that can provide more than one output level can improve efficiency by improving part-load performance and reducing compressor cycling[182]. The reduction in compressor cycling can also help improve humidity management in buildings.

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[180] Based on http://www.esource.com/BEA/hosted/PNM/PA_37.html
[181] http://www.appliancemagazine.com/editorial.php?article=1721
[182] "Modulating Compressors for Residential Cooling", Roth K., Dieckmann J., ASHRAE Journal Oct 2004 pg 56-57

Data Summary

Market Sector	Market Application	End Use	Fuel Type
Residential and Commercial	New/Replace on Burnout Long Life	Cooling	Electricity
Current Status	**Date of Commercialization**	**Product Life (years)**	**Source**
Commercialized		15	Lennox Case Study

Basecase Energy Use		**Units**	**Notes, Explanation**	**Source**
Efficiency	13 11.5	SEER EER		
Electricity Use	5,118	kWh/year	ENERGY STAR Calc_CAC-1	
Summer Peak Demand	5.4	kW	0.9 coincidence factor assumed	ACEEE estimate
Winter Peak Demand	0	kW		
Fuel Use	0	MMBtu/year		
New Measure Energy Use				
Efficiency	16.5 12	SEER EER		
Electricity Use	4,032	kWh/year	ENERGY STAR Calc_CAC-1	
Summer Peak Demand	5.175	kW		
Winter Peak Demand	0.0	kW		
Fuel Use	0.0	MMBtu/year		
Savings				
Electricity Savings	1,086	kWh/year	subtract 200 kWh/year for ECM fan	
Summer Peak Demand Svgs	0.225	kW	Decremented to not include fan savings	
Winter Peak Demand Svgs	0.00	kW		
Fuel Savings	0.0	MMBtu/year		
Percent Savings	21%			
Percent Feasible	95%		Estimated maximum feasibility of SEER >14 units, high in long-summer regions.	
Industrial Savings > 25%?	No			
Costs				
Incremental Cost	$ 170	2007 $	Extrapolated from TSD, bounded by industry conversations, time-adjusted	
Other Costs/ (Savings)	0	$/ year		
Ranking Metrics				
2025 Savings Potential	58,700	GWh		
2025 Savings Potential	615	TBtu		
Cost of Saved Energy	0.01	$/kWh		
Cost of Saved Energy		$/MMBtu		

Unusual Market Barriers	Non-Energy Benefits		Current Activity	Next Steps
Perceived commoditization EER gains limited	May better control humidity		Manufacturer marketing	Test Procedure
Likelihood of Success	4	(1-5)		
Priority	Medium	Low, Med, High		
Data Quality Assessment	B	(A-D)		
Principal Contacts				
Mr. Hung Pham, Copeland				
By Wilson Lin, with Harvey Sachs				

A multi-speed compressor or multiple single-speed compressors can be used to modulate maximum capacity. By controlling the operation of multiple compressors in such a system, it is possible to achieve step-wise modulation of system capacity with single speed compressors. While this may be relatively inexpensive, the gain is limited by the large steps of the modulation.

Inverter systems modulate the system capacity by controlling the compressor motor speed. This allows for continuous capacity control, limited by the minimum motor speed required for lubrication, etc. In North America, inverter systems are more expensive than other modulation methods, but offer high system efficiency by matching capacity to heating/cooling demand.

The table below sketches the relative advantages and disadvantages of some modulation methods.

Comparison of Modulation Methods[183]

Modulation Technology	Advantages	Disadvantages
Hot Gas Bypass[184] (Obsolete for Space Conditioning)	▪ Lower upfront cost ▪ Less compressor cycling ▪ No extra oil management equipment needed ▪ No electromagnetic interference issue	▪ Poor operating efficiency ▪ Precise temperature and humidity control not possible
Multi-speed or multiple compressors, including "digital scroll"	▪ Least expensive form of modulation ▪ No extra oil management equipment needed ▪ No electromagnetic interference issue	▪ Efficiency is better than single-speed compressor, but limited by the step-wise nature of modulation—but steps only 10% on digital scroll ▪ Precise temperature and humidity control hard with big steps
Inverter Systems	▪ High system efficiency ▪ Able to modulate capacity to match load (but limited by minimum motor speed) ▪ Precise temperature and humidity control possible ▪ Good cost reduction potential	▪ High upfront cost due to more complex electrical and mechanical hardware, additional equipment ▪ Need for equipment to manage compressor oil ▪ High electromagnetic interference ▪ Capacity change must be gradual to avoid damage

Several manufacturers have introduced compressor designs that offer stepwise capacity modulation. These approaches are generally constant-speed, although the motor current will vary with load.

In 1999, Bristol Compressors introduced the TS ("Twin-Single") compressor[185]. The technology features compressors with 2 pistons that are able to operate in both forward and reverse crank rotation directions.

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[183] Adapted from http://www.emersonclimate.com/contractor/products/air-conditioning/commercial/comparison.shtm#MultipleCompressorSystems

[184] Hot gas bypass systems keep the compressor operating at near full-load by diverting high pressure refrigerant from the evaporator. We regard hot gas bypass as obsolete for space conditioning, and it is precluded for medium and large systems by ASHRAE 90.1. Hot gas bypass systems were occasionally applied to control capacity at low loads. However, this approach reduces the operational efficiency as the refrigerant that is diverted does no useful cooling. http://www.trane.com/commercial/library/vol32_2/ADM_APN007_EN_0503.pdf

[185] http://www.achrnews.com/Articles/Feature_Article/9b70c7226c75a010VgnVCM100000f932a8c0____

By idling one piston in one rotation direction but having both pistons operate in the other, 40% and 100% capacity steps are achieved.[186].

In 2001, Emerson Climate Technologies introduced the Copeland Digital Scroll, which uses a solenoid valve to unload the compressor[187]. By varying the fraction of time when the compressor is unloaded, the compressor is able to modulate its capacity between 10% and 100%.

In 2003, Emerson Climate Technologies introduced another scroll approach, the “UltraTech”.[188] This is a two-speed unit with capacities of 67%/100%. Bypass ports in the compression chamber partially unload the compressor and low speed. giving a constant-speed, two-capacity compressor.

Continuous modulation with variable-speed motors and compressors. Japanese and other far-eastern manufacturers generally provide variable capacity by varying the speed of the motor that drives the compressor. In response to cooling (or heating) demand, the control system adjusts drive frequency to control the speed of the motor. These are called "inverter" systems because the electronic power controls convert the AC line power to DC and then "invert" the DC to variable frequency AC to force variable speed of the motor.

Current Status of Measure

Multiple approaches are competing in the residential market today. The Bristol "TS" is used in northern climate air-source heat pumps, other niche markets, and in some premium units. The Emerson two-stage scroll is used in premium residential products, and the digital scroll is being marketed now for commercial refrigeration applications.

Inverter drives are almost ubiquitous on "mini-split" and "multi-split" ductless air conditioners, including relatively large systems with tens of terminal units. They are beginning to appear on residential-scale forced-air systems, too, notably on products manufactured by Nordyne, such as the "IQ Drive" on premium Maytag products.[189]

Savings Potential and Cost-Effectiveness

For a light commercial (roof-top) unit, we compute savings of 1100 kWh/yr, and a demand reduction of 0.2 kW, with a cost of saved energy of $0.01/kWh.

Key Assumptions Used in Analysis

Average Price of Electricity	$0.1032/kWh[190]
Average Price of Natural Gas	$10.97/MMBtu[191]
Projected 2025 End Use Electricity Consumption[192]	0.39 quads
Real Discount Rate	4.53%
Projected 2025 End Use Gas Consumption[193]	1.25 quads
Heat Rate	10.48 kBtu/kWh

Savings are calculated for average climate and operating hours.

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[186] http://www.appliancemagazine.com/editorial.php?article=922&zone=1&first=1
[187] http://www.digitalscroll.com/sb300/portal/home/normal/17/show/0/1
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[191] http://tonto.eia.doe.gov/dnav/ng/ng_sum_lsum_dcu_nus_m.htm
[192] EIA 2009. “Annual Energy Outlook 2009 with Projections to 2030”. Tables 4 and 5.
[193] Ibid.

Next Steps

Modulating compressor commercial air conditioning systems are ready for incentive programs. Savings will be principally in energy, but with some demand reduction, also.

Emerging Technologies Report

Automated Fault Detection and Diagnostics for Rooftop Units

August, 2009

Definition	RTUs with automated fault detection and diagnostics capability				
Base Case	5-ton RTU				
New Measure:	Incorporation of advanced features	Percent savings	2025 Savings TBtu (Source)	Cost of Saved Energy	Success Rating (1-5)
		10%	131	negative	4

Summary

Smart equipment that recognizes when it is failing or has failed, or when environmental conditions have drifted outside its optimum capability range, could save substantial amounts of energy if the equipment sent useful information to the owner's representative. The necessary capabilities are referred to as automated Fault Detection and Diagnostics (FDD). Implemented on commercial roof-top units (RTUs), these capabilities should save at least 10%.

Background and Description

Even the most efficient HVAC equipment will waste energy if it is operated incorrectly. In addition, the performance of HVAC equipment often degrades over time, so periodic maintenance is required to maintain equipment efficiency. Some of the problems that can affect the energy efficiency of RTUs include:

- Insufficient evaporator airflow
- Condenser coil fouling
- Incorrect refrigerant charge
- Compressor valve leakage
- Liquid line restrictions
- Economizer damper failure
- Sensor failure/degradation

Fault detection and diagnostics for roof-top air-conditioners refers to technologies that monitor components, sense problems as "faults," and can optimize operation and/or notify personnel, ensuring timely identification and correction of operating and service issues.

In recent years, advances in electronics have meant that sensor capability has improved and costs of sensors and controllers have declined significantly. Automated FDDs have been introduced for applications as diverse as nuclear power plants, aircrafts, chemical process plants, and automobiles.[194]

Manufacturers are producing "smarter" equipment that can self-diagnose faults, and some that can detect and adjust operations based on real-time conditions and performance data.[195] This is at least in part due to growing awareness by building operators for the need to monitor building performance, which has resulted in the growth of building operation and maintenance services, and demand for relevant data reporting. This, coupled with the increasing use of information technology in buildings and building equipment, has helped to create basic infrastructure to enable widespread adoption of automated FDDs in RTUs.

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[194] "Automated Fault Detection and Diagnostics for Vapor Compression Cooling Equipment", Braun

[195] http://www.achrnews.com/Articles/Feature_Article/BNP_GUID_9-5-2006_A_10000000000000125170

Data Summary

Market Sector	Market Application	End Use	Fuel Type
Commercial	New/Replace on Burnout; Long Life	Cooling	Electricity

Current Status	Date of Com	Product Life (years)	Source
Commercialized		15	DOE TSD[196]

Base Case Energy Use		Units	Notes, Explanation	Source
Efficiency	10.0	EER	Federal mandated energy efficiency, 2010	
Electricity Use	9,621	kWh/year	Using FEMP energy cost calculator and adding electricity consumption due to faults in refrigerant charge and airflow, assuming that the fault occurs midway through the year (since the fault can occur at anytime)	FEMP
Summer Peak Demand	3.24	kW	0.9 coincidence factor assumed	ACEEE estimate
Winter Peak Demand	0.0	kW		
Fuel Use	0.0	MMBtu/year		
New Measure Energy Use				
Efficiency	10.0	EER	Federal mandated energy efficiency, 2010	
Electricity Use	8,659	kWh/year	Using FEMP energy cost calculator	FEMP
Summer Peak Demand	3.24	kW	0.9 coincidence factor assumed	ACEEE estimate
Winter Peak Demand	0.0	kW		
Fuel Use	0.0	MMBtu/year		
Savings				
Electricity Savings	962	kWh/year		
Summer Peak Demand Svgs	0.0	kW		
Winter Peak Demand Svgs	0.0	kW		
Fuel Savings	0.0	MMBtu/year		
Percent Savings	10%			
Percent Feasible	70%		Assume in market 2010, replacement only (18.4 yrs lifespan), 50% takeup (due to upfront cost)	PIER
Industrial Savings > 25%?	No			
Costs				
Incremental Cost	$ 500	$	.5* PIER upper bound estimate	PIER
Other Costs (Savings)	-100	$/ year	From PIER analysis, annual non-energy benefit for diag. & monitoring	PIER

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[196] Technical support document: "Energy Efficiency Program for Commercial and Industrial Equipment: Commercial Unitary Air Conditioners and Heat Pumps**."** Chapter 8. *Life-Cycle Cost and Payback Period Analysis*, p. 8-45. http://www1.eere.energy.gov/buildings/appliance_standards/comm.

Ranking Metrics			
2025 Savings Potential	12,500	GWh	
2025 Savings Potential	131	TBtu	
Cost of Saved Energy	$ (0.026)	$/kWh	
Cost of Saved Energy	$ (2.46)	$/MMBtu	
Unusual Market Barriers	**Non-Energy Benefits**	**Current Activity**	**Next Steps**
	Improved maintenance and serviceability Increased reliability and robustness		Incentives Standards & Codes
Likelihood of Success	4	(1-5)	
Priority	Medium	Low, Med, High	
Data Quality Assessment	C	(A-D)	
Principal Contacts			
By Wilson Lin, with Harvey Sachs			

Besides the energy efficiency benefits arising from ensuring the proper operation of RTUs, automated FDD on RTUs can also help:

- Provide greater comfort to occupants by providing information for building management and control systems (BAS, EMS);
- Minimize interruptions to building operations due to system failures;
- Reduce time (and costs) needed for maintenance and troubleshooting; and
- Avoid damage to RTU components (and replacement costs) by predicting component failure (prognostics) and implementing preventive maintenance.

Automated FDD with prognostics analyses diagnostic data from sensors and generates trend lines to predict possible failures. It can also help promote other emerging technologies in HVAC: A common market barrier to emerging technologies is that consumers are concerned about the availability of the technology, such as whether spare parts would be quickly available if there is a need to replace them. Prognostics can help address this by allowing the HVAC supplier ample time to ship the necessary parts and replace them even before the failures occur. In an extreme case, the implications of the lack of FDD can be huge: It is estimated that a faulty VAV can waste 25–35% with a fully-closed damper fault, ~30% with a fully open damper for a unit on the interior side, and 20–50% if the minimum value of the demand airflow rate or set point of the supply air temperature is stuck at an abnormal value.[197]

Current Status of Measure

There is an existing program for the commercialization of advanced automated HVAC fault detection and diagnostics under the California Energy Commission's PIER initiative. A project under this program aims to embed FDD methods in selected controller components for use with RTUs.[198] Known as the ACRx Sentinel, the system is currently undergoing field tests.

Savings Potential and Cost-Effectiveness

Automated FDD can help reduce utility and maintenance costs. It allows building operators to take early action to correct faults in the RTUs, helping to reduce the amount of time the RTUs are operating in an inefficient manner due to these faults.

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[197] http://www.ibpsa.org/proceedings/BS2005/BS05_0777_784.pdf
[198] http://www.archenergy.com/pier-fdd/rtu_diagnostics/rtu_diagnostics.htm

Diagnostic data can help building operators better understand energy consumption patterns and may highlight ways in which to reduce energy consumption. The data allow building operators to take a more active approach towards building management, shifting towards a more "reliability-centered" approach from the current "reactive" one.[199] It can also reduce the cost for the building to undergo continuous commissioning, since the data needed for commissioning is already collected.

A meta-analysis of building commissioning reviewed the cost-effectiveness of commissioning in improving energy efficiency.[200] The analysis found that most of the reported building performance problems were due to the HVAC systems. A report by the International Energy Agency reported that typically 20–30% energy savings can be achieved in commercial buildings by correcting faulty operation in the HVAC system.[201] It is likely that the potential energy savings from intelligent HVAC systems will exceed this estimate, since intelligent HVAC systems provide opportunities for energy savings that go beyond just the correction of faults (such as dynamic matching of capacity to load when installed with variable output components).

In a 2005 paper for DOE,[202] TIAX estimated that FDDs could reduce national primary energy consumption by 0.025 to 0.14 quads for RTUs, assuming that they only address three key faults: insufficient evaporator airflow, condenser coil fouling, and incorrect refrigerant charge. This compares to the relevant energy consumption of 0.74 quads (3–18% savings).

A California PIER project on advanced automated HVAC fault detection and diagnostics commercialization estimates that at least 10% of the energy used in CA commercial buildings is wasted due to excessive run time and problems in the HVAC equipment and controls — problems that could be addressed by diagnostics/prognostics.

Based on a review of field studies on commercial rooftop units in the Pacific Northwest and California,[203] it was found that:

- An average of 46% of the units tested had refrigerant charge that deviated by more than 5% from the specifications. Correcting the refrigerant charge is estimated to result in 5–11% savings in the cooling energy;
- An average of 64% of the units tested had economizers that failed or required readjustment. Repairing a failed economizer is estimated to result in 15–40% savings in the cooling energy, depending on the climate zone and other factors; and
- An average of 42% of the units tested had airflow that was out of range. The correction of airflow is estimated to result in about 10% savings in the cooling energy.

Our study assumes 10% savings, a conservative estimate.

Market Barriers

The commercial roof-top air-conditioner market is fiercely competitive, and dominated by lower-efficiency commoditized products sold as least purchase price solutions. Utility incentives, such as those coordinated by the Consortium for Energy Efficiency (CEE), are considered essential for moving the market to higher performance.[204] It will be important for CEE to consider the results of field research and begin to require automated FDD measures for program eligibility.

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[199] http://www.peci.org/ncbc/proceedings/2006/17_Cherniack_NCBC2006.pdf
[200] Mills, et al. ""The Cost-Effectiveness of Commercial-Building Commissioning," 2004.
[201] "Technical Synthesis Report Annex 34," IEA Annex 34, 2006.
[202] "Energy Impact of Commercial Building Controls and Performance Diagnostics: Market Characterization, Energy Impact of Building Faults and Energy Savings Potential," TIAX LLC, 2005.
[203] Cowan, A. 2005. "Review of Recent Commercial Roof Top Unit Field Studies in the Pacific Northwest and California."
[204] http://www.cee1.org/com/hecac/hecac-main.php3.

Key Assumptions Used in Analysis

While automated FDDs can help to identify faults in the system, corrective action must still be taken by the building operator to fix these faults. It is conceivable that some operators would chose not to fix identified faults under certain circumstances. The analysis does not take these situations into consideration.

Average Price of Electricity	\$0.1032/kWh[205]
Average Price of Natural Gas	\$10.97/MMBtu[206]
Real Discount Rate	4.53%
Projected 2025 End Use Gas Consumption[207]	1.25 quads
Heat Rate	10.48 kBtu/kWh

Recommended Next Steps

The fastest way to increase market penetration of FDD could be through building energy code provisions in progressive states like California. However, it is not clear whether a state can adopt an efficiency-related equipment requirement without violating the preemption requirements of NAECA and EPACT.

In the absence of state action, voluntary programs such as utility and public benefit incentives are likely to work well for increasing penetration and understanding of the potential gains.

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[205] EIA, “Electric Power Monthly—Feb 2009,” (YTD-Nov08, Commercial Price).
[206] http://tonto.eia.doe.gov/dnav/ng/ng_sum_lsum_dcu_nus_m.htm.
[207] EIA 2009. “Annual Energy Outlook 2009 with Projections to 2030”. Tables 4 and 5.

Emerging Technologies Report

Liquid Desiccant Air Conditioner

June, 2009

Definition	A Liquid Desiccant Air Conditioner (LDAC) deeply dries air using natural gas, solar energy, waste heat, bio- fuel or other fossil fuel to drive the system. By providing mostly latent cooling, the LDAC controls indoor humidity without overcooling and reheating.				
Base Case	An electric air-cooled vapor-compression chiller or DX air conditioner with natural gas reheat, in an efficient building with relatively high latent loads.				
New Measure:	An LDAC that cools and dries the fresh air intake to a building, supplemented by an electric chiller or DX air conditioner that sensibly cools the building's recirculation air.	Percent Savings	2025 Savings TBtu (Source)	Cost of Saved Energy	Success Rating (1-5)
		66% elec., 83% gas	210	<$0	3

Summary

Emerging economic and indoor environmental concerns require HVAC innovation. New *Liquid Desiccant Air Conditioning systems* offer substantial energy savings and greatly improved humidity control in applications where latent loads (moisture) are very high relative to sensible loads. This includes hot-humid climates, and applications such as supermarkets where low indoor humidity is required to avoid condensation on case doors, etc. These systems have been common in industry, and new equipment that decreases maintenance and reduces concerns about desiccant salt carryover make them attractive for space conditioning.

Background and Description

The Liquid Desiccant Air Conditioner (LDAC) provides a cost-effective route to latent cooling needed to control indoor humidity while avoiding the high electrical demand of compressor-based approaches to reducing heat loads. The liquid desiccant is a concentrated salt solution that directly absorbs moisture without first cooling the air below its dewpoint. The sensible heat released as the desiccant absorbs the moisture is also removed from the air so the LDAC both cools and dries the air. The water absorbed by the desiccant is removed to ambient air by heating the desiccant to between 180 F and 200 F (or higher). This heat is the primary energy input to the LDAC. The source can be a boiler fired by bio fuel, natural gas or other fossil fuel; solar thermal collectors; or heat recovered from an engine or industrial process (CHP, or combined heat and power). The liquid desiccant air conditioner may be particularly attractive for building-scale CHP in applications like supermarkets where humidity control is important and there are high latent loads.

Thermal air conditioners reduce electricity use and peak electrical demand. Ones that use waste heat or solar energy also conserve fossil fuels now used to generate the electricity for compressor-based air conditioners. Compared to other thermal technologies, absorption or adsorption chillers, LDAC should show lower capital cost, easier application, lower cost for energy storage and lower hot-water temperature requirements.

Liquid desiccants have been used to dehumidify air in industrial applications for over 70 years, but adaptation to comfort conditioning faced two high barriers: carryover of salt-containing droplets, and high maintenance costs. Because of the high performance of the systems, these attributes have been acceptable in some industrial applications. The new "LDAC" should eliminate droplet carryover by using desiccant flow rates that are 20 to 50 times lower than those used in industrial systems.

Data Summary

Market Sector	Market Application	End Use	Fuel Type
Commercial	New/Replace on Burnout Long Life	Cooling	All
Current Status	**Date of Commercialization**	**Product Life (years)**	**Source**
Field Test	2010	15	GTI

Basecase Energy Use		**Units**	**Notes, Explanation**	**Source**
Efficiency	1.00	kW/ton	Equivalent to EER of 12	
Electricity Use	104,200	kWh/year	Assumes 1400 hrs average day and 300 hrs design day	
Summer Peak Demand	76.5	kW	Cooling only	
Winter Peak Demand	0	kW		
Fuel Use	840	MMBtu/year	Reheat for dehumidification	
New Measure Energy Use				
Efficiency	1.15	COP	Output in Btu / Fuel input in Btu	
Electricity Use	35,300	kWh/year	LDAC and DX	
Summer Peak Demand	28	kW	Cooling only	
Winter Peak Demand	0.0	kW		
Fuel Use	140.0	MMBtu/year	Fuel to LDAC	
Savings				
Electricity Savings	68,900	kWh/year		
Summer Peak Demand Svgs	48.5	kW		
Winter Peak Demand Svgs	0.00	kW		
Fuel Savings	700.0	MMBtu/year		
Percent Savings	66%			
Percent Feasible	12%		Assuming population of counties is a proxy of commercial building distribution, some 17.7% of commercial buildings are in warm-humid climates; Assume 70% of commercial building cooling is directly amenable or via ventilation system.	US Census, CBECS
Industrial Savings > 25%?	No			
Costs				
Incremental Cost	$ 30,000	2009 $	Since base case is 1 kW/ton and has peak of 76.5 kW, need ~80 ton cooling. 80 ton RTU is RS means is $155500	
Other Costs/ (Savings)	0	$/ year		
Ranking Metrics				
2025 Savings Potential	9,800	GWh	Incremental cost assumes oversized 6000 CFM production unit (price at 1000 units/yr), and NO savings from downsizing chiller.	
2025 Savings Potential	210	TBtu		
Cost of Saved Energy	0	$/kWh		
Cost of Saved Energy	4.00	$/MMBtu		

Unusual Market Barriers	Non-Energy Benefits	Current Activity	Next Steps
Public Awareness Concerns about liquid desiccant Cooling tower requirements	Can use renewable energy like solar thermal Improve humidity control and IAQ	Demonstration sites Marketing materials being prepared	Demonstrations Incentives
Likelihood of Success	3	(1-5)	
Priority	Medium	Low, Med, High	
Data Quality Assessment	B	(A-D)	
Principal Contacts			
Andy Lowenstein, AIL Research, Princeton (Developer/Licensee)			
By GTI, edited and reviewed by Wilson Lin and Harvey Sachs			

Current Status of Measure

Within the past five years, two companies—Drykor and American Genius—failed in attempts to introduce a liquid desiccant air conditioner for HVAC applications. The products of both companies used high desiccant flow rates comparable to industrial systems, which may have contributed to their failures. A third company—DuCool—is now manufacturing and selling a high-flow LDAC. The DuCool air conditioner is expected to have higher pressure drops, higher parasitic power, lower thermal COP and more demanding maintenance requirements than a low-flow LDAC optimized for commercial applications..

Munters, Dectron, PoolPak, Desert-Aire and several other companies manufacture and sell high latent air conditioners that can be used to dry a building's ventilation air. These high-latent air conditioners all use vapor-compression technology and so they do not significantly reduce the peak electrical demands for cooling.

Munters, Seibu Giken and others supply solid wheel desiccants which are typically silica gel based thermally regenerated dehumidifiers. These systems are larger, less efficient, have higher air-side pressure drops and typically require considerably higher regeneration temperatures than the LDAC. In addition the heat generated as the moisture is absorbed flows into the conditioned space adding to the building sensible load.

Energy Savings and Costs

The most attractive applications for the LDAC will be in humid climates where its beneficial impact will include: (1) improved indoor IAQ that leads to improved worker productivity and student attentiveness, (2) improved indoor comfort that increases patronage of restaurants, movies and retail stores, (3) lowered indoor humidity that avoids remediation costs associated with mold and mildew, and (4) direct savings from the elimination (or reduction) of reheat as a means of humidity control. In humid climates with long cooling seasons, the elimination of reheat can reduce annual HVAC costs by 30% or more.

As a gas-fired alternative to high-latent electric air conditioners, the LDAC's operational savings will be largely determined by local gas and electric utility rates and the length of the cooling season. Capital costs may be lower for LDAC (goal is $5/cfm) than for high latent air conditioners ($8 to $10 per cfm of ventilation). At $0.10 per kWh and $1.00 per therm, the operating costs for the LDAC and electric alternatives will be comparable.

Market Barriers

The LDAC is unfamiliar to engineers and designers who specify HVAC equipment, and to the trades that install and maintain it. The little exposure that liquid desiccant equipment has had in the past pertains to high-flow systems, and this exposure has too frequently uncovered maintenance problems from desiccant carryover. Also, many LDAC applications need a cooling tower, which may also require more maintenance than some building owners will accept.

The high cost of solar thermal collectors combined with the relatively low cost of electricity in many parts of the U.S. are also barriers to the wider use of solar and gas fired LDACs.

Next Steps

Demonstrations are needed to document the benefits for the low-flow LDAC including operating and O&M costs. These early demonstrations, coupled with strong educational and promotional activities can move the traditionally cautious HVAC community to adopt the technology. In preparation for commercialization, further market analysis is needed to formulate a practical and effective marketing and sales strategy. In addition, further analysis of the synergies with renewable energy and CHP (combined heat and power) are required to help position LDAC in the "green" market. The thermally driven LDAC could greatly expand the use of CHP for smaller applications by increasing summer load factors. Finally, an LDAC driven by solar thermal collectors will be the lowest cost alternative to converting the country's cooling needs to a renewable energy source.

Key Assumptions Used in Analysis

Average Price of Electricity	\$0.1032/kWh[208]
Average Price of Natural Gas	\$10.97/MMBtu
Projected 2025 End Use Electricity Consumption[209]	0.39 quads
Real Discount Rate	4.53%
Projected 2025 End Use Gas Consumption[210]	1.25 quads
Heat Rate	10.48 kBtu/kWh

Next Steps

Demonstrations are needed to document the benefits for the low-flow LDAC including operating and O&M costs. These early demonstrations, coupled with strong educational and promotional activities can move the traditionally cautious HVAC community to adopt the technology. In preparation for commercialization, further market analysis is needed to formulate a practical and effective marketing and sales strategy. In addition, further analysis of the synergies with renewable energy and CHP (combined heat and power) are required to help position LDAC in the "green" market. The thermally driven LDAC could greatly expand the use of CHP for smaller applications by increasing summer load factors. Finally, an LDAC driven by solar thermal collectors will be the lowest cost alternative to converting the country's cooling needs to a renewable energy source.

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[208] EIA, "Electric Power Monthly—Feb 2009", (YTD-Nov08, Commercial Price)

[209] EIA 2009. "Annual Energy Outlook 2009 with Projections to 2030". Tables 4 and 5.

[210] Ibid.

Emerging Technologies Update

Residential Boiler Controls

August, 2009

Definition	Integrated and stand-alone controls for residential boilers that estimate changes in heat demand under part-load conditions and control maximum boiler water temperature, firing time, and/or circulating pump cycling and speed in response					
Basecase	Residential gas-fired non-condensing boiler (heat only) with standard safety and operating controls (alarms for high temperature limit, low water cut-off, high pressure cut-off, etc.) Standby/idle loss typically 2–3% of input energy					
New Measure:	Gas-fired boiler equipped with a control system, either direct or indirect, that reduces idle losses to ~0.3%	Percent Savings	2025 Savings TBtu (Source)	Cost of Saved Energy	Success Rating (1-5)	
		11%	262	$4.86/MMBtu	2	

Update

Section 303 of the US Energy Independence and Security Act of 2007[211] provides that all residential hot water boilers manufactured after September 12, 2012 shall have "…an automatic means for adjusting temperature." Its clauses effectively require the use of integrated controls that minimize off-cycle losses and keep the hot water return water temperature as cool as feasible for the particular boiler class (Attachment). This measure resulted from an agreement between boiler manufacturers, their trade association, and environmental advocates. The parties agreed that controls would save more energy than the most likely increase in federal ratings (AFUE). Unfortunately, the consensus agreement was rejected by DOE in 2007 as requiring both a performance level (AFUE) and design requirements.[212] EISA, in 2009, mandated the controls requirement on the joint recommendation of the boiler manufacturers and ACEEE.

When this report was completed (2006), few residential boiler systems had appropriate energy-saving controls. As the legislated date approaches, contractors will become more aware of the benefits of effective boiler controls. This should create an opportunity for efficiency program retrofit boiler controls based on the projected cost of saved energy less than $5.00/MMBtu, if the retrofit package with installation costs $500. This means that a $1000 package still has a cost of saved energy less than $1/therm. This measure will be most attractive if combined with seasonal check-out.

Background and Description

Conventional non-condensing boilers fire at a single fuel-burning rate. They turn on when the thermostat calls for heat, and turn off when the heat call is satisfied or when over-ride controls (high temperature limit, etc.) cut the cycle short. Typically, the high temperature limit is set at about 180ºF. This is designed to be hot enough to meet heating demand on the coldest day of the year. For most days during the heating season, maintaining this water temperature results in relatively high off-cycle heat losses. Several available control strategies are able to judge the current load on the system and lower the water temperature setpoint and/or delay burner firing accordingly. Depending on the system, they estimate load from indoor and outdoor temperatures, supply and return water temperatures, and/or the rates of change of these parameters.

The most common approach is the outdoor reset control. This uses outdoor temperature as a proxy for heat demand: when outdoor conditions are relatively warm, it changes the supply water temperature setpoint to an appropriate cooler supply temperature. All gas boilers can be controlled to a minimum temperature with light loads down to 140ºF, the point at which significant condensation can begin. Most gas boilers are "cold start," and will allow short operating periods below that temperature. Condensing

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[211] http://frwebgate.access.gpo.gov/cgi-bin/getdoc.cgi?dbname=110_cong_bills&docid=f:h6enr.txt.pdf
[212] 65150 Federal Register / Vol. 72, No. 222 / Monday, November 19, 2007 / Rules and Regulations

boilers can be controlled to arbitrarily low temperatures. "Keep-warm" boilers, primarily oil-fired, must be maintained above the condensing temperature[213]. Otherwise, boiler corrosion rates may accelerate, and condensate may leak from the system.

Other strategies for harvesting residual heat include controls that "purge" the residual heat at the end of a firing cycle, and controls that delay burner firing until all residual heat from the previous cycle is harvested. Two-stage thermostats and time-delay relays are examples of the latter, using warm water circulation to meet an initial call for heat before firing the burner.

Data Summary

Market Sector(s)	**Application(s)**	**End Use(s)**	**Fuel Type(s)**
Residential	New Construction Retrofit	Space Heating	Oil Gas
Market Segment	**National/Regional**	**Region(s)**	**State(s)**
	Regional	Northeast MidAtlantic Midwest	
Current Status	**Date of Commercialization**	***Notes***	
Commercialized	1980	approximate	
Life			
15 years			
Basecase Information			***Notes (Source)***
Efficiency	69	%	Annual Efficiency with 3% idle losses
Electric Use	0	kWh/yr	
Summer Peak Demand	0	kW	
Winter Peak Demand	0	kW	
Gas/Fuel Use	86.7	MMBtu/yr	
New Measure Information			***Notes (Source)***
Efficiency	77.3	%	Annual Efficiency with 0.3% idle losses
Electric Use	0	kWh/yr	
Summer Peak Demand	0	kW	
Winter Peak Demand	0	kW	
Gas/Fuel Use	77.1	MMBtu/yr	
Savings Information			***Notes (Source)***
Electric Savings	0	kWh/yr	Electricity use of boilers is poorly understood and thus left out of this analysis.
Summer Peak Demand Savings	0	kW	
Winter Peak Demand Savings	0	kW	
Gas/Fuel Savings	9.6	MMBtu/yr	
Percent Savings	11	%	
Feasible Applications (%)	70	%	30% of existing systems deemed too old to retrofit. Feasibility is 100% on new systems.
Industrial Savings Potential (>25%)	NO		
2025 Savings Potential	**0**	**GWH**	
2025 Savings Potential (Source)	**262**	**TBtu**	Lower CSE if installed on new systems ($2.88/MMBtu) based on a longer life expectancy and lower labor cost.
Cost of Saved Energy	**$4.86**	**$/MMBtu**	
Cost Information			***Notes (Source)***
Incremental Cost	$500	2006 $	
Other Costs / (Savings)	0	$/yr	
Success Factors			
Market Barriers	**Non-Energy Benefits**	**Current Promotional Activity**	**Next Steps**
- Public awareness - Contractor/Builder Training	- Cleaner boiler operations - Longer boiler life - Increased occupant comfort	- Advertising	- Utility Promotion/Incentives - Testing - Marketing
Priority (1-5)	**Likelihood of Success (1-5)**	**Success Rationale**	
Special	2	Feasibility is high and valuable non-energy benefits exist. Market barriers are surmountable, but overcoming them will take extensive effort.	
Data Quality Assessment (A-D)	**Data Explanation**		
B	Based on manufacturer data and reports by and discussions with boiler experts at the national laboratories		

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[213] ASHRAE 1993; Table 7

Current Status of Measure

Some of today's high-efficiency condensing boilers include temperature reset and load monitoring controls as standard features. These features are important for lowering water temperature enough to realize the full condensing function of these boilers. Several manufacturers (Weil McLain, Veissmann, Buderus, Lochinvar, and Munchkin, to name some of the larger) have introduced these systems on the U.S. market within the last 10 years. Other condensing boilers on the U.S. market provide outdoor reset as an option. The condensing boiler market share is not known but is fairly small (probably less than 5% of sales).

Controls can also be purchased separately and added to an existing conventional system. Honeywell, Tekmar, and several boiler manufacturers produce a wide range of controls of varying levels of sophistication and features. Altogether, these controls are present on no more than 1-2% of the existing boiler stock.

Savings Potential and Cost-Effectiveness

The savings potential of boiler controls is a measure of how effectively they cut out idle losses, regardless of system oversizing issues. For conventional boilers, adequate add-on controls may cost from $150 (time-delay relay) to over $1,000 (reset with automatic post purge) and save up to 6–8% or more of the fuel used. In most cases, the costs and fuel savings depend heavily on the existing system and plumbing. Add-on controls that can claim around 10% savings for most existing systems are roughly $300–400. We assume 8% savings in this analysis. In contrast, a new condensing boiler equipped with sophisticated controls will incur a similar incremental cost of $500–1,000, but will save 20% of fuel use compared to standard gas boilers based on reduction of idle losses to between 0.15 and 0.3%.

Market Barriers

Residential boiler controls that modulate supply water temperature have been available on the market for at least 30 years but have remained uncommon due to high up-front costs and a lack of aggressive promotional activity and marketing. With higher fuel costs, manufacturers are increasingly showcasing their most efficient systems, most of which are condensing models with controls that come as standard or optional features. For existing boilers, however, stand-alone controls have not been actively marketed to consumers. Public acceptance is likely hindered by the lack of a one-size-fits-all solution. Depending on the size, age, and type of boiler; plumbing configuration; and burner sophistication, the cost of purchasing and installing the components that are necessary to achieve significant energy savings can vary dramatically and be expensive.

Key Assumptions Used in Analysis

See Field Notes for specific assumptions.

Average Price of Electricity	$0.083/kWh
Percent New Res. Construction in 2025[214]	14.8%
Average Price of Natural Gas	$10.16/MMBtu
Projected 2025 End Use Electricity Consumption[215]	0.39 quads
Real Discount Rate	4.53%
Projected 2025 End Use Gas Consumption[216]	1.25 quads
Heat Rate	10.48 kBtu/kWh

Next Steps

Condensing boilers that are integrated with more advanced load measurement and response controls are now mainstream in the U.K. and Germany due to strict residential codes and standards. These products are increasingly popular in the U.S. But for the non-condensing boilers that dominate the U.S. market, consumers could be given greater access to information that helps them understand what controls would be appropriate and cost-effective for their existing systems. New field demonstrations and documentation of the clear fuel savings that modern controls provide would strengthen the case for such incentive programs. Utility promotions would be an appropriate channel for wider adoption by both consumers and manufacturers.

EISA Section 303, which mandates integrated controls for new boilers in 2012, will increase awareness and may lead to excellent opportunities for utility incentive programs for retrofits of decent existing boilers.

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[214] EIA 2009

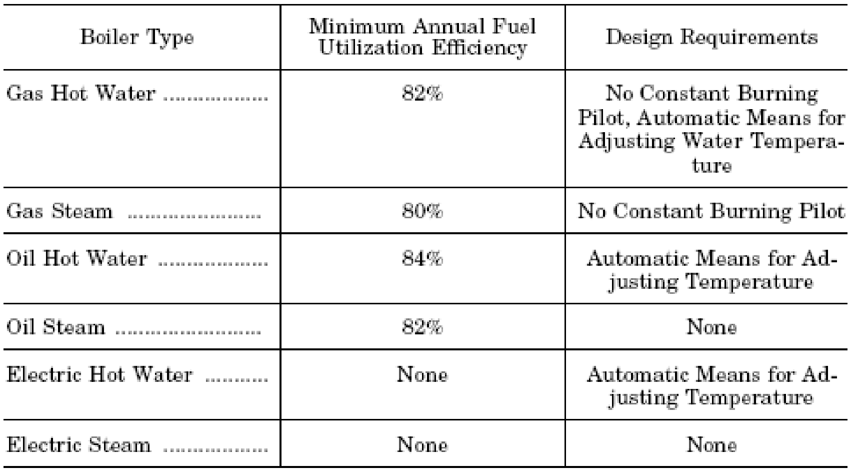
[215] Ibid

[216] Ibid

Attachment

H. R. 6. Short TITLE.—This Act may be cited as the ‘‘Energy Independence and Security Act of 2007’’[217]

SEC. 303. RESIDENTIAL BOILERS.
Section 325(f) of the Energy Policy and Conservation Act (42 U.S.C. 6295(f)) is amended—
(1) in the subsection heading, by inserting ‘‘AND BOILERS’’ after ‘‘FURNACES’’;
(2) by redesignating paragraph (3) as paragraph (4); and (3) by inserting after paragraph (2) the following:
‘‘(3) BOILERS.—
‘‘(A) IN GENERAL.—Subject to subparagraphs (B) and (C),
boilers manufactured on or after September 1, 2012, shall meet the following requirements:



Boiler Type	Minimum Annual Fuel Utilization Efficiency	Design Requirements
Gas Hot Water	82%	No Constant Burning Pilot, Automatic Means for Adjusting Water Temperature
Gas Steam	80%	No Constant Burning Pilot
Oil Hot Water	84%	Automatic Means for Adjusting Temperature
Oil Steam	82%	None
Electric Hot Water	None	Automatic Means for Adjusting Temperature
Electric Steam	None	None

‘‘(B) AUTOMATIC MEANS FOR ADJUSTING WATER TEMPERATURE.—
‘‘(i) IN GENERAL.—The manufacturer shall equip each gas, oil, and electric hot water boiler (other than a boiler equipped with a tankless domestic water heating coil) with automatic means for adjusting the temperature of the water supplied by the boiler to ensure that an incremental change in inferred heat load produces a corresponding incremental change in the temperature of water supplied.
‘‘(ii) SINGLE INPUT RATE.—For a boiler that fires at 1 input rate, the requirements of this subparagraph may be satisfied by providing an automatic means that allows the burner or heating element to fire only when the means has determined that the inferred heat load cannot be met by the residual heat of the water in the system.
‘‘(iii) NO INFERRED HEAT LOAD.—When there is no inferred heat load with respect to a hot water boiler, the automatic means described in clauses (i) and (ii) shall limit the temperature of the water in the boiler to not more than 140 degrees Fahrenheit.
‘‘(iv) OPERATION.—A boiler described in clause (i) or (ii) shall be operable only when the automatic means described in clauses (i), (ii), and (iii) is installed.

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[217] http://frwebgate.access.gpo.gov/cgi-bin/getdoc.cgi?dbname=110_cong_bills&docid=f:h6enr.txt.pdf

‘‘(C) EXCEPTION.—A boiler that is manufactured to operate without any need for electricity or any electric
connection, electric gauges, electric pumps, electric wires, or electric devices shall not be required to meet the requirements of this paragraph.’’.

Emerging Technologies Report

Dehumidification Enhancements for Air Conditioners in Hot-Humid Climates

April, 2009

Definition	Packaged air conditioners in hot-humid climates with the dehumidification enhancement feature				
Base Case	5-ton rooftop unit				
New Measure:	Incorporation of a Cromer cycle dehumificiation feature	Percent savings	2025 Savings TBtu (Source)	Cost of Saved Energy	Success Rating (1-5)
		30%	49	$0.00/kWh	3

Summary

Space conditioning in commercial buildings in hot-humid climates requires introducing large amounts of humid outdoor air to meet ventilation standards for indoor air quality.[218] The combined humidity and sensible loads can be beyond the ability of conventional vapor compression air conditioners to provide thermal comfort and protect the building. The Cromer cycle is a novel combination of a desiccant wheel and a vapor compression air conditioner. It is now commercially available.

Cromer Cycle HVAC systems can match building loads in humid areas better, especially at part-load conditions, and reduce the need for reheat. They can also allow smaller capacity cooling equipment to be used. Cromer cycle technology can produce supply air that has a dew point 0–10°F below the temperature of the refrigerant in the cooling coil, while a typical cooling coil can only dehumidify air to a dew point 5-10°F above the temperature of the refrigerant.[219] Manufacturer's literature estimates that for humidity-sensitive applications, a high-efficiency rooftop unit with the Cromer cycle can allow downsizing of equipment by 15-33%, improve the latent capacity by 40–160%, lower the dew point of the supply air by 2-5°F, reduce cooling energy by 10–30%, and reduce reheat and total energy by 30–90%.

Background and Description

Buildings in hot and humid climate conditions often require large amounts of air conditioning for achieve comfort, which includes both temperature and humidity. In the U.S., the hot and humid climate zone[220] (see figure on the next page) includes the southeast zone from eastern Texas to Florida and southern Georgia, as well as Puerto Rico and Hawaii.

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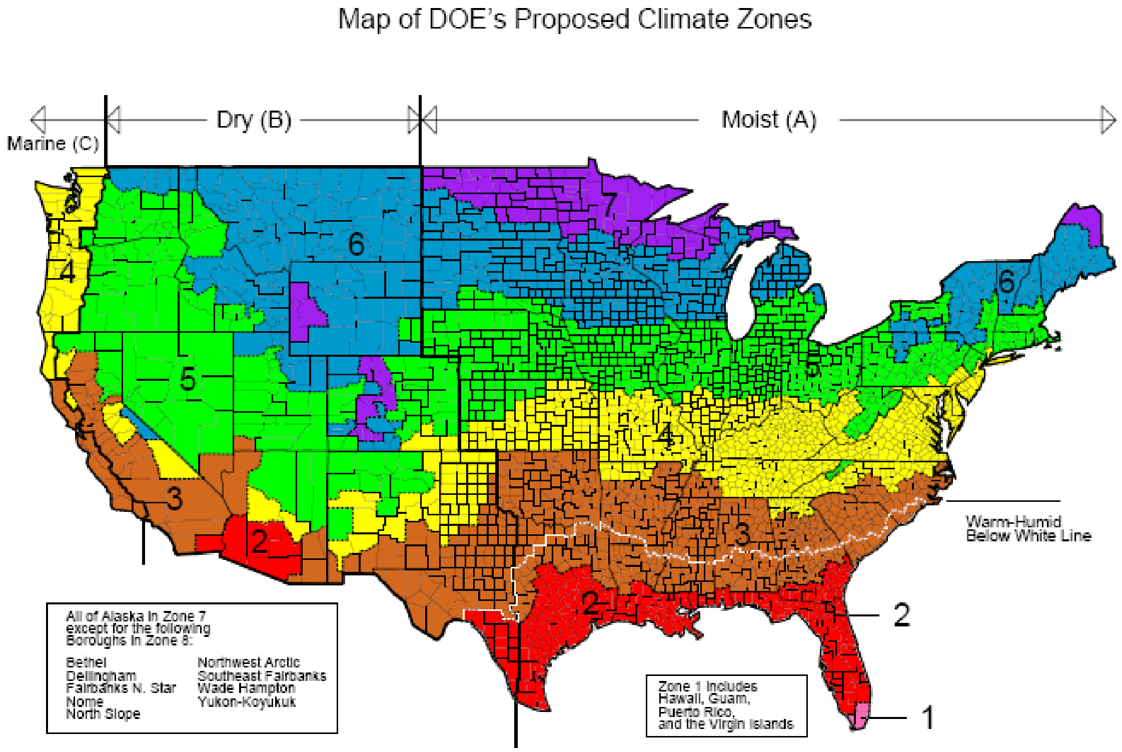
[218] Kosar, D., "Dehumidification System Enhancements", *ASHRAE Journal* Vol 48 Feb. 2006, 48-58
[219] Trane Engineering Bulletin "Trane CDQ Desiccant Dehumidification"
[220] http://www1.eere.energy.gov/buildings/residential/climate_zones.html

Climate Zones of the United States[221]



Notes: Hot-humid is Southeast, from the GA-SC border at the Atlantic through the coastal plain of Texas. Warm-humid extends from Delaware through the SE States, Arkansas, most of Oklahoma and Texas, and parts of the SW.

Internal gains and the intense solar radiation in the zone justify cooling. The humidity of the air also needs to be controlled, as high humidity is uncomfortable and could lead to mold and condensation problems, which could in turn impact occupant health and the structure. Overly high humidity can also result in higher cooling demand, as occupants reduce thermostat settings to achieve greater comfort. Generally, relative humidity needs to be kept to below 60%.

Air conditioning requires controlling both *sensible* heat (temperature measured by a thermometer) and *latent* heat (the water vapor in the air). During the past decades, building standards (e.g., ASHRAE 90.1) have become more stringent, reducing envelope, lighting, and equipment loads, and thus sensible heat requirements. But, more ventilation is required by ASHRAE 62.1, the standard for ventilation for indoor air quality. Because ventilation loads are increasing, relative latent loads are also increasing, because ventilation air is usually a much larger source of water vapor than any internal source such as respiration by occupants.

Although simple vapor compression air conditioners adapt by removing more humidity when latent loads are higher, they have clear limits, so there can be a mismatch between the normal sensible heat ratio of unitary air conditioners and that needed to condition the building in humid conditions.[222] Indeed, with conventional equipment, reducing humidity may require overcooling (to remove water vapor) and then reheating the air to a comfortable temperature. ASHRAE 90.1, the Energy Standard, strongly discourages reheat.

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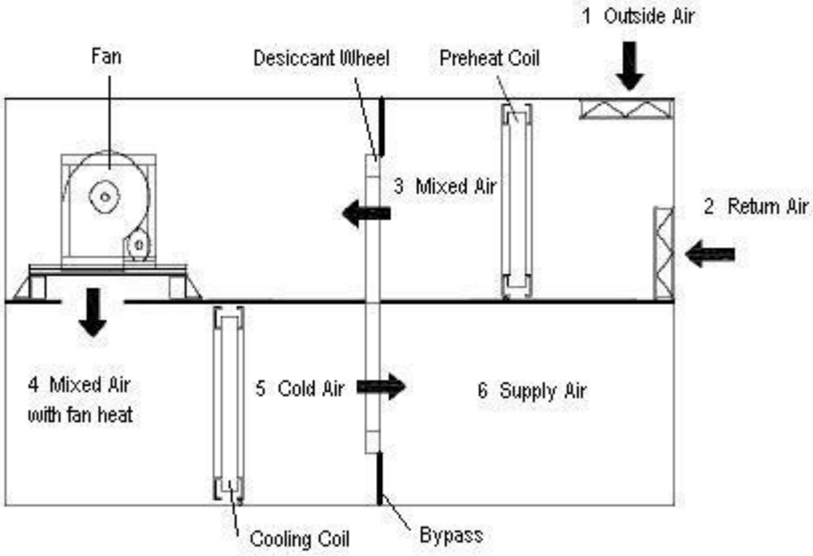
[221] http://www.energycodes.gov/implement/pdfs/color_map_climate_zones_Mar03.pdf

[222] TIAX LLC, "Matching the Sensible Heat Ratio of Air Conditioning Equipment with the Building Load SHR", Nov 12 2003, Pg 2-13

The Cromer cycle is a novel approach that positions a desiccant wheel across the supply air stream both before and after the cooling coils.



The Cromer Cycle (adapted from Trane literature)

With the Cromer Cycle, outside ventilation air (1) is mixed with return air from the space (2). The mixed air (3) may be preheated to increase evaporation from the wheel. The mixed air then passes across the desiccant wheel, which is relatively moist since it has just passed through the more humid cold air (5). The desiccant wheel thus releases moisture into the mixed air, raising its relative humidity.

The more humid mixed air is then blown across a cooling coil, generating cold, saturated air, since cold air can hold less moisture than warm air. Thus, water vapor condenses on the cooling coil and drains from the air conditioner (5). Some of the remaining moisture is then absorbed by the desiccant wheel, and the dehumidified air (6) is then supplied to the building area.

By moving moisture from the cold air (5) to the mixed air (3) using the desiccant wheel, as well as heating the mixed air using preheating and fan heat, the air passing across the cooling coil is both warmer and more humid. This increases the amount of moisture the cooling coil can remove from the air, enhancing the latent capacity of the cooling coil and lowering the dew point of the supply air.

Thus, Cromer cycle HVAC systems can match building loads in humid areas better, especially at part-load conditions. It can also allow smaller capacity cooling equipment to be used. Cromer cycle technology can produce supply air that has a dew point 0-10°F below the temperature of the refrigerant in the cooling coil, while a typical cooling coil can only dehumidify air to a dew point 5-10°F above the temperature of the refrigerant.[223] A manufacturer estimates that for humidity-sensitive applications, a high-efficiency rooftop unit with the Cromer Cycle can allow downsizing of equipment by 15-33%, improve latent capacity by 40-160%, lower the dew point of the supply air by 2-5°F, reduce cooling energy by 10-30%, and reduce reheat and total energy by 30-90%.[224] In addition, the Cromer cycle is applicable to chiller-based systems.[225]

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[223] Trane Engineering Bulletin “Trane CDQ Desiccant Dehumidification”
[224] Trane, “CDQ Dehumidification with Trane Rooftop Units”, CDQ-SLB001-EN
[225] Trane, “CDQ Dehumidification with Climate Changer Air Handlers”, CDQ-SLB002-EN

Data Summary

Market Sector	**Market Application**		**End Use**	**Fuel Type**
Commercial	New/Replace on Burnout Long Life		Cooling	Electricity
Current Status	**Date of Com**		**Product Life (years)**	**Source**
Commercialized			15	Trane
Basecase Energy Use		**Units**	**Notes, Explanation**	**Source**
Efficiency	10	EER	Federal mandated energy efficiency, from 2010	
Electricity Use	9000	kWh/yr	Using FEMP energy cost calculator	FEMP
Summer Peak Demand	6	kW	5 ton, 10 EER (5*12/10)	
Winter Peak Demand	0	kW		
Fuel Use		MMBtu/year		
New Measure Energy Use				
Efficiency	11.4	EER	Using FEMP energy cost calculator and estimated annual electricity use (see below)	FEMP
Electricity Use	6300	kWh/yr	Assuming 30% electricity use reduction, based on lower end of range of estimates for total energy reduction in literature	
Summer Peak Demand	4.2	kW	4 ton, 11.4 EER (4*12/11.4)	
Winter Peak Demand		kW		
Fuel Use		MMBtu/yr		
Savings				
Electricity Savings	2700	kWh/year		
Summer Peak Demand Svgs	1.8	kW		
Winter Peak Demand Svgs		kW		
Fuel Savings		MMBtu/year		
Percent Savings	30%			
Percent Feasible	9%		Assuming population of counties is a proxy of commercial building distribution, some 17.7% of commercial buildings are in warm-humid climates; Assume 50% uptake	
Industrial Savings > 25%?	no			
Costs				
Incremental Cost	350	2009$	150% of cost of adding energy wheel,	
Other Costs/ (Savings)	-40	$/ year	Estimated first cost reduction for reduced size of RTU, using RS Means 2009, depreciated across 15 yr. lifespan	

Ranking Metrics				
2025 Savings Potential	4700	GWh		
2025 Savings Potential	49	TBtu		
Cost of Saved Energy	0.00	$/kWh		
Cost of Saved Energy		$/MMBtu		
Unusual Market Barriers	**Non-Energy Benefits**		**Current Activity**	**Next Steps**
Contractor/Builder Training	Cleaner boiler operations Longer boiler life Increased occupant comfort		Advertising	Incentives Field Testing Strategic Marketing
Likelihood of Success	3	(1-5)		
Priority	Medium	Low, Med, High		
Data Quality Assessment	B	(A-D)		
Principal Contacts				
Charles Cromer, Florida Solar Energy Center				
Ronnie Moffitt, Trane Corporation				

Current Status of Measure

The Cromer Cycle has been commercialized by Trane under the trade name "CDQ". The product, introduced in 2005, was named the "2006 HVAC Dehumidification Systems Product of the Year" by research and consulting firm Frost & Sullivan.[226]

The CDQ is currently being targeted at niche market segments which require significant humidity control, such as hospitals, museums, and storage. It is also being applied in LEED-type projects to improve the energy efficiency of DOAS.[227]

Energy Savings and Costs

Literature from Trane estimates that for humidity-sensitive applications, a high-efficiency rooftop unit with the Cromer Cycle can allow downsizing of equipment by 15-33%, improve the latent capacity by 40-160%, reduce cooling energy by 10-30%, and reduce reheat and total energy by 30-90%.

In a 2005 field test in Florida, a 3-ton prototype Cromer Cycle rooftop unit was run side by side with a standard 3-ton unit with a reheat coil. The result of the field test was that the prototype saved 75.7% of electricity consumption even though it was delivering cooler air at a lower relative humidity.[228]

Simulations were also run on Trane software to compare various energy recovery options with a dedicated outdoor air system (DOAS):

- Cool-reheat system (no energy recovery)
- Cool-reheat system (with energy recovery using an energy wheel)
- Cool-reheat system (with heat recovery using an air-to-air heat exchanger)
- Using an energy wheel to pre-condition the outdoor air and the CDQ for additional dehumidification

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[226] http://www.trane.com/Commercial/Uploads/PDF/1254/traneIND06.pdf
[227] Email correspondence with Ronnie Moffitt, Trane Corporation
[228] C. Cromer, "Field Test of Combined Desiccant-Evaporator Cycle Providing Lower Dew Points and Enhanced Dehumidification"

The simulations were based on the scenario of a 100,000 sf office building utilizing a DOAS system that delivers 10,000 cfm of ventilation air at 58°F, 47 gr/lbm, 46.6°F dew point conditions.

At design day conditions of 99.4°F and 109.4 gr/lbm outdoor air,

OPTION	COOLING REQUIRED (Tons)	CHILLER CAPACITY (kW)	REHEAT ENERGY REQUIRED (Btu/hr)	CHILLER CAPACITY REDUCTION
Cool-Reheat	85.1	111.2	102000	-
Cool-Reheat with Energy Wheel	55.4	72.4	102000	35%
Cool-Reheat with Heat Exchanger	71.8	93.8	102000	16%
Energy Wheel and CDQ	51.2	61.5		45%

At design day conditions of 83.0°F and 130 gr/lbm outdoor air,

OPTION	COOLING REQUIRED (Tons)	CHILLER CAPACITY (kW)	REHEAT ENERGY REQUIRED (Btu/hr)	CHILLER CAPACITY REDUCTION
Cool-Reheat	81.8	84.0	102000	-
Cool-Reheat with Energy Wheel	55.7	57.2	102000	32%
Cool-Reheat with Heat Exchanger	76.8	78.9	102000	6%
Energy Wheel and CDQ	50.6	48.3		42%

The integration of a CDQ with an energy wheel into a DOAS system can result in significantly reduced chiller capacity requirements, potentially generating significant first cost savings since a smaller chiller system can be used.

Key Assumptions Used in Analysis

Average Price of Electricity	$0.1032/kWh[229]
Average Price of Natural Gas	$10.97/MMBtu[230]
Real Discount Rate	4.53%
Projected 2025 End Use Gas Consumption (EIA 2009) [231]	1.25 quads
Heat Rate	10.48 kBtu/kWh

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[229] EIA, “Electric Power Monthly—Feb 2009”, (YTD-Nov08, Commercial Price)
[230] http://tonto.eia.doe.gov/dnav/ng/ng_sum_lsum_dcu_nus_m.htm
[231] EIA 2009. “Annual Energy Outlook 2009 with Projections to 2030”. Tables 4 and 5.

Recommended Next Steps

Good case studies by third parties will establish a basis for system performance comparisons, expanding the market and forcing innovation by competitors. LEED consideration of enhanced humidity control in humid regions would help, too.

Emerging Technologies Report

Air-Side Economizer Control Strategies[232]

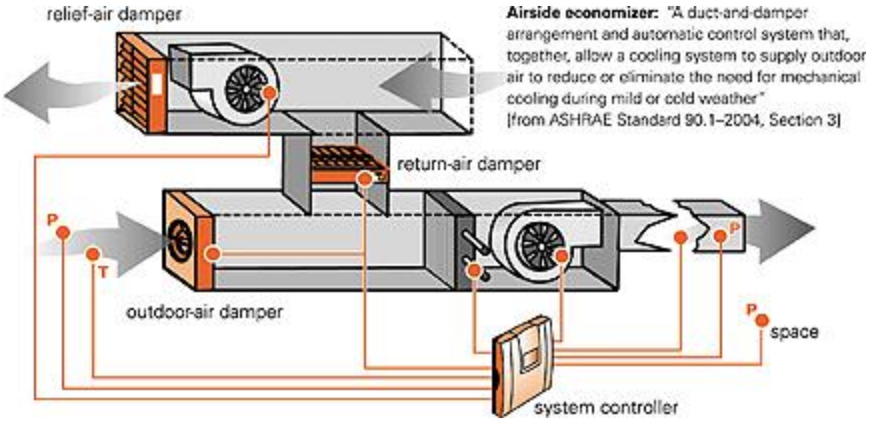
2009

Definition	Roof-top air conditioning unit (RTU) with factory-integrated economizer.				
Base Case	Ten-ton unit, inoperative or absent economizer				
New Measure:	Roof-top air conditioning unit (RTU) with factory-integrated economizer	Percent savings	2025 Savings TBtu (Source)	Cost of Saved Energy, $/MMBtu	Success Rating (1-5)
		16%	117	$7.58	3

Background and Description

To maintain the indoor air quality of a building, outside air needs to be introduced for ventilation and mixed with re-circulated indoor air. The mixed air then has to be conditioned to meet the needs of the building.[233] Thus, commercial buildings generally make provision for introducing outside air through dampers connected to the HVAC system. *Air-side economizers* just refers to the use of additional outdoor air when conditions are favorable to supplement or replace the cooling or heating equipment. For example, anytime it is cool outside when there are large internal loads, outdoor air can be used instead of the air conditioning compressors. In addition, in climates with large diurnal temperature swings, aggressive nighttime economizer operation will "precool" the building, by storing "coolth" in the mass of the building and its furnishings. Thus, the savings potential is climate-dependent. But, it is independent of the rated efficiency of unitary air conditioners, such as roof-top units (RTUs), since their efficiency metrics only reflect the refrigeration cycle.

Air-side economizers use ducts to move the air, dampers to control the flow of the various airstreams, and control systems to control the dampers. The control systems can be integrated with the air conditioning system so that the operation of both the economizer and the air conditioning system can be optimized to reduce energy consumption.



http://www.achrnews.com/Articles/Technical/8feb3c885a7bc010VgnVCM100000f932a8c0

An air-side economizer should only be used when the outside air conditions are suitably cold and/or dry. Drawing in warm and humid outside air will increase the cooling and dehumidification load on the HVAC system, resulting in increased energy consumption. There is thus a need for accurate and effective air-side economizer control systems. There are 2 types of control systems in common usage today: dry bulb temperature sensors and enthalpy sensors.

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[232] This report treats new equipment only. Some of the strategies described are relevant to retrofits, particularly for larger units.

[233] Alternatively, the outdoor air can be conditioned prior to introduction to the zones, as is done with *Dedicated Outdoor Air Systems.*

Dry bulb temperature sensors measure the sensible temperature of the surrounding air. These sensors activate the economizer whenever the outside air temperature is below the set temperature.

Enthalpy sensors measure the total sensible and latent (water vapor) energy load of the air. This the economizer from operating under cool but humid outdoor conditions, when additional outdoor air would require additional air conditioning to remove the humidity. Enthalpy controls come in fixed and electronic forms. Fixed enthalpy controls turn the economizer off whenever the calculated enthalpy (sensible + latent heat content) of the outside air exceeds a set enthalpy. Electronic enthalpy controls compare the measured temperature and humidity against a programmed range of temperature—humidity set points and disable the economizer when the outdoor air enthalpy (temperature and humidity combined) exceed the programmed range.

Both dry bulb and enthalpy controls can be implemented with a single set of sensors to detect the air conditions of the outdoor air, or with a second set of sensors to compare outdoor and return air conditions. The dual sensor system, known as differential dry bulb control or differential enthalpy control, allows the economizer system to compare the temperature or enthalpy of the outdoor air to that of the return air and to select the air stream with the lower temperature or enthalpy for air conditioning. These differential controls are more expensive, but they can improve the performance of the economizer system by only allowing suitable outdoor air in (beyond that required for ventilation, of course). This can result in lower energy consumption by the HVAC system.

Limitations of Existing Economizer Sensors

Dry bulb sensors are only able to measure the sensible load. They are unable to detect the latent (moisture) load in the air. As such, these sensors may allow cool but overly moist outdoor air to enter the building, which could result in increased energy consumption (due to the need for dehumidification), health issues (e.g. mold growth) and discomfort. Dry bulb sensors are thus unsuitable in humid climates.

Enthalpy sensors measure the total energy load by combining information on temperature and relative humidity. However, enthalpy measurements alone cannot provide information on the latent load. Other concerns with enthalpy sensors include the fact that enthalpy is affected by local barometric pressure and elevation (an error of 2% in the enthalpy value calculated can occur per 1000 feet of elevation[234]) as well as the accuracy of the sensors.

Dew Point and Dry Bulb Sensors

The dew point is the temperature at which the moisture in the air condenses. Passing air across a surface that is colder than the dew point will lead to water condensing on the surface. On suitable surfaces, this could result in mold and other moisture problems. Measuring the dew point of the outside air and programming the economizer to allow only air that has a dew point lower than that of the surfaces within the building to be brought in can help to prevent the introduction of overly moist air into the building.

The table below summarizes the relative advantages and disadvantages of the various control strategies.

CONTROL STRATEGY	ADVANTAGES	DISADVANTAGES
Fixed dry bulb	Inexpensive Suitable for dry climates	Considers only sensible load Not suited to humid climates
Differential dry bulb	Improved performance over fixed dry bulb Suitable for dry climates	Slightly more expensive than fixed dry bulb Not suited to humid climates
Single enthalpy sensor	Considers total load (sensible and latent) Improved performance over fixed dry bulb	More expensive than fixed dry bulb Does not separately consider sensible and latent load

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[234] AirTest "Economizer Control Design Guide: A White Paper"

	More suited to humid climates than dry bulb	Accuracy is an issue
Differential enthalpy	Considers total load (sensible and latent) Improved performance over single enthalpy sensor More suited to humid climates than dry bulb	Slightly more expensive than single enthalpy sensor Does not separately consider sensible and latent load Accuracy is an issue
Dew point and dry bulb	Separately considers sensible and latent load Improved performance over dry bulb and enthalpy sensors High accuracy Better able to address humid conditions than dry bulb and enthalpy sensors	More expensive than dry bulb and enthalpy sensors

Data Summary

Market Sector	Market Application		End Use	Fuel Type
Commercial	New/Replace on Burnout Long Life		Cooling	Electricity
Current Status	**Date of Commercialization**		**Product Life (years)**	**Source**
Commercialized			15	Higgins 2003
Basecase Energy Use		**Units**	**Notes, Explanation**	**Source**
Efficiency	11.00	EER	ASHRAE 90.1-2007 minimum as of 1/1/2010	
Electricity Use	16,400	kWh/year	Assume no economizer in FEMP calculator	FEMP calculator
Summer Peak Demand	9.8	kW	0.9 coincidence, EER = 12/(kW/ton)	
Fuel Use	0	MMBtu/year		
New Measure Energy Use				
Efficiency	13.20	effective EER	Assume nat. average 20% improvement w. economizer, net of increased fan power	
Electricity Use	13,700	kWh/year		
Summer Peak Demand	8.2	kW	0.9 coincidence	
Fuel Use	0.0	MMBtu/year		
Savings				
Electricity Savings	2,700	kWh/year		
Summer Peak Demand Svgs	1.6	kW		
Winter Peak Demand Svgs	N/A	kW		
Fuel Savings	0.0	MMBtu/year		
Percent Savings	16%			
Percent Feasible	38%		70% of packaged units (54% of total commercial cooling load)	
Industrial Savings > 25%?	No			
Costs				
Incremental Cost	$ 2,300	2008 $	Frankenfield estimate for incremental price, catalogue for economizer with control	GEG, 2003
Other Costs/ (Savings)	0	$/ year		
Ranking Metrics				
2025 Savings Potential	11,131	GWh		
2025 Savings Potential	117	TBtu		
Cost of Saved Energy	$ 0.079	$/kWh		
Cost of Saved Energy	$ 7.58	$/MMBtu		

Unusual Market Barriers	**Non-Energy Benefits**		**Current Activity**	**Next Steps**
Fast Payback Concerns Uncertainty about economizer benefit sustainability	Increases average ventilation rate		WECC specification Manufacturer promotions	Incentives
Likelihood of Success	3	(1-5)		
Priority	Special	Low, Med, High		
Data Quality Assessment	B	(A-D)		
Principal Contacts				
Peter Jacobs, Architectural Energy				
Cathy Higgins, New Buildings Institute				
Marshal Hunt, WCEC				

Current Status of Measure

Air-side economizers are required in many locales by the building code. They are required for cooling systems in commercial buildings by the 2006 International Energy Conservation Code, depending on climate zone and cooling system capacity.[235] The use of economizers is also required under ASHRAE Standard 90.1-2004 (section 6.5.1), although exceptions are made for some situations (see Appendix). It is estimated that about 60% of buildings in the US utilize economizers. Still, ACEEE regards air-side economizers as emerging technologies because field performance of available products has been very poor. In a significant California study that included 123 economizer-equipped roof-top units, 63% had substantial operational problems, and most of these had field-installed economizers instead of factory-integrated units.[236] California now requires integrated air-side economizers on commercial equipment above 75,000 Btu/h.[237]

There are some incentive programs available to encourage the installation of economizers. Some of these programs, such as NYSERDA, require the installation of differential enthalpy economizer controls.

Energy Savings and Costs

Air-side economizers have enormous cumulative energy savings potential—almost 0.2 Quad, but the savings vary from very large in drier climates with good diurnal temperature swings to minimal in hot-humid climates where outdoor enthalpy is too high for effective cooling. We estimate the cost of saved energy as <$0.08/kWh.

Key Assumptions Used in Analysis

Average Price of Electricity	$0.1032/kWh[238]
Average Price of Natural Gas	$10.97/MMBtu[239]
Real Discount Rate	4.53%
Heat Rate	10.48 kBtu/kWh

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[235] http://resourcecenter.pnl.gov/cocoon/morf/ResourceCenter/article//1639

[236] Higgins, C. 2003. Integrated Design of Small Commercial HVAC Systems. CEC Project 500-03-082. http://www.energy.ca.gov/pier/project_reports/500-03-082.html

[237] 2005 California Title 24, Part 4. Mechanical Systems. http://www.energy.ca.gov/title24/2005standards/nonresidential_manual.html

[238] EIA, "Electric Power Monthly—Feb 2009", (YTD-Nov08, Commercial Price)

[239] http://tonto.eia.doe.gov/dnav/ng/ng_sum_lsum_dcu_nus_m.htm

Our key assumption is that we can extrapolate from the inoperative fraction of California economizers to the savings is a very high fraction of economizers are parts of integrated systems with service expectations equivalent to those of the refrigeration components.

Recommended Next Steps

Today, RTUs are mostly marketed as "boxes," and system integration is left to the mechanical designer and installing contractor. This integration includes controls (either programmable thermostats or building automation interface), economizers, filtration, fan speed, and the critical commissioning step. The conceptual goal is a shift to selling RTUs with the economizer robustly integrated into the unit by the original equipment manufacturer. This is likely to require uniform ways to estimate relative efficiency of RTUs with specific economizer controls by climatic region. As important, it is likely to require reliability testing: a performance specification establishing the that economizer is likely to operate reliably for a given number of year that correspond to a large fraction of the expected unit life.

In the meantime, two approaches are promising:

- **Market Transformation**. ENERGY STAR, FEMP,[240] and the Consortium for Energy Efficiency (CEE) attempt to identify more efficient air conditioners, to help decision makers, and to help utilities and other incentive program operators to coordinate efficiency levels. This makes it easier for manufacturers to focus efforts on what these customers want. The current specifications from CEE do not include economizer specifications; ENERGY STAR's specification is in revision now.[241] The FEMP calculator does not seem to include economizer option benefits. The challenge for these programs is to include key regional features in their national standards.
- **Market Aggregation.** The Western Cooling Challenge[242] has developed a specification for an advanced hot-dry climate roof-top air conditioner, signed up national account retail purchasers, and is testing prototype air conditioners to determine suitability. This should lead to product availability in 2010. One product has already satisfied program conditions. The program target was a 40 percent reduction in energy use and peak electricity demand compared to conventional cooling units, but the first product's tests indicate almost 80 percent energy-use savings and over 60 percent peak-demand reduction.[243] Of course, not all the savings are due to the economizer: the design relies on indirect evaporative cooling rather than economizers for most of the hot-dry climate savings.

Appendix

Exceptions to Economizer Requirements in ASHRAE Standard 90.1-2004:

(a) Systems using fan-cooling units with individual capacities less than 65,000 Btuh (19 kW) in dry climates, less than 135,000 Btuh (40 kW) in cool-moist climates, and with any capacity, large or small, in warm-moist climates.

(b) Systems with gas-phase outdoor air cleaning to meet ASHRAE Standard 62.

(c) Systems that deliver more than 25 percent of the supply air to spaces humidified above 35°F dew point for process needs.

(d) Systems with condenser heat recovery.

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[240] http://www1.eere.energy.gov/femp/technologies/eep_unitary_ac.html

[241] http://www.energystar.gov/index.cfm?c=partners.pt_products_and_program_reqs

[242] http://wcec.ucdavis.edu/content/view/92/110/. Sponsored by the Western Cooling Efficiency Center of the University of California, Davis. http://wcec.ucdavis.edu/

[243] http://www.news.ucdavis.edu/search/news_detail.lasso?id=9200

(e) Any residential space system with a capacity that’s less than five times the applicable limit listed in Exception (a).

(f) Systems with space sensible cooling loads (excluding transmission and infiltration loads) equal to or less than transmission and infiltration loads at 60°F.

(g) Systems that are expected to operate less than 20 hours per week.

(h) Supermarket systems where outdoor air for cooling affects open refrigerated cases.

(i) Systems with high mechanical cooling efficiencies.