American Council for an Energy-Efficient Economy
WASHINGTON, DC

CRITERIA FOR ASSESSMENT OF NEW EQUIPMENT RESEARCH FOR CEE: CHILLER RETIREMENTS AND REPLACEMENTS (DRAFT)[1]

Harvey M. Sachs, Ph.D

One of a series of white papers by the
American Council for an Energy-Efficient Economy

Introduction

This paper summarizes three possibilities for incentive programs. Our goal is to help increase understanding of the role of chillers in the complex cooling systems of larger buildings.

The paper suggests three alternatives of increasing scope and engineering content:

- Incentives for chiller replacements
- Incentives for chilled water *system* efficiency
- Additional incentives for early retirement of CFC-based chillers for efficiency and environmental protection

Background

"Chillers" are the hearts of very large air conditioning systems for buildings and campuses with central chilled water systems. While smaller buildings, including houses, use factory-built assemblies (referred to as "packaged" or "unitary" equipment), larger buildings use "built-up" systems that may include components from many manufacturers. In addition to the chillers, the design engineer would separately specify the environmental heat exchanger (cooling tower), the cooling distribution systems (air handlers, terminal units, pumps, and piping), and controls.

The market for chillers is small (about 30,000 units per year) when compared with unitary equipment (about 5 million residential air conditioners and heat pumps per year). Table 1 gives an overview of the market as of 1999. For our purposes, we can divide the market by technology, recognizing that there are significant overlaps. As discussed in "Technology Overview," below, the largest chillers are centrifugal units, typically in sizes from 200 to several thousand tons. Non-centrifugal or positive displacement chillers include reciprocating, screw, and some large scroll compressors. Sizes range from about 20 to several hundred tons.

Table 2 suggests a perspective on differences between chillers and packaged equipment in terms of numbers, size, and design/install support required.

---

[1] Supported by a grant from the U.S. Environmental Protection Agency (EPA) for market transformation activities at ACEEE. May be circulated for comments. Requires completion of work in progress: validation of incremental cost estimates (see Table 6a) and replacement of payback analysis with fuller analysis based on building simulations.

Table 1. Market Descriptors for Chillers*

	Centrifugal	Non-Centrifugal	All Types
Units shipped, 1999	7,528	23,910	31,438
estimated average size, tons[2]	550	55	
estimated average price, shipped	$78,000	$20,000	$34,000

*Derived from data in U.S. Census' *Current Industrial Reports, 1999.*

Table 2. Characteristic Scales of Chillers vs. Residential Air Conditioners

	Chillers	Residential Central A/C & HP*
Units sold per year	ca. 30,000	> 6,600,000[3]
characteristic capacity	50–3,000 tons	1.5–5 tons
installation design time	days to weeks, PE or equiv.	person-hrs, sales rep.
installation time (w/o ductwork)	person-weeks to -months	1 person-day

* A/C = air conditioner; HP = heat pump

Reasons to Consider Programs

There are several reasons (amplified below) for considering incentive and technical assistance programs for chiller installations at time of new construction, replacement, and/or early retirement. This may include going beyond an incentive for the chiller to assistance for achieving efficiency in the balance of the HVAC system:

1. The full-load and part-load efficiencies of new products are much better than in the past. Where "standard" chillers typically consumed over 1 kW/ton of cooling (COP < 3.5), some units today achieve 0.5 kW/ton (COP > 7) or better at full-load and better than 0.4 kW/ton at part-load conditions. The chiller uses most of the electricity for the air conditioning system, so this doubling of efficiency is a remarkable technical achievement. The Air-Conditioning and Refrigeration Institute (ARI)[4] estimates that new chillers are 40% more efficient that the early-1990s centrifugal units.

2. Approximately 40,000 chillers still in place use CFC refrigerants whose production in the United States has been banned under the Montreal Protocol.[5] In addition to their inefficient use of energy, these typically leak much more refrigerant than more modern chillers, and their leaks (perhaps 1,000 pounds per unit per year) harm the atmosphere. Accelerating the phase-out of these machines has real environmental gains.

3. If the installation of a new chiller in an existing building triggers a review of the system's controls, operating strategies, and pumps and fans (and their motors), enormous additional

---

[2] Estimate by author from Census size class data.

[3] See http://www.ari.org/sr/2000/sr2000-12.pdf.

[4] Air-Conditioning and Refrigeration Institute (ARI) press release, April 11, 2001, "Half-Way Mark in Sight for Replacement and Conversion of CFC Chillers Used for Air Conditioning of Buildings," http://www.ari.org/pr/2001/041101chillers.html.

[5] Ibid.

gains are possible. These have been carefully studied and simulated,[6] and are important components of programs offered some utilities, such as Northeast Utilities and PGE.

4. Although the potential number of large installations each year is relatively small (typically tens per utility per year), the potential savings per installation are very large compared with the packaged equipment (typically 2–20 tons per machine) used in light commercial and residential applications. Consider a relatively large, older, 1,000 ton chiller. At 1 kW/ton, its peak power consumption is 1 MW. A simple replacement with a new, 0.5 kW/ton chiller would avoid 500 kW in the peak hour. To be conservative, assume that we only saved 300 kW per chiller and replaced 7,000 existing (U.S.) chillers each year with best-practice machines at 0.5 kW/ton. That would avoid 2,100 MW, or 7 medium-sized (300 MW each) power plants.[7] From a slightly different perspective, the full cost (not incremental cost) of high-efficiency (0.5 kW/ton) replacement chillers, about $300/ton, means that replacing a 1 kW/ton unit with a high-efficiency unit and paying the full cost of the unit give utilities a new resource for $600–700/kW of peak load capacity—with no fuel charges, customer-paid operations and maintenance, and freed-up distribution capacity.[8]

What Kinds of Programs?

The list above suggests that programs are easily justified by benefits to utilities, customers, and the environment, but does not suggest the program types. As extremes, we can recognize two approaches:

1. *Equipment-oriented.* The "pure" form is a posted rebate schedule, in $/kW, with all choices made by the customer. This is quite analogous to 1980s approaches to HVAC programs and programs for appliances such as refrigerators. It carries the implicit assumption that the unit rebated is virtually independent of other building components.

2. *System-oriented,* or *"integrated chiller retrofits" (term used for existing buildings).* These involve systematically reviewing the building (or plans) and all the systems to look for cost-effective ways to reduce loads and thus downsize the chiller. Measures to be considered would include lighting and fenestration load reduction, variable speed pumps and fans, and resized cooling towers. These programs start with a focus on system engineering, rather than concentrating on the chiller by itself.

---

[6] Dru Crawley, U.S. Department of Energy, Office of Building Technology, personal communication, 2001. Crawley did simulations for 5 different retrofit possibilities in 19 different cities and for several building types, as part of ENERGY STAR® buildings program development work.

[7] This is a naive calculation in that it assumes that the diversity factor among chillers is 0, i.e., that they all demand power at the same time on the peak day. To compensate, we assumed only 300 kW/chiller saved, rather than 500 kW. This effectively gives a diversity factor in the range of 0.6. Absent large-scale time-of-day rates or load curtailment programs, it is not completely unrealistic. However, it should be taken as illustrative rather than definitive. Even if the net value were only two-thirds as much, it would still be very large.

[8] As a very rough comparison, one could consider an alternative utility peak load investment of a 10–20 MW peaking turbine. With switchgear, it might cost $1,200/kW installed (Neal Elliott, ACEEE, personal communication, 2001). At the peak hour, transmission and distribution losses will be in the range of 10–20%, so the cost of power delivered to the customer is higher.

The value added of the system approach probably increases with the size of the system: Although engineering support may save the same fraction of the energy in a 50-ton installation as in a 1,000-ton installation, the transaction costs may be too high to justify intervention for the smallest installations. Thus, a "one-size-fits-all" approach to systems whose capacity varies by a factor of at least 20 may not be optimal.

Table 3 attempts to characterize the technologies and sizes in terms of program types that might be suitable. In this table, *custom design assistance* refers to efforts to achieve a more efficient HVAC system than is standard practice. It could include engineering assistance and incentives, or measures (perhaps including incentives) directed at *parasitic loads*—the energy requirements of the ventilation fans, and various pumps that circulate chilled water and cooling tower water.

Table 3. An Inventory of Possible Chiller Efficiency and Related Programs, with Preliminary Estimates of Impact

Potential Chiller Programs	Building Activity and Incentive Type					
Chiller Size	New Construction		Replacement		Early Retirement	
	Incentive, Such as $/kW	Custom Design Assistance Also	Incentive, Such as $/kW	Custom Design Assistance Also	Incentive, Such as $/kW	Custom Design Assistance Also
<100 tons (mostly positive displacement)	yes	6	yes	5	yes	6
100–300 tons (positive displacement + some newer centrifugal)	yes	8	yes	7	yes	7
> 300 tons non-CFC	yes	10	yes	9	yes	8
with CFC	yes	no units on market	yes	10	yes	10

For engineering assistance, 10 = most important and 5 = merely important.

There is a strong association among chiller age, efficiency, and likelihood of additional benefits from replacing the chiller: older units are much less efficient and much more likely to use ODPs (R-11, R-12, and R-22) as refrigerants. This correlation is one reason to consider a "screen" in an incentive program—initially focus the technical assistance component on older units and emphasize those with CFCs.

Older units tend to be less well sealed and thus leak much more refrigerant. Together, these factors are important enough that EPA is seriously studying a new collaborative program involving manufacturers and building owners. The program's goal would be to promote early retirement of these chillers and a simultaneous examination of other opportunities to upgrade the buildings and move toward greater overall efficiency.[9] A major conference on the topic will be held in March 2002.[10]

Recommendation to CEE

Based on this overview, ACEEE recommends that CEE and its utility members develop a package of three linked and complementary approaches.

A. *Incentives for new and replacement chillers.* For program efficiency, these can be set at the levels of the Federal Energy Management Program (FEMP) recommendations.[11] We recommend that rather low incentives be set in this kind of program for smaller chillers in order to encourage owners to base decisions on more comprehensive analyses.

B. *Incentives for HVAC system analyses and upgraded HVAC components.* To complement Type A chiller-oriented programs, we recommend incentives to defray the cost of building studies and the incremental cost of upgraded piping, variable speed pump drives, and other equipment that will improve performance and system efficiency, and thus allow downsizing the chiller itself. These incentives should rise with system size. Some utilities will not find them warranted for the smaller chilled water system sizes, perhaps below 100–150 tons.

C. *Incentives* for comprehensive "integrated chiller retrofits." These programs should primarily address larger and older centrifugal chiller-based systems, particularly those with CFC refrigerants. They can be linked to other incentive programs, such as for improved lighting, envelopes, and ventilation systems that also serve to reduce chiller size and energy.

Figure 1 on the next page summarizes the ranges and approaches we suggest.

Technology Overview

In contrast to residences and smaller buildings, larger structures and campuses generally use site-built ("built-up") HVAC systems to meet comfort needs. In the generic case, one or more chillers, generally driven by electric motors,[12] chill water for a circulating loop. Water-to-air coils in large air handlers tap the chilled water loop to cool and dehumidify the air for the building. On the condenser side of the chiller, a second water loop delivers hot water to one or more cooling towers, which cool the water so it can circulate through the condenser again.

---

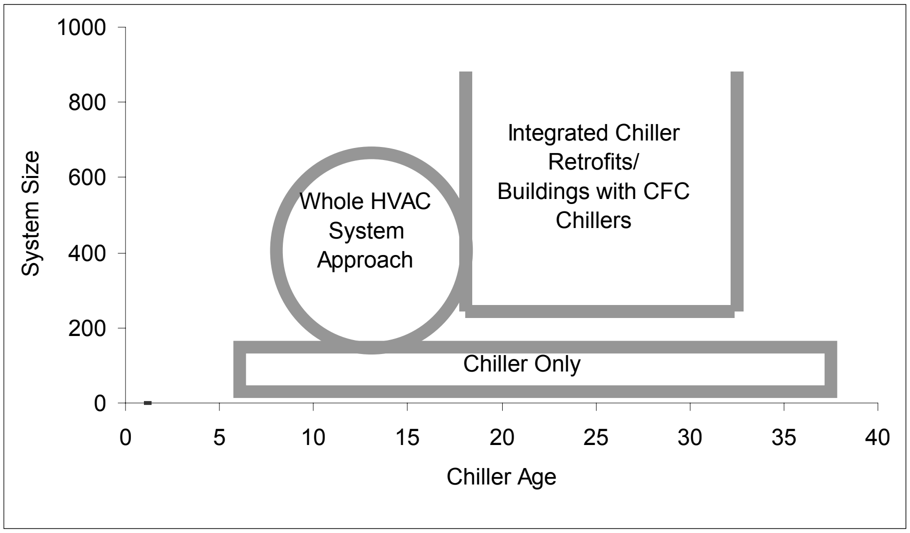
[9] Anderson, Stephen, Environmental Protection Agency, personal communication, 2001.

[10] Ibid.

[11] See http://www.eren.doe.gov/femp/procurement/pdfs/le_chiller.pdf. These should represent the top quartile (25%) of the models available, in terms of efficiency. FEMP differentiates its recommendations by chiller size and technology.

[12] A small but growing number of chillers is powered by natural gas-fired internal combustion engines. Some very large chillers use natural gas for an absorption cycle instead of a vapor compression (mechanical) cycle.

Figure 1. Three Complementary Program Approaches for Improving Chilled Water System Performance. See text for discussion.



Description of the Technology

The chiller is the heart of a classical mechanical vapor compression refrigeration system. It receives low-pressure gaseous refrigerant from the evaporator. Compressing this gas yields a hot, high-pressure gas that surrenders its heat and turns to a liquid in the condenser. This high-pressure liquid passes through a metering device that reduces its pressure and then flows to the evaporator, where it captures heat and evaporates to return to the compressor.

Positive displacement chillers include piston types (similar in configuration to an automobile engine, but used as a compressor) and screw types (which lack good analogues in common experience). Centrifugal compressors work just like the compressor side of an automotive turbocharger, or a furnace fan: refrigerant enters the center of the rapidly rotating blade assembly and is accelerated rapidly. The gas under pressure exits along a tangent to the blade circumference into a pipe leading to the condenser. The kinetic energy is converted to pressure.

The typical chiller assembly includes the rest of the components of the vapor compression cycle in a single factory-designed package. For a built-up chiller-based system, the evaporator and condenser are both water-to-refrigerant heat exchangers, typically of tube-in-shell design. Metering is done by a variable orifice system analogous to a thermal expansion valve on high-quality packaged equipment. In general, systems are much more complex than this description suggests and include very sophisticated proprietary controls (frequently with advanced diagnostic capabilities, as well).

ARI rates chillers by coefficient of performance (COP) at full load (FL) and part load (IPLV). In addition, manufacturers often advertise their products by kW/ton. One kW/ton = 3.517 COP, so 0.5 kW/ton is slightly over 7 COP. ARI does not prescribe minimum performance levels, but an ARI representative suggested that 80% of the models offered meet the criteria of ASHRAE 90.1-

1999, presented in Table 4. Some states have adopted or will adopt 90.1 as a minimum performance level.

Table 4. Minimum Performance Values According to ASHRAE 90.1-1999

Equipment Type	Tonnage Range	ASHRAE 90.1-1999	
		COP	IPLV
AC with condenser	< 150 tons > 150 tons	2.80 2.80	3.05 3.05
WC reciprocating	all capacities	4.20	5.05
WC screw and scroll	< 150 tons 150–300 tons ≥ 300 tons	4.45 4.90 5.50	5.20 5.60 6.15
WC centrifugal	< 150 tons 150–300 tons ≥ 300 tons	5.00 5.55 6.10	5.25 5.90 6.40
AC absorption single effect		0.60	
WC absorption single effect	all capacities	0.70	
absorption indirect-fired	all capacities	1.00	1.05
absorption direct-fired	all capacities	1.00	1.00

Notes: Only the units in the *shaded* areas of the table are considered in this paper. AC = air cooled and WC = water cooled.

This paper is concerned only with water-cooled mechanical chillers (in the shaded area*)*; the other technologies are shown only for illustrative purposes. However, some notes are in order.

1. Air-cooled units are rated with their condensers, the analogues to cooling towers. They do not need cooling tower water pumps, but they do include condenser fans.

2. To some extent the different performance levels for alternative water-cooled chiller technologies reflect accommodations required in the consensus process of standards development and may reflect differences in purchase prices.

3. COP values are based on site energy. Absorption units do not suffer the (roughly) 3:1 energy penalty of conversion from chemical or nuclear energy to electricity measured on site.

The 2001 California *AB 970 Energy Efficiency Standards for Residential and Non-Residential Buildings* also have requirements that vary with equipment type and size.[13]

---

[13] The California AB 970 standards as of 10/29/2001 are identical to those in ASHRAE 90.1-1999 for full-load COP, but somewhat less rigorous for part-load (IPLV).

Description of the Market

In general, the chiller is specified by a consulting engineer with responsibility for the entire HVAC system. The HVAC designer is considered the most important market influencer, and leading manufacturers dedicate substantial resources to software development and other forms of support for these designers.

From an applications perspective, the market is rather differentiated, as suggested by Table 3.

1. *New construction* includes major retrofits and building expansions, which is when building codes generally require that buildings be brought up to the current code levels. These situations give maximum opportunities to lock in energy efficiency by adopting a system approach and choosing both efficient equipment and designs that minimize parasitic losses. The energy required by the fans and pumps in a large variable air volume (VAV) system may be about as much as for the chiller itself.[14] Utilities may have early enough indications of new construction (real estate transactions, etc.) to be able to have some impact.

2. *Early retirements and programmed replacements* are planned by the owner. Typically, these reflect a decision to upgrade a system to save energy or reduce peak demands, to retire a CFC-using system, or to avoid catastrophic failure of a unit nearing the end of its service life. Utilities can play a role if they can reach designers and owners with information on program availability.

3. *Catastrophic replacements* are considered rare (<5% of the market for larger chillers) by industry sources. Still, utilities may not have knowledge of these change-outs.

Estimated Demand and Energy Savings from the Three Program Approaches[15]

Equipment Only, Smaller Units: We assume as baseline an ASHRAE 90.1-1999 compliant, positive displacement, 100-ton unit for a new building or retrofit. Its COP equals 4.2 at full load, or 0.84 kW/ton. Assume the alternative is slightly lower than the FEMP level for a 250-ton screw compressor (0.55 kW/ton vs. 0.49 kW/ton for the screw compressor). Then, at 2,000 equivalent full-load cooling hours, $0.06/kWh energy, and $10/kW demand charge for six months per year, the better chiller shows a 2.3 year payback.

---

[14] For example, see Figure 1.5 in Westphalen, D. and S. Koszalinski, 1999, *Energy Consumption Characteristics of Commercial Building HVAC Systems, Volume II: Thermal Distribution, Auxiliary Equipment, and Ventilation,* Reference No. 33745-00, available at http://www.eren.doe.gov/buildings/documents, Arthur D. Little.

[15] This section is a surrogate for continued work to build a section or paper based on simulation work by Dru Crawley.

HVAC System, Medium-Sized Units: In this case, we build on a FEMP example with a 250-ton screw chiller.[16] We use IPLV (part load efficiency) as our metric and compare a 0.78 kW/ton base case with a 0.49 kW/ton FEMP recommendation. Using the assumptions above (2,000 equivalent full-load cooling hours and the same tariffs), we estimate 37% energy savings, for a 2.6 year payback. If we allow some additional expenditures to improve some system components, say pumps, we can actually improve both savings and payback. Assume that we pay a 50% premium for improved chiller *and* improved system performance equivalent to a 0.1 kW/ton, moving first cost from $250 to $375/ton. However, the energy and demand savings improve from an estimated $13,050 per year to $15,255 per year, and payback is better than 2.1 years. Under these cost assumptions, the payback for a chiller-only program would have been even faster (on lower investment and lower energy/demand savings), but we are likely to have overestimated the system change costs.[17]

Integrated Chiller Retrofit, Older and Larger Units: Table 5 suggests that cooling system energy savings are very dependent on system size (tons), building load,[18] equipment specifications, and system configuration. For example, if a system study suggests that changes in lighting, pumps, air handlers, and other devices could cost-effectively downsize an existing building load, then the cooling tower will be "oversized." That allows it to be dispatched at lower temperatures, improving the "off-rated" efficiency of the chiller and further improving savings. Table 5 suggests the potential *demand* savings from replacing CFC-using centrifugal chillers.

Table 5. Estimated Demand Savings from Replacing Centrifugal Chillers

Older Unit, in Place	
553 tons	assumed capacity, per unit
0.9 kW/ton	assumed efficiency
2,000 hr/yr.	assumed full-load equivalent run time
995,400 kWh/yr.	annual energy use, older unit
553 kW	peak demand, older unit
Newer Unit	
553 tons	assumed capacity, per unit
0.4 kW/ton	efficiency[19]
2,000 hr/yr.	assumed full-load equivalent run time
442,400 kWh/yr.	annual energy use, newer system
221 kW	peak demand, newer system

---

[16] See http://www.eren.doe.gov/femp/procurement/pdfs/le_chiller.pdf.

[17] Engineering analysis is likely to show that the conventional pumps are vastly oversized, for example, so the change to smaller variable-speed drive pumps will have little or no cost impact for the project.

[18] Approximated in Table 5 as equivalent full-load cooling hours. For units whose part-load efficiency varies from the full-load value, hourly simulation of the specific building is the only way to get realistic estimates.

[19] System efficiency, for integrated chiller retrofit. Includes benefits of improvements in demand (lamps, etc) and in the HVAC system (including pumps, piping, and cooling tower controls).

Although a given utility may only have a "handful" of opportunities for major chiller change-outs each year (numbers of 10–30 might be expected for a relatively large utility), the cumulative avoided demand is very large, about 2 GW per year from early retirements alone.

Summary. More detailed studies in preparation suggest that the most aggressive programs—integrated chiller retrofits—typically have the best paybacks, particularly for larger units.[20] The analyses outlined above is summarized in Table 6.

Table 6. Preliminary (and Possibly Optimistic) Estimates of Savings for Alternative Situations

Size, tons	Scenario	Cost Increment over Baseline	Payback, Year
100	chiller only	40%	2.3
250	chiller only	25%	1.2
250	chiller + chilled water system	40%	1.6
553	integrated chiller retrofit (inc. building)	50%	1.4

The lesson is that chiller incentives and integrated chiller retrofits can be extremely cost-effective.

Why Isn't the Market Addressing This Already?

Contributing factors include:

- Strong first cost orientation by customers and strong emphasis on very quick payback by many owners. Building simulations suggest that the return on investments or payback on investments in integrated chiller retrofits is much faster than for simple chiller change-outs[21]—but more capital is required. For utilities, there may be a large opportunity to profit and serve customers by taking on the financing role as energy service companies (ESCOs).

- Information and other barriers that affect design engineers. Cost pressures prevent doing more than "cookie-cutter" solutions, and conservatism leads to risk-aversion about newer technologies. In many cases, designers simply do not understand the opportunity or how to evaluate it. Training programs (such as ASHRAE Short Courses and Professional Development Seminars) are required.

Equipment Availability

Chillers are large pieces of equipment. The total market is about 31,000 units per year, including about 8,000 large centrifugal units per year. Capacities run from under 100 tons to multi-thousand ton. These units are expected to be largely built-to-order. Delivery times can range from weeks to many months, depending on demand. Demand varies with the building cycle. Table 1 gives an overview of the market for chillers.

---

[20] Author's inferences from simulations provided by Dru Crawley.

[21] Extensive simulation work was done by Dru Crawley.

Manufacturers Producing Equipment

Seven manufacturers belong to the Air-Conditioning and Refrigerant Institute (ARI) chillers section. The seven firms participating in the ARI 590 ratings program are Carrier, Dunham-Bush, Edwards Engineering, McQuay, Rae Corporation, Trane, and York. Not all of these produce the large centrifugal chillers that are the most prominent candidates for early change-out, which are particularly those that use R-11 or R-12 CFC refrigerants.

Range of Efficiencies

Chillers are rated under ARI 590, for both full and partial load, referred to as “FL” and “IPLV,” respectively. Table 4 gives minimum values under ASHRAE standard 90.1.[22] As noted above, ARI does not set an efficiency floor, but estimates that 80% of units shipped conform to 90.1. The values in Table 4 are minima adopted in ASHRAE 90.1, which has been prepared in language for adoption by code officials.

Full-Load and Part-Load Efficiencies

California requires compliance with mandated efficiency levels both at full load and part load. CEE should do the same. Ironically, ARI notes that “Because IPLV represents an average single chiller application it may not be representative of a particular job installation. It is best to use a comprehensive analysis that reflects the actual weather data, building load characteristics, number of chillers, operational hours, economizer capabilities and energy drawn by auxiliaries such as pumps and cooling towers, when calculating the overall chiller plant system efficiency.” This is particularly true since the IPLV represents the blended average conditions for 29 cities, rather than a specific site.[23]

Stratification of Efficiency Levels over Range of Equipment Sizes/Categories

From Table 4, we can draw some general conclusions about equipment efficiency for chillers.

1. Part-load efficiencies tend to be higher than full-load values for all technologies and size classes.[24] IPLV is calculated as a weighted average of performance at varying temperatures, and only 1% of the test method hours are at full load.

2. Within a technology, bigger units tend to be more efficient.

3. Water-cooled equipment is more efficient than air-cooled.

4. Across mechanical technologies, efficiency rises, such that in general reciprocating are less efficient than screw-type, which are generally less efficient than centrifugal. We expect many exceptions to this where screw and centrifugal chillers compete, particularly in the range

---

[22] ASHRAE, 2000, Energy Standard for Buildings Except Low-Rise Residential Buildings. Atlanta, Ga., ASHRAE.

[23] Air-Conditioning and Refrigeration Institute, undated, *White Paper: ARI STANDARD 550/590-98 Standard for Water Chilling Packages Using the Vapor Compression Cycle*, Arlington, Va., Air-Conditioning and Refrigeration Institute.

[24] This assumes that “IPLV,” the measure of part-load efficiency, is comparable to full-load efficiency.

from one hundred to several hundred tons full-load capacity. Centrifugal chillers tend to be more expensive than other types.

Cost Data

From U.S. Census data,[25] we infer the following approximate costs for chillers (see Table 7).

Table 7. Chiller Sales Volumes and Costs

	Smaller (<300 tons), Mostly Positive Displacement	Large, Mostly Centrifugal
number sold, 1999	23,919	7528
average price	$19,800	$77,777
estimated average price/ton	$360	$140

Who Else Has Standards Specified and What Are They?

Minimum standards are set by ASHRAE 90.1 (see Table 4), and will be adopted by some states. California AB-970 standards have been adopted for equipment manufactured on or after October 29, 2001.

The Federal Energy Management Program has established recommended efficiency levels for federal procurement[26] (see Table 8). FEMP also provides a convenient web-based calculator for estimating economic benefits of chiller replacements at http://www.eren.doe.gov/femp/procurement/calc_chillers.shtml.

Table 8. Efficiencies Recommended for Federal Purchases by FEMP

Product Type	Recommended		Best Available	
	Full Load (kW/ton)	IPLV (kW/ton)	Full Load (kW/ton)	IPLV (kW/ton)
centrifugal 150–299 tons	0.59 or less	0.52 or less	0.5	0.47
centrifugal 300–2,000 tons	0.56 or less	0.44 or less	0.47	0.38
rotary and screw >150 tons	0.64 or less	0.49 or less	0.58	0.46

Source: http://www.eren.doe.gov/femp/procurement/le_chiller.html. See its footnotes for additional guidance.

---

[25] Current Industrial Reports, 1990, MA333M(99) – 1: Refrigeration, Air Conditioning, and Warm Air Heating Equipment. centrifugal chillers in 333415106x; reciprocating, screw, and scroll compressors in 3334151085, 3334151087, 3334151089, and 3334151091. Estimates are by author and are very sensitive to the assumed average unit size.

[26] The FEMP program description, at http://www.eren.doe.gov/femp/procurement/pdfs/le_chiller.pdf, states, "Executive Order 13123 and FAR section 23.704 direct agencies to purchase products in the upper 25% of energy efficiency, including all models that qualify for the EPA/DOE ENERGY STAR® product labeling program." This implies that the levels stipulated reflect the top quarter of the market.

Are Other Utilities Promoting Certain Levels?

Under New Jersey's SmartStart buildings program,[27] incentives are offered that vary with condenser type (water-cooled or air-cooled) and equipment size (<70 tons, 70 to <150 tons, 150 to <300 tons, and ≤300 tons). The program has some praiseworthy attributes.

- It is technology neutral, not giving different incentives for screw, reciprocating, or centrifugal chillers (there is, however, a separate program for natural gas-powered chillers).

- Within a size class, incentives rise steeply with increasing performance. For example, in the 150–300 ton class, incentives rise from $16/full load ton at 0.65 kW/ton to $141/full load ton at 0.40 kW/ton. (There are also IPLV requirements for larger sizes.)

- The SmartStart program also offers support for design assistance, building simulations, and other activities to assure an integrated, efficient design.

Connecticut Light and Power has an unusual but apparently very effective program. It does not disclose incentive levels but encourages meetings with owners and their engineers to discuss opportunities. CL&P uses these meetings to negotiate a package that encourages full engineering analysis, with particular attention to often neglected areas such as optimum dispatch rules for the cooling tower.

Pacific Gas and Electric has a very comprehensive set of tools in its program, and strongly supports an integrated, system-level approach.[28]

Findings

1. Chillers and associated systems offer large demand and inferred large energy savings. For example, the economics look good in a crude comparison with purchasing peaking turbines, with many advantages to utility members.

2. Existing standards are low and provide ample "headroom" for incentive programs. There are relatively few large-scale chiller programs today.

3. For the complex and sophisticated systems in which chillers are employed, the published full-load and part-load efficiency measures are insufficient for design decisions. In addition, as building and system sizes increase, the importance of considering the entire building's demand profile and its HVAC systems as a whole (including cooling towers, fans, and pumps) increases. These facts argue for "integrated chiller retrofit" programs for existing buildings and a comparable integrated loads examination for new construction.

4. Some current chiller programs recognize varying efficiency levels attainable with different technologies, and their different costs. These include ASHRAE 90.1, FEMP, and California AB 970. Others, such as New Jersey's Smartstart buildings program, are technology neutral.

---

[27] See http://njsmartstartbuildings.com/main/app_forms.html

[28] See http://www.pge.com/003_save_energy/003c_edu_train/pec/toolbox/hvac/003c1b4_HVAC_resource.shtml.

They differentiate between water-cooled and air-cooled units and among four size classes, but they do not offer different incentives for centrifugal vs. positive displacement compressors.

Recommendations

1. CEE should evaluate, design, and implement common programs for built-up HVAC systems used in larger buildings.

    - "Appliance-type" programs with incentives for new chillers may be appropriate up to some small size limit, perhaps 100 tons.
    - For larger loads and older chillers, the opportunities are so great that a "system-type" program should be implemented. Such a program would integrate opportunities across building systems ranging from lighting to pumps, as well as the chillers.
    - For systems that use CFCs as refrigerants, which tend to both large and old, we recommend programs that include very comprehensive analysis of energy saving opportunities at all levels in the building. Both program suggestions for older and larger buildings require significant site-specific engineering input, which has costs but great benefits.

2. The Northeast Utilities' program and New Jersey's SmartStart program appear to be excellent models to consider. Programs like PG&E's that focus on system studies have great potential and their best aspects should be incorporated into a CEE offering.

3. We know of no reason to consider adopting a program with qualification levels lower than the FEMP recommendations in Table 8.

4. Since utility, owner, and public benefits are derived from efficiency, not technology, we do not recommend that CEE adopt different incentive levels for different technologies, such as screw vs. centrifugal chillers.

5. There are substantial public benefits associated with early retirement of the 40,000 large centrifugal chillers that use ozone-depleting CFC refrigerants. These installations warrant coordinated attention and additional incentives.