MARKET POTENTIAL ESTIMATES AND R&D PLANNING FOR ADVANCED ABSORPTION SYSTEMS FOR LARGE COMMERCIAL BUILDINGS

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ABSTRACT

There has been considerable activity in recent years to develop alternative technologies that could reduce or level cooling electrical use in large commercial building space. A market assessment was performed to determine whether the potential benefits of a new, multi-effect absorption technology justified further research and development (R&D) to allow potential commercialization. The approach, results, and conclusions of that market assessment are presented here. The assessment required hourly DOE-2 building loads calculations and a detailed gas/electric rate analysis for 37 cities. The results show (for a three-year payback) that standard, direct-fired, double-effect technology could capture on the order of 30% of the chiller market, and the advanced, multi-effect technology could capture about 60%. The ability to estimate potential national benefits significantly improves the framing of R&D strategies. The advanced technology also yields primary energy savings, while the double-effect technology leads to negative primary energy savings.

INTRODUCTION

There has been considerable activity in recent years to develop alternative technologies that could reduce or level cooling electrical use in large commercial building space. (Reference to commercial buildings in this paper also includes institutional buildings.) Among these are the development of more efficient electric-motor-driven chillers, diurnal cool storage, more efficient absorption chillers, desiccant cooling systems, and gas-fired, engine-driven chillers (DOE 1989; Dolan 1989; GRI 1989).

In recent years, a program of the U.S. Department of Energy (DOE) has been responsible for the invention of several new multi-effect absorption cycles suitable for application in packaged chillers for large commercial buildings (DeVault and Marsala 1990). One of these cycles has been licensed to a major American heating, ventilating, and air-conditioning (HVAC) equipment manufacturer, and a program to develop the required hardware is under way (GRI 1989). Another cycle with similar performance potential required some basic R&D to demonstrate that reduction to practice would result in a competitive product. Multiple paths increase the likelihood of future success and of future competition for the benefit of end users.

A two-phase development program was defined for the new, multi-effect absorption technology. Phase I involved a market assessment to determine whether the potential benefits of the new, multi-effect absorption technology justified proceeding with the program. If this assessment was positive, the phase II program to develop the technology could be initiated. The approach, results, and conclusions of the phase I market assessment are presented here.

A methodology was developed for estimating the benefits of advanced, packaged chiller technologies applied to large buildings in the U.S. commercial sector. The methodology builds on previous work to estimate the economic benefits of gas cooling equipment in large office buildings in one location (McLain et al. 1991; Hamblin et al. 1990) and generalizes this method to provide national-level estimates of market potential for the large-building (commercial) sector.

The investigation was directed specifically at comparing a new, advanced, multi-effect absorption technology to electrically drive centrifugal chillers and to current standard double-effect absorption chillers. The market potential estimates were calculated using practical assumptions for the period 1996-2010, when this advanced technology may be available for commercialization. Diurnal cool storage was not considered in this study because it can be applied in systems with any of the chiller technologies with little impact on the underlying chiller technology comparison.

APPROACH

The purpose of the market assessment was to generate information to support a go/no-go decision on phase I of the technology development project.

A comprehensive survey of recent large-scope assessment work (Brodrick and Patel 1990; Briggs et al.

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1987; McLain et al. 1991; Ritschard and Huang 1989) indicated a trend toward development of increased sophistication in simulating energy loads and systems energy use while national-level assessments of benefits were limited or not addressed. The increased simulation capabilities satisfy needs for estimating benefits at a greater level of detail, such as for individual buildings and for local markets such as cities. However, such detailed estimates of national-level benefits were not possible within the constraints of this study. Other methods better suited for national-level assessments (Hughes et al. 1980, 1981) were employed.

The objective of the assessment was to estimate the potential benefits of a new, multi-effect absorption chiller that could be available to the market in 1996. It was decided to estimate the cumulative potential benefits from 1996 to a horizon year of 2010. The new absorption technology can be applied to packaged chillers for large commercial buildings. Electrically driven centrifugal chillers were selected as the base technology because they currently dominate this market segment in North America. Benefits of the new absorption technology occur in proportion to the cumulative 1996-2010 market share it can be expected to obtain when competing against electric centrifugals. The total available market equals the projected shipments of centrifugals from 1996 to 2010.

National market share is estimated using a market segmentation approach. An end-user economic criterion provides a pass/fail indicator for each market segment. Simple payback was used as the economics criterion because it is easy to understand and communicate results. (For life-cycle cost analyses, where all parameters are fixed except first cost and annual savings, translation between simple payback and life-cycle cost results in a fixed function.)

A ranking analysis of potential segmentation parameters was conducted, and any parameter that influenced the end-user payback calculation was considered as a candidate segmentation parameter. With the pass/fail approach for each market segment covering the *cumulative* market over the 15-year period from 1996 to 2010, the desire was to select segmentation parameters that would retain the highest validity possible for each segment. On the other hand, each parameter included leads to more market segments and greater assessment cost. Thus, we were constrained to include only those parameters that have the greatest influence on payback and that could be considered with the available assessment resources.

Our analysis indicated that candidate segmentation parameters should be ranked as follows for packaged chiller payback calculations in large commercial buildings:

1. *Rates:* Relative gas/electric rates were most important because of the demand charges imbedded in electric rates for this customer class, the variability of demand charges among utilities, and the strong influence of demand charges on end-user cost and payback.
2. *Chiller plant substitution level:* A chiller plant can be all centrifugal, all absorption, or a combination of both. In other words, absorption can substitute for centrifugal at various levels in any particular application. The substitution level has a large influence on end-user cost and payback.
3. *Building type:* Building type influences end-user payback by having an impact on chiller load factor (or operating hours) and the relative importance of peak chiller load vs. cumulative load met over time. Building type is less important than one might think because demand rates have the effect of placing additional importance on monthly peak charges and discounting the importance of monthly consumption charges.
4. *Location:* Large commercial buildings tend to have core loads that overdrive the weather-influenced perimeter and ventilation load components. As a result, weather influences deriving from location are less important than might be expected.
5. *Building characteristics:* After building types are selected, there are many specific characteristics, such as insulation levels, number of glazings, etc., that influence load on the chiller plant and end-user cost and payback.

Based on this ranking, the market segments were developed while treating candidate segmentation parameters in order of importance. We worked to keep the assessment logic reasonable and consistent from start to finish within our given constraints.

The selected assessment design can be described as follows. The population centers of the country have been agglomerated into climatic groups for building energy analysis (Anderson et al. 1985; Brodrick and Patel 1990). We used the five-climate agglomeration, and a city with the most representative weather (compared to the population-weighted average) is designated to represent the weather for the whole region. The low number of climates results from the lower ranking of this segmentation parameter. Population centers in each climate were further divided into three groups based on the favorable, neutral, or unfavorable pricing of gas vs. electricity for this application. The high number of gas/electric rate cells ($3 \times 5 = 15$) stems from the primary importance of this segmentation parameter.

Two building types—large offices and hospitals—were selected to bound the application load factors encountered by chiller plants in the large commercial sector. The office building type was further split to account for the expected variations in loads between new buildings with air-side economizers (new construction) and older (replacement market) buildings without economizers. The hospital type was considered to have high economizer or heat recovery penetration in both new construction and replacement markets because of its high load factor and because hospital owners tend to have relatively more favorable economic criteria for energy-saving projects. Only the two building types were used because the entire market can be represented by upper and lower bounds, and further definition of the market by additional building types is not justified by the moderate importance of this parameter.

Chiller plant substitution was considered at the 25%, 50%, 75%, and 100% levels. The high segmentation is justified by the relative importance of this factor.

The assessment design required that the cumulative total 1996-2010 market be divided into 30 segments (5 climates × 3 rate cells × 2 new/replacement = 30). Building type was used as a boundary scenario instead of a market segment because the analysis was easier when the entire chiller market was assumed to be represented by 100% hospitals or 100% offices as boundary conditions. No special segmentation was performed for building characteristics because of the boundary representation used.

Chiller plant substitution level did not influence segmentation directly because it was assumed that end-users would use the highest substitution level that met their payback criterion. The payback criterion did not directly influence segmentation because it was more informative to use payback as a defining parameter for representing results and sensitivities. Thus, payback hurdles (one, two, three, four, and five years) were used as market scenarios, and total market share was calculated for each hurdle.

The assessment design required hourly DOE-2.1C (LBL 1984) building loads calculations for 15 cases (3 buildings [office with and without economizer, hospital] × 5 climates = 15). Rate cells within a climatic region use the same loads. The office building had characteristics that served to define a reasonable lower bound on the market, and the hospital had characteristics that defined a reasonable upper bound. Chiller plant substitution level impacts were calculated using the specific building loads for a given climate but varying the efficiency and fuel use effects of the different equipment mixes.

The assessment design required a detailed gas/electric rate analysis to determine average incremental electricity and gas prices for the buildings with the different equipment substitution levels and equipment types in 37 cities based on actual utility rate schedules (Rogers et al. 1988) and hourly energy use data (including impacts of hourly average electric demand). Based on the analysis, the rate cell segments for favorable, neutral, or unfavorable gas pricing relative to electric pricing were defined in each of the climatic regions. Additional detail on elements of the assessment analysis are outlined in the following sections.

REFERENCE CITIES AND WEATHER DATA

Building loads were calculated in a given climate using the DOE-2.1C program (LBL 1984). National Oceanic and Atmospheric Administration (NOAA) typical meteorological year (TMY) weather data were used for the five population-weighted climatic regions, with the regions and the representative cities shown below and in Figure 1.

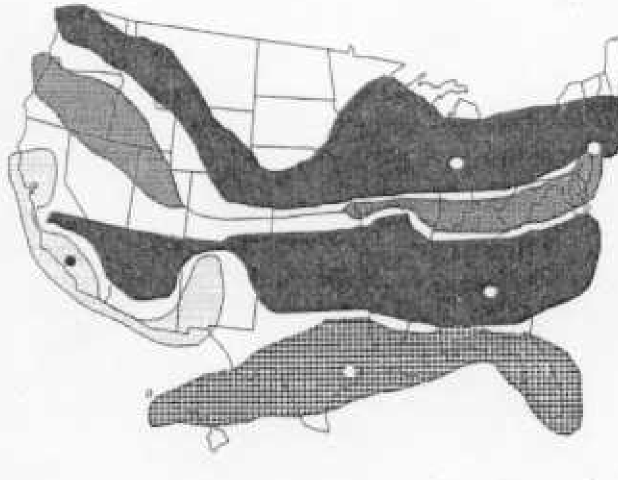

Figure 1 *Climatic zones for market analysis.*

Region	City
North	South Bend, IN*
Middle Latitudes	New York, NY
South	Atlanta, GA
California	Los Angeles, CA
Gulf Coast	Houston, TX

*The representative city for the North region is Detroit, but the TMY data for Detroit have problems. Therefore, South Bend was used since the weather is very similar to that in Detroit.

Significant variations in climate can exist among areas of the country included in the same climatic region. However, in the tradeoffs among segmentation parameters and their expected impact on results, the relative impact of climates was judged to be less than other factors; thus fewer climatic regions were chosen than some might expect to be necessary.

GAS/ELECTRIC RATE CELL ANALYSIS

The available market is segmented by climatic region and rate structure regime. Three rate structure regimes were defined for each of the five climatic regions. The three regimes are favorable (to gas), neutral, and unfavorable.

Routines extracted from the Building Innovations Economic Analysis (BIEA) program (Flanagan et al. 1985) were used to calculate the building energy charges. BIEA is designed to use hourly or monthly energy consumption data together with actual utility rate structures to calculate building energy consumption charges. With data on investment costs for building efficiency measures, BIEA generates a diverse array of economic results. It was previously modified slightly to run on a personal computer (McLain et al. 1991). A new computer program, referred to as BRATES, was developed from BIEA modules to calculate electricity and natural gas costs, including demand and time-of-day charges.

BRATES was used to calculate gas and electricity charges for all building configurations in 37 cities, using available data summaries of the actual utility rate structures for those cities (Rogers et al. 1988). Building energy loads were obtained from the DOE-2 simulations for the representative city for each region (Figure 1). The building utility charges were used to calculate incremental energy costs for gas and electricity for each building in each city for each chiller substitution level. The results for each city were used to develop population-weighted average costs for three clusters of cities defining the three rate segments for each building and each substitution level in all five regions.

The rate regime segments were determined by manual clustering, where the size of each cluster was established by judgment. However, reasonableness of the segment is controlled because, for example, increasing the size of the favorable segment by switching an additional city from the neutral segment cluster makes the favorable segment less favorable to gas. This occurs because the economic payback calculations for each market segment defined by a rate regime in a given climatic region are based on the population-weighted mean electricity cost (per kWh, including demand, seasonal, and time-of-day pricing effects) and the mean gas cost (per therm, including demand and seasonal pricing effects). Increasing segment size and making a segment less favorable will reduce the possibility that the given segment will meet the pass/fail economic criterion, while reducing segment size decreases the potential benefits from the segment when it passes the criterion.

The population-weighted incremental energy prices for each market segment are shown in Table 1. Although the analysis included examination of rate cells for both the hospital and the office building, the difference in incremental energy prices for these two buildings was too small to include. Similarly, the difference in incremental energy prices for the double-effect absorption equipment and the advanced, multi-effect absorption equipment was too small to include. Thus, Table 1 shows only the incremental prices used for two HVAC system types (centrifugal and absorption) at four substitution levels in each of fifteen cells defined by climatic region and utility rate cell.

The rate cells for the North, Middle Latitudes, and South regions were populated by several cities, and the rate cells are reasonably well defined. There were only three cities in the California region, so there is less variety there. However, this region is dominated by Los Angeles and San Francisco, which have 75% of the population of the region, and the region is acceptably characterized by three cities. The Gulf Coast region has only four cities in the analysis, and some bias may be present in the analysis from this limitation. But this region typically represents only 5% to 10% of the total market estimated to be captured by absorption technologies, so any inaccuracies introduced by

TABLE 1
Incremental Energy Prices for Electricity and Natural Gas

Substitution Level	Rate Cell: Favorable	Neutral	Unfavorable
North Region			
Electricity to operate centrifugal chiller, \$/kWh			
25%	\$0.1380	\$0.1100	\$0.0850
50%	\$0.1500	\$0.1200	\$0.0890
75%	\$0.1600	\$0.1250	\$0.0930
100%	\$0.1730	\$0.1300	\$0.0950
Natural gas to operate absorption chiller, \$/10⁶ Btu			
25%	\$4.35	\$4.40	\$5.30
50%	\$4.33	\$4.36	\$5.40
75%	\$4.31	\$4.32	\$5.45
100%	\$4.30	\$4.30	\$5.50
Mid-Latitudes Region			
Electricity to operate centrifugal chiller, \$/kWh			
25%	\$0.1740	\$0.1100	\$0.0900
50%	\$0.2100	\$0.1300	\$0.1150
75%	\$0.2300	\$0.1450	\$0.1270
100%	\$0.2400	\$0.1540	\$0.1350
Natural gas to operate absorption chiller, \$/10⁶ Btu			
25%	\$4.20	\$3.37	\$5.00
50%	\$3.40	\$2.60	\$4.00
75%	\$3.00	\$2.20	\$3.50
100%	\$2.80	\$2.00	\$3.30
South Region			
Electricity to operate centrifugal chiller, \$/kWh			
25%	\$0.1200	\$0.0830	\$0.0750
50%	\$0.1300	\$0.0850	\$0.0650
75%	\$0.1380	\$0.0880	\$0.0645
100%	\$0.1440	\$0.0900	\$0.0640
Natural gas to operate absorption chiller, \$/10⁶ Btu			
25%	\$4.40	\$3.90	\$4.90
50%	\$4.36	\$3.90	\$5.00
75%	\$4.34	\$3.87	\$4.95
100%	\$4.33	\$3.85	\$4.90
California Region			
Electricity to operate centrifugal chiller, \$/kWh			
25%	\$0.1370	\$0.0965	\$0.1036
50%	\$0.1450	\$0.1010	\$0.1070
75%	\$0.1550	\$0.1060	\$0.1130
100%	\$0.1620	\$0.1120	\$0.1163
Natural gas to operate absorption chiller, \$/10⁶ Btu			
25%	\$3.80	\$5.94	\$7.50
50%	\$3.80	\$5.96	\$7.50
75%	\$3.80	\$5.97	\$7.50
100%	\$3.81	\$5.98	\$7.50
Gulf Coast Region			
Electricity to operate centrifugal chiller, \$/kWh			
25%	\$0.0990	\$0.0580	\$0.0510
50%	\$0.0970	\$0.0530	\$0.0510
75%	\$0.1000	\$0.0530	\$0.0520
100%	\$0.1040	\$0.0530	\$0.0520
Natural gas to operate absorption chiller, \$/10⁶ Btu			
25%	\$5.31	\$2.49	\$4.90
50%	\$5.29	\$2.14	\$4.80
75%	\$5.28	\$2.20	\$4.77
100%	\$5.28	\$2.26	\$4.75

Notes: The substitution capacity is the percent of the design cooling capacity that is displaced by gas equipment. The incremental costs of energy are based on actual utility rate schedules and the calculated monthly demand, energy, and time-of-day charges and energy consumption and demand incurred for the two fuels. The incremental cost is the difference in average costs per unit of fuel consumption between the base case and the substitution level shown. For reference, the average cost of total consumption of electricity for all building end uses in the North region is about \$0.10/kWh for the favorable cell, \$0.07 for the neutral cell, and \$0.05 for the unfavorable cell at 100% substitution.

the rate cells have only a small impact on the national totals.

Previous work indicated that chillers fueled by natural gas should be run as base-load machines, with the electric unit as the peaking unit when both electric and gas units were used (less than 100% substitution). For this investigation we again analyzed this assumption with respect to the incremental costs and verified that base loading of the natural gas machine is preferable for maximizing dollar savings to the end user.

REFERENCE BUILDINGS AND LOADS

The office building has been described previously (McLain et al. 1988, 1991) and is considered to be reasonably representative of this class of structure (McLain et al. 1988; Briggs et al. 1987). Two variations of the office building (with and without an air-side economizer) were considered to provide different loads for the new and replacement markets. Both variations represent a building with an energy-efficient envelope that meets the requirements of ASHRAE (1980), which is probably a conservative assumption for estimating a lower bound on the market. The glazing type, 30% of the external wall surface, depends on location and the requirements of ASHRAE (1980).

The heating, ventilating, and air-conditioning (HVAC) system for the office building includes variable-air-volume (VAV) air-handling equipment. Primary HVAC equipment is an electric centrifugal chiller for the base case, with cooling towers to dissipate the extracted heat to the atmosphere and gas-fired boilers to provide space heating and domestic hot water. Whether the office building represents new construction or the replacement market is delineated by the presence or absence of the economizer. An economizer reduces annual loads and benefits for gas cooling systems in most cases.

The HVAC systems were assumed to be operated efficiently—only during working hours and when needed for freeze protection during unoccupied hours in severely cold weather. The systems are scheduled to operate from 6:00 a.m. to 6:00 p.m. Monday through Friday, except for holidays. For further description of this building, the previous work (McLain et al. 1988, 1991) should be consulted.

The hospital building is a four-story, 348-bed facility, described by Bos and Davis (1985). Data for the hospital were obtained in the form of a DOE-2 program input data file. The building's air ventilation rates and envelope construction were modified to satisfy the hospital and medical facility guidelines published by the American Institute of Architects (AIA 1987).

The hospital HVAC system includes three types of air handlers—constant-air-volume systems for the medical treatment areas; variable-air-volume systems for the administrative offices, lobbies, and educational areas; and fan coil units for the patient rooms and doctor offices. The base-case primary HVAC equipment is again gas-fired boilers and electric centrifugal chillers with cooling towers.

The hospital HVAC system was assumed to be operational at all times. Occupancy in the hospital is at its peak from 8:00 a.m. to 5:00 p.m. on weekdays and is variable the rest of the time. No temperature setback was assumed for this analysis.

EQUIPMENT MODELS AND COSTS

To stay within the available assessment resources, the hourly loads from DOE-2 (chilled-water "PLANT" loads) were converted to ambient air temperature bin loads so that the chiller analysis could be performed with bin algorithms. For the centrifugal chiller and direct-gas-fired, double-effect absorption chiller, the calculations performed at each temperature bin were identical to the methods performed each hour in DOE-2. Since the DOE-2 PLANT algorithms are algebraic with no linkage in time (i.e., no time delay effects from one hour to the next), the bin calculations yield approximately the same result that DOE-2 provides. The bin algorithm for the advanced absorption chiller was developed from cycle analysis using judgment and experience to place "reduced-to-practice" performance relative to theoretical (Bierman 1990).

The chilled-water loads were defined as the loads on the base-loaded chiller (dual-chiller plant assumed) for cases where the base-loaded chiller represents 25%, 50%, 75%, and 100% of the installed chiller capacity. The seasonal COP was calculated as the weighted average of the COP values for each bin, where bin weights equal the bin load divided by the seasonal load.

The baseline electric centrifugal chillers have a nominal COP of 5.05 (0.7 kW/ton) for the compressor without pumping and cooling tower power included, when electricity is assumed to have no generation and transmission losses (3,412 Btu/kWh). If generation and transmission loss estimates are included (11,600 Btu/kWh), then the nominal COP based on primary energy becomes about 1.5. All values of COP presented below for electric chillers are on a primary energy basis. The seasonal COP of the electric chillers exceeds the nominal rated value in most cases because the part-load efficiency of the chiller tends to increase at some values of part load (a function of available heat exchanger area relative to the load, compressor efficiency at part load, and outdoor wet-bulb temperature).

Some may view the assumed rated COP for centrifugal chillers as being too low. There is considerable uncertainty about the impact of (CFC) refrigerant replacements on centrifugal chiller cost and efficiency. The assumptions used here were based on the best available information.

All chiller technologies were modeled for each substitution level for each building in each location. Thus, when a comparison is made between centrifugal and absorption chillers at a 25% substitution level (base-loaded absorption machine substituting for 25% of total installed capacity), the comparison is based on a COP determined as if each technology (centrifugal or absorption) were base loaded at 25% of total installed capacity. Stated another way, an all-electric dual-chiller plant (25% and 75% chiller sizes) is compared to a mixed-fuel dual-chiller plant (25% and 75% chiller sizes). This approach tended to favor the baseline electric chillers because the seasonal COP of the electric units was noticeably higher at lower substitution levels.

The seasonal COP of the baseline electric chiller was typically about 1.7 for most building types and chiller substitution levels in most locations. The COP dropped to 1.5 at 100% substitution for the hospital and the office building with an economizer (economizer buildings) in the Gulf Coast region. The seasonal COP of the double-effect absorption chillers was typically about 1.1 for most buildings in most locations, but the COP was 1.3 (or close to 1.3) for the office building without an economizer in the Middle Latitudes and North regions. For the advanced, multi-effect absorption chiller, the seasonal COP was typically about 2, with a decrease to about 1.9 for the Gulf Coast region and an increase to 2.15 for the office building without an economizer in the North and Middle Latitudes regions.

The costs for the different equipment types are shown in Figure 2. (See McLain et al. [1991] for a discussion on costs of the baseline electric technologies.) The advanced, multi-effect absorption (AMA) system evaluated is estimated to be less costly than current standard, direct-fired, double-effect absorption (SDA) systems. (Note that this lower cost is only an estimate based on initial unpublished feasibility studies.) Higher AMA firing temperatures, although requiring more expensive materials than SDA systems, are expected to allow less overall heat exchange area. Less heat exchange area, coupled with greater overall marketability and production volumes, leads to the potential for lower overall cost. If this technology can be produced at a cost lower than SDA technology and still deliver higher efficiency (on a primary basis) than high-efficiency electric centrifugal chillers, an important advance will have been made.

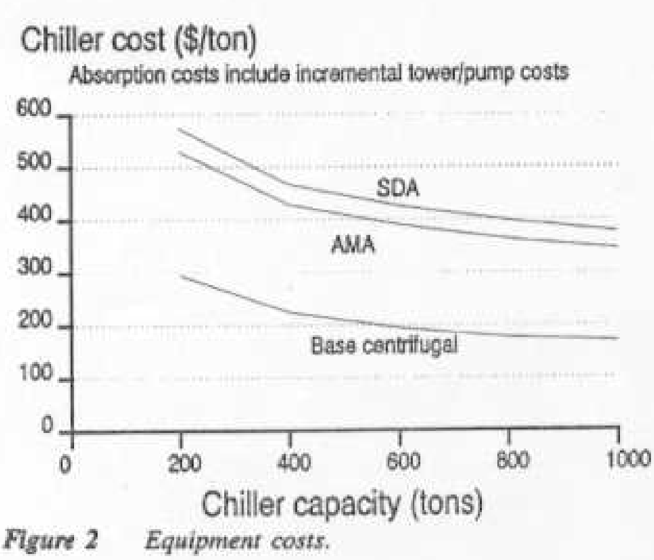

Figure 2 *Equipment costs.*

RESULTS

The market share depends on the differential first costs of the absorption equipment compared to the baseline electric centrifugal chiller and on the energy cost reduction resulting from higher efficiency or the pricing structure of the gas markets relative to electric pricing. The double-effect absorption systems are not more efficient than the baseline electric chillers, so these systems obtain a market share only from favorable relative pricing (rate structures) for gas. The advanced, multi-effect absorption units benefit from both higher efficiency and favorable pricing or rate structure. The differential first cost is divided by the first year's energy cost reduction to obtain a simple payback value.

Market share is either 100% or 0% of the total potential share for each market segment, depending on whether the (simple) payback hurdle is met. The total market for each market segment for the period 1996 to 2010 is allocated from the total of 12 million tons for replacement and 9 million tons for new construction. Market shares for new construction and for the replacement market are calculated separately and then added to arrive at a total for each segment. Shares for each segment can be added to arrive at a national total. The national market shares can then be examined for different payback criteria to determine potential energy savings and displacement of summer peak electrical power.

National market share results are shown in Table 2 and represent the portion of the combined market for electric centrifugal chillers in both new construction and replacement/rehabilitation that could potentially be captured for each payback hurdle by each technology option. The market fractions for the AMA option are depicted for the costs shown in Figure 2 and also for constant cost-per-ton differentials relative to baseline centrifugal chillers.

If all large commercial buildings were like office buildings, we estimate that the AMA technology could capture 20% of the total market (pairwise comparison—when the only competing option is an electric centrifugal chiller) with a two-year simple payback hurdle and 60% of the market with a five-year hurdle. If all large commercial buildings were like hospitals, we estimate that the AMA technology could capture almost 60% of the total market with a two-year simple payback hurdle and 85% of the market with a five-year hurdle. The market estimates indicate interesting potential, as it appears that the AMA technology could capture 20% to 40% of the market.

The market analysis indicated that, at the two-year payback hurdle, the captured market was mostly in the "favorable" rate cell. Thus, the importance of the rates segmentation was confirmed. The largest regional contribution to the market share at the two-year payback hurdle comes from the Middle Latitudes region, which includes New York City, and the North region is close behind. The North and Middle Latitudes regions accounted for more than 90% of the market share at the two-year payback

TABLE 2
Potential Market Share

OFFICE BUILDING

Option	Payback Hurdle 1 yr	2 yr	3 yr	4 yr	5 yr
SDA	0%	8%	20%	29%	38%
AMA	0%	20%	37%	49%	61%
AMA-250	0%	16%	38%	48%	56%
AMA-200	4%	26%	44%	56%	67%
AMA-100	26%	56%	80%	85%	85%

HOSPITAL BUILDING

Option	Payback Hurdle 1 yr	2 yr	3 yr	4 yr	5 yr
SDA	13%	28%	42%	47%	57%
AMA	15%	58%	69%	84%	87%
AMA-250	12%	50%	66%	78%	83%
AMA-200	21%	57%	74%	83%	88%
AMA-100	57%	83%	93%	93%	100%

SDA — standard double-effect absorption

AMA — advanced multi-effect absorption

AMA-250, -200, -100 — fixed price differential between the advanced multi-effect absorption and electric centrifugal chillers of 250, 200, and 100 \$/ton

The cost curves for the technology options SDA and AMA are shown in Fig. C.

hurdle for the office building case and about 60% of the market share at the two-year payback hurdle for the hospital case, where the distribution of market shares across regions is more in line with population. The distribution of market shares for both cases is more in line with population at the five-year payback hurdle.

Assuming that all chillers installed for the new and replacement markets in large commercial buildings in each captured market segment during the 15-year period from 1996 to 2010 are one of the technology options in Table 2, energy savings and electrical power displacement can be calculated for the whole country for each option.

The percentage of primary energy used to operate chillers that is saved in large commercial buildings in the United States in the year 2010, based on the above assumption, is shown for each of the boundary conditions (hospital and office) in Figure 3. The total annual energy use of all installed new and replacement equipment (21 million tons) in the year 2010 is estimated to be 0.2 quadrillion Btu/yr of primary energy (where electricity generation and transmission losses are included in the total) if all the equipment is electric centrifugal chillers. The energy savings are calculated for each market segment and are based on differences in seasonal COP for the AMA, SDA, and baseline electric technologies. The percentage savings are based on the national totals of energy use for the technologies.

The use of standard, direct-fired, double-effect absorption (SDA) technology leads to negative energy savings

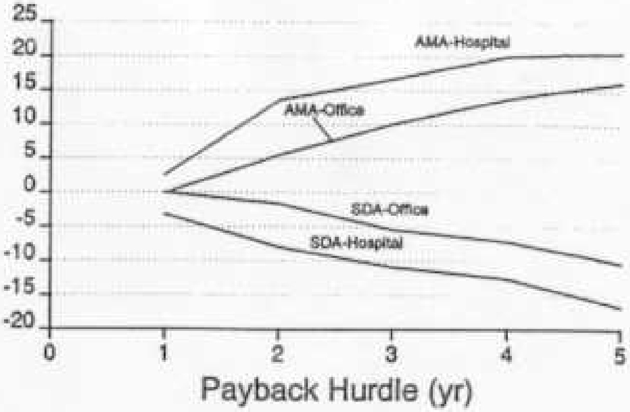

Figure 3 Percentage of energy saved.

because the SDA chillers use more energy than the baseline electric centrifugal chillers (on a primary basis). This negative savings has important implications for a national program looking to improve the overall efficiency of energy use. Since SDA chillers are already in the marketplace, the primary energy savings attributable to AMA chillers are derived from the vertical distance between the SDA and AMA lines in Figure 3.

The total electric power requirements displaced in the year 2010 for the boundary cases using the above assumption are shown in Figure 4. The results in this figure are also based on the simplifying assumptions that the peak cooling loads for all electric cooling capacity displaced by natural gas are coincident with utility peak loads and that 100% of the cooling capacity (which is well matched to simulated loads) is needed at peak times in all cases.

CONCLUSIONS

For the advanced absorption technologies, the results of the market analysis show savings potential that justifies further R&D efforts to develop a better understanding of the likely performance and costs. The ability to estimate

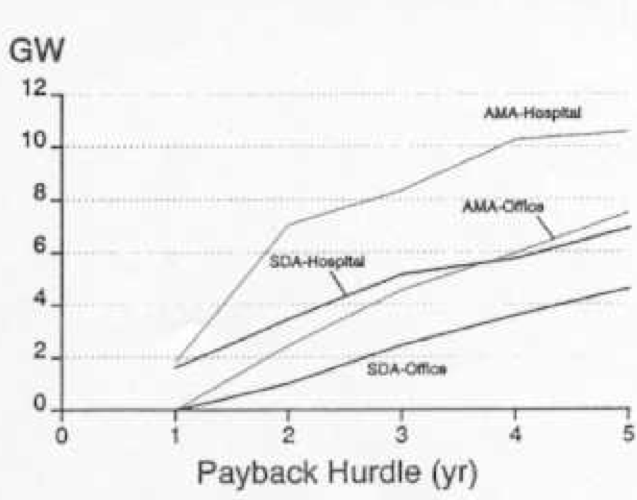

Figure 4 Displaced electric power.

potential benefits significantly improves the framing of R&D strategies.

For a three-year payback, Table 2 indicates that SDA technology could capture on the order of 30% of the chiller market (average of office and hospital) and AMA could capture about 60% of the chiller market (i.e., the SDA market plus an additional 30%). Under this set of assumptions, the cumulative 1996 to 2010 market would be

- 70% centrifugal and 30% SDA or, if AMA is successfully developed and commercialized,
- 40% centrifugal and 60% AMA.

The benefits of the AMA scenario vs. the non-AMA scenario are compelling. Figure 3 indicates annual primary energy savings of approximately 20% (difference between AMA and SDA) or 0.04 quadrillion Btu/yr (0.04 EJ/yr) in the year 2010. Primary energy consumption relates directly to atmospheric emissions resulting from the combustion of fossil fuels, which implies important potential environmental benefits from the energy savings. Figure 4 indicates that approximately 3 GW of new electric generation capacity could be avoided by the year 2010. This 3 GW translates to potentially $3 to $6 billion in power plant capital savings (depending on the generation system), more than enough to fully fund the incremental cost of AMA chillers, estimated to be $1.9 billion ($300/ton premium over centrifugals, no discount below SDA equipment). If the R&D program to reduce AMA technology to practice costs $10 million, a successful program would generate 100 to 400 times that amount in net capital savings that could be used to finance additional programs to reduce energy and power requirements for the commercial sector.

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