The Benefits of Integrated Chiller Retrofits: Excerpts from Case Studies

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ABSTRACT

An integrated chiller retrofit is an effective way to turn the CFC phaseout into an opportunity for energy efficiency and money savings. The 1996 moratorium on CFC production means many chillers will soon have to be replaced or converted to use alternative refrigerants. Integrating building load reductions and system improvements with chiller replacements and/or conversions can solve building comfort and maintenance problems, increase energy efficiency, save money on utility bills, increase a building's asset value, and produce a more financially attractive project.

The Cool $ense program at Lawrence Berkeley National Laboratory has been gathering integrated chiller retrofit case studies from its regional workshops. This paper presents some of the best examples of different aspects of integrated retrofits. Example projects include:

- a chiller conversion,
- a chiller replacement,
- an effective cooling system renovation,
- a model building load reduction scheme,
- an illustration of integrated chiller retrofit economics,
- a chiller sizing cautionary tale,
- an environmentally friendly *and* cost-effective retrofit.

These projects enumerate retrofit measures to consider, and show how much more effective it is to widen your focus from the chiller alone to the entire building when facing the CFC phaseout.

Introduction

The production of chlorofluorocarbon refrigerants (CFCs) was halted in the United States in January of 1996 due to the Montreal Protocol, an international agreement to protect the earth's ozone layer. Equipment using CFCs, including chillers to cool commercial buildings, will need to be replaced or upgraded to use the next generation of refrigerants. This phaseout is moving more slowly than expected. In the United States approximately 80,000 chillers originally used CFC refrigerants. It's estimated that only 48% of these chillers will be replaced or retrofitted to use an alternate refrigerant by the year 2001, a full five years after the CFC production ban.[1] With over 41,000 chillers still using CFCs, demand for CFCs is expected to increase markedly by the year 2001.

Most new refrigerants being used are hydrochlorofluorocarbons (HCFCs) or hydrofluorocarbons (HFCs). When released into the atmosphere each of these refrigerants impact the ozone depletion potential and the global warming potential of the stratosphere (Table 1).

1 Woolsey, 1998.

Table 1. Common Refrigerants

Refrigerant	Ozone Depletion Potential	Global Warming Potential[2]	Phase-Out Schedule
CFC-11	1	3400	January 1996
CFC-12	1.0	7,100	January 1996
HCFC-22	0.05	1,600	2010, 2020[3]
HCFC-123	0.02	90	2020, 2030[4]
HFC-134a	0.0	1,200	no phase-out

Chiller operators are commonly given three options for dealing with the phaseout: "containment", "conversion" or "replacement". These options deal only with the chiller, without looking at the building or any other systems. "Containment" means keep operating your chiller, fixing any leaks and stockpiling enough CFCs to keep your chiller running throughout it's useful life. "Conversion" of a chiller involves replacing its CFC refrigerant with either an HCFC or HFC refrigerant, usually at some sacrifice to its capacity or efficiency. "Replacement" of chillers with a CFC-free model takes a larger capital investment than the most complicated chiller conversion, but is a smart choice when dealing with older, unreliable and inefficient chillers.

An even better option is to look beyond the chiller to perform an "integrated chiller retrofit". The integrated retrofit combines building load reductions and system improvements with chiller work to increase energy savings, improve overall operation and comfort, and increase the building's asset value. Improvements to the rest of the building also frequently lower the cooling loads, so new chillers can often be smaller and less expensive.

Integrated retrofits take advantage of proven advanced technologies in cooling and air distribution equipment, "free" cooling and thermal storage, control systems, energy efficient lighting, improved appliance efficiencies, and building. Adding these new technologies in conjunction with a chiller upgrade makes sense not just for the opportunity to down size the chillers, but also to produce an economically attractive package. Adding lower cost, high energy saving measures into a chiller project usually reduces the payback period, and if properly financed can provide positive cash flow. Examples of these economics will be shown later in this report.

The Cool $ense program was initiated at Lawrence Berkeley National Laboratory to promote integrated chiller retrofits as an important opportunity when facing the CFC phaseout. Funding for this project comes from the U.S. EPA, U.S. DOE and U.S. GSA. The program concentrates primarily in three areas: a web site, a national forum, and regional workshops.

The Cool $ense web site (http://eande.lbl.gov/CBS/Ateam/COOLSENSE/coolsense.html) serves as a clearinghouse for information about CFCs, chillers, system and load improvements, economics, case studies, rebate programs, and seminars and conferences related to integrated retrofits. More information on each of the case studies presented in this paper are also on the site.

The Cool $ense National Forum brought experts in integrated chiller retrofits together with those wishing to learn more. This forum was held in San Francisco on September 23 & 24, 1997 and covered both a "technical" track (covering cooling systems, load and system improvements, monitoring and operations) and a "market transformation" track (economics, project planning,

2 CO2 has a global warming potential of 1.0.

3 The first year listed is for phaseout of new equipment, the second is for existing equipment.

4 Ibid.

government and utility programs, energy service performance contracts). A second national forum is tentatively being planned for the fall of 1999.

Cool $ense regional workshops target facility managers and building owners and explain the concepts and benefits of integrated chiller retrofits. Each workshop covers information about CFC phase-outs, the basics of integrated retrofits, regional case studies, a panel of local utility representatives and perhaps a tour of a local facility. Each participant is equipped with a workbook containing what was covered in the workshop as well as lists of local and national resources. Workshops have been held by Lawrence Berkeley National Laboratory in Boston, Denver, San Diego, Kansas City, Washington D.C. and Atlanta. Future workshops will be held by local organizations throughout the country with technical support from the Cool $ense staff.

The case study examples presented in this paper were originally gathered for use at each of the regional workshops. These projects were found through intensive telephone contacts with utilities, engineering consultants, equipment manufacturers and others in each workshop region. The case studies, with their local buildings and knowledgeable regional turned out to be the highlight of the workshops. These collected case studies have also become a good information source about what is being done effectively in current retrofit projects. At this writing , more than fifteen case studies have been gathered for use in the regional workshops.

Workshop case studies were chosen primarily by how well they illustrated the ideal integrated retrofit. Ideal retrofit projects replaced or retrofitted the chillers and both improved cooling systems and reduced building loads. Even better, the chiller's capacity would be reduced, building comfort or maintenance problems would be solved, and the entire package would be more financially attractive than a simple chiller replacement on its own. In actuality, it was tough to find any single case study that illustrated all these characteristics. But all of these case studies show one or more positive aspects of an integrated chiller retrofit

The examples shown in this paper highlight exemplary features of various projects, including chiller retrofit and replacement work, cooling system improvements, building load reductions, and integrated economics. A couple of examples are also given to show how typical integrated retrofit projects can be improved even further. Details for the case studies mentioned in this paper, and for others not mentioned, can be found at the web site http://eetd.lbl.gov/CoolSense/casestudy.html.

Chiller Retrofits and Replacements

Of the case studies gathered for presentation at the Cool $ense regional workshops, almost all the buildings used chillers to provide cooling prior to the retrofit, although one building used water-source heat pumps, and two used additional rooftop package units for computer room. Chillers were between 14 and 30 years old at the time of the retrofit with full-load efficiencies rated between 0.72 and 0.90 kW/ton. Most of the original chillers were electrically powered and used CFC refrigerants (CFC-11, CFC-12 and R-500, which is a mixture of CFC-12 and HFC-152a). The average chiller capacity before the retrofits was 260 tons per 100,000 square feet.

In most of the case studies, the electrically powered chillers were replaced with new electric chillers, with a couple of projects adding gas-fired or absorption chillers to add multi-fuel capability in an effort to avoid high electricity demand charges. Full-load efficiencies of the replacement chillers ranged from 0.48 to 0.65 kW/ton, and the average capacity was reduced slightly to 245 tons per 100,000 square feet. Examples are given below for two chiller conversion and replacement projects.

between 0.85 and 0.90 kW/ton, but there was never more than a single chiller running and this one chiller was often operating at inefficient part-load conditions. Even though the system had plenty of capacity, discharge water temperatures were often at 48-49°F, failing to reach the design 42°F. This resulted in an inability to comfortably cool the terminal buildings.

Kansas City International Airport, Kansas City, MO

Money became available to improve the system, but as is often the case in municipal and government projects this money was to be used strictly for the purpose of revamping the cooling plant. A future project for an extensive terminal remodel was also being planned, but this second chunk of money had not yet been fully approved. The potential remodel would reduce cooling loads by including new energy-efficient lighting and air handler units. The challenge for the cooling plant remodel was produce a system to meet both present and future loads efficiently.

The key to the new, more flexible system was to replace the two 2,750 ton chillers with three 1,500 tons chillers. The new chillers used R-134a refrigerant and had full-load efficiencies of 0.65 kW/ton, saving 0.25 kW/ton. The new system met the 42°F water discharge temperature on even the hottest days. Not only was total capacity reduced from 5,500 tons to a more appropriate 4,500 tons, the smaller chillers could run closer to full-load capacities for higher overall efficiencies. The third chiller will serve as a backup chiller when the cooling loads are reduced in the terminal remodel.

The cost of the new chillers is given in Table 3. Chiller replacement generally gives greater efficiency gains, and thus greater energy savings than chiller conversions. But payback periods are still higher in most cases for replacement than for conversion since chillers are very expensive items.

Table 3. Kansas City International Airport Chiller Replacement Cost

	Purchase & Installation Cost	**Annual Energy Savings**	**Payback Period (years)**
New Chillers	$800,000	$63,500	12.6

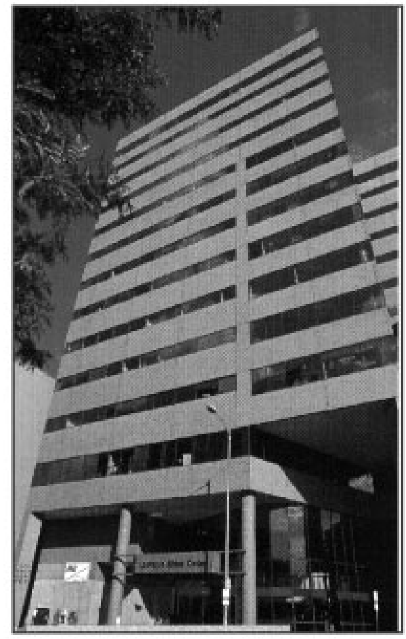
Cooling System Improvements

Besides chiller work, the bulk of the retrofit work in the collected regional case studies involved improvements to cooling systems. The most common retrofit system improvements were the addition of cooling system controls, usually in the form of direct digital controls and energy management and control systems. New fans, pumps and motors were introduced in most of the retrofits, taking advantage of improved efficiencies and variable speed technologies. Piping changes were also frequently made to consolidate systems, or primary/secondary and even tertiary systems were built for more operating flexibility.

Free or low-cost cooling technologies were implemented more rarely. Cooling towers were replaced with 2 or 3 cell, two-speed towers, and these new towers were often used for evaporative cooling. New plate-and-frame heat exchangers were also added to provide year-round economizer

Lawrence Street Center Chiller Conversion[5]

Lawrence Street Center is a Class A, fourteen-story office building with 140,000 square feet of rentable space built in 1982 in Denver, Colorado. Some of its tenants are radio stations, so they have a need for reliable 24-hour a day HVAC services. The original chiller was a 400-ton electric centrifugal chiller using R-11 refrigerant and attaining a full-load efficiency of 0.72 kW/ton. The chiller was less than 15 years old and still running reliably, but it was only operating at a maximum of 60% of its capacity. The facility manager at Lawrence Street Center heard about a local retrofit rebate program from the local utility and decided to convert the chiller to a non-CFC refrigerant.



Lawrence Street Center, Denver, CO

Table 2. Lawrence Street Center Chiller Conversion Cost

Retrofit Cost	Rebate	Annual Energy Savings	Payback Period (years)
$ 94,000	$ 32,000	$ 12,500	5.0

There are many different types of chiller conversions. The simplest replaces the refrigerant, adjusting oils and seals so they are compatible with the new refrigerant, but makes no other changes to the chiller. This type of conversion usually results in a loss of both capacity and efficiency, as the thermodynamic properties of the replacement refrigerant won't match the design properties of the original refrigerant. The most complicated and expensive retrofit involves retrofitting the chiller driveline plus adding a new, larger heat exchanger to compensate for the refrigerant property changes. This retrofit can allow your chiller to maintain capacity and actually improve efficiency.

The manager of Lawrence Street Center decided to take the middle road, and retrofit only the driveline. The driveline retrofit involves replacing the chiller's starter, motor, compressor, purge unit and controls. The condition of the heat exchanger's shell and tubes was checked with eddy-current testing and deemed to be in acceptable shape, so the heat exchanger was left alone. The full-load efficiency of the chiller after the conversion improved to 0.59 kW/ton, but the capacity was reduced from the original 400 tons down to 290 tons. Since the chiller was originally running at inefficient part-loads of no more than 60%, the capacity reduction actually enabled the chiller to run much more efficiently overall while still meeting the building's cooling loads. Table 2 gives the cost, rebate, energy savings, and simple payback period statistics for this work.

Kansas City International Airport Chiller Replacement[6]

Kansas City International Airport in Kansas City, Missouri, has one million square feet in 3 airport terminal buildings and one administration building. The terminals are two stories and were built in 1970. The two original 2,750 ton electric centrifugal chillers were still operating using R-12 refrigerant, but had no refrigerant containment system. The chillers were rated at full-load efficiencies

5 Griffiths 1997; York International Corporation 1995.
6 Glasker 1997.

cooling. Heat recovery technology was implemented only once, where an old system was restored to working order. Thermal storage was implemented in three projects - new systems were added in two projects and an old system was brought back to life in a third project. The Rhode Island Hospital Trust Building is an example of the addition of thermal storage and free cooling systems.

Rhode Island Hospital Trust Building Cooling System Improvements[7]

The Rhode Island Hospital Trust building is a one story, 140,000 square foot building built in 1983, and used mainly for computer operations and administrative office work. The building was planning to expand by 50%, or 70,000 square feet, with plenty of space to add new equipment. The original 275-ton electric centrifugal chiller used R-11 refrigerant and had a full-load efficiency of 0.75 kW/ton. The chiller was supplemented by 208 tons of rooftop cooling units running all year long to cool the computer rooms. Along with the expansion plans, there was a need to reduce electrical on-peak demand charges.

Rhode Island Hospital Trust Building

The resulting cooling system design reduced peak electricity demand by using an ice storage system. A 390-ton brine chiller was used to create ice at night, storing it in three 760 ton-hour ice banks. Cooling loads were diverted to the ice banks during the day. The computer room rooftop units were retrofitted with chilled water coils and hooked up to a heat exchanger for year-round use of outdoor air as a heat sink. The rooftop units were in good working order, so they were kept functional for backup capacity. In addition, variable speed drives, high efficiency motors and a new energy management and control system were added. The project cost, including the addition of T-8 fluorescent lights and occupancy sensors, is listed in Table 4. The overall payback period of the project is quite low despite the expensive chiller replacements, since measures were included which produced high energy savings at low cost.

Table 4. Rhode Island Hospital Trust Cooling System Improvement Cost

Project Cost	Rebate	Annual Energy Savings	Payback Period
$1,200,000	$ 575,000	$ 196,000	3.2 years

Building Load Reductions

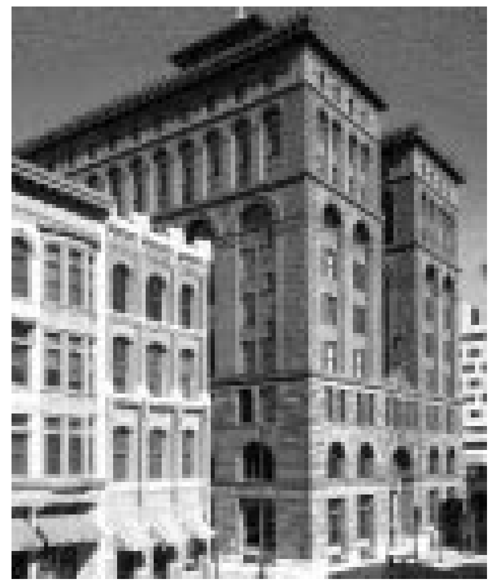
Lighting improvements are the most common and cost effective load reduction measure undertaken in this collection of case studies. Most projects replace old fluorescent fixtures and magnetic ballasts with T-8 lamps and electronic ballasts. A few also replace incandescent fixtures and exit signs with their low-energy incandescent, halogen, fluorescent or LED counterparts. Occupancy sensors, at typical costs of $0.25 to $0.50 per square foot, are used somewhat less often to turn off lights when no one is present. Additional daylighting is rarely introduced and/or compensated for by

7 Leach 1997; Sanders 1997.

lighting sensors and dimmable control systems, at typical costs of $1 to $2 per square foot.

Building envelope improvements are undertaken less often than lighting measures. The addition of low-emissivity window films is the most common envelope improvement made. These films block infrared heat from the sun but let through visible light. Insulation is generally not added to walls, floors or ceilings since this is not only very disruptive in an occupied building but not terribly cost effective by itself. The outside wall and roof reflectivities were not increased with paint or coatings on any of these case study buildings. The New York Life Building is the only retrofit project found which reduced cooling loads through both lighting and envelope improvements.

New York Life Building Load Reductions[8]



New York Life Building
Kansas City, MO

The New York Life Building is a registered historic building and is the first high-rise built in Kansas City, Missouri in 1888. After sitting vacant and seriously neglected for five years, it was bought by Utilicorp United extensively renovated to serve as their corporate headquarters. This building is twelve stories high with 220,000 square feet of office space. Its features include original woodwork and tile floors and a central atrium.

Since the building was initially vacant, the designers had the luxury of adding R-11 fiberglass insulation to the exterior masonry walls, adding a new roof with R-20 insulation, and installing double-pane, low-emissivity windows with insulated frames. These windows were made especially for this building, and are not only operable but also meet historical building codes. Due to Kansas City's heating and cooling climate, these measures save enough energy to rate 5 to 7 year simple payback periods.

The designers were also able to install an exemplary lighting system. All overhead lighting consists of T-8 fluorescent lamps and low-energy, dimmable electronic ballasts. The interior design incorporates light shelves to bring light into the interior spaces, uses light reflective colors on walls and ceilings, and slopes the ceiling down from the windows to reflect even more light into the interior. A computer controlled system adjusts overhead light levels according the amount of daylight in the spaces, and occupancy sensors are also used to turn off the lights when no one is present. This lighting/daylighting system has a 3-4 year payback period.

This building also extensively revamped the cooling system, introducing an ice storage system. Overall, the New York Life Building is saving Utilicorp United $0.50 to $0.80 per square foot over the operating expenses incurred in its previous headquarters. The renovated building is comfortable and modern while retaining its historic charm.

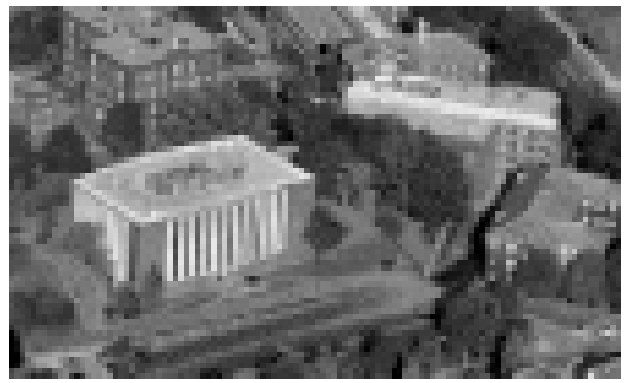
8 Patterson 1997; Young 1997.

Integrated Chiller Retrofit Economics

About half of the projects were paid for up front and half were financed through various schemes, including municipal bonds, energy service companies, and state tax incentive programs. The majority of the projects took advantage of utility rebate programs. The effect of rebate programs was to reduce the project payback periods by an average of 2 years. Inclusion of all other retrofit measures with chiller work reduced the project payback period by an average of 5 years.

Worcester Polytechnic Institute Integrated Economics[9]

A project at Worcester Polytechnic Institute (WPI) in Worcester, Massachusetts retrofitted two buildings, the Gordon Library and the Fuller Laboratory. Together the buildings comprised 128,700 square feet of floor space for a library and computer lab. The buildings are four and six stories high, and were built in 1958 and 1985, respectively. Retrofit measures made were:



Worcester Polytechnic Institute, Worcester, MA

- a 290-ton, 0.85 kW/ton, R-12 centrifugal chiller was replaced with a 170-ton, 0.62 kW/ton, R-22 screw chiller;
- air handler unit controls were updated to respond to CO_2 sensors;
- variable speed drives were added to pumps with control by an energy management system;
- T-12 fluorescents and incandescent lighting were replaced by T-8 lamps and compact fluorescents;
- a new 200-ton cooling tower was hooked up to an outdoor air heat exchanger for wintertime computer room cooling.

Table 5 lists these measures, what they cost, their energy savings, and their payback periods. Since the chiller must be replaced and it tends to have a high payback period, it is attractive to add lower payback measures to the project. With deft use of utility rebate programs, the 16.5 year payback of a chiller replacement project is reduced to 5.2 years for an expanded project. Even without using rebates, a 17.1 year chiller payback is reduced to 8 years.

Table 5. Worcester Polytechnic Institute Retrofit Measures Costs

Integrated Retrofit Measures	Cost ($)	Utility Rebate ($)	Annual Energy Savings ($)	Payback (years)	Payback w/o Rebate
New Chiller	110,240	4,250	6,430	16.5	17.1
AHU Controls	6,900	4,430	560	4.4	12.3
EMS plus VSD pumps	75,000	6,670	4,650	14.7	16.1
Lighting Retrofits	159,600	43,940	38,710	3.0	4.1
CoolingTower/HeatEx	221,400	141,280	21,070	3.8	10.5
Total	**$573,140**	**$200,570**	**$71,420**	**5.2**	**8.0**

9 Kennedy 1997.

Payback period is by no means the only important value to consider when putting together an integrated retrofit project. Since a tax-exempt bond at 4.5% interest financed this project, the energy savings from the project ended up being greater than the bond payments, resulting in a net positive cash flow from the facilities budget. With correct financing, any project can add in not just the "low hanging fruit" – measures like lighting retrofits with low paybacks and virtually guaranteed energy savings – but higher payback measures to improve cooling system operation. The WPI project was also able to add the longer payback AHU controls and EMS/VSD pumping system measures.

Improving Integrated Chiller Retrofits

There are two things that separate good integrated chiller retrofits from great retrofits: accurate guaging of cooling loads and proper sizing of the chiller capacities, and seeing the retrofit project as an opportunity to improve both the indoor and outdoor environment. The Hurley Building and the Green Building illustrate these points.

Hurley Building Chiller Replacement[10]

New 600 ton chiller for the Hurley Building, Boston, MA

The Hurley Building in Boston, Massachusetts is a six-story 355,000 square foot building used for office and some computer operations. This 1971 building had a catastrophic failure of its absorption cooling plant in 1992. In record time the facility managers put together a solid integrated retrofit, including included lighting improvements, changes to the computer room cooling and water heating systems and installation of an energy management system. The absorption chiller was replaced with a gas-fired chiller/heater, eliminating use of increasingly expensive steam to heat and cool the building.

As impressive as this project was, especially in light of its 11 month time span (or 16 months total including bringing the heating system on line), it had one flaw. The 600-ton replacement chiller had exactly the same capacity as the previous chiller, despite lighting load reductions and improved chiller and system efficiencies. Downsizing the new chiller to compensate for the lower cooling loads would have resulted in additional energy savings and reduced capital costs. Or perhaps replacing a single chiller with two smaller chillers of equal or different size could have met building loads with higher overall efficiency and lower energy use.

It is important to understand your building cooling loads and how they vary over a day, a season, and throughout the year. Most buildings have more cooling capacity than they need, and the cooling is delivered in inconveniently sized batches. This oversupply seemed prudent when many of these buildings were built, but is no longer so smart today with higher utility prices and increasingly efficient building systems. The effects of new equipment on cooling loads must be estimated accurately and accounted for in the sizing of replaced or retrofitted chillers.

10 American Gas Cooling Center, Inc. 1996; Mohammadipour 1997.

Green Building Environmental Motivation[11]

The most common motivations behind an integrated retrofit are:

- the need to deal with the CFC phase-out;
- the use of old equipment that might soon fail, or has already failed;
- high utility bills, high on-peak demand charges or increasing fuel costs;
- the desire to take advantage of a rebate or service program.

The most successful projects, including the Green Building of San Diego, stem from a broader outlook motivated by:

- a desire to improve the building's comfort or indoor air quality;
- a desire to meet stringent a efficiency or environmental goal;
- an opportunity for extensive building renovations.

The Green Building is a three-story 73,000 square foot office building built in 1981 and bought by the City of San Diego in 1994. The City wanted to use this building as office space for its Environmental Services Department, but they also wanted it to be a model of sustainable design practices. They set some ambitious goals for energy, environmental and financial performance:

Green Building, San Diego, CA

- to use less than 9kWh per square foot per year;
- to use environmentally friendlier materials;
- to meet a four year payback period in terms of energy savings.

Table 6. Green Building Retrofit Measure Costs

Measures Taken	Purchase & Installation ($)	Annual Energy Savings ($)	Payback Period (years)
High Efficiency Heat Pumps	15,000	13,700	1.1
New Lobby Heat Pumps	10,250	1,400	7.3
New Cooling Towers	57,000	1,650	34.5
VSDs on Pumps	18,100	14,900	1.2
Reduced Supply & Outside Air	0	7,100	0.0
Light Fixture Revisions	40,100	13,100	3.1
Lighting Controls	45,500	6,700	6.8
Occupancy Sensor Interlock	5,100	2,100	2.4
CRT Occupancy Sensors	21,000	5,900	3.6
Window Films	46,000	3,850	11.9
Panels in Sloped Glass Offices	9,700	750	12.9
Total	**$267,750**	**$71,150**	**3.8**

11 City of San Diego 1996; Saling 1997.

The Green Building met all their goals! Table 6 lists the measures taken, their cost, energy savings and payback periods. The building uses 8.0 kWh per square foot annually, below the 9 kWh limit. Recycled and environmentally friendly "green" materials were used wherever possible. And to quiet those who believe a sustainable retrofit cannot also be cost effective, the payback period goal was also met with an overall project payback of 3.8 years.

Summary

The case study examples given illustrate how effective it is to include other building improvements when facing the CFC phaseout. Converting or replacing the chiller is just one piece of an integrated chiller retrofit. It's also important to upgrade the cooling and air delivery systems, take advantage of applicable free cooling techniques, evaluate the effectiveness of thermal storage, and reduce building cooling loads by improving the building envelope and increasing the energy efficiency of lighting and other appliances. The most effective retrofit projects also take advantage of these improvements by downsizing and/or staging your new chillers to meet your building loads.

The examples also reveal that integrated chiller retrofit projects have lower simple payback periods and can produce positive cash flow with the right financing. An integrated retrofit can cost effectively solve building comfort and air quality problems and mitigate the effects of your building on the environment. Before replacing or converting your chiller, examine your entire building, set high goals for energy efficiency, environmental friendliness and cost effectiveness, then use an integrated chiller retrofit to meet these goals.

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