CASE STUDY IN ENERGY EFFICIENT OFFICE RENOVATION; NRDC'S HEADQUARTERS IN NEW YORK CITY

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In April of 1989, The Natural Resources Defense Council (NRDC) moved into a new office space in a gut-rehabilitated industrial loft building in New York City.

Installed lighting power density was reduced 80% compared with a base case system. State of the art lighting and advanced window and wall treatments substantially reduced internal and external gains. Cooling and heating loads are estimated to be reduced by 50% and 70%, respectively, which allowed mechanical equipment to be downsized. One year of aggregated billing data shows that preliminary calculations are nearly identical to actual energy consumption, but peak power estimates are over-estimated by 20%.

Engineering calculations performed by NRDC using a simple design load calculation program and a personal computer spreadsheet are compared with DOE-2 runs of the building performed by Southern California Edison and billing data received by NRDC.

Cost-effectiveness calculations based on the above energy savings estimates and costs incurred are included. Preliminary indications are that the energy improvements will pay back in about five years.

INTRODUCTION

The Natural Resources Defense Council, Inc. (NRDC), is a national environmental organization dedicated to protecting public health and conserving natural resources. Two years ago, NRDC decided not to renew the lease of its New York headquarters office, instead choosing to purchase the top four floors of a 1920's industrial loft building. For demonstration purposes and economic self-interest, NRDC decided to make the 25,000 sq. ft. space a model of energy efficiency.

NRDC gut-rehabilitated the open-bay space into enclosed offices for its staff. Special emphasis was place on the energy-efficiency of the lighting system, while the HVAC system and building shell were made as energy-efficient as possible, given architectural and situational constraints.

In this paper, we compare two engineering estimates of energy consumption for the building with the results of a DOE-2 simulation and one year of electricity billing data. Overall building electricity use was reduced by 38% compared with a typical energy saving retrofit, and by 50% compared with a typical existing space. The calculated cost of conserved energy for the entire retrofit is approximately -$0.02 per kWh.

BACKGROUND

NRDC undertook this project to demonstrate that large energy savings in commercial office buildings could be cost-effectively captured under real-world conditions. The commercial sector is the fastest-growing electricity-using sector of the U.S.

economy.[1] Commercial buildings currently consume about 100,000 megawatts of electrical peak power and office space represents over 27% of this.[2]

Advocates of energy efficiency have shown on paper that most commercial occupancies can be lit to Illuminating Engineering Society (IES) specifications with up to 75% less energy than is commonly used today.[3] These calculations show that if all new commercial space built by the year 2020 were lit to the densities suggested below, the lighting efficiency resource could reach 100,000 Megawatts.[4]

LIGHTING DESIGN STRATEGIES

As Table 1 shows, predicted energy consumption is far below the "typical case" estimates, with savings ranging between 50% and 70%. Current lighting practice consumes 3 to 4 times as much energy as needed. We estimate average new commercial lighting power densities are about 2.2 W/sq.ft., while the commercial sector could be lit for an average of 0.5 W/sq.ft.[5]

The lighting strategies used in most commercial buildings provide significantly more light than necessary because they light the most remote corners of rooms as brightly as areas where people are working. NRDC's task-ambient strategy provides light where it is needed, reducing waste by eliminating excess illumination.

Background lighting levels are consistent with IES recommended illuminance for D-level tasks--20-50 footcandles (fc)[6]--and are generally between 20-25 fc. This minimum background illuminance level was chosen to agree with LEM-1 recommendations that a no greater than 3-1 ratio between task and ambient light levels be maintained for good lighting quality. The task lighting system is designed to provide between 50 and 70 fc to the work surface, depending upon whether one or two of the task lights is on. This lighting level corresponds with IES illumination categories D and E for "visual tasks of medium contrast or small size: *e.g.* reading medium pencil handwriting, poorly printed or reproduced material..."[7] It should be obvious that this type of task is performed very seldom in the modern office space.

Natural Light

The Crystal Building has a large amount of glazing, which allows much direct and indirect solar gain to enter the space. Direct beam radiation is controlled using louvered blinds and low-emissivity film in the windows, as discussed below.

Clerestories on the interior walls of the outer offices and the placement of open-plan offices at the ends of the north-south axis corridors brings natural light to the corridors and interior offices, something the architects considered an important component to a satisfactory working environment. This layout contributes to an open feeling, despite the fact that the floor plan is predominantly composed of enclosed offices. Light finishes on walls and work surfaces maximize reflected luminance and provide a bright and airy work environment.

A three-story internal stairwell located beneath skylights brings natural light to circulation areas on each floor. A continuous dimming system in the stairwell monitors the amount of daylight present,

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[1] *Energy Information Administration,* Annual Energy Review, 1988, *p. 207. Between 1980 and 1988, commercial electricity consumption grew an average of 4.8% per year, as compared with an annual rate of 2.7% and 1% for the residential and industrial sectors, respectively. By the year 2000, the commercial sector is expected to use over 1 trillion kWh per year, compared with about 710 billion kWh today. Energy Information Administration,* Annual Outlook for U.S. Electric Power, *1987, p.9.*

[2] Id. *at 61; David B. Goldstein and Robert K. Watson, "Deriving and Testing Power Budgets for Energy Efficient Lighting in Non-Residential Buildings"* Proceedings from the 1988 American Council for an Energy Efficient Economy (ACEEE) Summer Study on Energy Efficiency in Buildings.

[3] Id. *See also: David B. Goldstein, "Preventing Wasted Light"* The Construction Specifier, *1983.*

[4] *This is the generating capacity equivalent of 285 large coal-fired power plants. The calculation assumes 500 MW plants operating at 70% capacity factor.*

[5] *See Note 3, above.*

[6] *The IES defines a D-level visual task as one of "high contrast or large size:* e.g., *reading printed material, typed originals, handwriting in ink and good xerography..." IES Committee on Recommendations for Quality and Quantity of Illumination of the IES RQQ Report #6, published in* Journal of the IES, *pp 188-189, April 1980. (Subsequently referred to as* RQQ.*)*

[7] *Id.*

Table 1. Summary of Energy Performance

ANNUAL ENERGY USE	Engineering Calculations Typical Retrofit	Engineering Calculations NRDC Case (3)	DOE-2 Simulations Existing Building	DOE-2 Simulations Title 24 Lighting	DOE-2 Simulations NRDC Case (3)	Billing Data
Electricity (kWh/yr)						
Lighting	151,000	38,000	217,700	125,500	57,000	
HVAC & Cooling	237,000	170,000	289,100	254,200	203,000	
Plugload (2)	65,000	65,000	65,000	65,000	65,000	
Total Annual Electricity	453,000	273,000	572,000	445,000	325,000	284,600
Fuel (MBtu)						
Annual Heating	600	170	390	481	263	N.A.
DESIGN LOADS						
Lighting (3)						
Total (W/sqft)	2.21	0.73	2.8	1.5	0.55	
Adjusted (W/sqft)	2.21	0.55	2.8	1.5	0.55	
Cooling (kBtu/hr)	609	300	542	407	285	
Heating (kBtu/hr)	530	150	663	666	520	
CONNECTED LOAD (KW)						
Lighting	50	17				
HVAC & Cooling	152	111				
Plugload	29	29				
BEPS REPORT						
Annual Site (kWh/sqft)			29.1	24.8	8.9	
Annual Source (kWh/sqft)			74.7	59.8	29.9	

Notes

(1) Plugload calculated by NRDC was assumed for all cases to derive annual electricity consumption.

(2) Adjusted lighting density includes California Title 24 and ASHRAE 90.1 30% credit for occupancy sensors and daylight dimming controls on those areas where used. The DOE-2 analysis did not model these devices explicitly, but used the adjusted density as a proxy.

(3) The differences between the engineering calculations and the DOE-2 simulations result from the different usage assumptions behind each analysis. The hours of use for the engineering calculations is based on guesses about the total number of hours a system is run, whereas the DOE-2 simulation is based upon a fairly detailed building system schedule for the building type.

Numbers may not add up due to rounding.

and will vary the intensity of electric light according to need. Other skylights are located above the main conference room on the 12th floor and above open-plan offices on the west end.

Electrical Light.

The office floor plan for NRDC is comprised mainly of small enclosed offices, one of the most difficult layouts to illuminate efficiently. Typical room-cavity ratios are between 4 and 7, whereas most open-plan offices have a RCR of 2 to 3.[8] Rooms with large

[8] *The formula for the room-cavity ratio is given by RCR = (5*H)*(L+W)/(L*W), where H is the height of light to task, L is the length of the room and W is the width. Typically, the smaller the room, the larger the RCR.*

RCRs are more difficult to light due to the higher surface to volume ratio, which means there is more surface area to absorb reflected light relative to the amount of floor- or task-space being lighted.

Exterior Offices. The perimeter offices have excellent access to natural light from their tall windows and daylighting provides sufficient illumination under most daytime conditions. For the electric lighting system, pendant fixtures were chosen to bring the light source closer to the task, since it was architecturally desireable to leave the 12-foot-high ceilings exposed. The pendant strategy avoids the need to compensate for the long throw by installing more lighting power or installing a drop ceiling. Four different lighting configurations were used for the ring of window offices, as shown in Figure 1.

Each office had the furniture plan developed before the lighting plan. This allowed the designers to optimize the placement of the lighting system. In general, the single-lamp luminaires were placed in batwing formation to either side of the task area, at right angles to the work-plane.

Interior Offices. Offices in the core area tend to be smaller than those along the perimeter and have lower ceilings. The offices are rectangular in shape and along one of the long sides cabinetry has been installed. Typical RCR is between 6 and 7, so shadows from the shelving and indirect glare from excessive illuminance are the primary lighting quality concerns. Luminaires were placed at right angles to the work-plane and away from the cabinetry to avoid shadows (see Figure 2). Single-lamp recessed troffers with specular parabolic reflectors provide directed ambient light and glare is minimized by louvers.

Because the overhead lighting could not be placed optimally due to the location of the shelving in these offices, the task lighting system in these offices is even more important for good lighting quality. The PL lamp system chosen is located underneath the shelving and is adjustable by the occupant in the parallel plane to the work area to provide a wider range of area that can be lit. The fixtures are placed to minimize veiling reflections and provide even lighting of the work surface.

General Illumination. As an alternative to lighting general and accent areas, which are usually grossly overlit with incandescent bulbs or 4-foot fluorescent troffers, NRDC installed compact fluorescent fixtures. Hallways and other circulation areas are self-evidently B-level task areas for "simple orientation for short temporary visits," thus do not need lighting levels above 10 footcandles.[9] An integral part of the task lighting, compact fluorescents were used in reception areas, large offices and conference rooms, where incandescent lights would typically be used. Compact fluorescents use 75 percent less lighting energy than incandescents to provide the same number of lumens and they last approximately ten times longer.

The lighting design incorporates T-8 lamps and dedicated two- or three-lamp electronic ballasts. PL-9 compact fluorescents were used for task lighting and PL-13's were used for accent lighting. Single-lamp pendant fixtures with specular parabolic reflectors that provide both up-lighting and down-lighting were used in the perimeter offices. Single-tube recessed troffers with specular diffusers were used in the interior offices. PL-lamps were used in recessed can downlights, wall-washers and wall sconces. Two different styles of task lamps were used; a desk-mounted swivel-arm version and an under-cabinet model. Infra-red occupancy sensors control lights in each of the offices, while a daylight dimming system controls light levels in the 3-story atrium.

OCCUPANT REACTIONS

The author has conducted informal interviews with a number of the staff--especially those new to the organization who had just moved from a different office--about the quality of lighting system. Almost uniformly, the reaction has been overwhelmingly positive with a typical comment from new employees being "This is the most pleasant office I have ever worked in."[10]

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[9] *See* RQQ *note 6, above.*

[10] *Personal communication with Jennifer Kasalow, NRDC, May 31, 1990 and Ann Rassmussen, NRDC, June 18, 1990.*

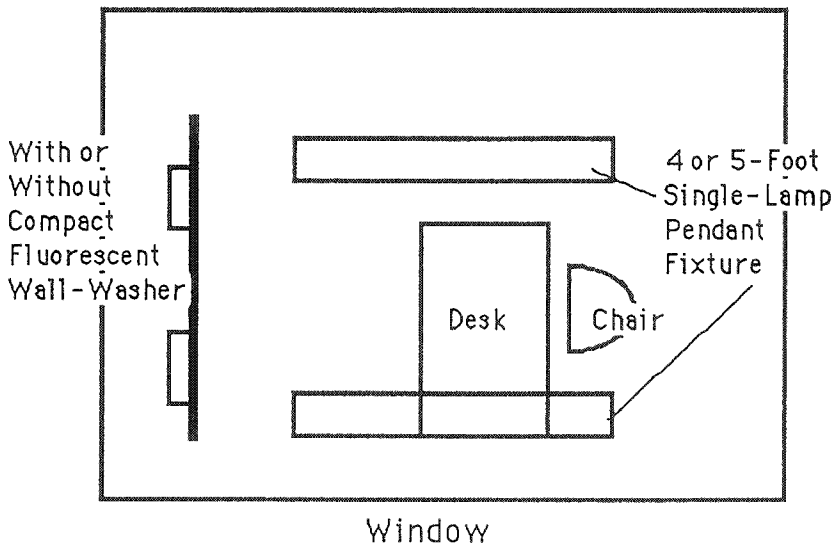

Figure 1. Typical Window Office Layout

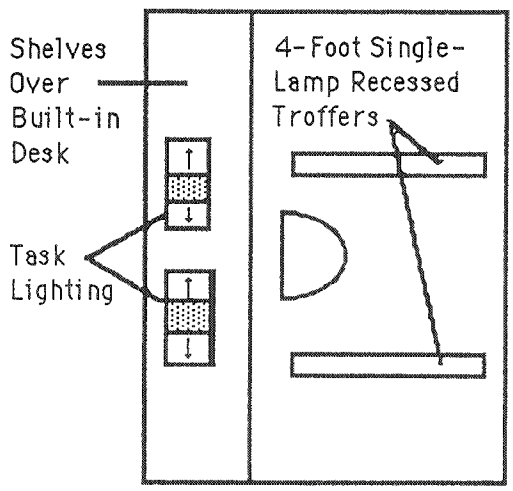

Figure 2. Typical Interior Office Layout

BASE CASE LIGHTING SYSTEM

Since there is no meaningful comparison[11] between NRDC's old offices and the present space, a "Base Case" lighting system needed to be developed that would reflect a typical retrofit lighting system in New York City. Most existing lighting systems are designed "for flexibility" and the mistaken notion that large quantities of light have a uniquely positive effect on productivity; at best, the results of the few studies done are ambiguous. Standard ambient illumination is designed to achieve 70 footcandles delivered from the ceiling. The lighting level was calculated using the lumen method shown in the following equation:

[11] *NRDC's old offices were located in the middle floors of a highrise building with a different layout and square footage. Furthermore, the energy costs were billed on a prorated basis to tenants based on square footage, so actual consumption was not known.*

$$IL*N*LLD*CU*BF*LDD/A = FC \quad (1)$$

where:

- IL is initial lumens per lamp,
- N is the number of lamps in a space,
- LLD is the lamp lumen depreciation factor,
- CU is the luminaire coefficient of utilization,
- BF is the ballast factor,
- LDD is the luminaire dirt depreciation factor,
- A is the area of the space being illuminated.

The footcandle levels derived from this formulation reflect the minimum number of footcandles the system will provide over its life, taking into account various effects of normal working environments that reduce light output.

The values assigned to the different factors in Equation 1 are based on certain assumptions about the type of equipment used and the office environment. We assumed a typical RCR of 4, a cavity reflectance of 70 for the ceiling, 50 for the walls, and 20 for the floor, in addition to a "medium-clean" office environment.[12] The typical fixture assumed is a 3-lamp fluorescent parabolic troffers with white enamel finish, housing three F40 warm-white energy-saving (34W) bulbs and one energy-efficient core-coil ballast for every two lamps.[13] These assumptions give rise to the following values for the factors used in Equation 1:[14] 2750 = initial lumens per lamp; the number of lamps in a space, N, varies depending upon the floor area; LLD = 0.88; CU = 0.67 BF = 0.88; LDD = 0.81; A, the area of the space being illuminated, varies.

For accent lighting--which was not included in calculating footcandle levels--we assumed that 150 Watt incandescent floodlamps were used in the reception area, main conference room, certain areas of the corridors and some of the larger private offices. These floodlamps were assumed to be installed either in recessed cans or in track lighting, depending upon the application. The default assumption was that incandescent accent lighting was installed where PL accent lights were used in the actual design.

The overall power density, which was calculated by a detailed lighting audit of the space, was 0.73 W/sq.ft. When adjusted for occupancy sensors, the final power density is 0.55 W/sq.ft.

THE COOLING AND VENTILATING SYSTEM

The decision to condition the NRDC Headquarters space using a floor-by-floor packaged HVAC system, reflects the many compromises we needed to make to bring the project to fruition. Despite the fact that this system does not achieve full energy efficiency potential, we believe it reflects the best system possible given the constraints we faced and accurately reflects many of the market barriers to full implementation of cost-effective energy-saving technologies and designs.

The design of the air conditioning system NRDC installed took into account the very low lighting load, high shading coefficient windows and well-insulated building shell. The building is ventilated to the levels recommended in ASHRAE 62-1989.[15] Due to the large volume of air moving through the space, the system can take advantage of "free" cooling from outdoor air during most of the year. This free cooling is enhanced by a water-side economizer cycle that runs water from the rooftop cooling tower through a cooling coil to supplement the chiller.

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12 *The RCR of 4 reflects the predominant use of individual enclosed offices. This value is actually too low, but was chosen as a conservatism. Having a higher RCR will reduce the amount of useful light from the fixture and reduce some of the footcandle levels assumed in the calculations. We chose medium-clean to describe the office environment because the office is located in New York City and has operable windows that can allow dirt into the building.*

13 *This luminaire is quite common in recently-built New York office space. The use of 34-Watt lamps and energy-saving ballasts--required by the New York state energy code--is considered "energy-conserving" practice.*

14 *Values for the LLD, CU, BF, and LDD come from the* 1984 IES Handbook Reference Volume, *Chapter 9.*

15 *Standard 62-1989 calls for 20 cubic feet per minute (cfm) per person for office space. The default ventilation rate used is at least 6 cfm per person, as specified in ASHRAE 62-1981.*

The system relies on a variable air volume system (VAV) to more closely match cooling system operation with building cooling loads. Changing the air flow in the VAV system is achieved through adjusting the aperture of the fresh air inlet vanes, rather than by using a variable speed drive (VSD), which was rejected as non-cost-effective. The potential savings possible from a VSD were substantially reduced due to NRDC's low heating loads, and additional volume control from special VAV diffusers installed in each room.

Inlet vanes provide system variable air volume control of fresh air entering the distribution system and minimum outdoor air is set at 10% of total volume. Temperature control of individual rooms is accomplished through special VAV diffusers. These devices are solenoid-controlled dampers that open and close depending upon how close the room temperature is to the preset condition of the thermostatic valve. One advantage of the existing configuration is that since each office is its own zone,[16] there is no overlap between heating and cooling zones, which avoids "fighting"--or simultaneous heating and cooling--between the heating and cooling systems.

The system is comprised of floor-by-floor packaged (self-contained) water cooled units. The twelfth floor houses a 32-ton unit, while the 10th and 11th floors have 29-tons of cooling each.[17] Each packaged unit contains three compressors, water-cooled condensers, an evaporator coil, a single fan with inlet guide vanes, a control panel that allows the system to be controlled locally or by remote computer, and a water-side economizer.[18] The units' cooling capacity can be stepped down to 62% and 39% of full load, depending on how many compressors are running.[19] The stepping of compressor capacity allows the cooling system to run more efficiently when cooling needs are less than the full cooling capacity of the system.

The cooling and ventilation system is controlled by an energy management system (EMS) run off of a remote computer.[20] Normally, the system relies exclusively on outside air for cooling at ambient temperatures between 40 and 55 degrees Fahrenheit. When outside temperature drops to about 40°F, the system throttles back to minimum air (10%). Between 55 and 75 degrees, the chiller works at part-load, supplemented by the economizer; above 75 degrees, the chiller does all of the work.

BASE CASE COOLING SYSTEM

We have defined the Base Case HVAC system as the identical type of system installed, with the exception that total cooling capacity would be 120 tons, as opposed to the 90 tons.[21] This downsizing is the result of many of the efficiency measures NRDC installed. Base Case design-day cooling loads were determined using a load calculation program: about 600 kBtuh.[22] Comparing this estimated cooling load with the 300 kBtuh calculated for the installed system easily demonstrates that the smaller HVAC system is warranted. In fact, the results from our design cooling load calculations indicate that we could have reduced the HVAC system by another 20% to approximately 70 tons of cooling.

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16 *Each perimeter office is supplied with cool air from the diffusers and contains a convective steam radiator.*

17 *A "ton" of cooling represents 12,000 Btu/hr of capacity.*

18 *Water was chosen as the condenser and economizer heat-removing medium due to its superior ability to absorb heat.*

19 *The installed system has an energy efficiency ratio (EER = cooling capacity in Btu/input Watts) of 14.75, and a coefficient of performance (COP = EER/3.414) of 4.32. The default value used in some computer energy simulation programs is 2.70 COP for direct expansion water-cooled chillers.*

20 *The system also allows manual override from the computer. This happens fairly frequently because the accounting office was located right next to the mechanical room. Vibration, noise and a wind-tunnel effect due to a return air intake near the back of the room make the space very unpleasant to work in for extended periods. Thus, at the accounting department's request, the 12th floor system is turned off for extended periods. The "solution" to the problem is likely to be relocating the accounting office to a different floor and locating temporary interns in that space. Installing partially-enclosed carrels should alleviate the wind-tunnel problem and acoustical insulation will be installed if electrical and mechanical code clearances can be maintained.*

21 *The system capacity calculated for the design cooling load is 66 tons. The design cooling load calculated by NRDC's consulting engineers for the space was 51 tons and the resulting system specified was 90 tons. This implies a "safety factor" of 1.76. Multiplying 66 tons by 1.76 is 116, which is rounded to 120.*

22 *The engineering analysis took NRDC's lighting measures into account but ignored the window and shell measures.*

There should actually be a relatively small energy penalty for this oversizing, due to the partial-load cooling feature of the compressors. However, nearly $50,000 in capital expense could have been avoided, as well as increased demand charges due to the higher peak KW consumed by the larger system. Table 2 compares the different packaged HVAC options considered.

INSULATION

To minimize heat transfer through the building envelope, NRDC installed all architecturally feasible insulation. In the ceiling this translated into a six-inch cavity that was filled with R-5-per-inch Dow styrofoam insulation[23] and about 2 inches of rigid foam in the wall.[24] These insulation levels are approximately 2 to 2 1/2 times greater than that normally used in commercial buildings in New York City.[25] Total R-value for the wall assembly, including air films, is about R-15, while that of the ceiling is about R-34.

WINDOWS

The double-paned, low-emissivity windows will provide nearly the same insulating value as conventional walls--about 3 times as much insulation as an ordinary window. The infrared-reflecting properties of these windows increase the mean radiant temperature of the room so that the occupant will experience the same perception of thermal comfort at a lower ambient temperature.

The new windows also radically cut street noise. The window assembly consists of a transparent low-emissivity film suspended between two panes, which is designed to transmit visible light and varying amounts of short-wave infrared, while reflecting the long infrared wavelengths (radiant heat). The film can be specially "tuned" for optimal performance on each exposure. On the northern exposure, which has less direct light, we installed a film that is designed to maximize transmission of visible and short-wave infrared wavelengths, while reflecting long-wave infrared. Window assembly U-value for these windows is 0.37, while the shading coefficient is 0.58. On the southern and western exposures we

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23 *We examined non-CFC insulations such as cellulose and fiberglass, but space constraints and insulating values made those choices undesirable. The choice in this instance came down to increased carbon dioxide emissions or increased CFCs and we gave the CO_2 more weight when combined with the other considerations. We also explored "no-drift" phenolic foams that have the CFCs chemically bonded within the insulation and are not readily given up to the atmosphere. The insulation we were exploring was not certified by the New York Fire Marshall because of the glue used to adhere the foil backing to the foam, so we were unable to install it. There are now new products on the market that use fully-halogenated CFCs, which have 20 times less ozone-destroying capability than the CFCs currently used to blow foam, with little or no energy penalty.*

24 *Additional insulation would have required furring out from the wall. We decided that the additional expense and loss of floorspace would not be paid back by the marginal insulation in New York's climate.*

25 *Normal insulation values are R-2 to R-4 in the wall and R-11 in the ceiling.*

Table 2. Summary of Characteristics of Cooling System

Element	Base Case	Installed Case	Savings	Optimal Case
Cooling Load	609 kBtuh	300 kBtuh	309 kBtuh	300 kBtuh
Chiller Size	120 Tons	90 Tons	30 Tons	69 Tons
Fan Size	42.5 HP	30 HP	12.5 HP	30 HP
Peak Power	152 KW	111 KW	41 KW	94 KW
Annual Energy (kWh)	237,060	169,503	68,000	155,503
Demand Charges	$26,343	$20,140	$6,203	$18,243
Energy Charges	$55,531	$40,436	$15,095	$37,995
Capital Costs	$8,441	$0	$8,441	($5,908)
ANNUAL COST SAVINGS			$29,739	$39,985

used a low-e coating that is designed to maximize visible light transmission while minimizing solar gain (short-wave infrared). This film has a U-value of 0.37 and a shading coefficient of 0.33. On the top floor, NRDC installed low-e skylights, which reduce radiant heat losses and solar transmission gains even further. The U-value and shading coefficient are 0.37 and 0.25, respectively.[26] By reducing solar gain from the south and west, air conditioning needs are reduced by 15 tons of cooling; a capital cost savings of $36,000.

ECONOMICS

Table 3 summarizes the predicted levelized financial performance of the space over ten years and a 3% real discount rate. Total renovation costs for the NRDC headquarters were $2.8 million. Energy efficiency measures cost an extra $170,000, a $7.50 (6%) per square foot premium over the same build-out without any attention paid to saving energy. Total extra first costs are as follows: Lighting System: $166,000; HVAC System: -$72,000 (this is a result of down-sizing the cooling capacity by 30 tons at $2,400 per ton); Windows and Insulation: $76,000.

Real payback (including the cost of capital) for all installed measures is about 5.5 years, while simple payback is about 4.4 years. The cost of conserved energy is between -$0.01 and -$0.02 per kWh for the lighting.[27] Since the installed HVAC system is about 30 tons smaller than the Base Case system, the cost of conserved energy is also negative at -$0.02/kWh. Cumulative economic benefit to the organization of the energy efficiency measures over ten years is estimated to be about $780,000, of which about $450,000 comes from energy savings. None of the financial calculations include the $100,000 grant NRDC received from the local New York utility. The levelized cost for equipment, maintenance, and energy and demand charges for the Base Case System is calculated to be $292,000, while the NRDC Case space has a levelized cost of $214,000.[28]

MONITORING ENERGY CONSUMPTION

To measure the performance of the building, a monitoring system is being developed which will allow NRDC to verify the actual energy consumption of the systems we install. The monitoring protocol will take readings every 15 minutes on power and energy draw for 12 different zones for the ceiling lights, plug-load lights and other plug load. In addition, HVAC use will be measured and

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[26] *Shading coefficients for the glazing are adapted from manufacturer-reported data and interpolated values from the* 1989 ASHRAE Fundamentals Handbook, *Table 26 in Chapter 27. All shading coefficient values assume that the window has light-colored venetian blinds that are 1/2 closed. The average shading coefficient for the building glazing is 0.37. Calculation: 20% of total glazing area @ SC of 0.58 + 70% @ SC of 0.33 + 10% @ SC of 0.25.*

[27] *The Cost of Conserved Energy (CCE) is defined as follows:*

$$\frac{(\text{investment rate} \times \text{capital recovery rate}) + (\text{incremental O\&M})}{\text{annual energy savings}}$$

where:

The "investment rate" is the initial marginal energy efficiency investment, plus the net present value (evaluated at 3% and 7% real interest rate in this analysis) of replacement equipment over a 10- or 20-year investment horizon.

The "capital recovery rate" (CRR) is defined by the formula

$$\frac{d}{1-(1+d)^{(-n)}}$$

where: d is the real discount rate (3% or 7%)
n is the lifetime of the equipment evaluated

The "O&M incremental cost" is the difference in net present value of the annual labor cost of replacing and cleaning equipment for the NRDC and Base Case lighting systems (may be negative).

The cash-stream for the replacement equipment and maintenance labor are discounted to net present value using the following formula:

$$\frac{(\text{investment})}{(1+d)^{n}}$$

where: d is the real discount rate (3% or 7%)
n is the future time at which the investment is made

[28] *The levelization calculation takes all expenses that would be incurred over 10 years--including initial and replacement capital, maintenance, and energy and demand charges--discounts them to present value, and splits them into 10 equal parts. The cumulative present value of these savings over ten years is over $750,000.*

compared with other spaces in the building. The data will be accessible by computer, even from remote locations. The monitoring system will provide NRDC with invaluable data to verify the practical benefits of an energy efficient space. In addition to the $100,000 grant, NRDC's local utility generously donated the monitoring equipment and its installation, and evaluation of the resulting data.

Table 3. Summary of Financial Performance (1)

	Lights	HVAC	Heating (2)
Extra First Cost (3)	$130,000	$0	$40,000
Levelized Energy Savings	$28,000	$23,000	$2,200
Levelized Equipment and Maintenance Savings	$17,000	$10,000	N.A.
TOTAL	$45,000	$33,000	$2,200
Cost of Conserved Energy	-2¢ /kWh	-3¢ /kWh	$4.60/MMBtu
REAL PAYBACK (4)			
Lighting System	6.2 years		
HVAC	N.A.		
Windows and Insulation	3.1 years		
All Measures	5.5 years		

Notes

(1) Levelized cost calculations are based upon a 3% real discount rate and a time horizon of 10 years.

(2) Windows and insulation are considered "heating" measures in this table.

(3) Extra first costs are calculated by subtracting capital savings from downsizing the HVAC from the extra first costs for lighting and heating. Thus: Lighting = $166,000 - $36,000; Heating = $76,000 - $36,000. Capital savings of $76,000 (30 tons saved @ $2,400 per ton) are evenly divided between Lighting and HVAC.

(4) Real payback assumes a 10% real interest rate and a 5% real fuel escalation rate. Assumes that HVAC first cost savings are distributed evenly between the lighting system and the windows and insulation.

N.A. = Not available or not applicable