Advantages of Staged Implementation of Efficiency Upgrades

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As an integral part of its new Energy Star Buildings Program, EPA has developed a relatively simple, broadly applicable strategy for implementing energy efficiency retrofit upgrades in existing commercial buildings. A key element of this strategy is to approach comprehensive efficiency upgrades as a series of technical stages, and can be summarized as follows:

Stage 1: Green Lights.
Stage 2: Building Tune-Up.
Stage 3: Heating and Cooling Load Reductions.
Stage 4: Improved Fans and Air Handling Systems.
Stage 5: Improved Heating and Cooling Plant.

This approach offers a number of advantages, and can be applicable to a broad range of building types. This staged implementation strategy concentrates those measures that serve directly or indirectly to reduce HVAC loads in the early stages, and incorporates those load reductions into the sizing calculations for equipment associated with latter stages.

The advantages to this approach include the following:

- Uncertainty in determining revised HVAC loads is reduced, given that empirical measurements can be used (e.g., monitoring inlet vane position on peak cooling days) to augment or supplement building energy simulation.
- Organizational momentum is enhanced, and initial reluctance to begin the upgrades is reduced, given that the scope of the initial stages is limited.
- Limited capital can be accommodated.

The paper draws comparisons with alternative approaches, including an ala carte menu approach, and an approach based solely on an up-front building simulation, and cites several specific advantages of this staged strategy.

In addition, EPA has completed a DOE-2 parametric modeling analysis that details the savings and returns associated with the application of this staged strategy to three sizes of office buildings in eight different U.S. locations. The results of this analysis show the potential to reduce overall energy consumption by up to 60 percent in existing buildings, while realizing rates of return on efficiency investments of an average of 54 percent. The staged implementation strategy is a key factor in these overall savings and the overall economic returns, due to reduced costs of upgrading HVAC systems sized to match significantly reduced peak loads.

Introduction

The EPA Energy Star Buildings Program is a new Federal program that targets whole-building efficiency improvements, and has been developed to expand and continue the energy savings and environmental benefits that have been realized through the EPA Green Lights Program. The Green Lights program, started in 1991, currently has over 1300 participants which have committed to upgrade approximately 5 percent of the total U.S. commercial and industrial floorspace within five years.

The Green Lights strategy has now been extended with the introduction of the Energy Star Buildings program, which focuses on whole-building efficiency upgrades instead of a lighting-only retrofit.

Background: EPA Energy Star Buildings Program

The Energy Star Buildings Program focuses on retrofit opportunities within existing buildings, a strategy designed to maximize the energy savings realized nationwide, given the relative amount of floorspace represented by older buildings, and by their relative inefficiency. Another early focus for the Energy Star Buildings Program is buildings with central chilling systems—buildings that are most affected by the impending phase-out of CFC refrigerant production.

A goal for the Energy Star Buildings Program is to provide a strategy and supporting tools that enable facility managers and other participants to better plan and manage whole-building efficiency upgrades. To that end, EPA developed a step-by-step strategy that is designed to realize the maximum possible energy savings at a profitable rate of return on investment. This strategy is outlined in more detail below and is the overall focus for this paper. The Energy Star Buildings Program couples this building-level technical strategy with a broader marketing and publicity program that establishes a top-down commitment within participating organizations, and that highlights participants' environmental contributions.

Overview of Staged Implementation Strategy

A central component of the Energy Star Buildings Program is the recommendation that participants upgrade their buildings through a staged implementation program. By deliberately planning the series of upgrades in a way that allows for direct measurement of the interactive system effects of individual measures, additional energy savings can be achieved while lowering capital expenditures. The five stages are:

Stage 1: Green Lights.
Stage 2: Building Tune-Up.
Stage 3: Heating and Cooling Load Reductions.
Stage 4: Improved Fans and Air Handling Systems.
Stage 5: Improved Heating and Cooling Plant.

The initial focus on loads-reduction and re-calibration in Stages 1 through 3 can significantly reduce the size and cost of equipment associated with Stages 4 and 5. Uncertainties in proper sizing of upgraded cooling equipment [chillers and direct-expansion (DX) units] are reduced, leading to potential equipment down-sizing and cost savings.

This staged approach provides a broad strategic framework for making comprehensive efficiency upgrades in a range of commercial building types. However, the strategy is deliberately flexible. For example, there will be some cases where it makes more sense to design and implement all stages at once. The stages are outlined in more detail below.

Stage 1: Green Lights

A realistic goal for many commercial facilities is to reduce the lighting energy used by 50 to 70 percent. It should be noted that efficient replacement equipment (e.g., T-8 lamps and electronic ballasts) represents only a portion of this total. To maximize profitable energy savings from a lighting upgrade, it is equally important to adjust ambient and working-surface light intensity to levels that are consistent with IES standards, and in many cases to include occupancy controls for the lighting. In addition, a lighting analysis should include the indirect costs and benefits, including disposal costs, and the benefits of reduced lamp depreciation and reduced maintenance costs. In this Stage 1 analysis, the cooling load reduction and heating load impacts that result from the lighting upgrade should also be considered.

Stage 2: Building Tune-up

There are several components associated with this stage of the upgrade. First, the building managers or project engineers start by reviewing historical energy data, as-built drawings where possible, maintenance logs, operating sequences and existing monitoring and control systems. The goal here is to identify problem areas, unusual usage patterns, and to construct an approximate pie-chart of building energy end-uses, as a tool in establishing priorities within each stage of the building-specific upgrade strategy. To facilitate measurement of peak demand, it may be necessary to add additional energy management system data points or data loggers to collect energy usage trend data for a representative sample of HVAC sub-systems (e.g., CFM or velocity pressure for a VAV fan system), while short-term measurements will suffice for other loads (e.g., plug loads). The rule of thumb is that meters should be installed on each system where the annual cost of energy for that system is more than five times the cost of the meter. It is also important to minimize the cost of additional monitoring equipment by focusing on the specific data that will be used in designing future upgrades. For example, it may not be necessary to add an airflow monitoring station to collect trend data for a given VAV fan system. Instead, relative airflow demand could be tracked using a simpler and less expensive velocity pressure probe.

In the second part of this stage, the building managers identify those steps that can be completed with a minimum of capital investment (e.g., re-calibrating controls, reducing excessive pressure in air and water systems, installing weatherstripping and caulking). The building-wide survey associated with this stage can also be coupled with an inspection of indoor-air quality-related building systems, such as outside air filters.

Finally, Stage 2 is the logical point within a building's upgrade plan to review, improve, and implement a comprehensive building preventative maintenance schedule. The preventative maintenance plan contains maintenance procedures for each type of equipment and maintenance logs for each piece of equipment. Managers may consider using one of several commercial software packages designed for use in setting up and tracking a preventative maintenance program.

Stage 3: Additional HVAC Load Reductions

In addition to peak cooling load reductions from more efficient lighting and better-tuned equipment, it may be possible to reduce loads further at a profitable rate of return, through retrofit installation of high-efficiency windows, window films, or better insulated and more reflective roofs. In Stage 3, participants are encouraged to change their procurement policy for computer equipment—so that all new equipment complies with the EPA Energy Star Computers program. This can significantly reduce plug load and related sensible heat gains in the occupied space due to computers and printers.

Stage 4: Improved Fan Systems

This area is of critical importance in maximizing energy savings in commercial buildings—the first opportunity for taking advantage of indirect effects from earlier stages upgrades. Using current commercial technology, it is possible in many retrofits to reduce fan system energy consumption by 50 percent or more, while adhering to *ANSI/ASHRAE Standard 62-1989* (ASHRAE 1989a) guidelines on minimum ventilation. Upgrades included in this stage include:

1. convert constant-air-volume systems to variable-air-volume operation, where technically and economically feasible;

2. reduce equipment size (e.g., through adjusting or replacing the fan pulley) to meet lower peak loads (including sizing margin of 10 percent), and

3. adding variable speed motor controls to operate the fan systems more efficiently at the reduced loads that prevail through most of the year in most locations.

EPA has done extensive field work in this area in the past year, including the following two studies:

1. Field survey of 47 air handling units in 26 buildings nationwide during the summer of 1993, measuring the actual airflow in specific air handling systems in those buildings on design cooling days to gauge the extent of system oversizing (Enviro-Management and Research 1993). It was observed that in 58 percent of the buildings, the fan systems included in the survey were oversized (fan design CFM was more than 110 percent of observed peak CFM), with an average of 60 percent oversizing. For all fans in the survey, including those that were observed to be undersized, the average margin of oversizing was 38 percent.

2. Field measurement of the energy consumption of 10 individual air handling systems, operated alternately with inlet-vane controls, and with variable speed drive motor controls (EPA 1993, Appendix B). Direct submetering of the fan systems on consecutive testing periods showed average energy savings of 53 percent when the fan systems were operated with variable speed motor controls. Projected *annual* energy savings based on these measured results averaged 62 percent for all of the test sites, with these savings yielding internal rates of return ranging from 12 percent to 76 percent.

These studies support two key elements of this portion of the EPA staged strategy. First, the fan systems of commercial buildings are typically substantially oversized for the load, and the degree of oversizing will increase with additional load reductions. Building owners should take steps to determine the actual loads, and adjust the capacity of the fan systems to match this actual peak load more closely. Second, for buildings with VAV air handling systems, variable speed drive controls offer the potential for dramatically improving the operating efficiency of fan systems at the part load conditions that prevail through most of the year.

Stage 5: Improved HVAC Plant

It is at this final point in a building upgrade that the benefits of staging the upgrades really pays off, especially for building owners who are dealing with the impact of the CFC refrigerant production phase-out. By taking advantage of the reduced loads on the central plant resulting from the retrofits of Stages 1 through 4, and by utilizing direct peak load measurements in specifying replacement equipment to more closely match actual peak loads, the relative cost of replacement equipment can be dramatically reduced. The option of replacing (vs. rebuilding) the existing chillers is enhanced. In fact, given the substantial advances that have been made in the efficiency of centrifugal chillers over the past 20 years, the relative energy savings of replacement will likely yield a very attractive rate return on investment of the cost differential between the two options. One example of this economic analysis is shown below in the DOE-2 parametric modeling analysis.

Heating system upgrades will similarly benefit from the staged implementation strategy. While peak heating demand will likely increase as a result of the lighting upgrade in Stage 1 or window films in Stage 3, peak demand will be reduced by envelope-related (e.g., caulking) and boiler-related Building Tune-up measures, as well as such Stage 3 load reduction measures as an air-to-air heat exchanger. Recommended Stage 5 heating system upgrades will depend on the heating system configuration. For all-electric buildings with electric reheat, the best profitable option may be to modify controls to ensure minimized use of reheat. For buildings with boilers, participants will evaluate equipment replacement. The cost of replacement equipment may be reduced by using empirical measurements to reduce uncertainty about revised peak heating loads.

Advantages of Staged Implementation

Step-by-Step Approach Improves on Other Approaches

Traditionally, upgrades have been pursued in an a la carte menu fashion, with energy efficiency measures considered individually. In the process of establishing a budget for the upgrades, this usually results in those measures with the shortest payback being accepted while those that have a longer economic return do not get funded. The drawback of this approach is that it does not in most cases explicitly consider the collective or interactive impacts of the set of efficiency measures. As a result, the projected economic returns and energy savings are conservatively skewed, and considerable cash is left on the table.

Another strategy used in planning building efficiency upgrades is to utilize a whole-building modeling analysis. Using DOE-2 (Winkelmann et al. 1993) or similar energy simulation program, a building's energy performance can be simulated for a number of scenarios, including the proposed upgrades individually or in conjunction. Typically, the starting point for this approach is to construct a simulation model for the building, calibrate the model by adjusting the assumptions until the modeled energy consumption for some historical period matches that actual historical consumption pattern, and then to model the operating performance of the building after one or more efficiency upgrades. This approach is a great improvement over the simpler alternative of estimating impacts for individual measures alone, and planners are less likely to overlook the potential savings that arise as a result of interactive system effects. However, this modeling analysis is expensive and may not be sufficient to address the uncertainties that will arise in specifying the size of replacement HVAC equipment, decisions that are important to the overall economic value of the project,

The staged strategy outlined in this paper offers a more systematic way of considering efficiency upgrades that takes full advantage of the inter-system effects, and that offers the opportunity to include direct measurement of equipment peak loads prior to specifying replacement equipment.

The Plan Is Applicable to Many Building Types

The stages describe general technology upgrades, and are deliberately not written to address specific equipment types—allowing the participant to customize the upgrades to the individual building or building type. For example, upgrade options for Stages 4 and Stage 5 for a strip mall shopping center (load-matched, high efficiency packaged units, or ground source heat pumps) will be somewhat different than those for a typical 500,000 ft^2 office building (load-matched fans and high efficiency chillers, with variable speed controls). However, in either case, the overall economic value of the upgrades is significantly increased by the previous loads reductions in Stages 1 through 3, and by correctly sizing existing or new equipment.

Focusing on Simpler Upgrades to Develop Momentum

One key lesson of the early years of the Green Lights program is the importance of establishing momentum and a winning track record early. While arguments can be made for a different order of the load reduction and tune-up stages, the Energy Star Buildings Program begins with a lighting upgrade because of its relative simplicity and the dramatic and easily demonstrable (non-seasonal) energy savings that result. In many cases, the same facility personnel will be involved in planning, designing and implementing the remaining upgrades. With the positive results from the Green Lights upgrades, and they will go into those projects with an additional degree of experience in planning, designing, and financing for the other stages efficiency upgrades.

Accommodates Limited Capital

In many cases, participants will finance their upgrades through capital budget allocation, and there is a high probability that some attractive efficiency investments will not be funded. One solution is to take advantage of operating lease financing or other third-party financing arrangements that will provide for off-budget financing for these projects. In cases where this is not possible, however, the staged implementation strategy will allow for implementing upgrades one step at a time, in an order that maximizes energy savings in the long run.

Addresses Issue of Overly Conservative HVAC Design

Major HVAC equipment is often designed with a margin of over-capacity that well exceeds the ASHRAE recommendation of 10 percent for cooling and 30 percent for heating (ASHRAE 1989b), even for new installations. The reasons for this trend are well documented. Building managers and design engineers face uncertainty about future loads and about actual building performance, with few incentives or rewards for careful load-matching, and potentially serious professional liability for undersizing equipment. The five-stage strategy provides the building manager or engineer with the opportunity to measure revised peak loads directly, thereby reducing the uncertainty about actual building performance, and providing additional engineering support for more precise load-matching.

Results of DOE-2 Modeling Analysis

EPA recently completed a parametric modeling analysis study to estimate the energy savings and economic returns that would result from applying the five-stage Energy Star Buildings strategy to a range of sizes of office buildings in eight different U.S. locations. The DOE-2.1E hourly energy simulation program was used to estimate the energy impacts of the five stages. The goal of the modeling exercise was not only to demonstrate the overall energy savings potential, but also to detail the system-specific energy savings (or penalties) associated with each step. For example, the modeling results show not only the direct savings that result from a Green Lights upgrade, but also the net HVAC energy savings resulting from the reduced sensible heat load because of the efficient lighting.

Modeling Assumptions

Building sizes. The simulations were performed in each location for three different office building sizes. The building sizes chosen for this modeling analysis were based on mean values within building size categories using data from the 1989 Commercial Building Energy Consumption Survey (EIA 1989). The sizes and configurations that were selected are shown in Table 1.

Table 1. Three Existing Office Building Models

Building Size	Floor Area, ft^2	Number of Floors	Aspect Ratio (L:W)
Lowrise	48,000	3	2
Midrise	196,000	7	3
Highrise	840,000	20	3

Average size, massing, and other characteristics from CBECS used when available.

Building locations. The simulations were performed in eight U.S. locations:

Los Angeles, California
Miami, Florida
Minneapolis, Minnesota
Omaha, Nebraska
Phoenix, Arizona
San Antonio, Texas
Seattle, Washington
Washington, D.C.

Local utility rates were used in the analysis to calculate cost savings and rates of return.

Building Baseline. Table 2 summarizes the equipment and operations assumptions that pertained to all buildings.

Table 3 presents the results from DOE-2 for the baseline energy usage profile for each of the building types in each location.

Stage 1: Green Lights Upgrade. The modeling assumed that the existing 4-lamp, T-12 fixtures were upgraded to 2-lamp T-8 configuration with electronic ballasts, and that equivalent full-load operating hours (EFLH) could be reduced from 3271 to 2742 through the broad application of occupancy sensors lighting controls. The proposed upgrades were reduced lighting power from 2.3 to 0.8 W/ft^2 at estimated upgrade costs of $0.82 to

Table 2. Assumptions: Building Equipment and Systems

Description	Equipment/System Assumptions
Lighting	2.3 W/ft^2, T-12 fluorescent 4-lamp 2 x 4 Fixtures, 3271 Equivalent Full-Load Hours (EFLH)
Office Equipment	1.0 W/ft^2 (computers, laser printers, photocopiers, and faxes), 2616 EFLH.
Envelope	40% WWR, glazing varies by location—primarily single-pane, tinted/reflective in southern locations; double-pane, tinted in northern locations.
Ventilation	20 CFM/person outside air.
Air System	Inlet Vane VAV System, 7" W.C. supply static pressure, 30% oversized, outside air damper stuck open at 40% outside air position.
Central Plant	Centrifugal chillers, CFC refrigerant, 0.9 kW/ton (COP 3.9), 30% oversized chiller, cooling towers, and pumps, electric heat/reheat.

$1.12/ft2 depending on building size. In two locations, Seattle and Minneapolis, the above upgrade did not meet the profitability threshold for the Energy Star Buildings Program (prime rate plus 6 percent), and an alternative upgrade configuration was selected—2-lamp fixtures with T-10 lamps and high efficiency magnetic ballasts. This provided reduced lighting power of 1.19 W/ft^2 at an estimated cost of $0.39/ft2.

Stage 2: Building Time-up. For this stage of the modeling, we assumed first that the outside air damper that had been stuck at 40 percent open was repaired. Note that this is but one example of typical tune-up problems found in commercial buildings—other typical problems include controls and sensors that no longer work properly or that are out of calibration. In addition, it was assumed that through the inspection of filters and air-side equipment calibration, the static pressure across the fan could be reduced by l/2-in. (from 6.5-in. to 6.0-in.). Finally, we assumed a 10 percent reduction in office equipment operating hours, assuming a successful employee information campaign.

Stage 3: Additional HVAC Load Reduction Measures. There were three elements included in the portion of the upgrade that falls under Stage 3. First, we assumed that window films are applied to the existing windows to reduce insolation and cooling load. Second, we assumed that the existing roof was leaking and in need of replacement (wet insulation, reduced R-value), and that the replacement insulation would have an R-value equal to current design practice as recommended in Standard 90.1 (ASHRAE 1989b).

Finally, we assumed that the building owners and tenants would change their procurement of desk-top computers so that all new computer equipment would be Energy Star compliant (i.e., the computer and monitor will use less than 30 Watts each when not in active use). The modeling analysis assumed that 20 percent of the computer equipment in the building had been upgraded to this Energy Star Computer standard, and that the Energy Star equipment is available at no incremental cost.

Stage 4: Fan System Upgrades. The upgrades that were collectively modelled for this stage included the following:

1. Fan system capacity adjusted to match the revised (and lower) peak airflow requirements, with a oversizing margin of 10 percent.

2. Outside air economizer installed.

3. Supply air static pressure reduced from 6-in. WC to 4-in. WC (because of reduced airflow requirements).

4. Variable speed drives installed to control fan motors, and to greatly improve the operating efficiency of the fan system, especially at prevailing part-load conditions throughout the year.

Stage 5: HVAC Plant Upgrades. The upgrades that were collectively modelled for this stage included the following:

1. Replace 20 to 25-year-old (late 1960s/early 1970s) centrifugal chiller (with CFC refrigerant) with new non-CFC high efficiency chiller (0.55 kW/Ton, COP 6.9), equipped with a variable speed drive controlling the compressor motor. The chiller was sized to meet the significantly lower peak cooling loads, with an oversizing margin of 10 percent.

Table 3. Summary Results: Overall Performance for Each Size Category

Location	Annual Energy, kWh/ft²	Annual Energy Cost, \$/ft²	Peak Demand, kW	Peak Chiller Load, tons	Fan Supply Air, CFM	Fan Motor Size, HP (kW)
Lowrise Office, 48,000 ft², 3 floors						
Los Angeles	22.38	2.87	434	136	61,392	97 (72)
Miami	26.52	2.24	491	202	65,783	103 (77)
Minneapolis	30.60	2.07	1,023	154	57,488	88 (66)
Omaha	27.78	2.20	934	182	59,488	90 (67)
Phoenix	26.45	2.50	490	201	76,469	116 (87)
San Antonio	26.82	1.64	817	203	75,912	116 (87)
Seattle	23.58	0.92	665	110	57,915	90 (67)
Washington, D.C.	25.54	2.24	740	189	58,046	90 (67)
Midrise Office, 196,000 ft², 7 floors						
Los Angeles	17.21	2.10	1,343	511	218,467	344 (258)
Miami	21.23	1.78	1,555	731	231,480	364 (272)
Minneapolis	22.61	1.56	3,399	584	208,645	319 (238)
Omaha	20.78	1.64	3,019	683	215,375	326 (243)
Phoenix	20.74	1.76	1,535	717	267,262	404 (301)
San Antonio	20.86	1.26	2,523	733	265,676	406 (303)
Seattle	17.41	0.66	1,987	417	209,390	326 (243)
Washington, D.C.	19.29	1/67	2,179	697	207,742	324 (242)
Highrise Office, 840,000 ft², 20 floors						
Los Angeles	16.45	1.97	5,372	2,049	839,322	1,321 (986)
Miami	20.16	1.68	6,161	2,886	880,636	1,386 (1,034)
Minneapolis	20.43	1.37	12,531	2,387	811,622	1,240 (926)
Omaha	19.12	1.48	10,668	2,745	836,105	1,265 (944)
Phoenix	19.45	1.58	6,034	2,778	1,007,697	1,524 (1,137)
San Antonio	19.45	1.17	8,561	2,872	1,002,965	1,532 (1,143)
Seattle	16.28	0.60	6,426	1,696	812,275	1,265 (944)
Washington, D.C.	18.00	1.53	7,584	2,784	800,958	1,248 (932)

2. Variable speed drives added to chilled water and condenser water pumps.

Costs of upgrades. The costs assumed for each of the modeled upgrades are summarized in Table 4.

Limitations of Modeling Analysis. There are some limitations of this modeling analysis that it is important to keep in mind. First, the package of upgrades was predetermined and was uniformly applied to office buildings in all locations. As a result, the modeling results include some examples of technologies that were included but may not be the best combination for that location, and at least as many examples where other technologies or upgrades might make better economic sense. In actual buildings, the Energy Star Buildings staged strategy would result in a more customized approach, where for each building and each stage of the upgrade, energy savings were maximized subject to the prime plus 6 profitability test. For example, while we modelled the office building in Phoenix only with reduced loads and a new high-efficiency chiller, in reality, the economic value of the project might have been increased further by additionally incorporating an evaporative cooling system, operating on its own or in conjunction with a much smaller chiller.

In addition, the economic analysis does not account for any subjective consideration of inter-stage capital cost savings. One of the features of the staged approach is that the basket of upgrades that are selected for each stage are

Table 4. Upgrade Costs by Stage

Stage	Upgrade	Units	Cost	Economic Life, years
Stage 1 Green Lights	Lighting System	$/ft^2	0.82	15
Stage 2 Building Survey and Tuneup	Building Survey and Tuneup	$/ft^2	0.10	3
Stage 3 Loads Reduction	Energy Star Computers	$/ft^2	0.00	5
	Window Films	$/ft^2 window area	2.00	5
	Roof Insulation	$/ft^2 roof area	0.50	15
Stage 4 Air Distribution Systems	System Survey, Fixed Cost	$/building	200.00	15
	System Survey Costs per AHU	$/AHU	50.00	15
	Fan VSD Equipment	$/hp	121.75	15
	VSD Installation	$/motor	200.00	15
	High Efficiency Motors	$/hp	44.40	15
	High Efficiency Motors Installation	$/motor	90.00	15
Stage 5 Central Plant	Chiller Retrofit Costs	$/ton	47.18	30
	Chiller Replacement Costs	$/ton	180.33	30
	Net Chiller Costs	$/ton	83.16	30
	Pump VSD Equipment	$/ton	10.04	15
	VSD Installation	$/building	400.00	15

Sources: Konkel 1987, McCoy et al. 1993, R.S. Means 1993, Washington State Energy Office 1994.

evaluated on a stand-alone basis to determine if the upgrade alone has a sufficient return on investment. This approach has the appeal of simplicity, and in general the ordering of the stages will assure that the inter-system impacts are taken into account. Note that the modeling analysis *does* take credit for the indirect *energy savings* that result from a given upgrade, but does not take credit for potential downsizing *equipment cost* savings associated with another stage. For example, upgrading to more efficient lighting directly reduces the peak load and operating cost of the existing chiller. It also indirectly affects the cost of replacement chiller because of the reduction in peak load. For this example, the economic analysis includes the operating cost cooling savings for the existing chiller as a part of the total energy savings associated with Stage 1, but does not include consideration of future equipment cost savings that result when the chiller was replaced. In the case of technology upgrade options whose the economic return is marginal, participants are encourage to consider those inter-stage effects. This might be the case, for example, with the evaluation of window films or other envelope load reducing measures in Stage 3.

Another related economic accounting issue concerns where credit is taken for reducing equipment capacity due to original oversizing. The clearest example is fan systems, which we modeled to be 30 percent oversized in the baseline building. The energy savings credit due to minimizing wasteful part-load operations might be associated with changing the fan pulley in Stage 2 as a part of an overall building commissioning project, or might be associated with Stage 4, where the installation of a VSD would ensure that the fan would operate efficiently at part loads, even if the equipment itself were oversized.

Results of DOE-2 Parametric Analysis

Substantial Overall Energy Savings and Equipment Cost Reductions. The overall results for the eight locations are summarized in Table 5. In all cases, the EPA Energy Star Buildings staged approach resulted in substantial reductions in the size and cost of replacement of HVAC equipment, as well as substantial energy savings. Total savings for the office buildings results presented here averaged 49 percent, and ranged from 27 to 60 percent. The estimated cost for these upgrades was approximately $0.72 to $2.00/ft2, depending

Table 5. Summary Results for All Sizes and Locations

Size/Location	Annual Energy	Annual Energy Cost	Internal Rate of Return	Peak Demand	Peak Chiller Load	Fan Supply Air CFM	Fan Motor Size
	Percent Reduction Average (Min/*Max*)						
All Sizes/All Locations	**49%** (42/*57*)	**47%** (40/*55*)	**54%** (21/*79*)	**39%** (23/*48*)	**50%** (42/*55*)	**35%** (32/*39*)	**64%** (63/*67*)
Lowrise/All Locations	**39%** (27/*47*)	**38%** (26/*47*)	**52%** (30/*86*)	**33%** (21/*37*)	**48%** (35/*54*)	**32%** (28/*35*)	**63%** (61/*64*)
Midrise/All Locations	**51%** (45/*58*)	**49%** (42/*57*)	**52%** (16/*75*)	**41%** (35/*48*)	**50%** (43/*54*)	**35%** (33/*37*)	**64%** (63/*66*)
Highrise/All Locations	**54%** (49/*60*)	**52%** (46/*59*)	**59%** (20/*80*)	**41%** (12/*56*)	**52%** (44/*56*)	**38%** (34/*43*)	**66%** (64/*69*)
Los Angeles/All Sizes	**50%** (40/*55*)	**48%** (37/*54*)	**73%** (67/*75*)	**38%** (29/*49*)	**50%** (48/*54*)	**37%** (32/*43*)	**66%** (63/*69*)
Miami/All Sizes	**57%** (49/*60*)	**55%** (47/*59*)	**72%** (63/*80*)	**48%** (36/*56*)	**53%** (52/*54*)	**33%** (31/*34*)	**63%** (62/*64*)
Minneapolis/All Sizes	**43%** (30/*49*)	**42%** (32/*46*)	**55%** (43/*86*)	**43%** (37/*45*)	**50%** (42/*53*)	**36%** (29/*39*)	**64%** (61/*66*)
Omaha/All Sizes	**46%** (37/*51*)	**44%** (36/*48*)	**52%** (46/*57*)	**40%** (35/*42*)	**54%** (53/*55*)	**37%** (35/*39*)	**66%** (64/*67*)
~~**Phoenix**/All Sizes~~	~~**55%** (47/*58*)~~	~~**51%** (42/*56*)~~	~~**61%** (47/*71*)~~	~~**47%** (35/*55*)~~	~~**49%** (49/*50*)~~	~~**35%** (34/*36*)~~	~~**64%** (63/*65*)~~
San Antonio/All Sizes	**52%** (44/*56*)	**51%** (43/*55*)	**43%** (30/*51*)	**34%** (31/*36*)	**51%** (50/*52*)	**34%** (32/*35*)	**64%** (63/*64*)
Seattle/All Sizes	**43%** (27/*50*)	**40%** (26/*46*)	**43%** (16/*30*)	**26%** (12/*37*)	**42%** (35/*44*)	**34%** (28/*37*)	**64%** (61/*65*)
Washington, D.C./All Sizes	**48%** (38/*53*)	**47%** (38/*51*)	**58%** (50/*65*)	**35%** (34/*35*)	**55%** (54/*56*)	**36%** (34/*37*)	**65%** (64/*66*)

on building size, location and upgrade options; yielding internal rates of return ranging from 20 percent to 80 percent. In addition, the size required for replacement fan and chiller equipment was dramatically reduced at each site by 50 percent or more as a result of reducing the existing oversizing, and matching the replacement equipment to the reduced loads (with a margin of 10 percent).

Detailed Results Show Advantages of Staged Approach. Table 6 shows the stage-by-stage modeling results for a high-rise building in Washington, D. C. These results demonstrate two important points. First, the first three stages (lighting upgrades, building tune-up and other HVAC load reductions) each have a significant impact on peak HVAC demand. Second, the economic value of the upgrades is enhanced by these load reductions, and each stage individually generates a profitable rate of return.

Substantial Opportunist y to Realize Savings Through Commissioning and Load-matching. The savings associated with Stage 2 of the upgrade (Building Tune-up) are particularly noteworthy. They demonstrate clearly the economic penalty associated with building systems that are over-sized or are operating inefficiently. The broader and more significant value of this commissioning work is to formalize a system of comprehensive, regular preventative maintenance and building monitoring. Providing facility managers and other participants with the tools to easily compile a pie-chart snapshot of energy consumption in the building improves upgrade-planning decision-making. These data can also provide the basis for more precise equipment specifications, further enhancing overall energy savings.

Conclusions

The staged strategy of the EPA Energy Star Building program is one that offers a number of advantages for building energy efficiency upgrades, and can result in higher levels of energy savings than other approaches such as the a la carte measure selection, or a modeling approach that does not incorporate field confirmation or refinement of engineering estimates. The DOE-2 parametric modeling analysis summarized above confirms the potential savings that can be realized through the application of this staged strategy.

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Table 6. Summary Results for All-Electric Highrise Office in Washington, D.C.

Energy Performance

Energy Star Buildings Stage	Total Energy Cost, $/ft^2	Total Energy, kWh/ft^2	Peak Demand, kW	Peak Cooling, tons	Supply Air, CFM	Fan Motor Size, hp
Existing Building Conditions	$1.53	18.00	7,584	2,784	800,958	1,248
Stage 1 Green Lights	$1.12	12.34	8,148	2,405	800,958	1,248
Stage 2 Building Survey and Tuneup	$1.00	11.53	6,514	1,551	800,958	1,159
Stage 3 Load Reductions	$0.96	10.85	6,464	1,507	800,958	1,159
Stage 4 Air Distribution Systems	$0.80	9.05	5,007	1,320	503,261	430
Stage 5 Central Plant	$0.74	8.51	5,007	1,235	503,261	430
Totals	$0.79	9.49	2,577	1,549	297,697	818
	51%	53%	34%	56%	37%	66%

End-Use Energy Performance

Energy Star Buildings Stage	Lights, kWh	Fans, kWh	Chiller, kWh	Heat, kWh	Equipment, kWh	Other, kWh
Existing Building Conditions	6,319,849	1,478,715	1,882,409	961,939	2,828,011	1,645,637
Stage 1 Green Lights	1,842,767	1,363,523	1,256,662	1,536,632	2,828,011	1,538,639
Stage 2 Building Survey and Tuneup	1,842,767	1,265,807	1,370,941	976,622	2,632,815	1,592,633
Stage 3 Load Reductions	1,842,767	1,231,942	1,266,661	995,397	2,205,287	1,575,420
Stage 4 Air Distribution Systems	1,842,767	195,790	903,716	1,021,407	2,205,287	1,431,080
Stage 5 Central Plant	1,842,767	195,790	512,131	1,021,407	2,205,287	1,369,999
Totals	4,477,082	1,282,925	1,370,278	-59,468	622,724	275,638
	71%	87%	73%	-6%	22%	17%

Economic Analysis

	Total Upgrade Cost, $	Upgrade Cost, $/ft^2	Internal Rate of Return	Net Present Value	Percent of Total Energy Cost Savings	Percent of Total Energy Savings
Existing Building Conditions	N/A	N/A	N/A	N/A	N/A	N/A
Stage 1 Green Lights	688,800	$0.82	51%	$1,746,123	53%	60%
Stage 2 Building Survey and Tuneup	84,000	$0.10	96%	$330,626	14%	9%
Stage 3 Load Reductions	21,000	$0.03	174%	$210,471	6%	7%
Stage 4 Air Distribution Systems	80,500	$0.10	164%	$845,015	20%	19%
Stage 5 Central Plant	121,887	$0.15	42%	$258,277	8%	6%
Totals	996,186	$1.19	65%	$3,390,511	100%	100%

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