Energy Savings In Relation To Indoor Environmental Quality

John D. Hall, ICF Consulting Group, Fairfax VA
David H. Mudarri, U.S. Environmental Protection Agency, Washington, D.C.
Eric Werling, ICF Consulting Group, Fairfax VA

ABSTRACT

Many actions taken to improve energy efficiency have secondary effects on the quality of the indoor environment. This secondary effect may be to improve indoor environmental quality(IEQ), leave IEQ relatively unaffected (provided that certain cautions and adjustments are adhered to), or degrade IEQ, sometimes substantially. These IEQ-related effects are often ignored in the design of energy efficiency projects because many energy professionals believe that protecting IEQ would necessarily lead to significant energy penalties. The resulting effects of energy efficiency improvements on IEQ are often surprising and sometimes unnecessarily harmful. Using the DOE 2.1E computer simulation program, it is estimated that a staged energy retrofit program using typical energy efficiency measures for an office building or education building can cut energy costs in half while still protecting or enhancing IEQ. Further, only modest energy penalties need to be associated with meeting the IEQ ventilation requirements of ASHRAE Standard 62-1989 (ASHRAE 1989) for both office and education buildings. For education or other buildings with high occupant densities, upward adjustments to variable air volume (VAV) box minimum settings as well as relative humidity control may be necessary to ensure that the minimum ventilation rates and thermal comfort requirements of ASHRAE Standard 62-1989 and ASHRAE Standard 55-1992 (ASHRAE 1989, 1992) are met. However, the energy penalty associated with these requirements can be greatly reduced or negated with the use of energy recovery technologies. Thus, counter to common perceptions, this paper demonstrates that energy efficiency and indoor environmental quality projects can be successfully integrated. It is suggested that energy professionals can improve the IEQ of the buildings they service, and consider these improvements as an opportunity to promote their projects on the basis of these added benefits.

***Disclaimer**: Any opinions or conclusions expressed in this paper are those of the authors and do not necessarily represent ICF Consulting Group or the U.S. Environmental Protection Agency.*

Introduction

Purpose of Study

Many energy professionals believe that indoor environmental quality (IEQ) necessarily leads to significant energy penalties and therefore deliberately ignore it in their projects. However, building owners and managers are under increased pressure from many circles to provide good IEQ. There are many opportunities to advance IEQ during the course of energy projects without sacrificing energy efficiency. These opportunities provide energy professionals with the potential to gain a competitive edge by marketing proposals that are responsive to IEQ needs to a clientele that is becoming increasingly sensitive to this issue.

Actions taken to improve energy efficiency often have a secondary effect on the quality of the indoor environment. This secondary effect may be to improve indoor environmental quality (IEQ), leave IEQ relatively unaffected (provided that certain cautions and adjustments are adhered to), or degrade IEQ, sometimes substantially. The purpose of this paper is to help reconcile the desire to provide a quality indoor environment that supports the health and comfort of occupants, with the very important objective of reducing energy use. The paper assesses energy projects in commercial (non-residential) and education buildings. Using strategies outlined in this paper, energy professionals can design projects for clients that result in both improved energy efficiency and improved indoor environments, and as a result potentially gain a competitive edge over those that offer "business as usual" energy efficiency improvements.

Relationship Between Energy Efficiency and Indoor Environmental Quality

The indoor environmental factors that most influence occupant health and welfare are thermal conditions, lighting, and the concentrations of indoor pollutants. Thermal control and lighting are familiar subjects in energy management. Accordingly, energy professionals are in a strong position to affect these two important aspects of the indoor environment. However, energy professionals are often less knowledgeable about the third factor--indoor pollutant concentrations. Pollution concentrations are strongly influenced by the HVAC system's characteristics and operating parameters. Although energy professionals are often responsible for the design, control, and modification of the ventilation systems, they are often not fully aware of the resulting effects of these systems on IEQ.

Much of the perceived conflict between IEQ and energy efficiency derives from just two elements of an energy strategy-- the tendency to minimize outdoor air ventilation rates, and the willingness to relax controls on temperature and relative humidity to save energy. Energy activities that are compatible with IEQ, either because they are likely to enhance or have little effect on IEQ if properly instituted, are identified in Table 1. The compatibility with IEQ is critically dependent on the cautions and adjustments which are outlined in this table.

Some energy projects may inadvertently or needlessly degrade the indoor environment. The energy project activities that have the greatest potential for degrading the indoor environment are listed in Table 2. Energy project managers and their clients should be extremely cautious with these activities to ensure that the indoor environment is not compromised.

Methodology

Energy simulation modeling using the DOE-2.1E computer program was used to estimate the relative energy impacts of various energy efficiency measures and of selected indoor environmental controls. This was done in the context of a staged energy retrofit program for an office building and an education building in three representative climates--Washington D.C. (temperate), Miami (hot/humid), and Minneapolis (cold). A description of the buildings modeled is presented in Table 3.

The staged retrofit included operational (tune-up) measures in Stage 1, load reduction measures in Stage 2, air distribution system upgrades in Stage 3, central plant upgrades in Stage 4, and selected IEQ upgrades in Stage 5. The building and HVAC parameters of the base office and base education buildings that were modeled are presented in Table 4. Elements of Table 1 that describe the adjustments required for the protection of IEQ are implicit in the modeling of these activities in Stages 1-4. Specific improvements to the outdoor air ventilation rate and controls are modeled in Stage 5. All of this modeling is part of a larger project: *Energy Costs and IAQ Performance of Ventilation Systems and Controls*, selected results of which have been reported elsewhere (Mudarri et al.1993,1996a,b).

Table 1: Energy Measures that are Compatible With IEQ

Measure	Comment
Improve building shell	- May reduce infiltration. May need to increase mechanically supplied outdoor air to ensure applicable ventilation standards are met.
Reduce internal loads (e.g. lights, office equipment)	- Reduced loads will reduce supply air requirements in VAV systems. May need to increase outdoor air to meet applicable ventilation standards. - Lighting must be sufficient for general lighting and task lighting needs
Fans, motors, drives	- Negligible impact on IEQ
Chiller/ boiler	- Negligible impact on IEQ
Energy recovery	- May reduce energy burden of outdoor air, especially in extreme climates and/or when high outdoor air volumes are required (e.g. schools, auditoria).
Air-side economizer	- Uses outdoor air to provide free cooling. Potentially improves IEQ when economizer is operating by helping to ensure that the outdoor air ventilation rate meets IEQ requirements. - On/off set points should be calibrated to both the temperature and moisture conditions of outdoor air to avoid indoor humidity problems. May need to disengage economizer during an outdoor air pollution episode.
Night pre-cooling	- Cool outdoor air at night may be used to pre-cool the building while simultaneously exhausting accumulated pollutants. However, to prevent microbiological growth, controls should stop pre-cooling operations if dew point of outdoor air is high enough to cause condensation on equipment.
Preventive Maintenance (PM) of HVAC system	- Various aspects of PM will improve IEQ and reduce energy use by removing contaminant sources (e.g. clean coils/drain pans), and insuring proper calibration and efficient operation of mechanical components (e.g. fans, motors, thermostats, controls)..
CO_2 controlled ventilation	- CO_2 controlled ventilation varies the outdoor air supply in response to CO_2 which is used as an indicator of occupancy. May reduce energy use for general meeting rooms, studios, theaters, educational facilities etc. where occupancy is highly variable, and irregular. A typical system will increase outdoor air when CO_2 levels rise to 600-800 ppm to ensure that maximum levels do not exceed 1,000 ppm. The system should incorporate a minimum outside air setting to dilute building related contaminants during low occupancy periods.
Reducing demand (KW) charges	- Night pre-cooling and sequential startup of equipment to eliminate demand spikes are examples of strategies that are compatible with IEQ. Caution is advised if load shedding strategies involve changing the space temperature set points or reducing outdoor air ventilation during occupancy.

Supply air temperature reset	- Supply air temperature may sometimes be increased to reduce chiller energy use. (However, fan energy will increase). Higher supply air temperatures in a VAV system will increase supply air flow and vice versa.
Equipment down-sizing	- Prudent avoidance of over-sizing equipment reduces first costs and energy costs. However, capacity must be sufficient for thermal and outdoor air requirements during peak loads in both summer and winter. Latent load should not be ignored when sizing equipment in any climate. Inadequate humidity control has resulted in thermal discomfort and mold contamination so great as to render some buildings uninhabitable. - Energy recovery systems may enable chillers and boilers to be further downsized by reducing the thermal loads from outdoor air ventilation.

Table 2: Energy Activities That May Degrade IEQ

Energy Measure	Comment
Reducing outdoor air ventilation	- Applicable ventilation standards usually specify a minimum continuous outdoor air flow rate per occupant, and/or per square foot, during occupied hours. They are designed to ensure that pollutants in the occupied space are sufficiently diluted with outdoor air. Reducing outdoor air flow below applicable standards can degrade IEQ and has low energy saving potential relative to other energy saving options.
Variable Air Volume (VAV) Systems with fixed percentage outdoor air	- VAV systems can yield significant energy savings over Constant Volume (CV) systems in many applications. However, many VAV systems provide a fixed percentage of outdoor air (e.g. fixed outdoor air dampers) so that during part load conditions when the supply air is reduced, the outdoor air may also be reduced to levels below applicable standards. - VAV systems should employ controls which maintain a continuous outdoor air flow consistent with applicable standards. Hardware is now available from vendors and involves no significant energy penalty.
Reducing HVAC operating hours	Delayed start-up or premature shutdown of the HVAC can evoke IEQ problems and occupant complaints. - An insufficient lead time prior to occupancy can result in thermal discomfort and pollutant-related health problems for several hours as the HVAC system must overcome the loads from both the night-time setbacks and from current occupancy. This is a particular problem when equipment is downsized. Shutting equipment down prior to occupants leaving may sometimes be acceptable provided that fans are kept operating to ensure adequate ventilation. However, the energy saved may not be worth the risk .
Relaxation of thermal control	Some energy managers may be tempted to allow space temperatures or humidity to go beyond the comfort range established by applicable standards. Occupant health, comfort and productivity are compromised. The lack of overt occupant complaints is NOT an indication of occupant satisfaction.

Table 3: Building Characteristics

Parameter	Office	Edu	Parameter	Office	Edu
shape	square	L-shaped	window R-value (hr ft^2 ^{0}F/Btu)	2.0	1.5
zones/floor	5	6	window shading coeff.	0.8	0.9
floor area (ft^2)	338,668	50,600	roof R-value (hr ft^2 ^{0}F/Btu)	14	10
number of floors	12	2	perimeter/core ratio (f^2/ft^2)*	0.5	1.0
floor height (ft)	15	15	infiltration rate (ach)	0.5	1.0
occupancy (occ./1000ft^2)	7	30	exhaust flow (cfm)	750	335
operating hours (hrs/day)	12	17	**ratio of perimeter to core floor area*		

Table 4: Modeling Parameters for the Base Office and Education Building

Building Parameter	Office Building		Education Building	
	Base	**Modification**	**Base**	**Modification**
Stage 1: Operational/Tune-up Measures				
Day Temp. Set Points	71° - 77° F	*(68° - 80° F)*	71° - 77° F	*(68° - 80° F)*
Night Set Back	+/- 10° F	*(+/- 15° F)*	+/- 10° F	*(+/- 15° F)*
Day HVAC Hours	8am - 6pm	*(9am - 5pm)*	7am -10pm	*(8am - 9pm)*
Seasonal Reset	No	Yes	No	Yes
Entries in parethesis were modeled separately–not partr of the retrofit project				
Stage 2: Load Reduction Measures				
Lighting	2.5 W/f2	30% reduction	3.0 W/f^2 rms 2.0 W/f^2 corr	30% reduction
Office Equipment	1.0 W/f^2	30% reduction	0.25 W/f^2	30% reduction
Stage 3: Air distribution System Upgrades				
VSD	no	yes	no	yes
Stage 4: Central Plant Upgrades				
Chiller COP	3.0	5.5	3.0	5.5
Boiler Efficiency	70%	85%	70%	85%
Stage 5: IEQ Ventilation Modifications Required to meet ASHRAE 62-1989				
Outdoor Air Setting	5 cfm/occ	20 cfm/occ	5 cfm/occ	15 cfm/occ
Outdoor Air Control	fixd dampr	constant flow	constant flow	const. flow-VAV box adjustment
Humidity Control	not needed	not needed	not needed	60% RH

Both buildings were modeled with a variable air volume ventilation system with an air side economizer. The base office building has a fixed outdoor air damper that supplies a constant percentage of outdoor air in the supply air stream. The damper is positioned to circulate 5 cfm of outdoor air per occupant at design (peak) load. The education building was modeled using damper controls that supply a constant volume of outdoor air and are positioned to circulate 5 cfm of outdoor air per occupant at all load conditions.

Results

Energy Savings from Stages 1-4

The results from the staged energy activities for the office building are presented in Table 5. Only one operational measure--seasonal reset of supply air temperature--was modeled in Stage 1. Other measures which are typically included in Stage 1 could either not be modeled or were modeled independently and are not part of the staged energy program. A discussion of operational measures typically included in Stage 1 is presented in a separate section below.

For the temperate climate of Washington D.C., the seasonal supply air temperature reset strategy in Stage 1 resulted in insignificant reductions (1%)[1] in total energy costs of the base building. A further reduction of 31% over Stage 1 was achieved through a lighting retrofit and increased efficiency of office equipment in Stage 2. The Stage 3 upgrades relied solely on variable speed drives (VSD) which reduced the energy costs an additional 8% over Stage 2. Finally, in Stage 4, central plant upgrades, including down-sizing the equipment because of reduced loads[2] added another 13% savings over the total energy cost in Stage 3, bringing the combined total energy cost savings to 45% over the base building. These results are consistent with EPA's experience in the Energy Star program where typical lighting retrofits result in 25%-30% savings, while other retrofits result in 5%-15% savings depending on the particular retrofit and the context of its application.

The results for the office building in Minneapolis and Miami, also shown in Table 5, are similar with some exceptions. The seasonal supply air temperature reset in Miami added an energy penalty due entirely to the increase in fan energy with no offsetting savings in cooling energy. The lighting retrofit achieved greater overall savings in Miami and lower savings in Minneapolis because of the attendant effects of reduced internal gains on the cost of heating (increase) and on the cost of cooling (decrease). Similarly, the savings from the VSD retrofit are greatest in Minnesota, where loads are variable, and lowest in Miami where the loads are more constant.

The results for the education building which are shown in Table 6, are similar to the office building results with some exceptions. The higher base building HVAC energy loads in the education building result primarily from the higher occupant densities and the associated higher ventilation rate, lower shell efficiencies, and higher perimeter to core ratio compared to the office building. Energy savings from lighting and office equipment retrofits were lower compared to the office building. Since the lighting and office equipment in the education building constitute a lower proportion of total loads, the secondary savings on the HVAC system in Stage 2 are less. Finally, the education building experienced greater energy savings from improved central plant efficiencies in Stage 4 because of the larger loads compared to the office building.

---

[1] Unless otherwise noted, all percentages reported in this paper are a percent of total (HVAC plus lighting and office equipment) energy as opposed to a percent of a specific end use.

[2] The equipment was downsized, but the final sizing was designed to accommodate increased outdoor air flow of 20 cfm per occupant for the office building, and 15 cfm per occupant for the education building as per ASHRAE Standard 62-1989.

While many of these activities implemented in Stages 1 through 4 above could impact IEQ, all the necessary adjustments identified in Table 1 were made or are implicit in the model's algorithms to ensure that IEQ would not be degraded. Thus, the modeling in Stages 1-4 suggests that it is quite feasible to cut the energy budget in office and/or educational buildings by 40%-50% or more without adversely impacting a building's IEQ, though this does not include the energy impacts of increasing outdoor air ventilation (see next section).

Table 5: Energy Cost for Office Building With Energy and IEQ Modifications

Parameter	Washington D.C. ($/f²)						Minneapolis ($/f²)			Miami ($/f²)		
	Fan	Cool	Heat	Total HVAC	Light/ Off. Equip	Total	Total HVAC	Light/ Off. Equip	Total	Total HVAC	Light/ Off. Equip	Total
Base Bldg	0.17	0.42	0.05	0.64	0.94	1.58	0.68	0.94	1.62	0.74	0.94	1.68
Stage 1 Seas. Rset	0.18	0.41	0.04	0.63	0.94	1.57	0.66	0.94	1.60	0.78	0.94	1.72
Stage 2 Ltng/OE	0.15	0.30	0.06	0.52	0.57	1.08	0.58	0.57	1.16	0.57	0.57	1.15
Stage 3 VSD	0.09	0.28	0.06	0.43	0.57	1.00	0.47	0.57	1.04	0.52	0.57	1.09
Stage 4 Chllr/Boilr	0.09	0.16	0.05	0.30	0.57	0.87	0.33	0.57	0.90	0.35	0.57	0.93
Stage 5 OA Setting	0.09	0.18	0.06	0.32	0.57	0.89	0.36	0.57	0.93	0.38	0.57	0.95
OA Control	0.09	0.19	0.06	0.33	0.57	0.90	0.37	0.57	0.94	0.40	0.57	0.97

Table 6: Energy Cost for Education Building With Energy and IEQ Modifications

Parameter	Washington D.C. ($/f²)						Minneapolis ($/f²)			Miami ($/f²)		
	Fan	Cool	Heat	Total HVAC	Light/ Office Equip	Total	Total HVAC	Light/ Office Equip	Total	Total HVAC	Light/ Office Equip	Total
Base Bldg	0.21	0.62	0.28	1.11	0.97	2.08	1.42	0.97	2.40	1.22	0.97	2.19
Stage 1 Seas. Rset	0.21	0.61	0.25	1.07	0.97	2.04	1.38	0.97	2.36	1.23	0.97	2.21
Stage 2 Ltng/OE	0.19	0.53	0.33	1.04	0.67	1.71	1.42	0.67	2.10	1.08	0.67	1.76
Stage 3 VSD	0.11	0.50	0.33	0.94	0.67	1.62	1.30	0.67	1.97	0.98	0.67	1.65
Stage 4 chllr/boilr	0.11	0.29	0.28	0.67	0.67	1.35	0.98	0.67	1.65	0.64	0.67	1.31
Stage 5 OA Setting	0.12	0.35	0.35	0.82	0.67	1.49	1.19	0.67	1.68	0.73	0.67	1.40
OA Control	0.13	0.36	0.38	0.87	0.67	1.54	1.20	0.67	1.87	0.71	0.67	1.38

Energy Impacts In Stage 5–Increasing Outdoor Air to Meet ASHRAE Standard 62-1989

The base buildings provided only 5 cfm of outdoor air per occupant (i.e. does not meet the current ASHRAE ventilation requirements for indoor air quality (ASHRAE, 1989)). To meet the ASHRAE ventilation requirements, a set of IEQ controls were instituted as part of Stage 5. The first control was to raise the outdoor air control setting at the air handler to 20 cfm per occupant in the office building, and 15 cfm per occupant in the education building. This increases the outdoor air design flow rate, but since the office building has a fixed outdoor air damper (constant outdoor air fraction), ASHRAE Standard 62-1989 requirements are not met at part- load conditions (Mudarri et al.1996b). To solve this problem, the fixed position outdoor air damper was replaced with a constant outdoor air flow control (e.g. modulating damper) in the office building. This control allows the outdoor air flow rate to remain at the design level even at part-load.

The education building also displayed humidity problems at the higher ventilation rate. The relative humidity sometimes rose above 60% and occasionally above 70% in all climates. This situation causes thermal discomfort (ASHRAE, 1992) and adds to the potential for microbiological contamination. Relative humidity was therefore maintained at 60% or less by lowering the cooling coil temperature when required to meet the latent load.

The results of these ventilation modifications for the office and education building are presented at the end of Tables 5 and 6. For office buildings, the cost of increasing outdoor air to meet ASHRAE 62-1989 is 3-4% of total energy use in all climates--less than many energy practitioners expect. These results are consistent with other studies (Eto, 1990; Eto and Meyer, 1988; Steele and Brown, 1990; Ventresca, 1991). This is because, during a large portion of the year, additional outdoor air provides free cooling during most of the year. In HVAC systems with economizers already installed, the energy penalty from additional outdoor air is only experienced in extreme weather conditions, and mostly during the summer months. In the winter months, the economizer would still provide 20 cfm of outdoor air per occupant in most office spaces even with outdoor air temperatures as cold as 0° F (Mudarri et al. 1996a,b; Ventresca, 1991).

In the education building, meeting ASHRAE Standard 62-1989 increased total energy costs by 5%-14% . Interestingly, the adjustments for outdoor air and humidity control for the education building had the highest energy penalty (13–14%) in Washington D.C. and in Minneapolis, but in Miami, the energy penalty was only 5%. This runs contrary to conventional wisdom but is explained by the fact that in temperate and cold climates, there is a substantial heating penalty associated with the outdoor air adjustments which is not present in hot/humid climates. Another counter-intuitive phenomenon is evident in Miami. Increasing the outdoor air setting accounts for a substantial energy penalty (7%). However, the VAV box and humidity controls reduced the increase to only 5%. This is because by lowering the cooling coil temperature when needed to control humidity, a considerable reduction in fan energy was achieved that more than offset the increase in cooling energy.

Measures to Mitigate the Energy Cost of Outdoor Air Ventilation

At higher occupant densities, such as in education buildings, satisfying ASHRAE Standard 62-1989 requires a substantial increase in outdoor air and this can create a substantial energy penalty. Outdoor air ventilation with an energy recovery system thus becomes an attractive method for reducing the energy cost of this ventilation requirement. Unfortunately, DOE-2.1E does not have capabilities which are sufficiently sophisticated to reliably model energy recovery technologies (especially latent heat recovery). However, available literature suggests that energy recovery systems can eliminate or substantially reduce the energy penalty created by raising outdoor air levels to meet ASHRAE Standard 62-1989, at least for office buildings in hot and humid climates (Rengarajan, et al. 1996; Shirey and Rengarajan, 1996). The efficiency of energy recovery systems ranges from 50% - 75%. Thus, the 5% to 14% cost of maintaining outdoor air ventilation rates at 15 cfm year round with humidity controlled in education buildings could well be reduced to 3% to 7% with the use of energy recovery.

Stage 1 Operational Measures Modeled Separately

Many energy measures with significant potential to adversely impact IEQ occur in Stage 1, and involve either relaxing temperature (and humidity) controls and/or reducing HVAC operating hours. Table 4 identifies modeling scenarios for relaxing daytime temperature controls, night time temperature controls, and HVAC operating hours. These scenarios were modeled separately. Table 7 summarizes the results of these modeling runs.

Table 7: Energy costs ($/f²) with operational measures having adverse effects on IEQ

	Washington D.C.						Minneapolis		Miami	
	Fan	Cool	Heat	Total HVAC	Light/ Office Equip	Total	Total HVAC	Total	Total HVAC	Total
Base Office Bldg	**0.17**	**0.42**	**0.05**	**0.64**	**0.94**	**1.58**	**0.68**	**1.62**	**0.74**	**1.68**
Day Temp. Set Pts	0.17	0.40	0.04	0.61	0.94	1.56	0.64	1.58	0.71	1.65
Night Set Back	0.16	0.41	0.04	0.62	0.94	1.56	0.66	1.60	0.72	1.66
Day HVAC Hours	0.17	0.42	0.04	0.63	0.94	1.57	0.66	1.60	0.75	1.69
Base Edu. Bldg.	**0.21**	**0.62**	**0.28**	**1.11**	**0.97**	**2.08**	**1.42**	**2.40**	**1.22**	**2.19**
Day Temp. Set Pts	0.18	0.55	0.22	0.95	0.97	1.93	1.25	2.23	1.06	2.03
Night Set Back	0.21	0.62	0.27	1.10	0.97	2.07	1.40	2.38	1.22	2.19
Day HVAC Hours	0.20	0.61	0.25	1.06	0.97	2.02	1.34	2.31	1.18	2.15

Widening the day time temperature dead band from 71-77^0 F to 68-80^0 F reduced total energy costs by 2%-3% in the office building, and by 7%-8% in the education building. Relaxing the night time temperature setback from +/- 10°F to +/- 15°F reduced total energy costs from 1%-2% in the office and from 0%-1% in the education building. Reducing the HVAC operating time by two hours (including a reduction of startup time from 2 hours to 1 hour), reduced total energy costs by 0%-1% for the office building and by 2%-4% in the education building. Had all these measures been included simultaneously in Stage 1, the total energy cost savings in Stage 1 would have increased to 3%-5% for the office building and to 7%-10% in the education building. While these operational measures are inexpensive to implement, they reduce energy costs only slightly when compared to the retrofits, and, they have a very high potential for degrading IEQ. Conversely, the retrofit measures in Stages 2-4 are more expensive to implement, but can result in substantial energy savings (40%- 50%) with little or no adverse effect on IEQ.

There are other operational measures for Stage 1 that do not degrade IEQ, are also inexpensive to implement, and provide much more significant savings than those described above. Simply commissioning the building to ensure that controls and equipment are functioning properly (not modeled) have been shown to typically reduce total energy costs by 10%-20%, and also tend to improve IEQ (Gregerson, 1997). In addition, reduced lighting usage during unoccupied hours can provide significant energy savings without adversely impacting IEQ. The base office building was modeled with lighting operated during unoccupied hours at 20% of daytime use and office equipment operated at 30% of daytime use. Table 8 compares the modeling results for this case (20%/30%) with both greater usage during unoccupied hours (40%/50%), and more significantly reduced usage (10%/15%) after Stage 4 modifications. As indicated in Table 8, had the usage of the lighting/office equipment in the base office building been modeled at 40%/50% of day time levels and then reduced to 20%/30%, savings of 12% in energy costs would have been possible in Stage 1 from this activity. This result is consistent with field data which shows that energy savings of 15% on average are associated with operational controls (mostly lighting) during unoccupied hours (Herzog, et al. 1992). In addition, an aggressive program to reduce nighttime use of lights and office equipment after the building is made energy efficient and IEQ compatible could provide additional reductions of equal magnitude.

Table 8: Energy savings from reduced lighting and office equipment when unoccupied

Operational Control	**Office Building in Washington D.C. ($/f²)**				
	Energy Cost			Saving	%
(% of daytime use during unoccupied hours)	HVAC	Lght/off equip	Total		
Stage 1					
40% lights/50% office equipment (base case)	0.71	1.08	1.79		
20% lights/30% office equipment	0.64	0.94	1.58	0.21	12%
Stage 4 (retrofitted building)					
20% lights/30% office equipment	0.33	0.57	0.90		
15%lights/20% office equipment	0.29	0.40	0.70	0.20	22%

Thus, in Stage 1, certain low cost operational controls--building commissioning, and reduced lighting and office equipment use during unoccupied hours--can achieve 20%-30% reductions or more in energy costs while improving, or at least not compromising IEQ. It is worthwhile, therefore, to avoid or to be extremely cautious with operational controls that can cause IEQ problems-- relaxed daytime temperature controls, relaxed nighttime setback, or reduced HVAC operating times. Not only are these measures apt to cause IEQ problems, they typically save considerably less (3%-10%)[3] than IEQ compatible controls.

Appealing to the Owners Bottom Line

Reductions in energy use reduce annual costs to the building owner. But when combined with improvements in IEQ, the added benefits can be even more valuable. Employees in buildings with good IEQ complain less, are more productive, and have lower medical expenses when compared with

[3]These results are more robust for the office building than the education building since there is more literature and modeling results to draw from.

complaint buildings. Even a small (<1%) improvement in productivity can be more valuable than saving 30%-50% in energy costs (Fisk and Rosenfeld 1997; USEPA 1989). Similarly, the revenue profile of a rental building may improve as well. For example, data on how tenants rank the importance of various building amenities places indoor air quality and/or good ventilation among the highest ranking tenant concerns (BOMA, 1988; IFMA, 1991). This suggests that improved IEQ may convince one or more tenants to renew their lease rather than seek alternative space. Retaining a tenant will reduce leasehold expenses associated with tenant improvements, reduce brokerage fees, avoid the delay in occupancy associated with a new tenant, and eliminate any offer of free rent that is often used to attract new tenants. The potential for improved net revenues (rents less the costs of renting) from even a modest decrease in vacancy rates because of an owner's ability to retain existing tenants can be substantial. For all of these reasons, improved indoor environmental quality can be as important an economic incentive for energy projects as the energy savings from these projects. Progressive energy service companies (ESCOs) which transform themselves into energy and environmental service companies (EESCOs), following the principles for IEQ outlined in this paper, will be positioned to take advantage of this potential.

CONCLUSIONS

This analysis suggests that energy projects can be made compatible with IEQ without substantial energy loss and with potential gain in client satisfaction. Reduced energy costs in the range of 20-30% are possible through inexpensive operational controls--commissioning and reduced lighting and office equipment use during unoccupied hours--without adverse effects on IEQ. Further energy savings of 40%-50% or more are achievable in a staged energy retrofit program which also does not degrade IEQ. Savings associated with operational controls that may compromise IEQ–relaxed temperature controls, relaxed nighttime setbacks, reduced HVAC operating hours--would likely save only 3%-5% in office buildings, and 7%-10% in education buildings and should be avoided or approached with extreme caution. Increasing the outdoor air flow to accommodate ASHRAE Standard 62-1989 during all operating conditions, and controlling humidity would increase energy costs by only 3-4% in the office building and 5%-14% in the education building. However, the use of energy recovery technology is likely to either eliminate or substantially reduce that penalty. Raising outdoor air flow during part-load required the use of constant outside air control dampers on the VAV systems in both the office and education buildings. In the education building, in order to deliver the high outdoor air volumes needed to meet ASHRAE Standard 62-1989, minimum VAV box settings had to be adjusted upward, and relative humidity controls were needed in all climates.

The attention paid to the indoor environment may provide a competitive edge as energy professionals market their projects to clients who are becoming increasingly sensitive to indoor environmental issues. The potential for building owners to improve worker performance and morale, reduce medical costs, and increase retention of existing tenants due to improved IEQ can enhance the economic viability of any energy project, sometimes significantly.

REFERENCES

ASHRAE, 1989. Ventilation for Acceptable Indoor Air Quality. ANSI/ASHRAE 62-1989. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. Atlanta.

ASHRAE, 1992. Thermal Environmental Conditions for Human Occupancy. ANSI/ASHRAE 55-1992. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. Atlanta.

BOMA. 1988. *Office Tenant Moves and Changes*. Building Owners and Managers Assoc., Washington, D.C.

Eto, J., 1990. The HVAC costs of increased fresh air ventilation rates in office buildings, part 2. *Proc. Of Indoor Air 90: The Fifth International Conference on Indoor Air Quality and Climate*. Toronto.

Eto, J., and C. Meyer, 1988. The HVAC costs of fresh air ventilation in office buildings. ASHRAE Transactions 94(2): 331-345.

IFMA, 1991. Office temperature, lack of storage space rank high among employee complaints. *IFMA News*. International Facility Management Association. Ocotober.

Fisk, W.J, and Rosenfeld A. J. 1997. Estimates of Improved Productivity and Health From Better Indoor Environments. *Indoor Air: International Journal of Indoor Air Quality and Climate*. Vol 7. No. 3.

Gregerson, Joan. 1997. Commissioning Existing Buildings. *Tech Update*. E Source, Inc. TU-97-3. March.

Mudarri, D., and Hall, J. 1993. Increasing outdoor air flow rates in existing bujildings. *Proceedings of Indoor Air '93*, Helsinki, vol. 5, pp. 21-26.

Mudarri, D., Hall, J., Werling, E., and Meisegeier D. 1996a. Impacts of increased outdoor air flow rates on annual HVAC energy costs. Paper presented at the *1996 Conference of the American Council for an Energy-Efficient Economy*. Asilomar, CA.

Mudarri, D., Hall, J. and Werling C. 1996b. Energy costs and IAQ performance of ventilation systems and controls. In *IAQ 96. Paths to Better Building Environments*. Conference of the American Society of Heating, Refrigerating, and Air Conditioning Engineers, Inc. Atlanta.

Rengarajan, K.; Shirey, D. B. III, and Raustad, R.1996. Cost-effective HVAC technologies to meet ASHRAE Standard 62-1989 in hot and humid climates. *ASHRAE Transactions*, V. 102(1).

Shirey D.B. and Rengarajan, K. 1996. Impacts of ASHRAE Standard 62-1989 on small florida offices. ASHRAE Transactions, V. 102(1).

USEPA. 1989. *Report to Congress on Indoor Air Quality; Volume II: Assessment and Control of Indoor Air Pollution*. EPA/400/1-89/001C. US Environmental Protection Agency. Washington, D.C.

Ventresca, J. 1991. Operation and maintenance for IAQ: implications from energy simulation of increased ventilation. *IAQ '91: Healthy Buildings*. Amer. Soc. of Heating, Refrigerating and Air-Cond. Eng. Atlanta.