EEBHUB Energy Efficient Buildings Hub

Triple Bottom Line Benefits of Investing in Lighting and Daylighting Retrofits

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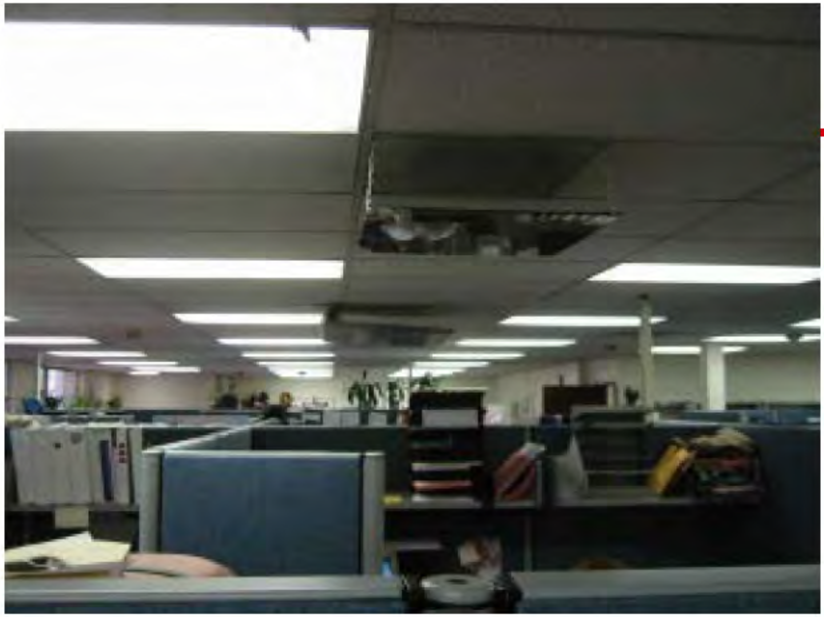
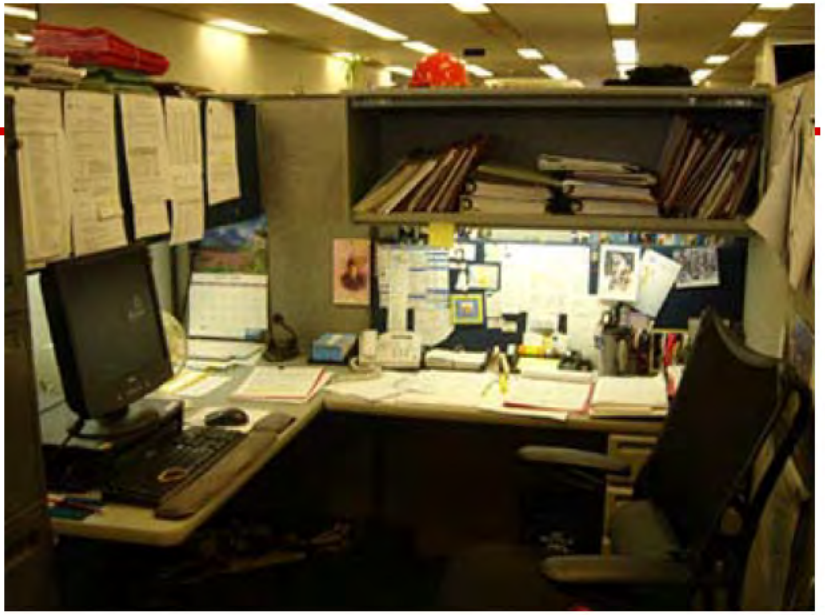
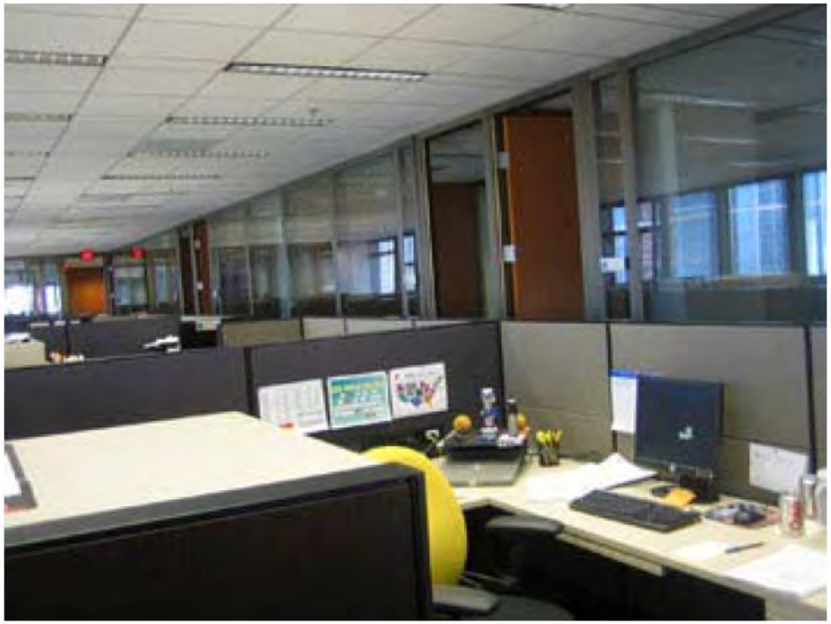
Six Energy Efficient Lighting Retrofits

Recommendations for Triple Bottom Line Savings

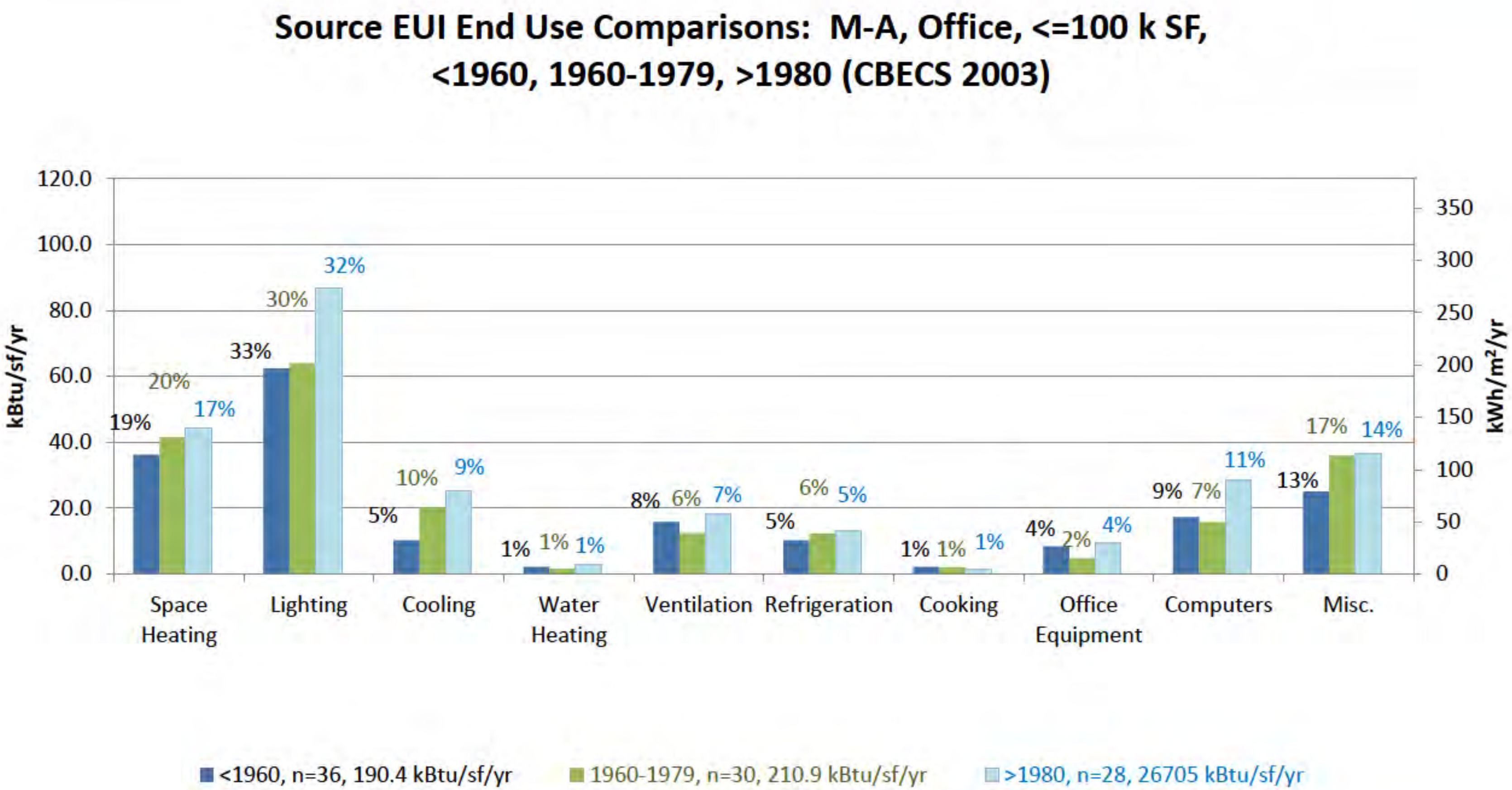
	Light Energy Saved
1 Install occupancy/vacancy sensors for closed spaces. Savings: Economic ROI = 52% Environmental ROI = 68%	13%
2 Install daylight harvesting for perimeter lights. Savings: Economic ROI = 21% Environmental ROI = 28% Equity = 354%	30%
3 Lower task-Ambient light levels and add task lights. Savings: Economic ROI = 32% Environmental ROI = 41% Equity = 142%	40%
4 Use blinds effectively for daylight, shade and glare control as well as for heat exchange control at night. Savings: Economic ROI = 5% Environmental ROI = 7% Equity = 94%	32%
5 Install individually addressable high performance fixtures with automation system. Savings: Economic ROI = 15% Environmental ROI = 19% Equity = 260%	65%
6 Install "vertically integrated" LED light fixtures (lamp, ballast, and fixture) plus add-ons for dimming and IP controlling. Savings: Economic ROI = 18% Environmental ROI = 22% Equity = 289%	85%

Center for Building Performance and Diagnostics Carnegie Mellon University



Lighting consumes > 30% of the electricity use in buildings



and newer buildings are worse!

Cost Effective Lighting Retrofits
can save 10-85% of this electricity demand

1. Install occupancy/vacancy sensors for closed spaces.

2. Install daylight harvesting for perimeter lights.

3. Lower task-ambient light levels and add task lights

4. Manage blinds for daylight, shade, views without glare as well as for heat exchange control at night.

5. Install individually addressable ballasts with automation.

6. Install "vertically integrated" LED light fixtures (lamp, ballast, fixture) plus add-ons for dimming and IP control.

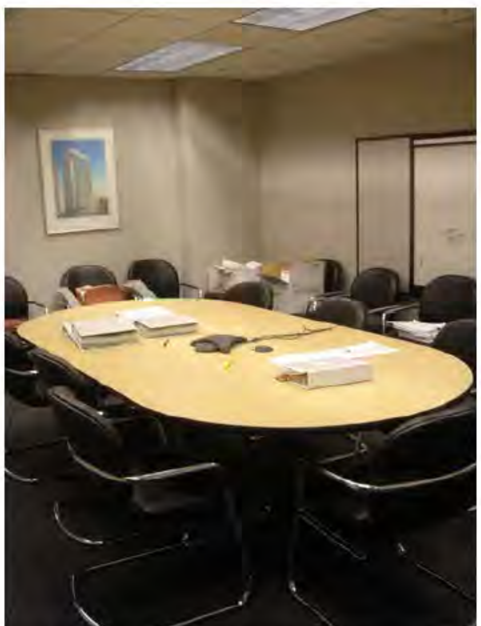
Triple Bottom Line calculations

The United Nations ICLEI Triple Bottom Line standard for full cost accounting quantifies three levels of benefits of investing in lighting upgrades.

Economic/ profit	Environmental/ planet	Equity/ people
Energy savings	Carbon benefits (related to electricity)	Task performance
Facilities Management?	Water (related to electricity)	Health
	SO_X / NO_X Outdoor Air Quality benefits	Satisfaction

In our EEBHub research, the NPV calculations are successive, based on a 15 year time frame, 10% discount rate, and average costs for lighting upgrades in existing medium sized office buildings.

#1 Install Occupancy Sensors in Closed Rooms

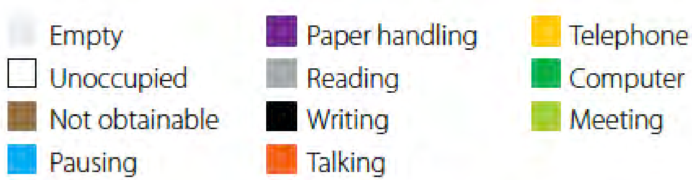


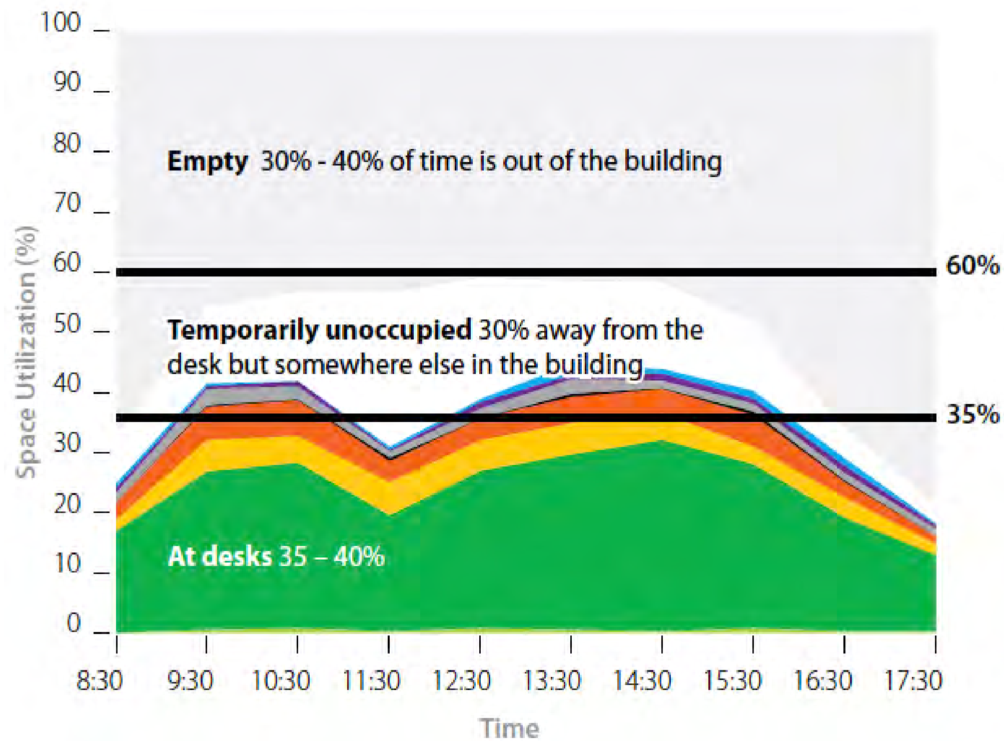
- Conference space occupancy ranges from 30%-70%.
- Closed office occupancy is as low as 35%.
- Kitchen, copy room and bathroom occupancy is less than 10% of the workday.

Sporadic use of as much as 40% of the floor area for up to 70% of the time offers significant energy savings opportunity.

DEGW uses shadowing to reveal 40% workstation vacancy

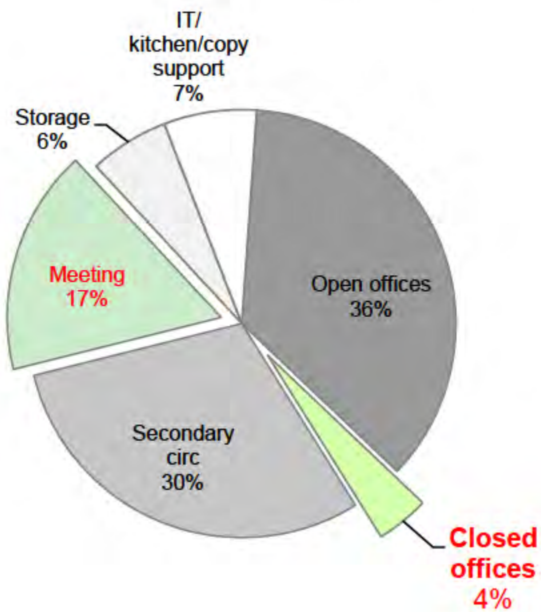
Figure 2: Activities in workspaces
DEGW Research in multiple client sites across the globe has indicated that individual time spent at the desk, and time spent generally in the workplace is declining. Whereas once "office work" was predominantly process work undertaken at individual worksettings, the workplace today is as much mobile / collaborative working as it is individual, and this trend is predicted to increase.





CMU uses 22 Studies to identify closed spaces as 25% of area

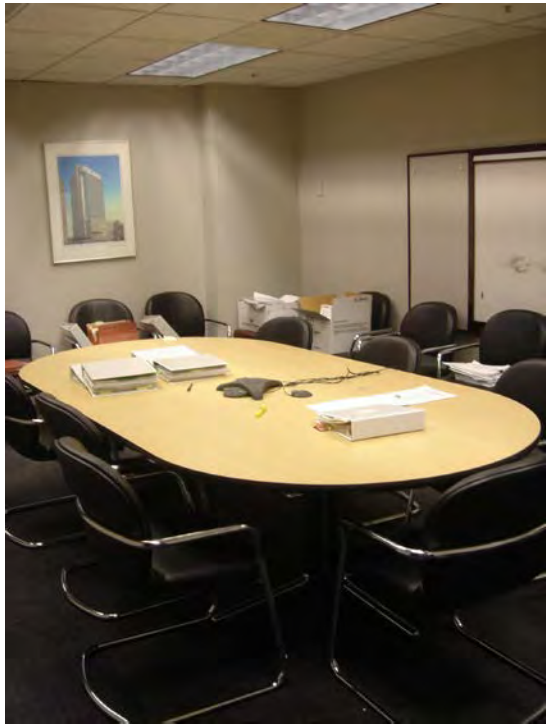
Workstation usability

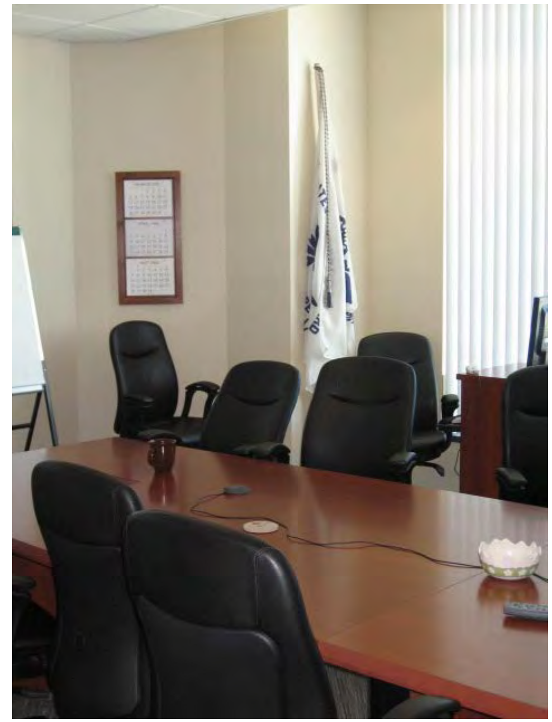


GSA building floor plan: Chicago, IL

Closed offices 4% + Meeting Rooms 17% + Service (WC and storage) 4% = 25%

California mandates vacancy rather than occupancy controls





California standards demand the occupancy sensors be set as “vacancy sensors” in all daylit spaces –

to turn off lights when no presence is detected, while avoiding automatically turning lights on when daylight may be perfectly adequate.

Lighting control = Energy savings

NCAR Office / Maniccia et al. 1999

In a 1997 field experiment at the National Center for Atmospheric Research in Boulder, Colorado, Maniccia et al identify a 43% reduction in lighting energy use in private offices due to occupancy sensors, and an additional 15% savings due to manual switching and dimming controls for each user.

Leviton Acenti Almond 1800W Manual-On Occupancy Sensor

First cost increase:	$100 / room
Annual energy savings:	$28 / room
ROI:	**28%**

D. Maniccia, B. Rutlege, M.S. Rea and W. Morrow. (1998) Occupant use of manual lighting controls in private offices. Illuminating Engineering Society of North America 1998 Annual Conference: Proceedings. IESNA: New York, NY. 490-512

Occupancy Sensors 1st Bottom Line - Profit

The baseline assumes a 100,000 sf building with 6.8 kWh/sf annual lighting energy use at $0.10/kWh.

VACANCY SENSORS: Costs to Install Vacancy Sensors

	Per sq ft	Per room
First Cost Investment *(for a 25% baseline building area)*	$0.50	$100
Installation labor cost	$0.15	$30
Initial Investment costs for 100,000 sq ft *(25% area)*	$16,250	

1 Profit Benefits of Installing Vacancy Sensors

	Per sq ft	Per employee
Lighting energy savings (50% in 25% space)[1]	$0.34	$68
Cumulative ROI (Economic)	**52%**	
Payback Period	**2 years**	
15 year Net Present Value (10% discount rate)	**$64,366**	

1. Average of: U.S. Environmental Protection Agency (1996) Occupancy Sensor Control in Commercial Office Space EPA 430-F-96-053; D. Maniccia, B. Rutlege, M.S. Rea and W. Morrow. (1998) Occupant use of manual lighting controls in private offices. Illuminating Engineering Society of North America 1998 Annual Conference: Proceedings. IESNA: New York, NY. 490-512; Jennings, J.D., Rubinstein, F.M., DiBartolomeo, D., Blanc, S.L. (2000). Comparison of Control Options in Private Offices in an Advanced Lighting Controls Testbed. Journal of the Illuminating Engineering Society, Summer 2000; Mahdavi, A.; Abdolazim, M.; Elham, K.; and Lyudmila, L. (2008): Occupants' Operation of Lighting and Shading Systems in Office Buildings: Journal of Building Performance Simulation; 1 (1): pp. 57-65.

Adding the Environmental Value of Electric Energy Savings

National average inclusive cost of electricity per kwh[1.]	
Electricity	$0.103/kwh
Costs related to national average of ton of pollutant concentrations per kwh[2.]	
CO2	$0.010/kwh
SOx	$0.012/kwh
NOx	$0.003/kwh
PM10	$0.001/kwh
Cost related to the national average gallons of water per kwh[3.]	
Water	$0.004

1. Energy Information Agency (EIA), 2003 Commericial Buildings Energy Consumption Survey Characteristics and End-Uses, Oct. 2006 and Sept. 2008, Table A1 and Table E1A.
2. *EPA – Clean Energy Programs eGRID - Emissions & Generation Resource Integrated Database* http://www.epa.gov/cleanenergy/egrid/ and *Leonardo Academy Inc.,* "Emission Factors and Energy Prices for the Cleaner and Greener[SM] Environmental Program", January 2003.*Emission impact value data for CO2, SOx, NOx and particulates from various sources (lincluded as an appenix in annual report are used to derive the baseline impact values*
3. Torcellini, P.; Long, N.; and R. Judkoff, 2003, "Consumptive Water Use for U.S. Power Production", National Renewable Energy Laboratory, NREL/TP-550-33905, December 2003.and EPA – "Water Facts", EPA 810-F-99-020, December 1999.

Occupancy Sensors 2nd Bottom Line - Planet

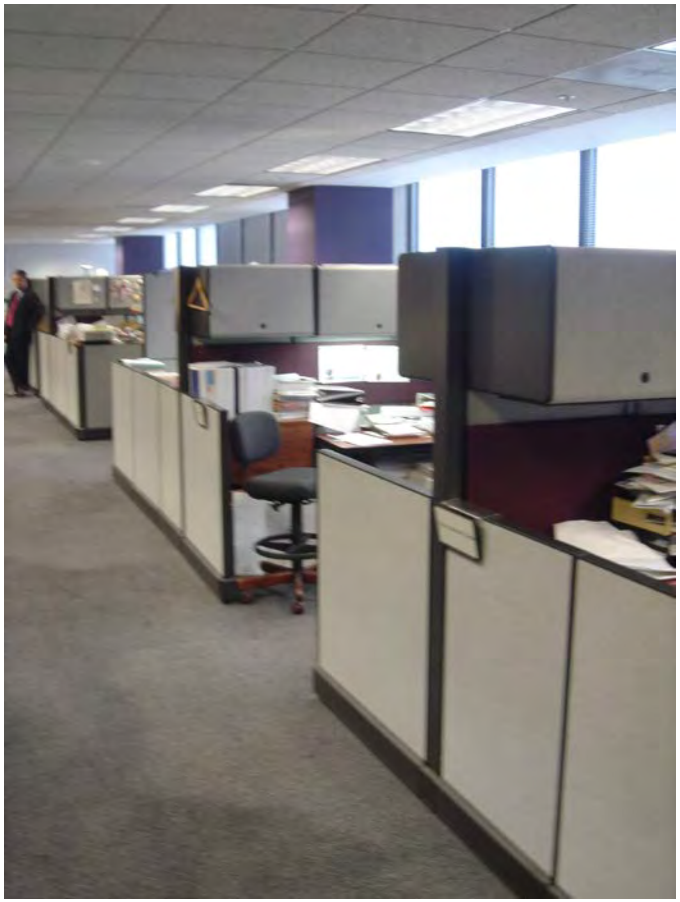
Carbon trading or corporate sustainability declarations
increase ROIs from 52% to 68% and shorten payback from 2 years to 18 months

2 Profit + Planet Benefits of Installing Vacancy Sensors

	Per sq ft	Per employee
Environmental benefits from energy savings of:	0.85 kWh	169 kWh
Air pollution emissions (SO_X, NO_X, PM)	\$0.054	\$10
CO_2 reductions	\$0.034	\$7
Water savings	\$0.014	\$3
Annual 2nd bottom line savings	\$0.102	\$21
Cumulative ROI (Economic + Environment)	**68%**	
Payback Period	**18 months**	
15 year Net Present Value (10% discount rate)	**\$83,697**	

Key References:
M.Deru and P.Torcellini. (2007) Source Energy and Emission Factors for Energy Use in Buildings, Technical Report NREL/TP-550-38617 June 2007
EPA Emission impact value data for CO2, SOx, NOx and particulates from various sources are used to derive the baseline impact values
Torcellini, P.; Long, N.; and R. Judkoff, 2003, "Consumptive Water Use for U.S. Power Production", NREL/TP-550-33905, December 2003
EPA – "Water Facts", EPA 810-F-99-020, December 1999. Cost of water supplied to a home

#2 Install Sensors for Daylight Harvesting at the Perimeter



Investment in new controls for groups of lights ensure up to 35% energy savings possible even in deeper buildings

Install on/off or dimming controls on the first and second row of lights on each building facade.

Require material and labor costs for introducing new controllers to each row of perimeter lights that can be placed on independent switching.

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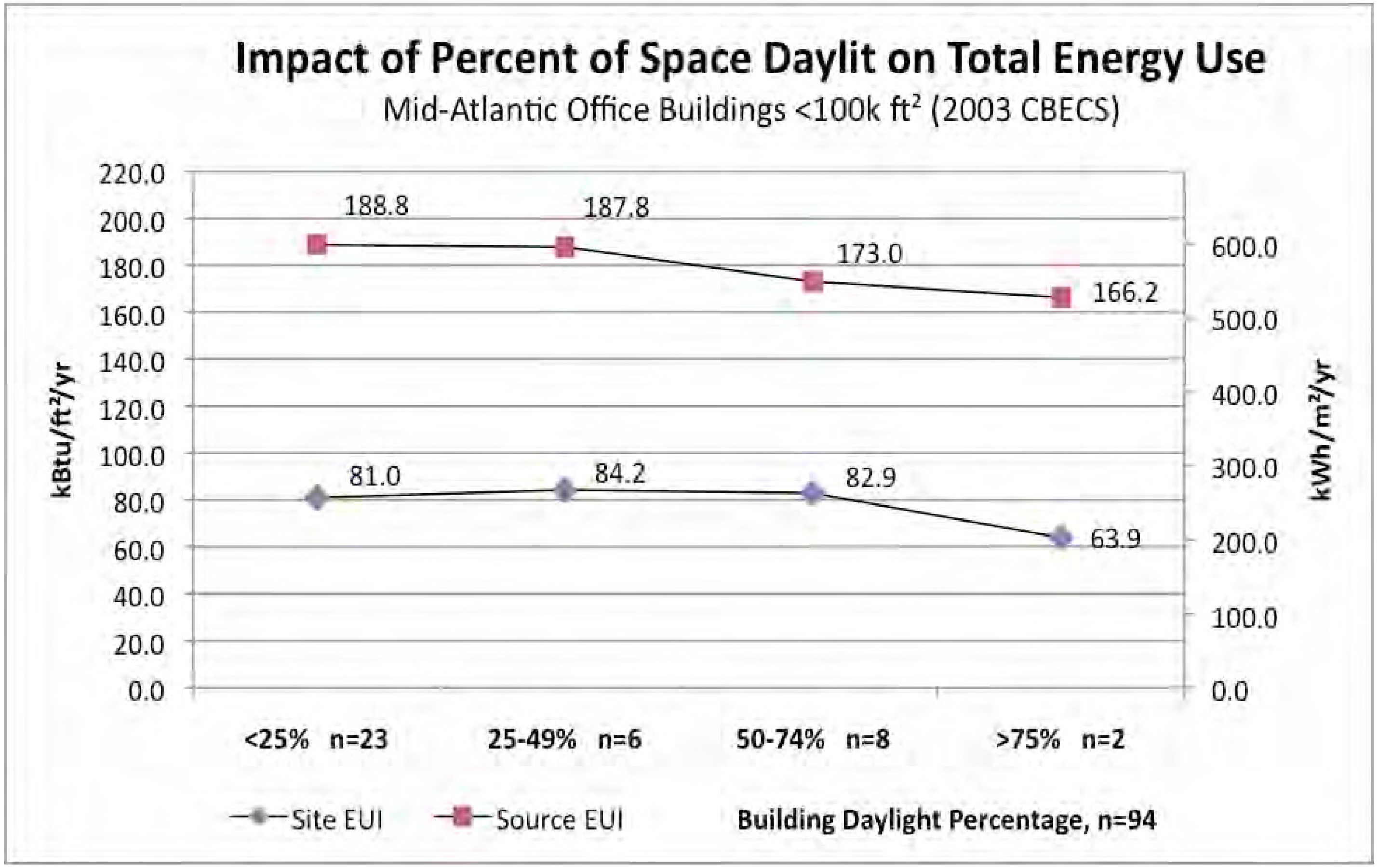
CBECS Data Reveals Daylighting Reduces Energy Use by 22%



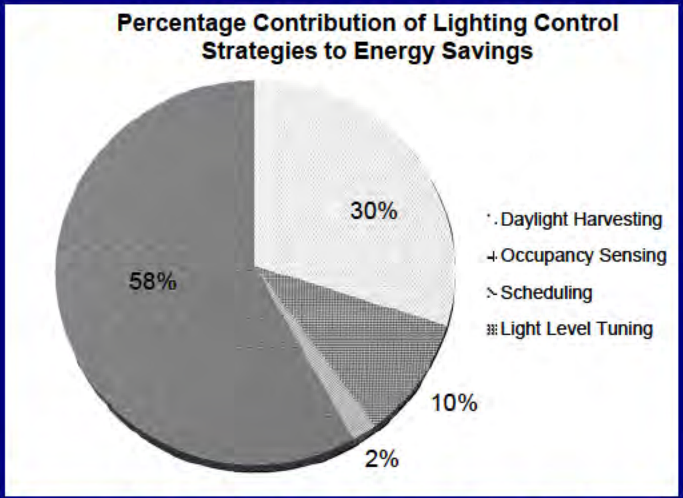
(CBECS database of buildings in the Mid-Atlantic)

Day Light Control = Energy Savingsz

Office/Lee and Selkowitz 2006

In a 2004 study involving the mock-up of the New York Times office building, Lee and Selkowitz identify a 59% savings in lighting energy consumption due to the use of daylight control systems with automated roller shades and DALI ballasts, as compared to a base case building with a conventional lighting system. Post occupancy, in 2008, the New York Times building achieved 70% lighting energy savings. Lighting power density reduced from 1.28/sf. to 0.39/sf. without affecting the design luminance level of 500 lux at workstations.

First Cost Increase:	$2,118 / employee
Annual Energy Savings:	$91.84 / employee
ROI:	**4.3%**



Lee, E. S. and Selkowitz, S. E. (2006): The New York Times Headquarters Day lighting Mockup; Monitored performance of the day lighting control system: Energy and Buildings; 38, pp. 914–929. LBNL-56979.
Lee, E. S.; DiBartolomeo, D. L.; Vine, E. L.; and Selkowitz, S. E. (1998): Integrated Performance of an Automated Venetian Blind/Electric Lighting System in a Full-Scale Private Office: Proceedings of the ASHRAE/DOE/BTECC Conference; Thermal Performance of the Exterior Envelopes of Buildings VII; Clearwater Beach, Florida; December 7-11, 1998. LBNL-41443.

Daylight Sensors 1st Bottom Line - Profit

The baseline assumes a 100,000 sf building with 6.8 kWh/sf annual lighting energy use at $0.10/kWh.

DAYLIGHT SENSORS

Costs to Install Daylight Sensors

	Per sq ft	Per employee
First Cost Investment *(for a 33% baseline building area)*	\$0.45	\$90
Installation + labor cost	\$0.50	\$100
Initial Investment costs for 100,000 sq ft *(33% area)*	\$0.95	\$190

1 Profit Benefits of Installing Daylight Sensors

	Per sq ft	Per employee
Annual Energy savings (30%)[1]	\$0.20	\$40
Cumulative ROI (Economic)	21%	
Payback Period	5 years	
15 year Net Present Value (10% discount rate)	\$51,493	

Average of : Lee, E. S. and Selkowitz, S. E. (2006): The New York Times Headquarters Day lighting Mockup; Monitored performance of the day lighting control system: Energy and Buildings; 38, pp. 914–929. LBNL-56979; Verderber, R., and Rubinstein, R. (1984) Mutual Impacts of Lighting Controls and Daylighting Applications.   Energy and Buildings 6:2, pp. 133-140.

#3 Lower task ambient light levels and add task lights

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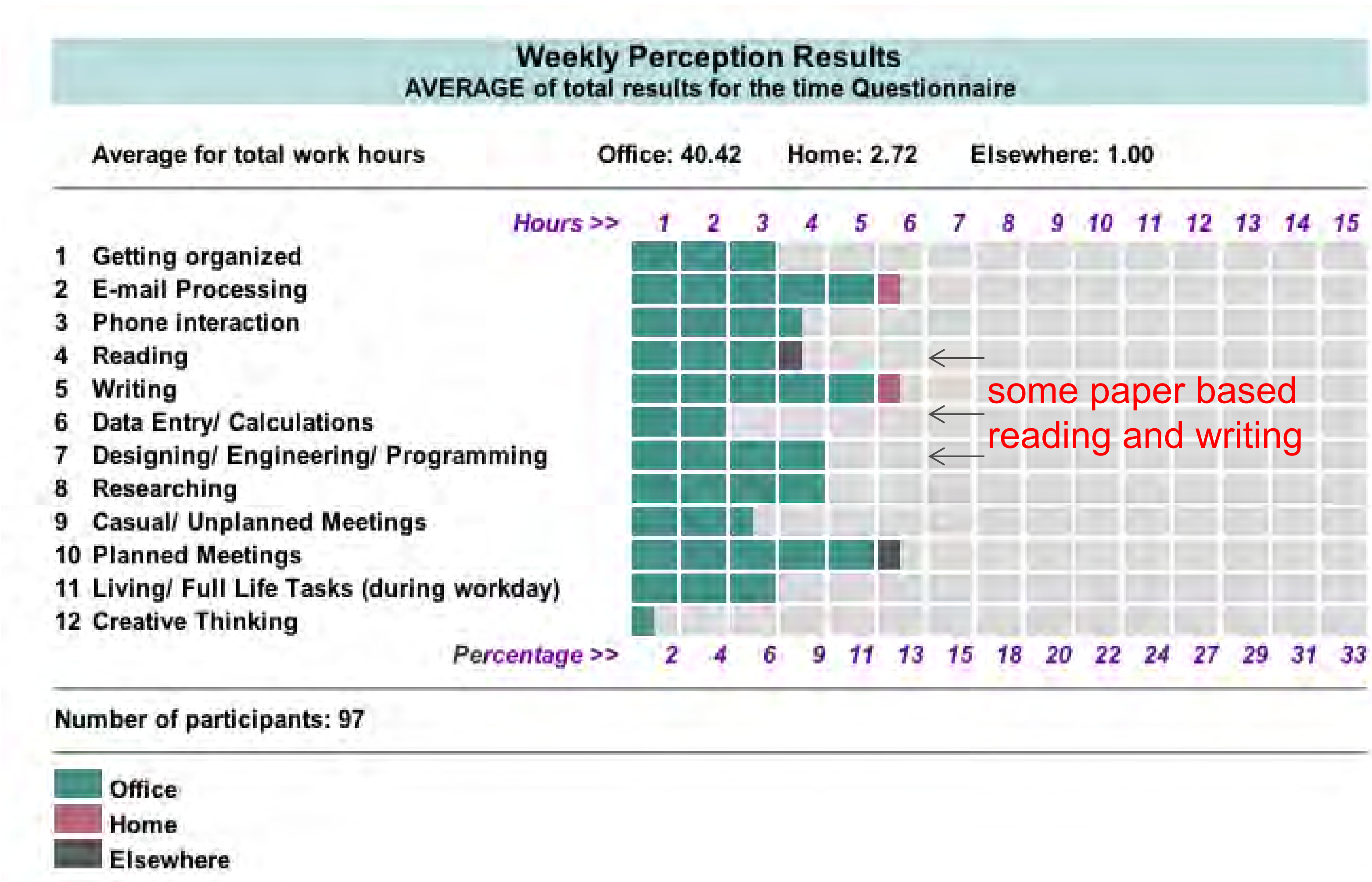
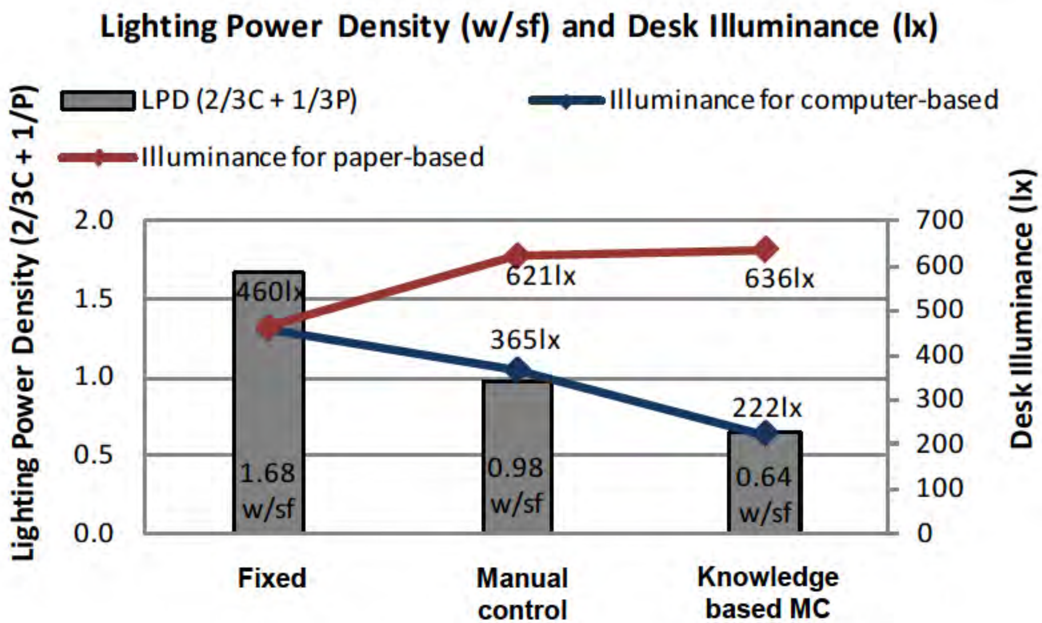
- Existing lighting power densities and light levels in US offices are excessively high given both today's available technologies and work tasks (average connected lighting in existing buildings is over 2 watts/sqft).
- Given the predominance of computer based work, ambient lighting levels can be lowered to 200-300 lux by de-lamping or reducing ceiling lighting output levels.
- High efficiency re-locatable, adjustable arm, 6-8 watt LED task lights for each workstation should be purchased for user control – saving over 40% of lighting energy, improving light levels for task, and increasing user satisfaction.
- Under-cabinet lighting should be removed, since it is far more energy intensive than today's task lights and rarely puts the light on the most critical task surfaces.

CMU surveys reveal less than 20% of the time is spent at paper based tasks



CMU PhD reveals Energy and Satisfaction Benefits of Lowering Ambient and adding Task (Gu 2011)



- Given control, occupants select significantly lower light levels for computer based tasks, the dominant activity in offices today (at least 100-200 lux lower)
- Individually controlled task lights allow higher light levels for paper-based tasks (over 600 lux), with 40-60% reduction in lighting energy.

Split Task and Ambient Lighting = Energy + Maintenance Savings

Knissel 1999

In a 1999 study of an office building in Frankfurt, Knissel from the Institut Wohnen und Umwelt Darmstadt (IWU) identified an 88% reduction in primary energy consumption, from 82 kWh/m² to 10 kWh/m², as a result of effective daylighting, split task and ambient lighting, high performance parabolic louver fixtures and daylight dimming controls.

Through cost calculations, the IWU also determined first cost savings of \$11/m² (\$1/sq.ft) and maintenance savings of 4.70/m² (\$0.05/sq.ft).

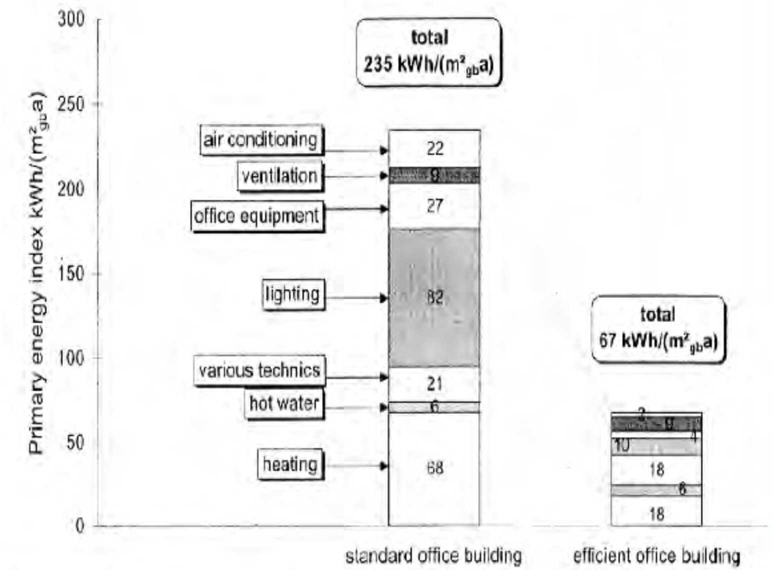


Figure 2: Primary energy index for the "standard" and the "efficient office building"

First cost increase:	\$1 / sf
Annual energy saving:	\$0.65/sf
ROI:	**65%**

Knissel, Jens. (1999) Institut Wohnen und Umwelt, Darmstadt, Germany (j.knissel@iwu.de)
Center For Building Performance and Diagnostics, Carnegie Mellon University

Lower Ambient & add Task 1st Bottom Line - Profit

The baseline assumes a 100,000 sf building with 6.8 kWh/sf annual lighting energy use at $0.10/kWh.

Costs to Reduce Ambient Lighting and Add Task Lights

	Per sq ft	Per employee
Cost for reducing ambient light levels	$0.16	$32
Cost for LED desk lamp	$0.82	$164
Initial Investment costs for 100,000 sq ft	$98,000	

1 Profit Benefits of Reducing Ambient Light and Adding Task

	Per sq ft	Per employee
Energy savings (40%)[1]	$0.27	$54
O & M Savings[2]	$0.05	$10
Annual 1st bottom line savings	$0.32	$64
Cumulative ROI (Economic)	**32%**	
Payback Period	**3 years**	
15 year Net Present Value (10% discount rate)	**$244,000**	

1. Gu Yun (2011), The Impact of Real time Knowledge Based Personal Lighting Control on Energy Consumption, User Satisfaction and Task Performance in Offices - Dissertation. Carnegie Mellon University, Pittsburgh,PA.
2. Knissel, Jens;(1999) Institut Wohnen und Umwelt, Darmstadt, Germany (j.knissel@iwu.de)

Lower Ambient & add Task 2nd Bottom Line - Planet

Carbon trading or corporate sustainability declarations
increase ROIs from 32% to 41% and shorten payback from 3 years to 2.

2 Profit + Planet Benefits of Reducing Ambient and Adding Task

	Per sq ft	Per employee
Environmental benefits from energy savings of:	2.71 kWh	542 kWh
Air pollution emissions (SO_X, NO_X, PM)	$0.04	$9
CO_2 reductions	$0.03	$5
Water savings	$0.01	$2
Annual 2nd bottom line savings	$0.08	$16
Cumulative ROI (Economic + Environment)	**41%**	
Payback Period	**2 years**	
15 year Net Present Value (10% discount rate)	**$305,860**	

Key References:
M.Deru and P.Torcellini. (2007) Source Energy and Emission Factors for Energy Use in Buildings, Technical Report NREL/TP-550-38617 June 2007
EPA Emission impact value data for CO2, SOx, NOx and particulates from various sources are used to derive the baseline impact values
Torcellini, P.; Long, N.; and R. Judkoff, 2003, "Consumptive Water Use for U.S. Power Production", NREL/TP-550-33905, December 2003
EPA – "Water Facts", EPA 810-F-99-020, December 1999. Cost of water supplied to a home

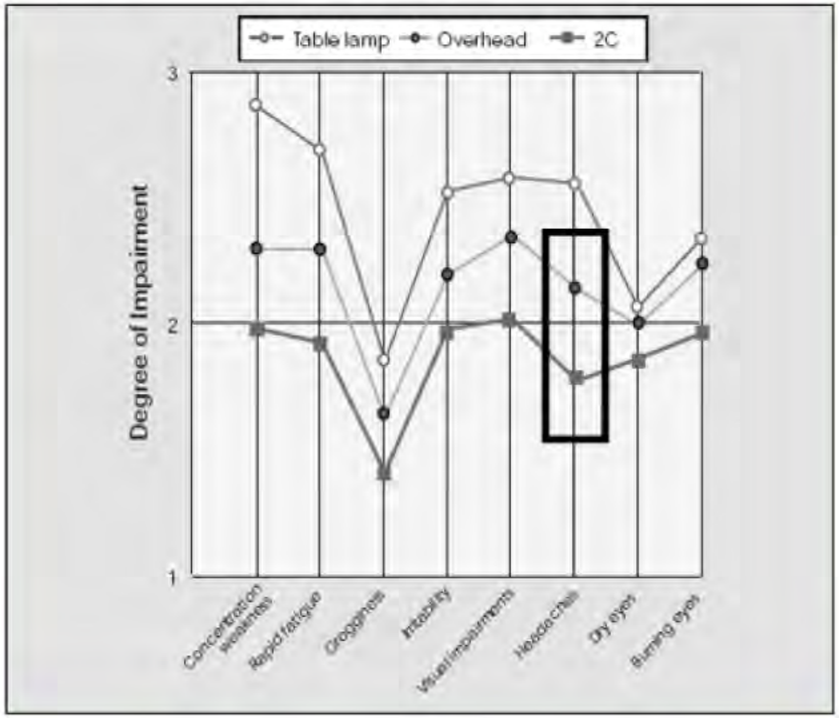
Lighting control = Health + related Individual productivity

Cakir and Cakir 1998

In a 1998 multiple building study in Germany, Çakir and Çakir identify a 19% reduction in headaches for workers with separate task and ambient lighting, as compared to workers with ceiling-only combined task and ambient lighting.

First cost increase:	$314 /employee
Annual health savings:	$14 /employee
Annual productivity savings	$87 /employee
ROI:	**32%**

Fig. 7.7 Influence of type of lighting on the degree of disturbances to health (1 = no disturbance, 4= strong disturbance)



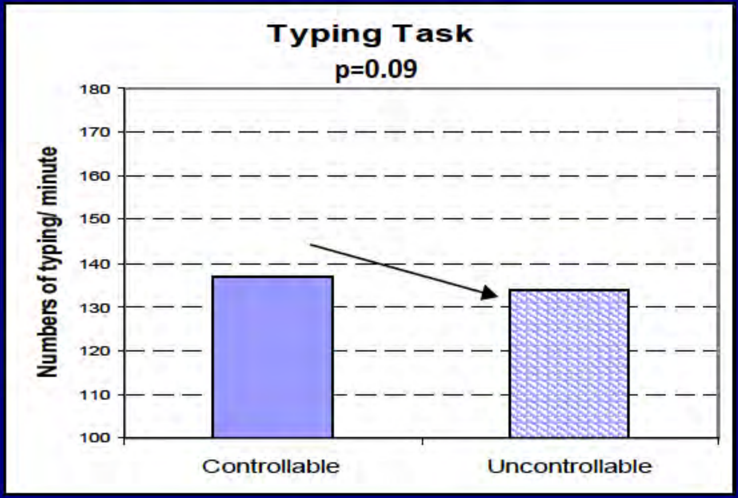
Cakir, A.E. and Cakir, G. (1998) Light and Health: Influences of Lighting on Health and Well-being of Office and Computer Workers, Ergonomic, Berlin.

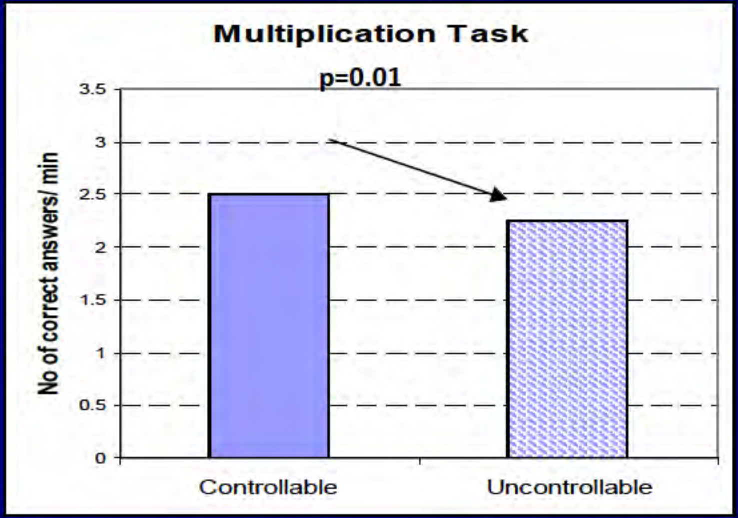
Split Task and Ambient Lighting = Individual productivity

Nishihara et al 2006

In a 2006 experiment at Waseda University in Japan, Nishihara et al identify an 11% improvement on a triple digit multiplication task on computer (p=0.01) when subjects could control their task lights as compared to when they could not. The performance on text typing also tended to be higher (p = 0.09) when task lights were controlled.

First cost increase:	$314 / employee
Annual productivity saving:	$178 / employee
ROI:	**57%**





Nishihara, N., Nishikawa, M., Haneda, M., and Tanabe, S. (2006) Productivity with Task and ambient lighting system evaluated by fatigue and task performance, Proceedings of Healthy Buildings 2006, Lisbon, Portugal, pp. 249-252
CBPD/Steffy (1999) Life Cycle comparisons of Direct and Indirect Lighting for Offices - Research Report. CMU Center for Building Performance and Diagnostics

Lower Ambient & add Task 3rd Bottom Line - People

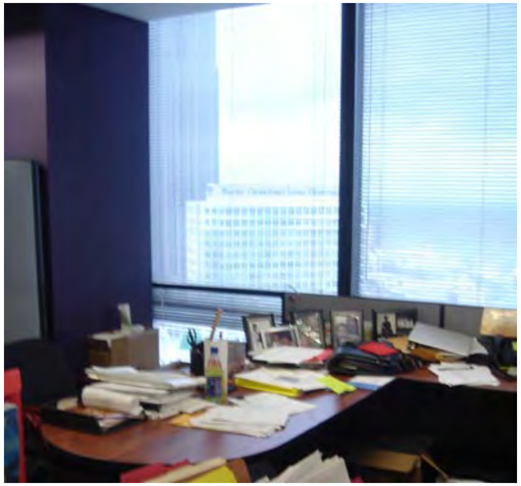
The baseline assumes 500 employees with an average salary of $45,000 and 256 workdays per year. According to U.S. EPA, per capita direct cost of headaches is $73 per worker per year. Schwartz et al[1] report an annual indirect cost of 2.5 workdays (1% of baseline workdays) due to absence from work and reduced work effectiveness attributed to headaches. In a baseline organization, a 11% productivity increase in office tasks[2] and 19% reduction in headache[3] results in cumulative ROI of 142%.

3 Profit + Planet + People Benefits of Reducing Ambient and Adding Task

	Per sq ft	Per employee
Absenteeism reduction (1%)[1]	$0.03	$6
Productivity increase (11%)[2]	$0.90	$178
Health benefits (19%)[3]	$0.07	$14
Annual 3rd bottom line savings	$1.00	$198
Cumulative ROI (Economic + Environment+ Equity)	**142%**	
Payback Period	**8 months**	
15 year Net Present Value (10% discount rate)	**$1,058,550**	

1. Schwartz et al (1997) Lost Workdays and Reduced Work Effectiveness Associated with Headache. Occupational & Environmental Medicine. 39(4), pp. 320-327.
2. Nishihara, N., Nishikawa, M., Haneda, M., and Tanabe, S. (2006) Productivity with Task and ambient lighting system evaluated by fatigue and task performance, Proceedings of Healthy Buildings 2006, Lisbon, Portugal, pp. 249-252.
3. Cakir, A.E. and Cakir, G. (1998) Light and Health: Influences of Lighting on Health and Well-being of Office and Computer Workers, Ergonomic, Berlin.

#4 Manage Blinds for Daylight, Shade and Views

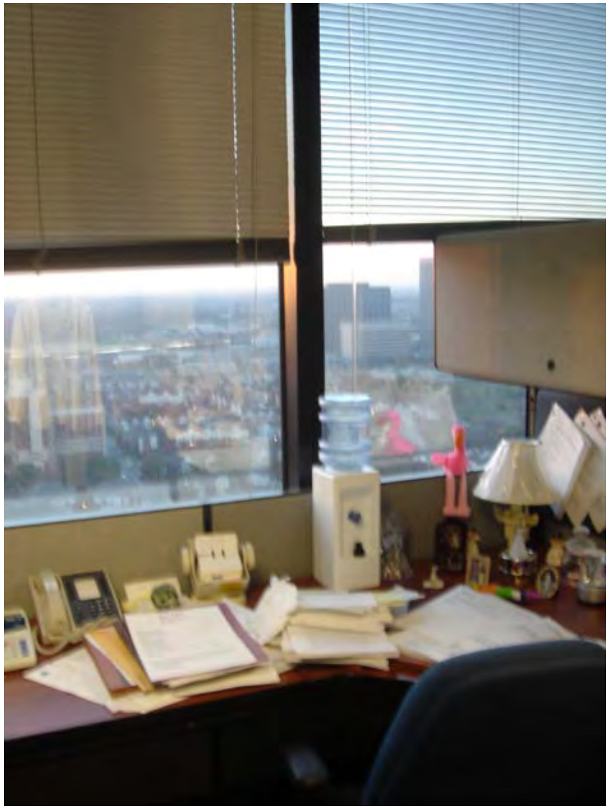


Use internal venetian blinds more effectively for daylight and views as well as shade and sun. While dependent on climate, orientation and activity, the rules are logical:

- Raise the blinds in cold periods if there is no glare for free heat and light.
- Lower blinds in hot periods but keep in a horizontal position for daylight and views.
- Lower and close the blinds during hot periods whenever spaces are unoccupied.

- And then there are some innovations…

Venetian blinds are still prevalent in over 90% of office buildings



A majority of office buildings already have venetian blinds installed, and they out-perform roller shades for effective daylight and views.

A least cost approach to increasing daylighting without excessive overheating is to set schedules and train occupants in effective blind management. The training could include an on-line video with occasional facility management oversight and communication.

Active User Behavior + Automated Controls = Energy Savings

Office/ De Carli and De Giuli 2009

In a 2009 building study, Carli and Giuli identified a 32% reduction in lighting energy in an office with blinds and lighting controls when users' behavior categorized as "mixed" compared to "passive". A 77% reduction in lighting energy was identified for a fully automated system with mixed user behavior, as compared to manual controls and passive user behavior.

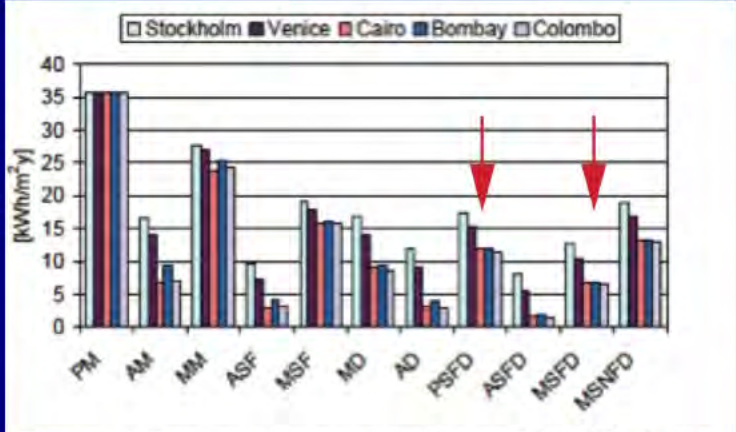
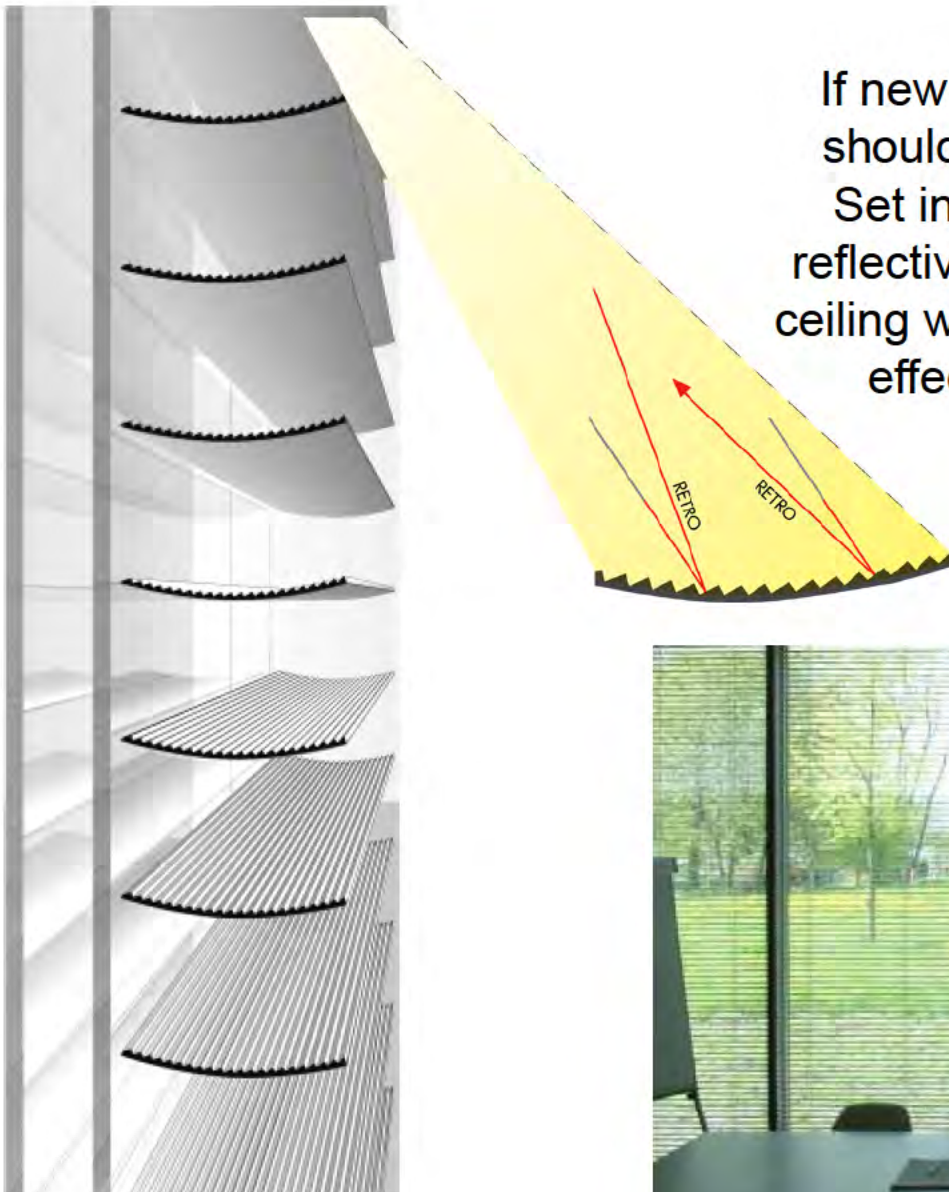


Figure 8 Energy requirement for artificial lighting, for the five investigated places, considering users' behaviour and different control strategies

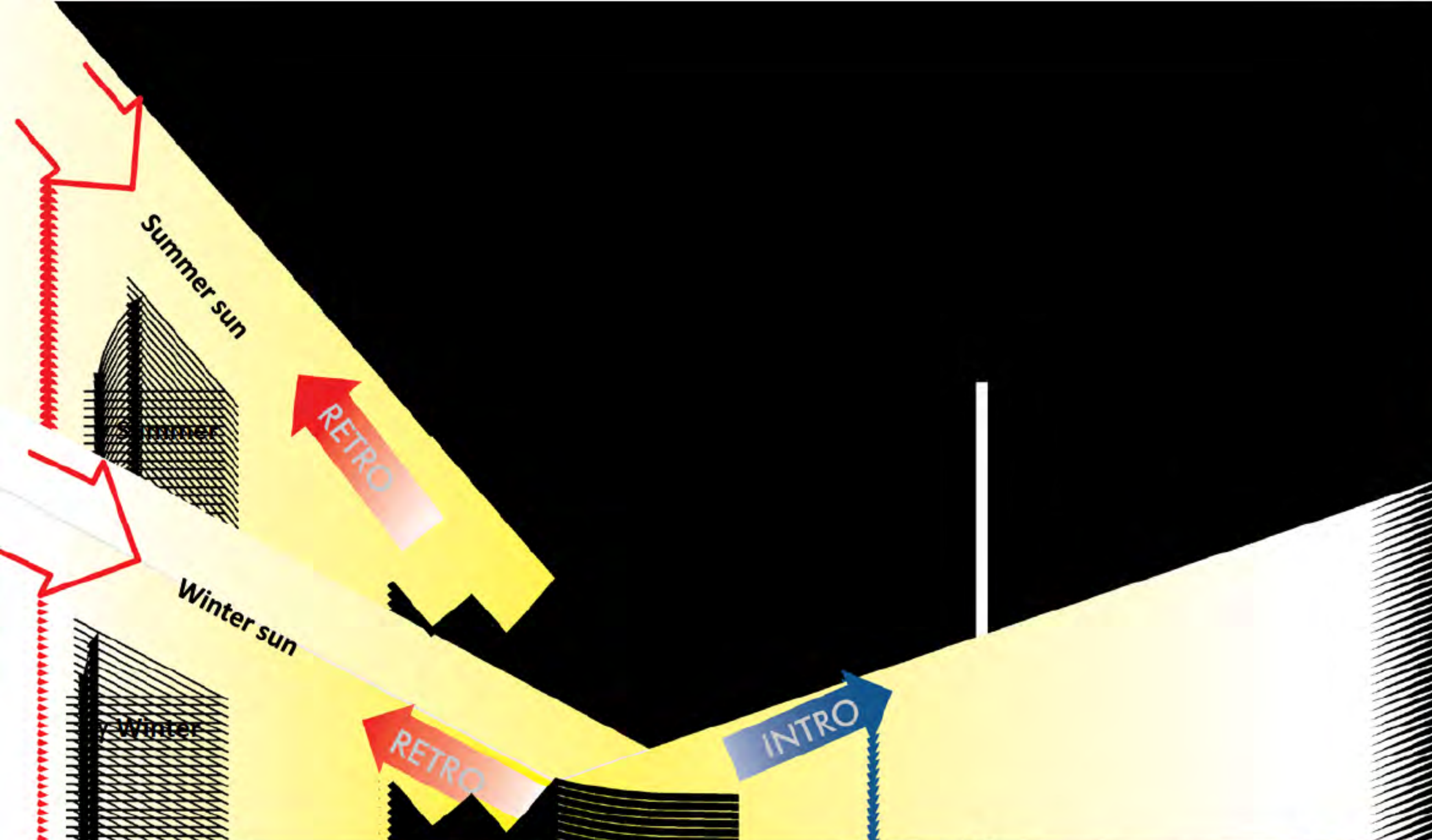
User beviour type		Lighting control	Blind control	Symbol
lighting	blind			
passive	passive	manual switch on-off	man	PM
active	active	manual switch on-off	man	AM
mix	mix	manual switch on-off	man	MM
active	active	automatic switch-off	autom	ASF
mix	mix	automatic switch-off	autom	MSF
mix	mix	dimmer	autom	MD
active	active	dimmer	autom	AD
passive	passive	autom switch off and dimmer	autom	PSFD
active	active	autom switch off and dimmer	autom	ASFD
mix	mix	autom switch off and dimmer	autom	MSFD
mix	mix	autom switch on/off and dimmer	autom	MSNFD

First cost increase:	$50.00 / employee
Annual cost increase:	$6.24 / employee
Annual energy savings:	$20.99 / employee
ROI:	**30%**

De Carli, M. and De Giuli, V (2009): Optimization Of Daylight In Buildings To Save Energy And To Improve Visual Comfort; Analysis In Different Latitudes: Eleventh International IBPSA Conference; Glasgow, Scotland: July 27-30.
http://www.iclei.org/fileadmin/user_upload/documents/ANZ/CCP/CCP-AU/Projects/Switch/Creating_an_awareness_campaign.pdf
RemoteLinc Wireless Remote Control For INSTEON automated lighting systems: www.cruthfield.com



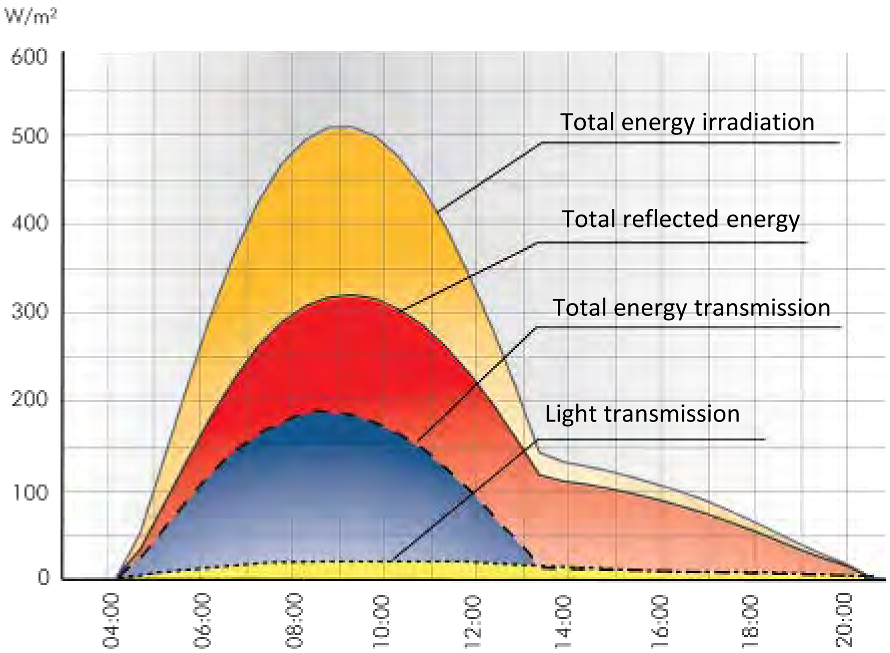
If new blinds are installed, profiles should be inverted for daylighting. Set in a horizontal position these reflective blinds reflect light up to the ceiling while providing clear views and effective shade (eg. Skyco™)



Blinds can even be shaped to vary reflection based on season (eg Retrosolar™)

This increases light while significantly decreasing heat

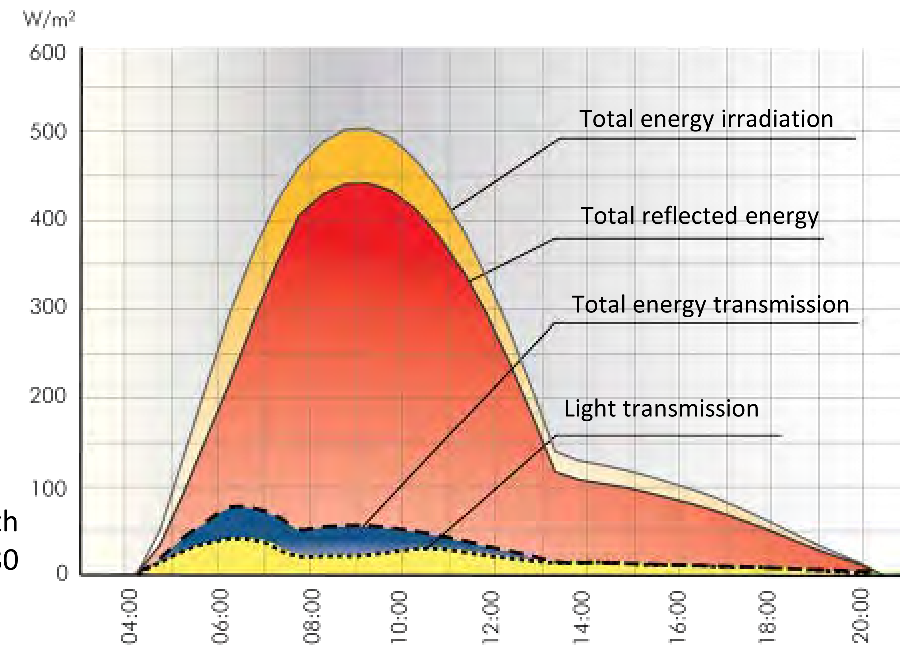
(reference Helmut Koester, Retrosolar)



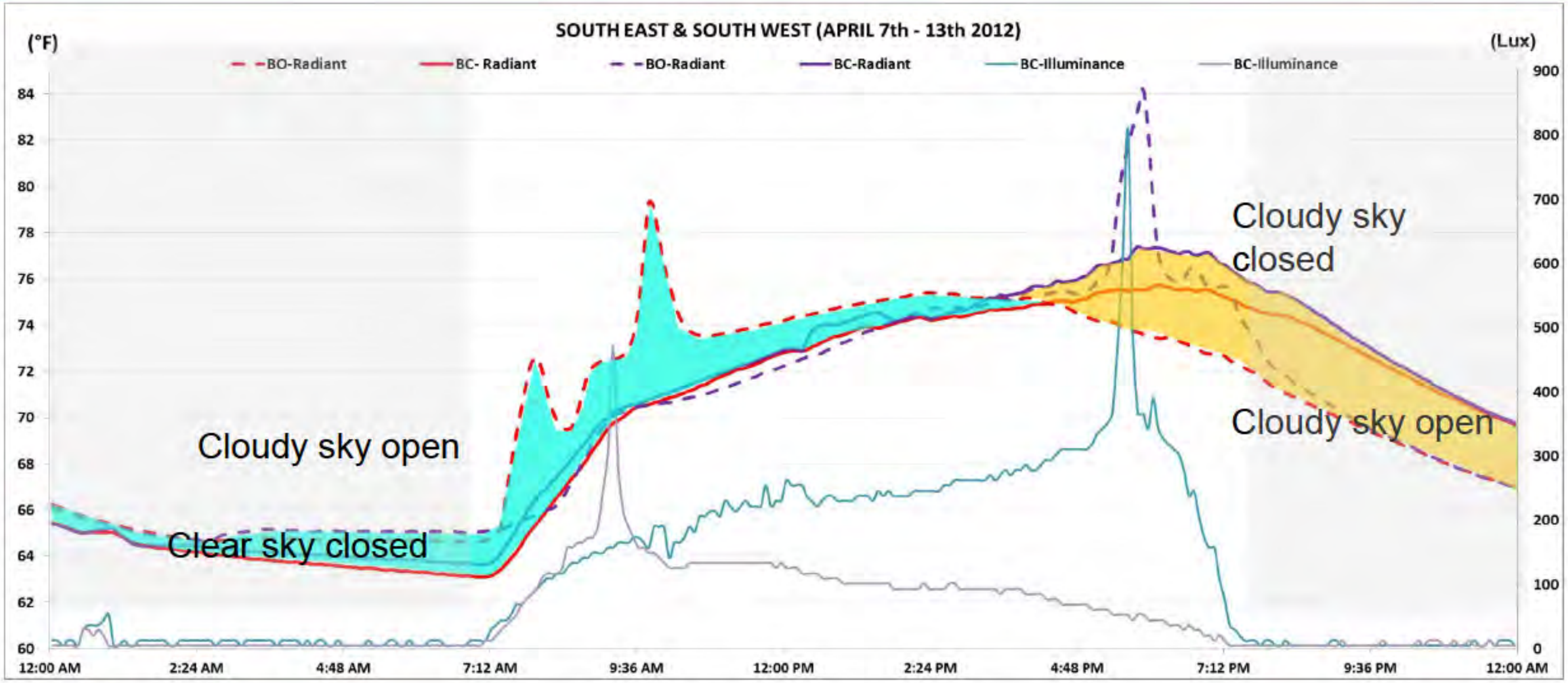
Time related energy control

Low-e glazing with standard blinds, internal, orient. S-E, 21.06.

Best practice façade with RETRO*Flex* 80



CMU MS thesis quantifies energy benefits of managing blinds (2012)



- Blinds placed at a 45° tilt will sustain daylighting while reducing radiant energy gains during the day for 20% cooling energy savings in summer.
- Opening the blinds on clear nights increases night cooling through radiant exchange, further reducing next day cooling energy savings.

Managing Existing Blinds 1st Bottom Line - Profit

The baseline assumes a 100,000 sf building with 6.8 kWh/sf annual lighting energy use at $0.10/kWh.

Costs to Manage Blinds

	Manage Existing Blinds		Buy New HP Blinds	
	Per sq ft	Per employee	Per sq ft	Per employee
First Cost Investment ***(40% window wall ratio, 33% floor area)***	-	-	$2.70	$540
Annual FM/Training Cost Estimate	$0.01	$2	$0.01	$2
Total Investment for 100,000 sq ft *(33% area)*	**$330**		**$90,000**	

1 Profit Benefits of Managing Blinds

	Manage Existing Blinds		Buy New HP Blinds	
10 cents/ kWh	Per sq ft	Per employee	Per sq ft	Per employee
Lighting energy savings (32%)[1] (54%)[2]	$0.07	$14	$0.12	$24
Cooling energy savings (20%)[2] (32%)[2]	$0.02	$3	$0.03	$5
Annual 1st bottom line savings (savings – annual cost training)	$0.09	$15	$0.14	$27
Cumulative ROI (Economic)	**791%**		**5%**	
Payback Period	**2 months**		**19 years**	
15 year Net Present Value **(10% discount rate)**	**$19,855**		**$34,850**	

1. De Carli, M. and De Giuli, V. (2009): Optimization Of Daylight In Buildings To Save Energy And To Improve Visual Comfort; Analysis In Different Latitudes: Eleventh International IBPSA Conference; Glasgow, Scotland: July 27-30. and Mahdavi, A.;
2. Lee, E.S., DiBartolomeo,D.L., & Selkowitz, S.E. (1998). Integrated Performance of an Automated Venetian Blind/ Electric Lighting System in a Full Scale Private Office, from http://gaia.lbl.gov/btech/papers/41443.pdf

Managing Existing Blinds 2nd Bottom Line - Planet

Carbon trading or corporate sustainability declarations
increase ROIs for new blinds from 5% to 7% and shorten payback from 19 years to 15.

2 Profit + Planet Benefits of Managing Blinds

	Manage Existing Blinds		Buy New HP Blinds	
Environmental benefits from energy savings of:	Per sq ft 0.72 kWh	Per employee 176 kWh	Per sq ft 0.72 kWh	Per employee 176 kWh
Air pollution emissions (SO_X, NO_X, PM)	$0.01	$3	$0.02	$5
CO_2 reductions	$0.01	$2	$0.01	$3
Water savings	$0.004	$1	$0.006	$1
Annual 2nd bottom line savings	$0.02	$6	$0.04	$9
Cumulative ROI (Economic + Environment)	**1059%**		**7%**	
Payback Period	**1 month**		**15 years**	
15 year Net Present Value (10% discount rate)	**$26,570**		**$46,080**	

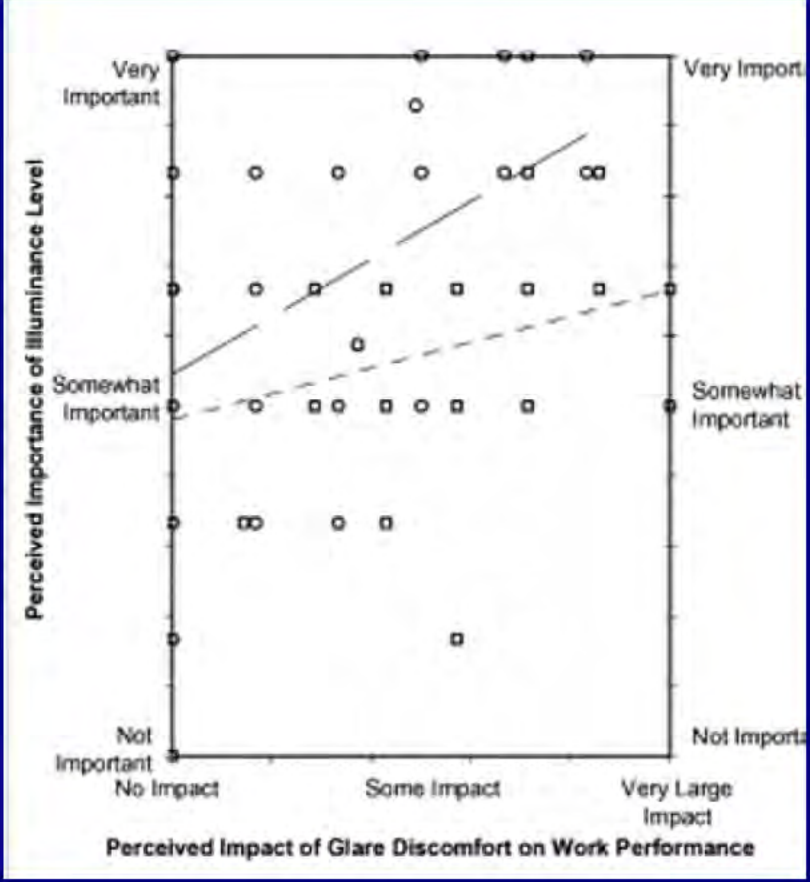
Key References:
M.Deru and P.Torcellini. (2007) Source Energy and Emission Factors for Energy Use in Buildings, Technical Report NREL/TP-550-38617 June 2007
EPA Emission impact value data for CO2, SOx, NOx and particulates from various sources are used to derive the baseline impact values
Torcellini, P.; Long, N.; and R. Judkoff, 2003, "Consumptive Water Use for U.S. Power Production", NREL/TP-550-33905, December 2003
EPA – "Water Facts", EPA 810-F-99-020, December 1999. Cost of water supplied to a home

Glare control = Individual Productivity

Osterhaus and Bailey 1992

In a 1992 lab experiment conducted using 6 female and 20 male subjects, Osterhaus and Bailey found a 3% productivity increase in visual task efficiency at the computer by reducing glare discomfort.

First cost increase:	$1,000 / employee
Annual productivity savings:	$299.73 / employee
ROI:	**30.0%**



Osterhaus, W. and Bailey, I. (1992): Large Area Glare Sources and Their Effect on Discomfort and Visual Performance at Computer Workstations: 1992 IEEE Industry Applications Society Annual Meeting; Houston, TX: LBL-35037.

Seated Views = Individual productivity

SMUD Call Center /Heschong Mahone Group 2003

In a 2003 building case study of the Sacramento Municipal Utility District (SMUD) Call Center, Heschong et al identify a 6% to 7% faster Average Handling Time (AHT) for employees with seated access to views through larger windows with vegetation content from their cubicles, as compared to employees with no view of the outdoors.

First cost increase:	$1,000 / employee
Annual productivity savings:	$2,990 / employee
ROI:	**299%**

Heschong, Mahone Group, Inc. (2003) Windows and Offices : A study of office worker performance and the indoor environments, California Energy Commission Technical Report

Managing Existing Blinds 3rd Bottom Line - People

The baseline assumes 500 employees with an average salary of $45,000 and 256 workdays per year. In a baseline organization, a 3% productivity increase in office tasks results in 1 year payback if purchasing new blinds.

Costs to Manage Blinds

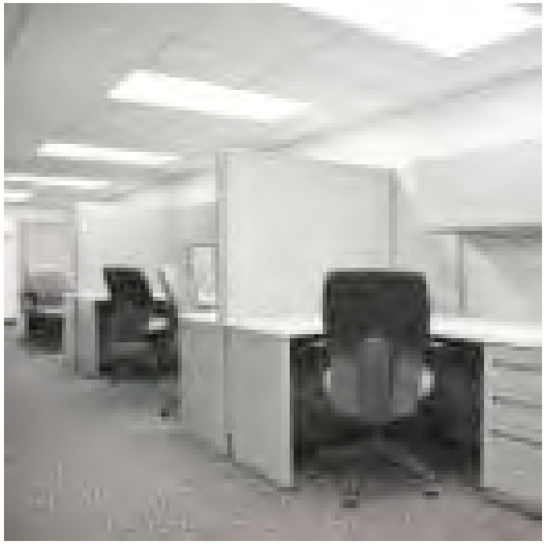
	Manage Existing Blinds		Buy New HP Blinds	
	Per sq ft	Per employee	Per sq ft	Per employee
First Cost Investment *(30% window wall ratio, 33% floor area)*	-	-	$2.70	$540
Annual FM/Training Cost Estimate	$0.01	$2	$0.01	$2
Total Investment for 100,000 sq ft *(33% area)*	**$330**		**$90,000**	

3 Profit + Planet + People Benefits of Managing Blinds

	Manage Existing Blinds		Buy New HP Blinds	
	Per sq ft	Per employee	Per sq ft	Per employee
Productivity increase (3%)[1]	$2.36	$472	$2.36	$472
Cumulative ROI (Economic + Environment + Equity)	**wild %**		**94%**	
Payback Period	**immediate**		**1 year**	
15 year Net Present Value (10% discount rate)	**$1,876,634**		**$645,050**	

1. Osterhaus, W. and Bailey, I. (1992): Large Area Glare Sources and Their Effect on Discomfort and Visual Performance at Computer Workstations: 1992 IEEE Industry Applications Society Annual Meeting; Houston, TX: LBL-35037.

#5 Install individually addressable ballasts with automation



In open plan workstations, individually addressable ballasts and a central lighting control system offers up to 72% energy savings through: daylighting in perimeter workstations; occupancy controls; and additional savings by daylight harvesting - adding appropriate electric light when daylight levels are diminishing.

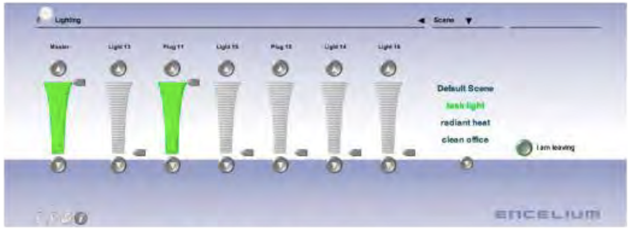
This is a first cost intensive retrofit with hardware, software and labor cost for installing individually addressable high performance fixtures and lighting automation systems. The purchase of the automation system will include installation, commissioning and training, as well as the facility manager and user control interfaces.

DALI ballasts provide IP wireless controls and the potential to link multiple sensors or control strategies

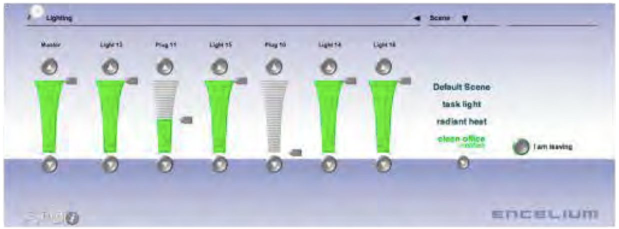
Lutron’s EcoSystem ballasts dim from 100-10% without flicker or noise, are instant on, and talk to a suite of different sensors, such as daylight sensor, and control interfaces for individual and shared spaces.

Osram QUICKTRONIC® DALI T8 or T5 Ballasts enable up to 60% energy savings through Encelium dimming, daylight sensing, occupancy sensing, local control, and when combined with high performance Sylvania lamps can produce over 100 Lumens/Watt.

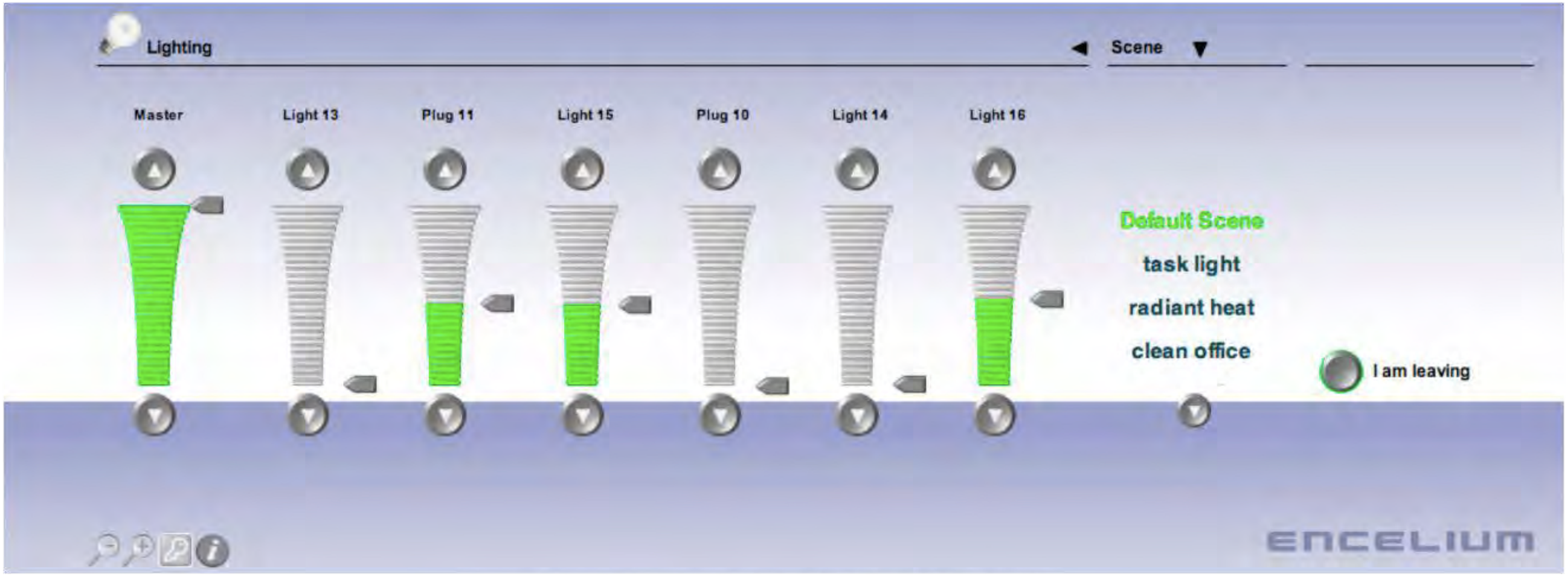
Encelium interface provides users with ability to create 'scenes' for lighting controls



Task light only



Lighting to clean office



User Interface for Lighting Control

Lighting Control = Energy Savings

Office / Energy User News 2001

In a 2001 case study of the Reynolds Metals Company office in Richmond, VA, Energy User News identifies an 87% reduction in lighting energy consumption following a retrofit with Ledalite's Ergolight intelligent lighting system, in which each luminaire provides personal dimming, occupancy sensing, daylight-responsive dimming and centralized network control.

First cost increase:	$0.82per sf
Annual energy savings:	$0.57per sf
ROI:	**70%**

Pre Retrofit lighting layout

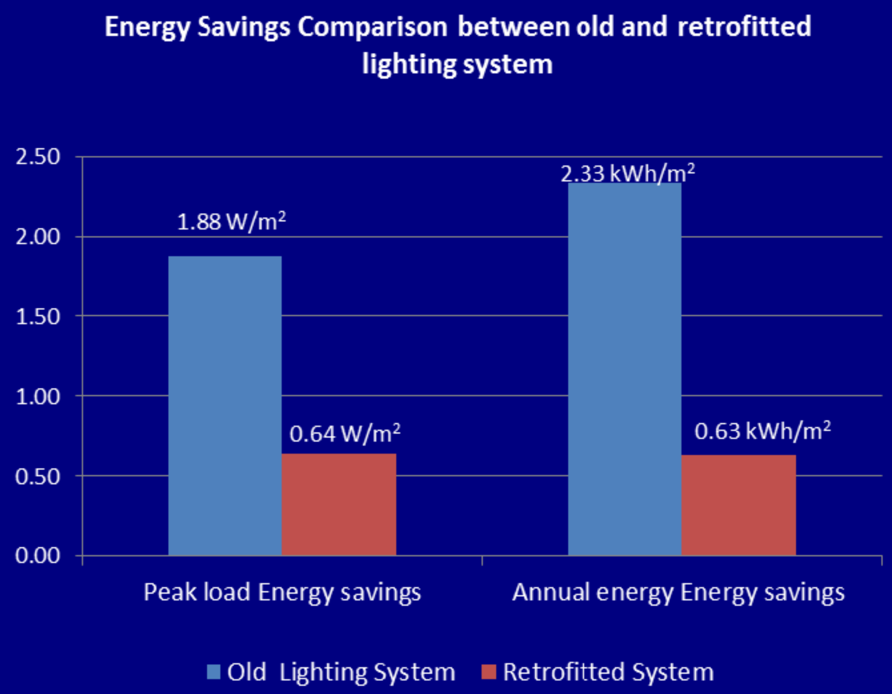
Post Retrofit lighting layout

Reynolds Saves Over 85% in Energy Costs, Improves Lighting Quality. (2001) Energy User News 26:2, pp. 26-27.
CBPD / Gary Steffy Lighting (1999) Life Cycle comparisons of Direct and Indirect Lighting for Offices - Draft Research Report. Center for Building Performance and Diagnostics (CBPD), Carnegie Mellon University, Pittsburgh, PA.

Lighting Control = Energy Savings + FM Savings

Swedish Office/ Hedenstrőm et al 2001

In a 1991 building case study of a lighting retrofit at a commercial office in Sweden, Hedenstrőm et al identify 74% annual lighting energy savings, 66% peak demand reduction, and 77% savings in lighting system maintenance costs savings due to a replacement of magnetic ballasts with new high-performance lighting fixtures, ballasts and occupancy sensors.



First cost increase:	\$6.26 per sq ft
Annual energy savings:	\$0.49 per sq ft
Annual O&M savings:	\$0.04 per sq ft
ROI:	**8%**

Claes Hedenstrőm, Lars Hedstrőm, Allan Ottosson, "Measure energy savings and cost-effectiveness of the lighting retrofit at Vattenfall's office in Racksta, Stockholm" Report, Uppdrag 2001

Individually addressable ballasts with automation 1st Bottom Line - Profit

The baseline assumes a 100,000 sf building with 6.8 kWh/sf annual lighting energy use at $0.10/kWh.

Costs of DALI Ballasts with automated control

	Per sq ft	Per employee
First cost	$1.75	$350
Installation + labor cost	$1.40	$280
Initial Investment costs for 100,000 sq ft	$3.15	$630

1 Profit Benefits of DALI Ballasts with automated control

	Per sq ft	Per employee
Lighting energy savings (65%)[1]	$0.44	$88
O & M Savings[2]	$0.04	$8
Annual 1st bottom line savings	$0.48	$96
Cumulative ROI (Economic)	15%	
Payback Period	7 years	
15 year Net Present Value (10% discount rate)	$365,126	

1. Average values from Center for Building Performance and Diagnostics, Carnegie Mellon University Lee, E. S. and Selkowitz, S. E. (2006): The New York Times Headquarters Day lighting Mockup; Monitored performance of the day lighting control system: Energy and Buildings; 38, pp. 914–929. LBNL-56979; Reynolds Saves Over 85% in Energy Costs, Improves Lighting Quality. (2001) Energy User News 26:2, pp. 26-27.
2. Claes Hedenstrőm, Lars Hedstrőm, Allan Ottosson, “Measure energy savings and cost-effectiveness of the lighting retrofit at Vattenfall’s office in Racksta, Stockholm” Report, Uppdrag 2001

Individually addressable ballasts with automation 2nd Bottom Line - Planet

Carbon trading or corporate sustainability declarations increase ROIs for individually addressable ballasts with automation from 15% to 19% and shortens payback from 7 years to 5.

2 Profit + Planet Benefits of DALI Ballasts with automated control

	Per sq ft	Per employee
Environmental benefits form energy savings of:	4.4 kWh	880 kWh
Air pollution emissions (SO_X, NO_X, PM)	\$0.07	\$14
CO_2 reductions	\$0.04	\$9
Water savings	\$0.02	\$4
Annual 2nd bottom line savings	\$0.13	\$27
Cumulative ROI (Economic + Environment)	**19%**	
Payback Period	**5 years**	
15 year Net Present Value (10% discount rate)	**\$465,648**	

Key References:

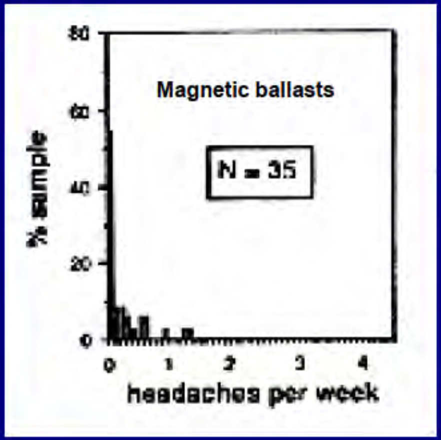
M.Deru and P.Torcellini. (2007) Source Energy and Emission Factors for Energy Use in Buildings, Technical Report NREL/TP-550-38617 June 2007
EPA Emission impact value data for CO2, SOx, NOx and particulates from various sources are used to derive the baseline impact values
Torcellini, P.; Long, N.; and R. Judkoff, 2003, “Consumptive Water Use for U.S. Power Production”, NREL/TP-550-33905, December 2003
EPA – “Water Facts”, EPA 810-F-99-020, December 1999. Cost of water supplied to a home

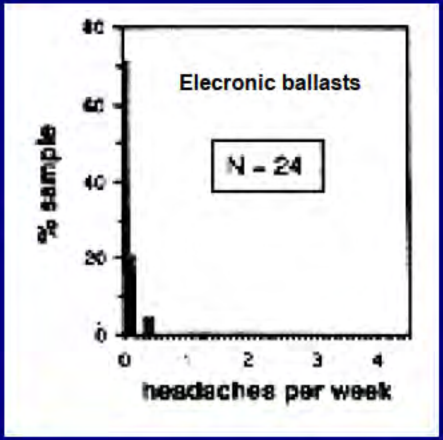
High Performance Luminaires = Health

Wilkins et al 1989

In a 1989 controlled field experiment at a government legal office in the UK, Wilkins et al identify a 74% reduction in the incidence of headaches among office workers when magnetic ballasts are replaced by high frequency electronic ballasts.

First cost increase: $109 / employee
Annual health savings: $54 / employee
Annual productivity savings from reduced headaches: $333 / employee
ROI: 355%





Frequency of headaches among employees

Reference: Wilkins, AJ, Nimmo-Smith, I, Slater, AI, Bedocs, L. (1989) Fluorescent lighting, headaches and eyestrain. Lighting Research and Technology 21(1), pp. 300-307.

Lighting Control = Individual Productivity + Energy Savings

PP&L / Romm and Browning 1994

In a 1994 before and after building case study of the Pennsylvania Power and Light (PP&L) drafting office in Allentown, PA, Romm and Browning identify a 13.2% increase in productivity, a 25% reduction in absenteeism and 69% lighting energy savings following a lighting retrofit introducing high-efficiency ballasts, T-8 fluorescent lamps and parabolic louver fixtures.

First cost increase:	$736/employee
Annual energy savings:	$91/employee
Annual Productivity Savings:	$6,131/employee
ROI:	**308%**

Romm, J.J., and W.D. Browning (1994). Greening the Building and the Bottom Line - Increasing Productivity Through Energy-Efficient Design. Rocky Mountain Institute.

Individually addressable ballasts with automation 3rd Bottom Line - People

The baseline assumes 500 employees with an average salary of $45,000 and 256 workdays per year. According to the U.S. EPA, the per capita direct cost of headaches is $73 per worker per year. In a baseline organization, a 27% reduction in headache[1] and 3% productivity increase[2] in office tasks and reduction in absenteeism by 25%[3] results in cumulative ROI of 260%.

3 Profit + Planet + People Benefits of DALI Ballasts with automated control

	Per sq ft	Per employee
Health benefits (27%)[1]	$0.10	$20
Productivity increase (3%)[2]	$6.75	$1,350
Absenteeism reduction (25% of 1.7%)[3]	$0.73	$146
Annual 3rd bottom line savings	$7.58	$1,516
Cumulative ROI (Economic + Environment + Equity)	260%	
Payback Period	9 months	
15 year Net Present Value (10% discount rate)	$6,230,844	

1. Aaras, A., Horgen, G., Bjorset, H., Ro, O., and Thorsen, M. (1998) Musculoskeletal, Visual and Psychosocial Stress in VDU Operators Before and After Multidisciplinary Ergonomic Interventions. Applied Ergonomics, pp. 335-354.
2. National Lighting Bureau. High Benefit Lighting: Federal Building and Courthouse Save Taxpayers Money. <http://www.nlb.org/publications/csh_federal.html>
3. Romm, J.J., and W.D. Browning (1994). Greening the Building and the Bottom Line - Increasing Productivity Through Energy-Efficient Design. Rocky Mountain Institute.

#6 Install "vertically integrated" LED light fixtures (lamp, ballast, fixture) with dimming and IP control

Replace existing 2x4, 1x4, or 2x2 troffers containing 2-4 T12 or T8 lamps with "vertically integrated" LED light fixtures (lamp, ballast, fixture) plus add-ons for dimming and IP controlling for higher luminous efficacy.

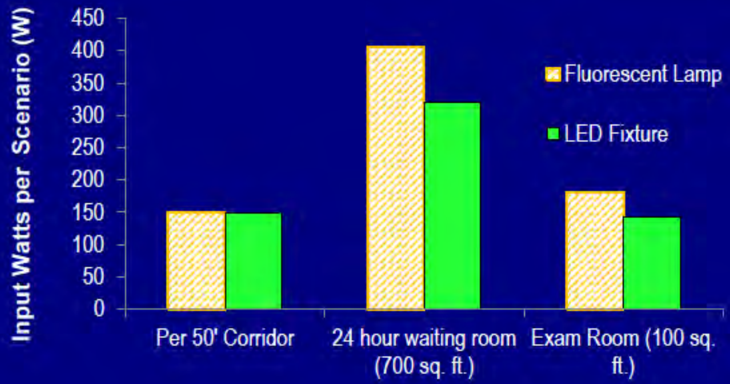
Energy savings exceed 75% and Maintenance savings exceed 8%.

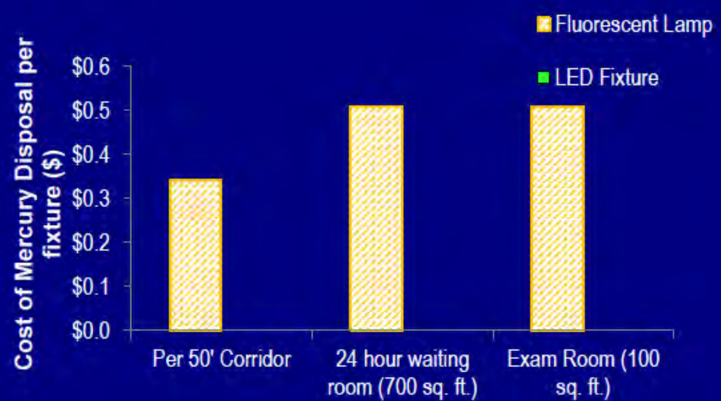
If you ensure LED sources have warm Color Temperatures (2600K to 3500K similar to incandescent) and excellent Color Rendering Index (CRI) in the 90s, productivity benefits of over 8% have been identified, ensuring paybacks of less than a year .

LED Lighting = Energy + Maintenance Savings

Meyers 2009

In a 2009 study of three layouts in healthcare facilities, Meyers identified a 76% energy savings, 80% savings in maintenance costs and 100% in mercury disposal costs by using LED fixtures instead of typical T8 fluorescent fixtures to deliver the same light levels in corridors, 24-hour a day waiting rooms and exam rooms[1].





First cost increase:	$3.99 per sf
Annual energy cost savings:	$1.23 per sf
Annual maintenance savings:	$0.58 per sf
Annual mercury disposal savings:	$0.0135 per sf
ROI:	**46%**

Meyers, A. (2009, July 15). Use of LED fixtures in Healthcare Facilities. M+NLB: Mazzetti, Nash, Lipsey, Burch.
Mercury Emissions Control Technologies. (n.d.). Library, PA, United States of America. Retrieved October 12, 2012.

“Vertically integrated" LED light fixtures 1st Bottom Line - Profit

The baseline assumes a 100,000 sf building with 6.8 kWh/sf annual lighting energy use at $0.10/kWh.

Costs to Introduce LED lamps and/or fixtures

	Replace Only Lamps		Upgrade to LED fixture	
	Per sq ft	Per employee	Per sq ft	Per employee
First Cost + Labor	**$2.40**	**$480**	**$4.50**	**$900**
Total Investment for 100,000 sq ft	**$240,000**		**$450,000**	

1 Profit Benefits of Replacing with LEDs

	Replace Only Lamps		Upgrade to LED fixture	
10 cents/ kWh	Per sq ft	Per employee	Per sq ft	Per employee
Lighting energy savings (40%)[1] (85%)[2]	$0.27	$54	$0.58	$115
Replacement, O & M Savings[3]	$0.25	$50	$0.25	$50
Annual 1st bottom line savings	$0.52	$104	$0.83	$165
Cumulative ROI (Economic)	**22%**		**18%**	
Payback Period	**5 years**		**5 years**	
15 year Net Present Value (10% discount rate)	**$396,120**		**$627,837**	

1. DesignLights Consortium (2003) (prepared by Weller & Michal Architects Inc. with WV Engineering Associates PA.). A Knowhow Case Study – 75 North Beacon Street, http://designlights.org/downloads/75%20N%20Beacon%20St.%20DLC.pdf
2. Center for Building Performance and Diagnostics (2012)
3. Meyers, A. (2009, July 15). Use of LED fixtures in Healthcare Facilities. M+NLB: Mazzetti, Nash, Lipsey, Burch.

“Vertically integrated" LED light fixtures 2nd Bottom Line - Planet

Carbon trading or corporate sustainability declarations
increase ROIs for upgrading to new LED fixtures from 18% to 22% and shorter payback.

2 Profit + Planet Benefits of LED lamps and fixtures

	Replace Only Lamps[1]		Upgrade to LED fixture[2]	
	Per sq ft	Per employee	Per sq ft	Per employee
Environmental benefits form energy savings of (40%)[1] (85%)[2]:	2.71 kWh	542 kWh	5.75 kWh	1151 kWh
Air pollution emissions (SO_X, NO_X, PM)	$0.05	$10	$0.10	$20
CO_2 reductions	$0.03	$5	$0.06	$12
Water savings	$0.01	$2	$0.02	$4
Annual 2nd bottom line savings	$0.09	$17	$0.18	$36
Cumulative ROI (Economic + Environment)	**25%**		**22%**	
Payback Period	**4 years**		**4.5 years**	
15 year Net Present Value (10% discount rate)	**$460,997**		**$762,306**	

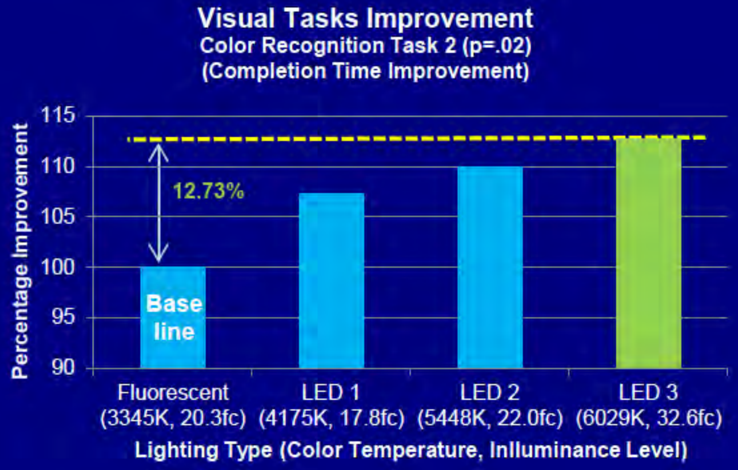
Key References:
M.Deru and P.Torcellini. (2007) Source Energy and Emission Factors for Energy Use in Buildings, Technical Report NREL/TP-550-38617 June 2007
EPA Emission impact value data for CO2, SOx, NOx and particulates from various sources are used to derive the baseline impact values
Torcellini, P.; Long, N.; and R. Judkoff, 2003, “Consumptive Water Use for U.S. Power Production”, NREL/TP-550-33905, December 2003
EPA – “Water Facts”, EPA 810-F-99-020, December 1999. Cost of water supplied to a home

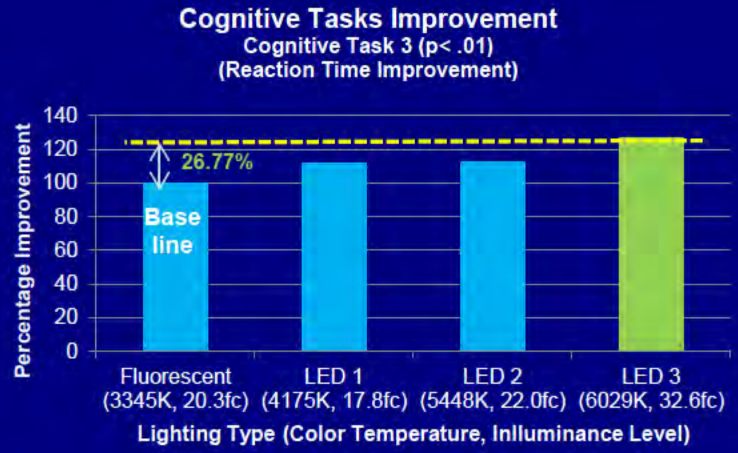
High Color Temperature LED Lighting = Improved Individual Productivity

Massachusetts Office/ Howes et al 2012

In a 2012 5-day study of 24 workstations in a Massachusetts office, Hawes et al identified a 8.3% improvement of work performance in visual and cognitive tasks due to the use of LED lighting with high color temperature and adequate illuminance level, as compared to traditional fluorescent lighting.

First cost increase:	$3,180 / employee
Annual productivity savings:	$3,780 / employee
ROI:	**119%**





Hawes, B. K., Brunye, T. T., Mahoney, C. R., Sullivan, J. M., & Aall, C. D. (2012). Effects of four workplace lighting technologies on perception, cognition and affective state. *International Journal of Industrial Ergonomics*, *42*, 122-128.
RS Means Default-Equivalent LED Lamp Cost Informaion (Online Retail Website): http://www.amazon.com/gp/product/B004M9WNSC/ref=olp_product_details?ie=UTF8&me=&seller=

“Vertically integrated" LED light fixtures 3rd Bottom Line - People

The baseline assumes 500 employees with an average salary of $45,000 and 256 workdays per year. In a baseline organization, a 8.3%[2] improvement of work performance in visual tasks and cognitive office tasks due to the use of new LED lighting fixtures with high color temperature and IP controlling as compared to traditional fluorescent lighting results in cumulative ROI of 300%.

3 Profit + Planet + People Benefits of LED lamps and fixtures

	Replace Only Lamps		Upgrade to LED fixture	
	Per sq ft	Per employee	Per sq ft	Per employee
Productivity increase (8.34%)[4]	$12.45	$2,490	$12.45	$2,490
Annual 3rd bottom line savings	$12.45	$2,490	$12.45	$2,490
Cumulative ROI (Economic + Environment + Equity)	**544%**		**300%**	
Payback Period	**4 months**		**6 months**	
15 year Net Present Value (10% discount rate)	**$9,930,467**		**$6,821,184**	

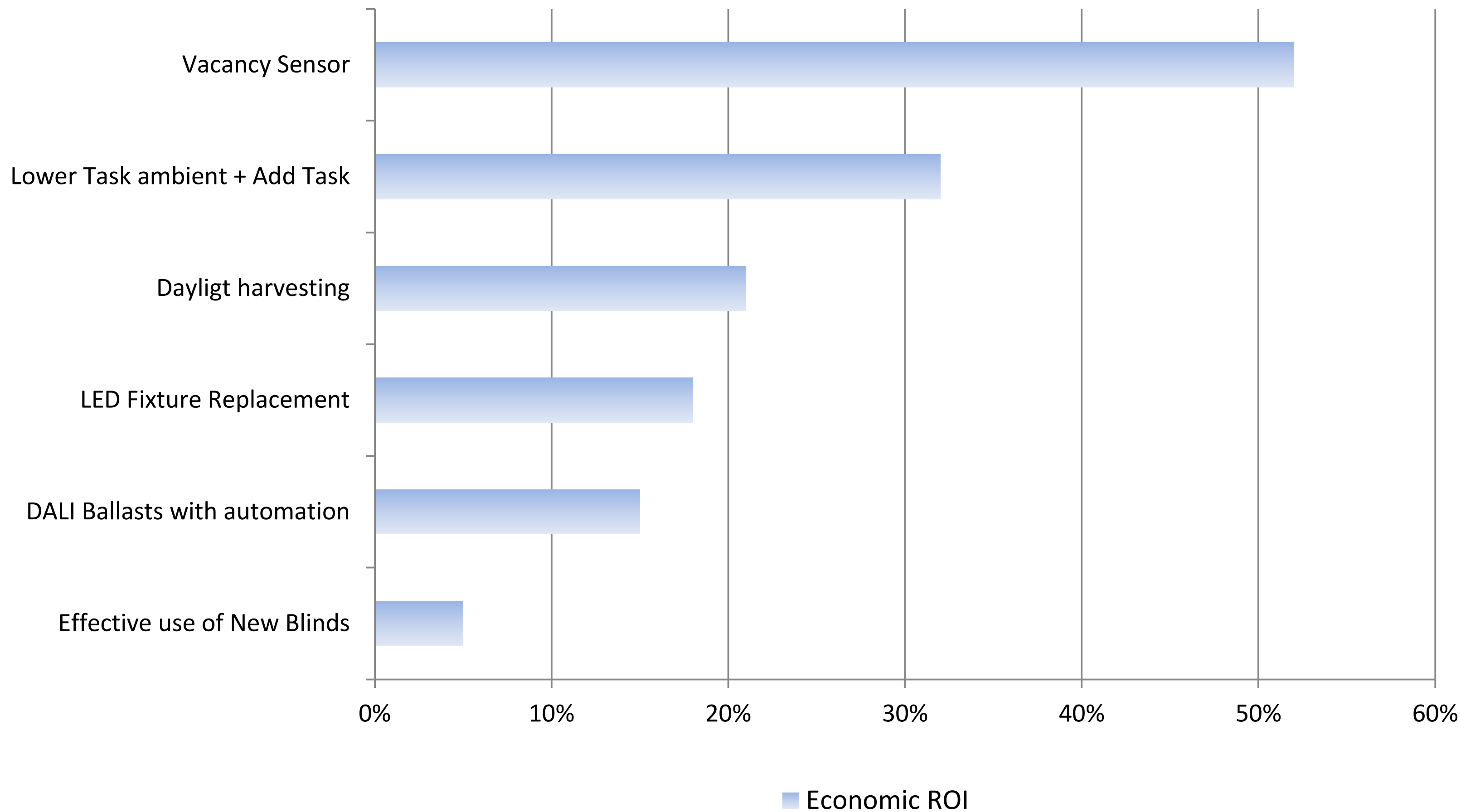
4. Hawes, B. K., Brunye, T. T., Mahoney, C. R., Sullivan, J. M., & Aall, C. D. (2012). Effects of four workplace lighting technologies on perception, cognition and affective state. International Journal of Industrial Ergonomics, 42, 122-128.

Six Energy Efficient Lighting Retrofits

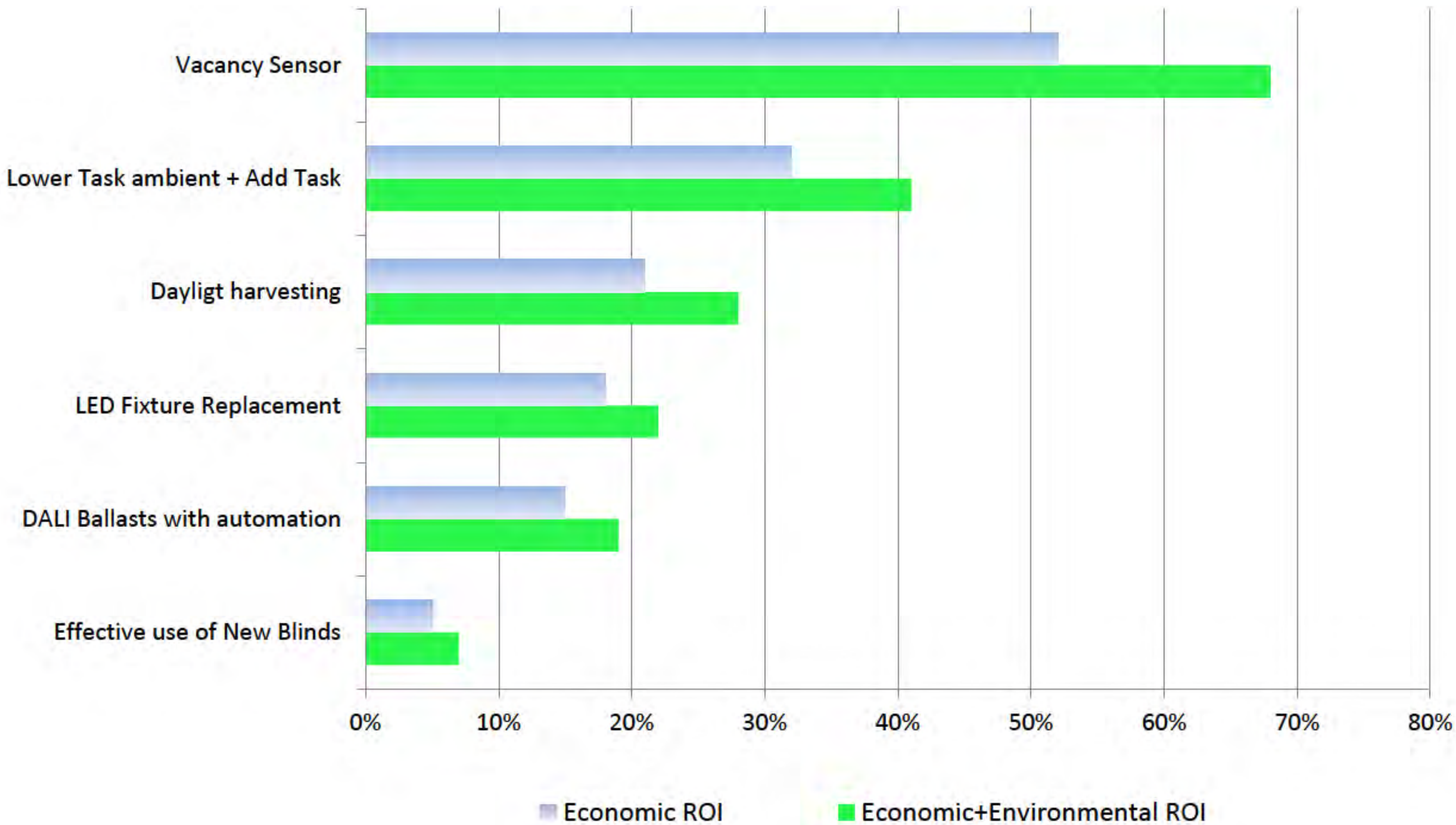
Recommendations for Triple Bottom Line Savings

Retrofit		Light Energy Saved
1 Install occupancy/vacancy sensors for closed spaces. Savings: Economic ROI = 52% Environmental ROI = 68%		13%
2 Install daylight harvesting for perimeter lights. Savings: Economic ROI = 21% Environmental ROI = 28% Equity = 354%		30%
3 Lower task-Ambient light levels and add task lights. Savings: Economic ROI = 32% Environmental ROI = 41% Equity = 142%		40%
4 Use blinds effectively for daylight, shade and glare control as well as for heat exchange control at night. Savings: Economic ROI = 5% Environmental ROI = 7% Equity = 94%		32%
5 Install individually addressable high performance fixtures with automation system. Savings: Economic ROI = 15% Environmental ROI = 19% Equity = 260%		65%
6 Install "vertically integrated" LED light fixtures (lamp, ballast, and fixture) plus add-ons for dimming and IP controlling. Savings: Economic ROI = 18% Environmental ROI = 22% Equity = 289%		85%

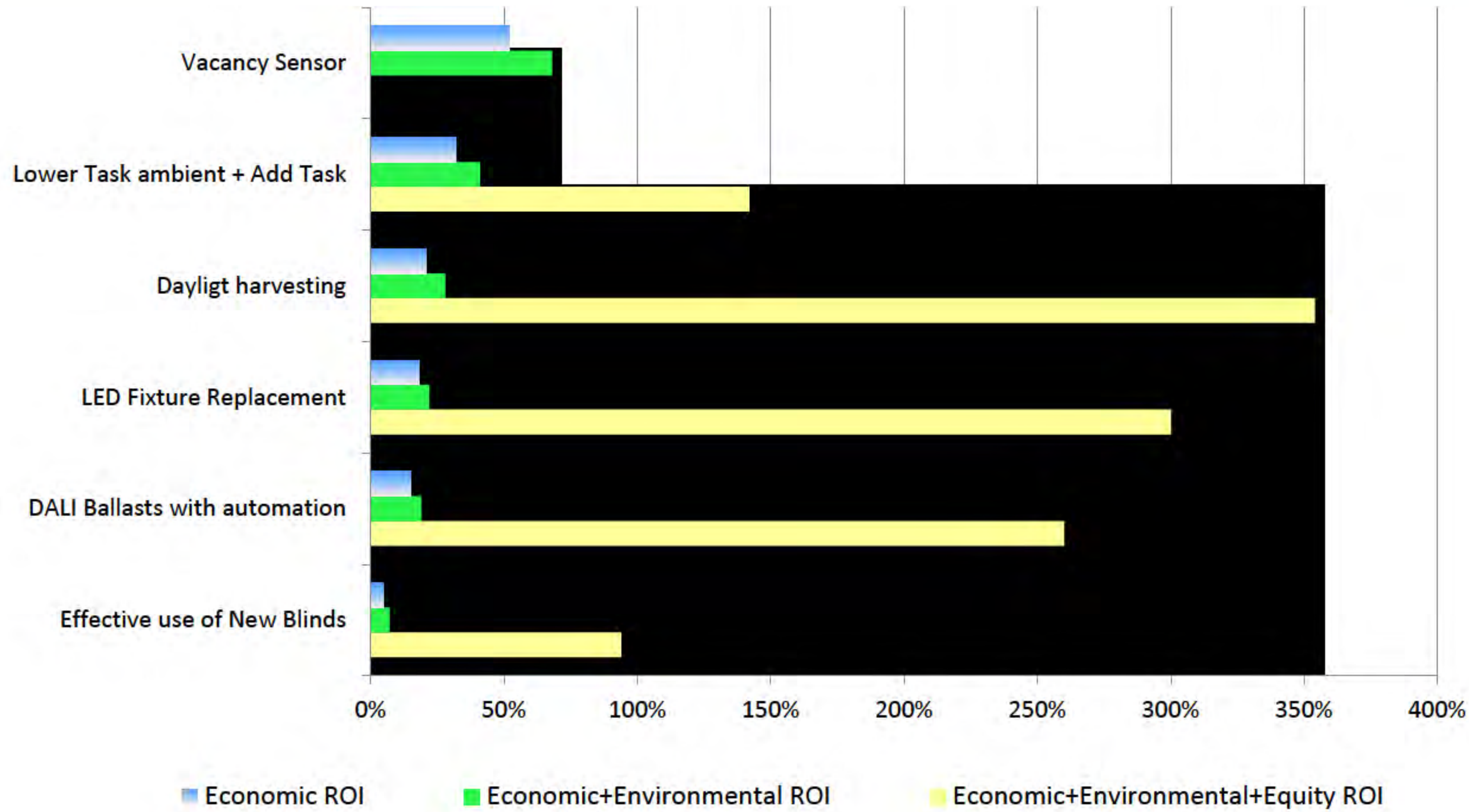
Priorities given Profit



Priorities given Profit and Planet



Priorities given Profit, Planet, and People



National Benefits of Lighting Energy Savings

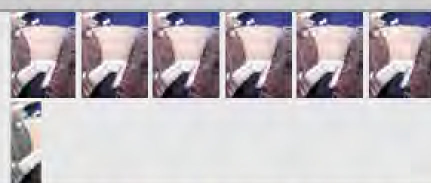
THE NATIONAL IMPACT

Energy Conservation

With a total area of 12 billion square feet, U.S. office buildings use over 86 billion kWh for lighting each year. Almost half of office buildings are using outdated lighting systems with T-12 fluorescent lamps and magnetic ballasts. At the 2003 U.S. average energy cost of $0.08 per kWh, the potential savings from implementing good practice high performance lighting systems (5-6 points) in 50% of office buildings is more than **$2.1 billion** each year. Over **25.8 billion kWh** would be saved annually—an amount of energy equal to:

One-third the annual energy production of the Three Gorges Dam

6.5 times the annual energy production of the Hoover Dam



The annual energy use of 955,000 U.S. households
(house icon = 10,000 houses)

The gasoline used by 1,288,000 cars in a year
(car icon = 10,000 cars)

(2007 CMU calculations of National impacts for lighting retrofits)

National Benefits of Lighting Energy Savings

Energy - Associated Benefits

The annual energy savings of **25.8 billion kWh** achieved by implementing high performance electric lighting systems in 50% of U.S. office buildings would generate valuable reduction in **emissions** and **water consumption** due to power generation, for a total additional savings of **$897.2 million annually**, and one-time **peak load** reduction with a value of **$6.98 billion.**

Peak Load Reduction

5,820 MW
with an estimated value of
$6.98 billion

(average 48.5% peak load reduction)

Emissions Reductions

Pollutant	*Annual reduction*	*Annual cost savings*
CO_2	36.1 billion lbs	$249.3 million
SO_2	156.7 million lbs	$374.7 million
NO_x	76.7 million lbs	$262.9 million
PM_{10}	3.3 million lbs	$7.5 million

Water Consumption Reduction

51.6 billion gallons / year
with an estimated value of
$103.2 million annually

(2007 CMU calculations of National impacts for lighting retrofits)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