Energy and Environmental Effects of High Light Reflectance Ceilings in Offices

Introduction

This study investigates the effects of increasing ceiling reflectance on several typical office plans. With standards like those developed by the American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE) and the International Energy Conservation Code (IECC) being adopted as code across the United States, there is a clear need to stretch our energy budget further than ever before. The Energy Policy Act of 2005 (EPAct 2005)[1] gives tax credits for energy efficient design below ASHRAE 90.1-2001[2] standards to encourage owners to reduce energy use below the code required minimum. In addition to code requirements and tax credits, many building owners are looking toward further improvements by applying the principles set forth by the United States Green Building Council (USGBC) in the Leadership in Energy and Environmental Design (LEED) program.

With so much at stake to reduce energy use and environmental impacts, much research is being conducted into new reflector and optical designs, as well as electronics and lamp technology and methods of integrating daylight. Relatively little research has been conducted on other factors affecting lighting design, including topics such as surface reflectance effects or light loss factors. Are the standard 80-50-20 room surface reflectances that most designers assume causing over- or under-design?

While more studies on light loss factor in modern environments need to be conducted, this study's focus is on the specific effects of ceiling reflectance on energy consumption. The effects were looked at in two different comparative sets. The first investigation held all room properties, including the lighting, consistent, then looked at the effect of the ceiling reflectance on ceiling uniformity and illuminance levels at the work plane. The second investigation used the same light fixtures, lamps, and ballasts, but optimized the design for a variety of ceiling reflectances to reduce as much energy as possible while meeting the Illuminating Engineering Society of North America (IESNA) recommendations in their Recommended Practices for Office Lighting (RP-1-2004) [3]. This information was then used to compare the effects of ceiling reflectance to energy saved, energy saved as compared to ASHRAE 90.1-1999[4] and 90.1-2004[5] and its effects on the LEED Version 2.1[6] and 2.2[7] rating systems respectively, and the effects the reduced lighting load has on the HVAC system.

Throughout the following studies, a target illuminance at the task plane of 50 footcandles (fc) was used, to comply with IESNA recommendations for private offices or open office plans with intermittent VDT use. Lower power densities are often achieved through lower ambient target light levels and the use of task lighting. These studies only consider the ambient lighting component.

Review of other Studies:

Previous studies have shown that there is a potential for significant energy savings when considering high reflectance surfaces. A recent study by Penn State University[8] showed a power density reduction in classroom spaces of 25 to 29 percent for the electric lighting when increasing the ceiling reflectance from 75% to 90%. This is also similar to the results found by the Weidt Group study[9], which found that a 25% increase in illuminance levels or an 18% decrease in operating costs could be achieved when using indirect luminaires. A study by Zhang and Ngai[10] has shown that as room reflectance increases, the ceiling uniformity also increases.

Other studies that were reviewed mostly involved surface reflectance of objects within the rooms rather than the room surfaces themselves. While these studies also showed promise in energy savings for proper furniture selection, the furniture system can change numerous times in a building's lifetime. Thus, many designers use standard values for these reflectances in case the systems change in the future. Unlike furniture systems or even wall color, ceiling systems are rarely changed unless there is a major renovation of a space. This provides a solid, reliable foundation upon which to base the lighting design. Thus any change in the ceiling system's reflectance could have long term impacts on the lighting system.

Software:

Each of the studies was conducted using a minimum of three lighting software packages to verify the results. It should be noted that while the results did vary between the programs, the variances were not statistically significant. The software packages utilized in these studies are as follows:

1. Lighting Analysts AGI32
    a. Radiosity Convergance
        i. Maximum Step size set to 1000 steps
        ii. Convergance set to 10% (0.1)
2. Luxicon 2.3.20
3. LitePro 1.02

Room Configurations:

Four room configurations were selected for being typical office spaces. Each space has a different shape and the spaces were selected to have Room Cavity Ratios (RCR) ranging from 1.0 to 7.5 in an attempt to limit any influence RCR might have on the results. The room configurations studied are as follows:

1. 10'x10' Private Office (RCR = 6.0 to 7.5)
2. 100'x30' Open Office (RCR = 1.3 to 1.6)
3. 60'x60' Open Office (RCR = 1.0 to 1.3)
4. Irregular Open Office (RCR = 2.0 to 2.5)

While additional room configurations should be considered with future studies, this study limited the number of room configurations to four to achieve preliminary information on the effects of ceiling reflectance.

Light Fixture Selection Information:

Two different light fixtures were utilized in this study. An indirect pendant and a recessed troffer were selected to view the effects of different photometric distribution types. The fixture selections were as follows:

1. Indirect light fixture
   Single T5HO lamp in cross section
   5000 initial lumens per lamp (assuming an under floor air system, which allows the room air to stratify and maintain 35 degree C ambient air temperature inside the fixture)
2. 2’x2’ Parabolic Troffer
   Two 32W T8 U lamps
   3150 initial lumens per lamp

For information on the exact light fixtures and photometric files used, please see the attached appendix.

Light loss factors are as follows:

a.	Room Surface Dirt Depreciation:	0.89
b.	Luminaire Dirt Depreciation:	0.95
c.	Ballast Factor:	1
d.	Lamp Lumen Depreciation:	0.9
	Total LLF:	0.761

The Studies:

Workplane Illuminance and Ceiling Uniformity Study:

Each room configuration was tested with 5 different ceiling heights: 10’, 9.75’, 9.5’, 9.25’, and 9’, while maintaining a luminaire height of 8.5’ from the floor plane. Work plane illuminances were calculated at 2.5’ above the floor surface. The ceiling uniformity portion of this study focuses only on the indirect fixture. Ceiling uniformity was calculated within the area above and between luminaires in compliance with IESNA RP-1-2004[3] recommendations.

The lighting layout in each room configuration was designed to meet 50 fc using a 75% reflective ceiling tile. In the case of the indirect light fixture, the best possible ceiling uniformity was achieved. It should be noted that at extremely low ceiling heights, the ceiling uniformity did exceed IESNA recommendations. All variables were held constant and only the ceiling tile reflectance was varied up to 90%. The calculations of work plane illuminance and ceiling uniformity for each fixture type were compared between the varying ceiling reflectances to determine a percentage change achieved with the higher reflectance value of the ceiling tile.

Lighting Layout 1

1. 10'x10' room:
    a. Indirect – 2 luminaires.
2. 100'x30' room:
    a. Indirect – 10 rows of 6 luminaires spaced 10 feet apart. Total of 60 luminaires.
    b. Direct – A grid of 12 luminaires spaced 8 feet apart by 4 luminaires spaced 7 feet apart. Total of 48 luminaires.
3. 60'x60' room:
    a. Indirect – 5 rows of 14 luminaires spaced 12 feet apart. Total of 70 luminaires.
    b. Direct – A grid of 7 luminaires spaced 8 feet apart by 8 luminaires spaced 7 feet apart. Total of 56 luminaires.
4. Irregular room:
    a. Indirect – 8 rows of 9 luminaires spaced 10 feet apart and 4 rows of 10 luminaires spaced 10 feet apart. Total of 112 luminaires.
    b. Direct – A grid of 10 luminaires spaced 8 feet apart by 5 luminaires spaced 8 feet apart, and 5 luminaires spaced 8 feet apart by 5 luminaires spaced 8 feet apart. Total of 75 luminaires.

Results:

For direct fixtures the work plane illuminance achieved modest increases ranging from 2% to 5% when increasing the ceiling reflectance from 75% to 90%.

The High Light Reflectance Ceiling (HLRC) compared to a 75% reflective ceiling achieves an average increase of approximately 22% in work plane illuminance with indirect lighting. This result was very consistent between room shapes and ceiling heights. The results are also very similar to results previously achieved in studies by Penn State University[8] and by the Weidt Group study[9].

The ceiling uniformity also improved. In a few instances, calculations showed that switching to a 90% reflective ceiling enabled the ceiling uniformity to come within IESNA RP-1-2004[3] recommendations, whereas it did not meet the recommendations with a 75% reflective tile. In the single 10'x10' office, an average of 3.67% improvement in ceiling uniformity was noted, whereas the open office plans had much higher average improvements of roughly 10-15%. Taking into account all instances where the layouts with the 90% reflectance ceiling had uniformity ratios within IESNA recommendations of 10:1, the average improvement in the uniformity ratio when switching from the 75% to the 90% reflective ceiling was 6.84%. These results are also very similar to results previously achieved in studies by Zhang & Ngai[10].

This research yields two important results:

1. HLRC ceiling systems show more improvement in larger office plans than single private offices, with ceiling uniformity ratios improving by an average of 12.58% and 3.67%, respectively.
2. HLRC ceiling systems provide an average of approximately 22% increase in work plane illuminance.

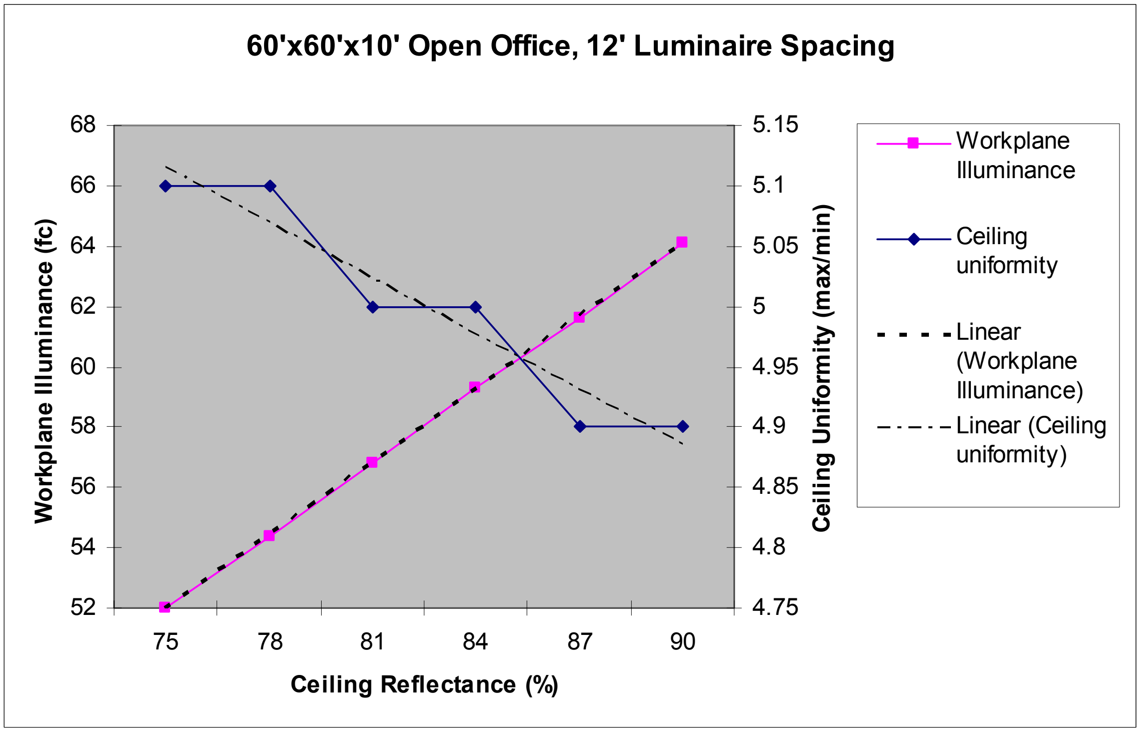
Below is a summary chart of the results found in this study.

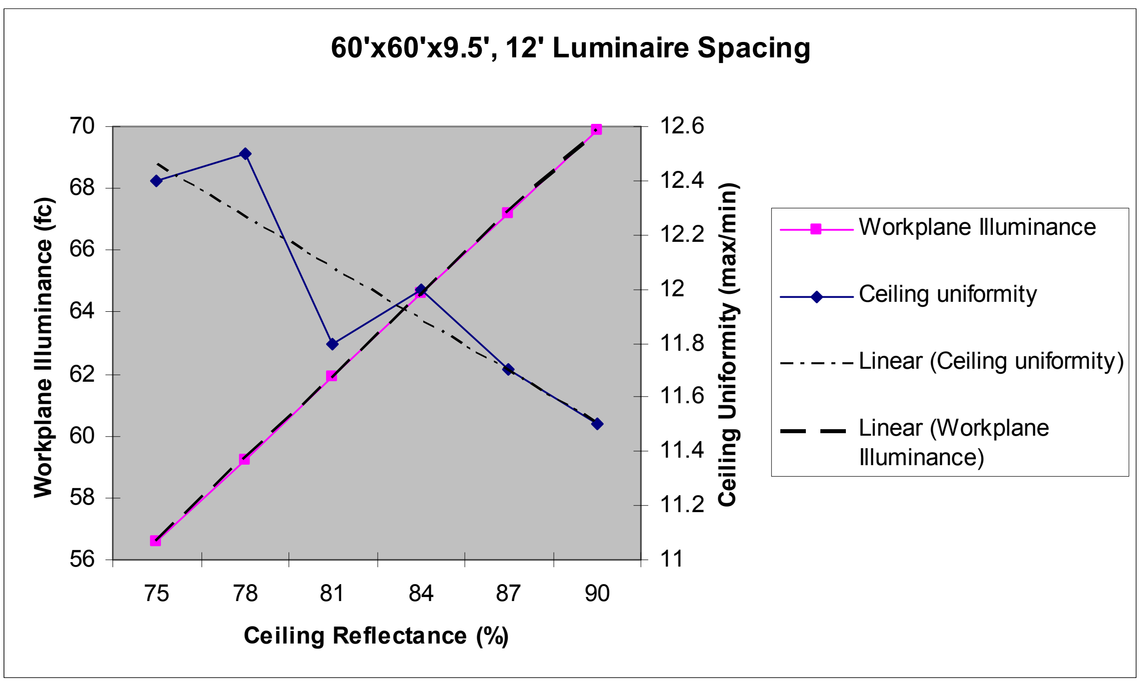
10' Ceiling Height		
Workplane illuminance increased by an average of	22.64	%
Ceiling uniformity improved by an average of	4.51	%
9'-9" Ceiling Height		
Workplane illuminance increased by an average of	22.76	%
Ceiling uniformity improved by an average of	6.25	%
9'-6" Ceiling Height		
Workplane illuminance increased by an average of	22.54	%
Ceiling uniformity improved by an average of	9.64	%
9'-3" Ceiling Height		
Workplane illuminance increased by an average of	22.87	%
Ceiling uniformity improved by an average of	13.92	%
9' Ceiling Height		
Workplane illuminance increased by an average of	22.86	%
Ceiling uniformity improved by an average of	19.45	%

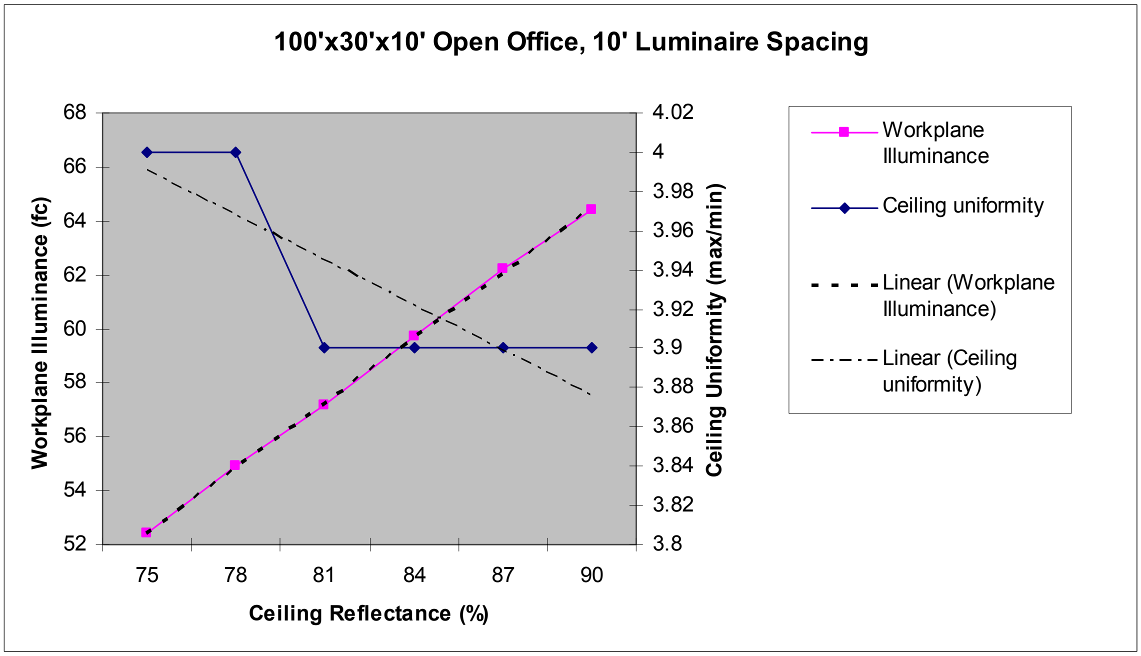
Note: Not all room and ceiling configurations met the IESNA recommended 10:1 ratio of luminance ratio (max/min).

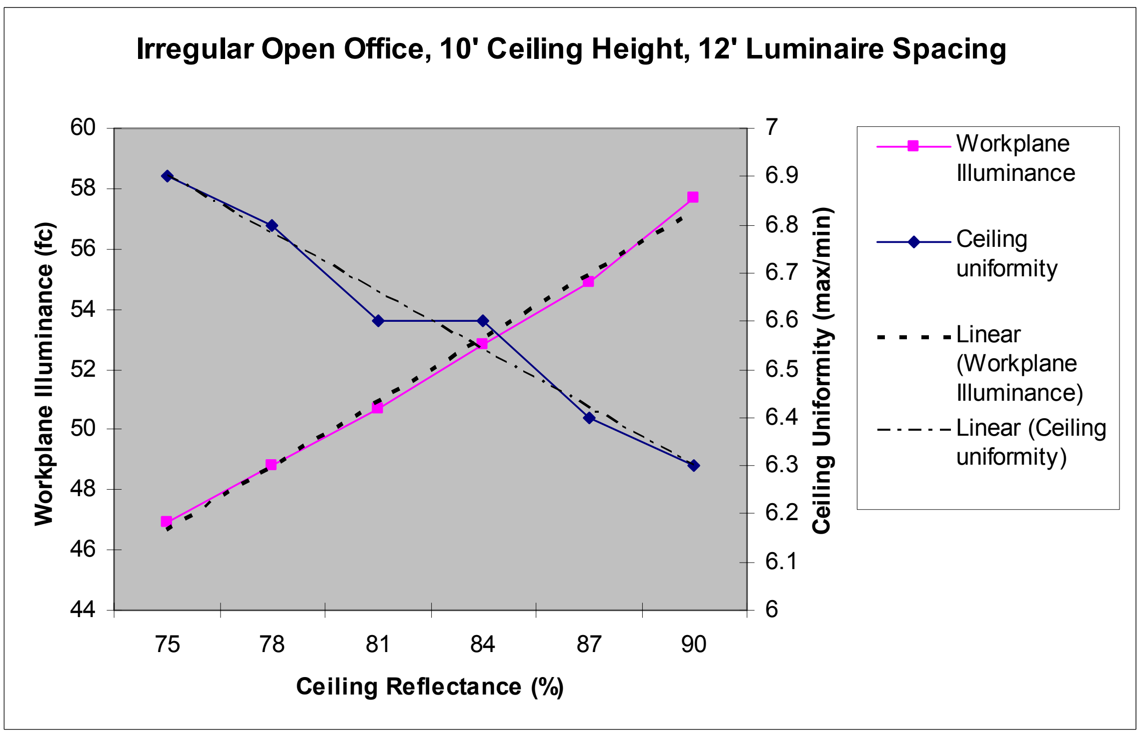
Comparing only the rooms that met 10:1 ratio, ceiling uniformity improved by an average of	6.84	%

Through analysis of the results for a variety of ceiling reflectance values, a nearly linear increase in illuminance levels was found when increasing the ceiling reflectance. This linear increase does not have a simple equation to apply to all conditions as the slope of the line is dependant on several factors including the room cavity ratio and the fixture's coefficient of utilization. However, it is interesting to see that, given all factors remain constant within a space except the ceiling reflectance, there is a linear equation for the given room's illuminance increase. The ceiling uniformity also appears to improve in a linear fashion, although due to the decimal point limitations of the calculations the graph is not smooth. Some example graphs are included below.


60'x60'x10' Open Office, 12' Luminaire Spacing
Workplane Illuminance (fc)
Ceiling Uniformity (max/min)
Ceiling Reflectance (%)
68
66
64
62
60
58
56
54
52
5.15
5.1
5.05
5
4.95
4.9
4.85
4.8
4.75
75
78
81
84
87
90
Workplane Illuminance
Ceiling uniformity
Linear (Workplane Illuminance)
Linear (Ceiling uniformity)


60'x60'x9.5', 12' Luminaire Spacing
Workplane Illuminance (fc)
Ceiling Uniformity (max/min)
Ceiling Reflectance (%)
70
68
66
64
62
60
58
56
12.6
12.4
12.2
12
11.8
11.6
11.4
11.2
11
75
78
81
84
87
90
Workplane Illuminance
Ceiling uniformity
Linear (Ceiling uniformity)
Linear (Workplane Illuminance)


100'x30'x10' Open Office, 10' Luminaire Spacing
Workplane Illuminance (fc)
68
66
64
62
60
58
56
54
52
Ceiling Uniformity (max/min)
4.02
4
3.98
3.96
3.94
3.92
3.9
3.88
3.86
3.84
3.82
3.8
75
78
81
84
87
90
Ceiling Reflectance (%)
Workplane Illuminance
Ceiling uniformity
Linear (Workplane Illuminance)
Linear (Ceiling uniformity)


Irregular Open Office, 10' Ceiling Height, 12' Luminaire Spacing
Workplane Illuminance (fc)
60
58
56
54
52
50
48
46
44
Ceiling Uniformity (max/min)
7
6.9
6.8
6.7
6.6
6.5
6.4
6.3
6.2
6.1
6
75
78
81
84
87
90
Ceiling Reflectance (%)
Workplane Illuminance
Ceiling uniformity
Linear (Workplane Illuminance)
Linear (Ceiling uniformity)

Energy Savings Study:

Utilizing the same spaces and fixtures as previously defined, a new lighting design was created for the indirect light fixtures to optimize the layout to achieve 50 fc with the 90% reflective ceiling tile with the best possible ceiling uniformity. In all cases the ceiling height was held constant at 10'. Indirect luminaires were mounted at 8.5'. These results were also compared against a typical office layout of 2'x2' recessed parabolic troffer style luminaires with standard spacing, as shown in the Workplane Illuminance and Ceiling Uniformity Study. All calculations were then compared against each other to determine a percentage change in energy use that was achieved with the higher value for the ceiling tile.

75% reflective ceiling tile - T5HO Indirect

1. 100'x30' room:
    a. Indirect – Ten rows of 24-foot sections spaced 10 feet apart for a total of 60 luminaires.
    b. Direct - A grid of 12 luminaires spaced 8 feet apart by 4 luminaires spaced 7 feet apart for a total of 48 fixtures.
2. 60'x60' room:
    a. Indirect – Six parallel rows of three 16-foot sections spaced 10 feet apart side to side and 4 feet apart end to end for a total of 72 luminaires.
    b. Direct – A uniform grid of 56 luminaires spaced on 8 foot centers in one direction and alternating 8 foot and 6 foot spacing in the other direction.
3. Irregular room:
    a. Indirect - Six parallel rows of three 16-foot sections spaced 10 feet apart side to side and 4 feet apart end to end for a total of 96 luminaires total.
    b. Direct – A uniform grid of 75 luminaires spaced out on 8 foot centers.

90% reflective Ceiling Tile - T5HO Indirect

1. 100'x30'x10' room:
    a. Eight rows of 24 foot sections spaced 12 feet apart for a total of 48 luminaires.
    b. Direct - A grid of 12 luminaires spaced 8 feet apart by 4 luminaires spaced 7 feet apart for a total of 48 luminaires.
2. 60'x60'x10' room:
    a. Four parallel rows of three 16-foot sections spaced 13 feet apart side to side and 4 feet apart end to end for a total of 60 luminaires.
    b. Direct – A uniform grid of 56 luminaires spaced on 8 foot centers in one direction and alternating 8 foot and 6 foot spacing in the other direction.
3. Irregular room:
    a. 16-foot sections spaced 12 feet apart side to side and 4 feet apart end to end for a total of 72 luminaires.
    b. Direct – A uniform grid of 75 luminaires spaced out on 8 foot centers.

Results:

Using the 90% reflective ceiling allowed the spacing between indirect luminaire sections to be increased, which reduced the total number of luminaires needed to achieve light levels similar to the 75% reflective ceiling. When changing from a 75% to 90% reflective ceiling tile utilizing direct fixtures there was a slight increase in light levels, but not a large enough increase to allow for the reduction of fixtures. As such, the layouts for all ceiling reflectances remained the same for the direct fixtures.

For the 100'x30'x10' room, utilizing the HLRC allowed a reduction of the lighting power density to 0.96 watts per square foot (w/ft^2), which is 20% better than a 75% reflective ceiling. This yields a savings of 0.24 w/ft^2, or a reduction in cooling load of 20% over a standard 75% reflective ceiling. This is also a reduction of 0.16 w/ft^2 as compared to using 2'x2' parabolic luminaires, which results in a reduction in cooling load by 14.29%.

The 60'x60'x10' room shows similar results. Moving from the 75% reflective tile with a 10' spacing to the 90% reflective tile with a 13' spacing resulted in work plane illuminances of 52.9fc compared to 51.7fc and ceiling uniformities of 6:1 and 7.4:1 respectively, which is within the IESNA RP-1-2004[3] recommendation of 10:1. Utilizing a 13' spacing allowed the deletion of one entire row of lights, dropping the power density to 1.00 w/ft^2. This yields a savings of 0.17 w/ft^2, or a reduction in cooling load due to lighting of 14.29% as compared to the 10' spacing with 75% reflective ceiling. When compared to the 2'x2' parabolic troffer, the cooling load energy savings rose to 31.43% when the recessed system achieved an average work plane illuminance of 54.3fc.

Below is a summary of the average power density reductions achieved when changing the ceiling reflectance from 75% to 90%:

The optimized layout with HLRC and indirect luminaires yielded a:	23.33%	lower average power density over the standard 75% reflective ceiling layout (Layout 2).
	21.14%	lower average power density over the standard 2'x2' parabolic troffer layout (Layout 4).
The breakdown is as follows:		
100x30	20.00%	better than the standard layout with 75% reflective ceiling
	14.29%	better than the 2'x2' layout with 75% or 90% reflective ceiling
60x60	14.29%	better than the standard layout with 75% reflective ceiling
	31.43%	better than the 2'x2' layout with 75% or 90% reflective ceiling
Irregular	35.71%	better than the standard layout with 75% reflective ceiling
	17.71%	better than the 2'x2' layout with 75% or 90% reflective ceiling

HVAC Savings:

Using the three open office room configurations previously defined, the effects of the reduced lighting load on the HVAC system was modeled using two different computer software programs. The building was assumed to be located in Atlanta, Georgia. Each model was run once with northern facing windows and once with southern facing windows for relative heat gain and loss only, as no daylight dimming was considered. The open offices were assumed to be located on an intermediate floor, where losses and gains due to the roof or floor structure are negligible. The wall structure was assumed to have a U-value of 0.094 btu/hr/sf/°F and be of standard ASHRAE 90.1-2004[5] configuration. The power densities used in each iteration were developed in the previous portion of this study. A detailed occupancy schedule can be found in the attached appendix under "scheduled hours of operation." In general the office was considered occupied from 6:00 am to 6:00 pm daily during the week and unoccupied on weekends and holidays. In the unoccupied mode some lights and equipment were considered "on" to account for late employees, cleaning or maintenance crews, security, etc.

Software Used:

1. DOE2
2. Trane Tracer

Results:

The results obtained from modeling the lighting and HVAC in Trane Tracer as it relates to heating and cooling loads showed roughly a 7% decrease in energy consumption with the indirect fixtures and 90% reflective ceiling, as compared to the 75% reflective ceiling or the 2x2 troffer layout on either ceiling. DOE2 showed similar results, although slightly lower savings. Due to the makeup of the building envelope, the internal heat gains kept the cooling system in operation year round. We predict that this is greatly dependant on climate. In cold climates, because of the decrease in watts used by the lighting system, the heating system will use more energy to compensate. For warm climates, the reduction in light power density will allow the cooling system to use less energy, holding all other variables the same.

Summary results of the study are shown below:

The reduction in lighting power density obtained by the 90% reflective ceiling enabled an average HVAC energy cost savings of	North Facing Façade:	
	9.10%	over the layout with a 75% reflective ceiling.
	7.40%	over the 2x2 troffer layout.
	South Facing Façade:	
	7.80%	over the layout with a 75% reflective ceiling.
	6.60%	over the 2x2 troffer layout.

Summary:

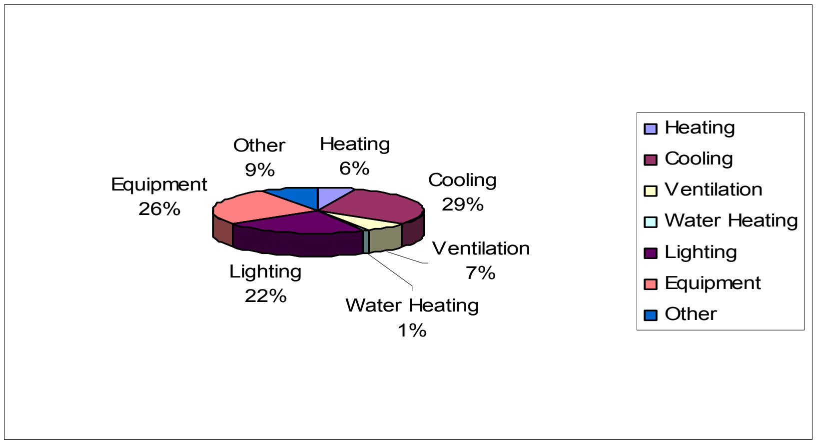
Based on the results of this limited study, there does appear to be a significant impact on the HVAC system from reducing the lighting load through the use of an HLRC. This impact can be positive in the form of energy savings if the building is in cooling year-round, as many large scale commercial building are. Even buildings that experience heating loads often only experience those loads at the perimeter and could still see overall positive impacts from the lighting savings. In buildings where the heating load is significant, the reduction of lighting will increase the HVAC system costs due to the additional heating load. It should be noted that even in this condition, the lighting savings significantly offset this additional heating cost.

LEED Credit Analysis Version 2.1 registered prior to 2006:

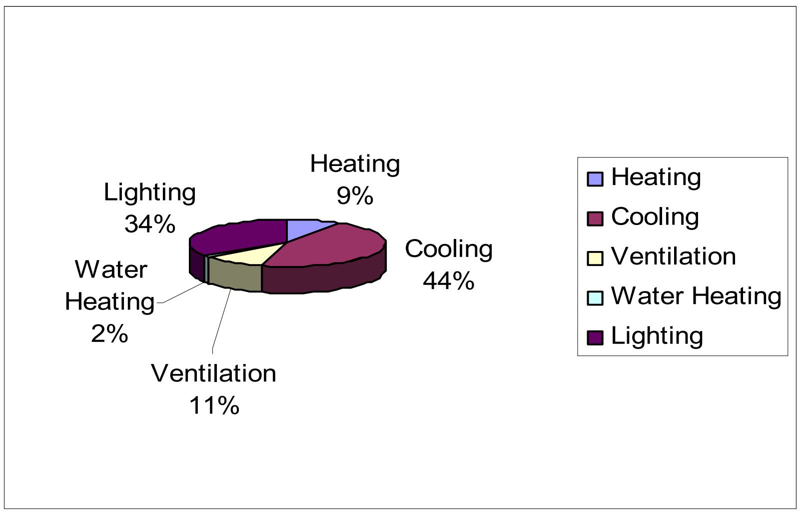
HLRC has proven to reduce the lighting power density by over 20% as compared to a typical 75% reflective ceiling using the same lighting system, while having a positive impact on the HVAC systems in buildings that are mostly in cooling. To relate this to the LEED point system, it is necessary to look at lighting power densities rather than percentage reductions, as in previous portions of this study. LEED NC 2.1[6] refers to ASHRAE 90.1-1999[4] as the base model of energy use and then applies credits for a reduction in total building power to that specified limit.

The specified lighting power density limit for open office areas is 1.3 w/ft^2. The average power densities achieved for this study are listed in the graph below and compared to the ASHRAE 90.1-1999[4] limit as a percentage saved.

The Energy Information Administration (EIA)[11], which administers the official energy statistics for the United States Government through the Department of Energy (DOE), states that about 35% of a typical U.S. office building's energy is used in equipment and other energy using devices (see the graphs below). While these internal loads were included in the HVAC calculations for this study for heat gain purposes, they remained the same in all conditions since this study is limiting the variables to the ceiling reflectance only and associated lighting improvements only. The LEED point system is only affected by the total building energy for HVAC (heating, cooling, fans, and pumps), service hot water, and interior lighting, and thus, we can disregard the equipment and other energy users. According to the EIA[11] statistics, HVAC accounts for 63% and lighting accounts for 34% of the remaining energy used in U.S. office buildings.



Percent of energy used by US office buildings according to the Energy Information Administration[11].



Percent of energy used by US office buildings related to LEED NC version 2.1[6] energy calculations according to the Energy Information Administration[11].

Indirect Layout with 75% Reflective Ceiling	
Percent Saving Lighting	2.3%
Percent Saving HVAC	0.9%
Total Percent Energy	1.8%
Maximized Indirect Layout with 90% Reflective Ceiling	
Percent Saving Lighting	27.4%
Percent Saving HVAC	11.0%
Total Percent Energy	21.6%
2x2 Parabolic Troffer Layout	
Percent Saving Lighting	6.9%
Percent Saving HVAC	2.8%
Total Percent Energy	5.5%

Percentage energy savings compared to ASHRAE 90.1-1999[4]

Summary:

Based on the spaces used for this study, high light reflectance ceilings do have an impact on LEED points. In this limited study, additional energy points were achieved through nothing more than increasing the ceiling reflectance. The total building energy savings as defined by LEED NC version 2.1[6] could be as high as 21.6% when optimizing the lighting layout with respect to the HLRC. This savings qualifies for up to 2 points in a new building or 4 points in an existing building.

LEED Credit Analysis Version 2.2 registered after to 2006:

The pure energy savings in comparing LEED NC version 2.2[7] are very similar to those used in LEED NC version 2.1[6]. The biggest difference in regards to the Energy and Atmosphere credit for Optimized Energy is that version 2.2[7] refers to ASHRAE 90.1-2004[5] whereas version 2.1[6] refers to ASHRAE 90.1-1999[4]. As a result, credits become more difficult to achieve because energy restrictions in ASHRAE 90.1-2004[4] are tighter. For example, the specified lighting power density specified limit for office areas was reduced from 1.3 to 1.1 w/ft^2. The point structure also changed slightly. Under LEED NC version 2.1[6], a minimum reduction of 15% for new buildings and 5% for existing buildings was required to achieve the first point and then an additional point was given for every 5% additional savings beyond that. In LEED NC version 2.2[7], the first point is achieved at a reduction of 10.5% for new buildings and 3.5% for existing buildings and then an additional point is earned for each additional 3.5% savings achieved. The net result is stricter energy guidelines, but a slightly easier point system.

The average power densities achieved for this study are listed in the graph below and compared to the ASHRAE 90.1-2004[5] limit as a percentage saved.

Indirect Layout with 75% Reflective Ceiling	
Percent Saving Lighting	-15.6%
Percent Saving HVAC	-5.6%
Total Percent Energy	-11.8%
Maximized Indirect Layout with 90% Reflective Ceiling	
Percent Saving Lighting	14.1%
Percent Saving HVAC	5.1%
Total Percent Energy	10.6%
2x2 Parabolic Troffer Layout	
Percent Saving Lighting	-10.2%
Percent Saving HVAC	-3.6%
Total Percent Energy	-7.7%

Percentage energy savings compared to ASHRAE 90.1-2004[4]

Summary:

Based on the spaces used for this study, high light reflectance ceilings do have an impact on LEED points. In this limited study, additional energy points were achieved through nothing more than increasing the ceiling reflectance. The total building energy savings as defined by LEED NC version 2.2[7] could be as high as 10.6% when optimizing the lighting layout with respect to the HLRC. This savings qualifies for up to 1 point in a new building or 3 points in an existing building.

Discussion:

This study focuses primarily on the effects that increasing ceiling reflectance has on illuminance levels, uniformity ratios, and building energy use. While the study attempts to take a wide variety of space configurations into account, the study is still very limited in scope and thus, only general conclusions can be drawn.

Partitions and office furniture were not included in the calculations for this study. As shown in previous studies, such as those by Choi and Mistrick[12], office partition color and style can have a significant impact on the lighting systems. Because this study is focused on the ceiling reflectance, the office partitions would have remained constant among all iterations and thus, the results should not be significantly different in terms of percentage increase or decrease had they been included.

As previously noted, the HVAC savings will vary considerably dependant on location. Further investigation on the impact of lighting to HVAC costs should be conducted, as this study hinted toward a decrease in lighting load having a negative impact on HVAC costs when heating loads are high, although total building energy was still decreased.

Additional energy savings could be obtained through further optimization in the design by selecting a variety of fixtures, optics, ballast types, etc. These options were not considered, in order to maintain the consistency of evaluating the effects of the ceiling reflectance. Daylighting was also intentionally left out of this study but should be considered. The effects of daylight with high reflectance ceilings could add significant cost savings to the building, particularly when dimming is considered. Evaluation of these additional factors will not be easy due to the large number of variables to deal with, but initial research seems to be warranted.

As stated in the introduction, this study used 50 fc average as the target work plane illuminance per IESNA recommendations for private offices or open office plans with intermittent VDT use. Additional energy reductions could be achieved through the use of a task/ambient lighting system where the ambient system only targets 30 fc. While further research is suggested, this study did not look at the effect of high reflectance ceilings at light levels other than 50 fc.

Overall Summary:

In general, increasing the reflectance of the ceiling has a very positive impact on the lighting and building energy use as a whole, particularly relative to indirect lighting designs. The following conclusions can be made when increasing the ceiling reflectance from 75% to 90%:

- The illuminace levels for the same lighting design increase in a linear fashion up to 22%.
- The ceiling uniformity improves in a linear fashion.
- The ceiling uniformity improves by a greater percentage as the distance between the ceiling and the luminare is reduced.
- An average reduction in lighting energy of over 20% can be achieved, however this is widely dependant on the space configuration.
- The building's cooling system can see an average savings of 7%.
- The total building energy consumption (as calculated by LEED NC version 2.1[6]) can be reduced by 16 to 19 percent.
- 1 to 3 LEED NC version 2.1[6] points can be achieved for the energy reduction point for new or existing construction, respectively.

It should be recognized that each building and situation is very unique and this study in no way claims that increasing the reflectance of the ceiling system will ensure any specific energy savings or LEED points. However, the indications are that lighting designers and architects should be looking at the ceiling system as an integral portion of the building's energy reduction techniques. The overall cost impact to potential energy savings may make high reflectance ceilings a good solution for achieving energy reductions without the need for expensive new technology.

References:

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