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Using high light reflectance acoustical ceilings to increase the energy efficiency of buildings

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Acoustical ceilings with white, highly light-reflecting surfaces can be used as an effective, passive means to significantly improve the energy efficiency of a space. When a ceiling with high light reflectance is coupled with an indirect lighting system, illumination can be increased by 20% or the energy directly associated with lighting can be reduced by 20%. In addition, lower lighting loads can reduce cooling costs by 7%. A highly light reflective ceiling can also be used to reflect daylight into a space, increasing the amount of light in interior areas away from the windows by as much as 20%; alternatively, the surface area of windows may be reduced by 11% while maintaining the same illumination levels. In all cases, the increased reflectance of light allows the number of fixtures to be decreased, further increasing the savings related to initial cost, energy use and maintenance. The percentage of energy savings associated with lighting is proportional to the percentage increase in the ceiling's light reflectance value; therefore, even small increases in light reflectance provide energy savings. When the acoustical performance of two products is comparable, light reflectance could be a critical differentiator in determining total building performance and occupant comfort.

1 Introduction

As a result of efforts to reduce the environmental impact of buildings, there has been an emphasis placed on the use of materials that can increase the energy efficiency of a space. There has been a simultaneous effort by some specifiers to reduce the material usage in a space, in the belief that using less material is better for the environment. Frequently, one of the first casualties of dematerialization is the traditional acoustical ceiling; if other acoustically absorptive materials are not included in the space, the acoustic comfort and productivity of the occupants will be compromised. For example, open office spaces with no acoustical ceiling treatment suffer from long reverberation times and reduced speech privacy; both of these will adversely affect worker productivity and comfort. Studies of indoor environments have linked poor acoustics to increased worker distractions and lowered productivity [1, 2, 3].

What is less obvious is that the elimination of the suspended ceiling can also create a space that is not as energy efficient as it might be. A highly light reflective ceiling plane can be used as part of the lighting strategy for the space, helping to enhance both natural and artificial light within the space, and reducing the energy associated with lighting.

The United States Department of Energy has published data showing that lighting fixtures are the largest users of energy in American office buildings, and the second largest in commercial buildings overall, using 23-29% of the total energy consumed [4]. The ability to use a single product to significantly reduce the energy used to light a space while providing acoustical conditions that can increase worker productivity is a powerful argument in favor of the use of suspended acoustical ceilings.

2 The role of an acoustic ceiling in saving energy

There are several ways in which a suspended acoustical ceiling can be used to save energy in a building. First, many acoustical ceilings are manufactured from insulating materials such as fiberglass, rock wool, and slag wool (the latter two are generically known as mineral wools). The published thermal insulation values for these products range from 0.26 – 0.30 m²W/K for mineral wool products to 0.62 m²W/K for fiberglass products. However, given the fact

that ceilings tend to be thin (less than 20 mm is typical) the actual insulating effect is somewhat minimal.

A suspended ceiling can play a role in energy savings when it is used as a component of the air distribution system. Modelling work commissioned by the Ceilings and Interior Systems Construction Association (CISCA) found that the use of a suspended ceiling as part of a return air plenum HVAC system (a common building practice in the United States) reduced the energy to operate an office space by 5 – 7.6% as compared to an open plenum design for the same space. This is largely due to the need for reduced horsepower fans, and an increased ability to remove heat from lighting fixtures [5].

There is a third attribute of suspended acoustical ceilings that can have a profound impact on the energy efficiency of the space: light reflectance. Light Reflectance, or LR, is a physical property that represents the percentage of incident illuminance that is reflected off a flat surface after being directed at that surface. For example, a surface with a light reflectance value of 0.75 will reflect 75% of the incident light and absorb 25%. A surface with a light reflectance value of 0.90 reflects 90% of the light, absorbing only 10%. The light reflectance values of most white suspended ceiling products fall in the range of 0.75 – 0.90, as measured by ASTM E1477 [6] or ISO 7724-2 [7]. As the amount of texturing or fissuring increases, the light reflectance will decrease; the products with the highest values, greater than 0.85, tend to have smooth surfaces and are painted with high quality coatings containing highly refractive pigments such as TiO₂. Non-white surfaces have much lower light reflectance values.

Research has shown that a high LR ceiling can play a significant role in enhancing energy efficiency in two main ways:

1. The artificial illuminance generated by pendant or other indirect lighting fixtures is bettered scattered, increasing the quality and quantity of light available to the space below. This in turn allows the number of fixtures to be reduced, reducing the energy associated with lighting.
2. Natural light from windows can be harvested more fully, reflecting this light deeper into the interior of the space. This diminishes the need for artificial light in the space, and when used with a daylight switching or dimming system strategy, the energy associated with lighting will be reduced.

Recognition of the positive impact of light reflective surfaces on energy usage is addressed in the IESNA Handbook [8], and in recent updates to ASHRAE 90.1,

Energy Standard for Buildings Except Low-Rise Residential Buildings [9]. Both give recommended light reflectance values for various surfaces.

2.1 The Use of High LR ceilings with Indirect Lighting

When a high LR ceiling is used in conjunction with an indirect lighting system, the total illumination required for the space can be decreased [10, 11] because the ceiling plane becomes an integral part of the lighting distribution system. High LR ceilings have smooth finishes that diffuse light equally in all directions, greatly reducing offensive glare, creating a more comfortably lit space for occupants. This property, known as uniformity, also improves the brightness ratio. When coupled with its inherent low absorption of incident light, a high LR ceiling increases the effectiveness of the lighting system. This in turn reduces the number of fixtures needed in the space, reducing the energy needed to provide light.

An extensive study commissioned by Armstrong and performed by Brinjac Engineering evaluated the effect of high light reflectance ceilings on energy usage in buildings, when used in conjunction with indirect lighting systems [11]. The study eliminated the potential impacts of day lighting and task lighting within the space, and focused on the impact of the light reflectance value of the ceiling on ceiling uniformity, work place illumination, and the ability to reduce energy while meeting the requirements of the IESNA Recommended Practices for Office Lighting. Atlanta, GA, was used at the locale.

The results of this work show that by increasing the light reflectance value of the ceiling from 0.75 to 0.90, the following improvements can be realized:

- A higher LR value improved ceiling uniformity regardless of ceiling height, reducing glare and creating a more comfortably lit space for the occupant.
- There was a 22% increase in illumination within the workplace, when designed for maximum illumination. This increases the effectiveness of the lighting design.
- There was a 23% savings in lighting energy when designed for maximum energy savings.
- There was a 7% decrease in energy consumption associated with the cooling system. In air conditioned buildings, the heat generated by lighting fixtures adds to the overall heat load in the building. By reducing the number of light fixtures, less heat was generated, and less cooling was required.

By using a high LR ceiling with an indirect lighting system, a building's total energy use can be reduced by 10.6%. Work done by Yoon and Moeck shows significant reductions in lighting power density as the light reflectance of the ceiling is increased [12].

Analysis of the Brinjac data suggests that there is a linear relationship between the percent increase in the light reflectance value of the ceiling and the percent decrease in energy needed for lighting. A 5.9% increase in light reflectance from 0.85 to 0.90 should result in an energy savings of approximately 6% [10]. Therefore, even small changes in light reflectance can have significant impacts on energy use.

The Weidt Group performed an extensive analysis of the overall lighting design of the newly built Keystone Building in Harrisburg, PA. Their results show that combining a reflective acoustical ceiling with under floor air delivery helped increase the energy efficiency of the space: the uninterrupted ceiling plane reflected even more light, enabling the number of light fixtures to be decreased to a level that was 30% of amount originally specified. The use of a highly light reflective ceiling was one component of an overall lighting design strategy for the building that resulted in a 50% decrease in the energy associated with lighting [13]. This case study suggests that omitting a highly reflective ceiling from spaces with under floor air systems can result in higher energy usage than is needed, and that the use of high LR ceilings is an important component of the lighting strategy.

2.2 The Impact of High LR ceilings with Natural Lighting

Natural lighting, or daylighting, is an important aspect for high performance spaces, improving energy efficiency [14] and increasing worker productivity [15]. Harvesting of natural light is a key component of effective lighting strategies, and is frequently used in conjunction with dimming and automatic switching systems. When a high LR ceiling is also used, there is an additional positive impact on the lighting and energy use of the space.

A highly reflective ceiling plane acts to redirect, or harvest, natural light that enters a space through windows or off a light shelf. The light rays hit the uniform ceiling, and are reflected down evenly into the occupied space. When no ceiling is present, the light hits a surface that is typically rough, unfinished, and full of obstructions; the surface is also frequently painted black. In this case, most of the light is absorbed by the dark surfaces, and the remainder is poorly or unevenly reflected into the space below.

The increase in the amount of daylight available associated with using a reflective ceiling can be measured. Weidt found that the use of an LR 0.89 ceiling increased by 15-20% the amount of daylight in spaces that were 3.6 – 6.7 m away from a window, as compared to the levels when an LR 0.75 ceiling was used [16]. Yoon and Moeck found that increasing the ceiling light reflectance to 0.90 from 0.75 increased the daylight factor in modeled spaces by 10%, regardless of the size of the window [12]. They also found that increasing the reflectance of the ceiling was more effective than increasing the reflectance of the walls, largely due to line-of-sight issues: the ceiling “sees” more of the window area than do the walls [12]. These studies show that ceilings are effective at directing more daylight more deeply into occupied spaces, enhancing the natural light available to the occupants.

Yoon and Moeck's work also shows that if the light reflectance of the walls is held constant (at LR 0.50) and the reflectance of the ceiling is increased to 0.90 from 0.75, it is possible to reduce the area of the window glazing by 11% and still achieve the recommended minimum daylight factor of 2% (per USGBC's LEED requirements) [12]. In hot climates, this would allow a smaller window area to be used, lowering the thermal load generated by solar heating of the space, which would in turn lower cooling costs.

In the Keystone Building, Weidt found that the high LR ceiling increased the efficacy of the light shelves that direct natural light into the space, helping to reduce electrical usage associated with lighting [13].

So by effectively harvesting and redirecting natural light in the spaces away from windows, high light reflectance ceilings can enhance the daylighting conditions of a space, reduce the number of light fixtures needed in spaces away from the windows, and help to lower energy costs even further. At the same time, they provide the proper acoustics needed by the occupants, while meeting their needs for natural light.

3 Acoustical Performance v. Light Reflectance

Most manufacturers of acoustical ceiling products publish the acoustical performance of their products: NRC, α_w , CAC and D_{ncw} are commonly given in the literature. Many acoustic professionals may not realize that most US and

European based manufacturers also list light reflectance values for their products. In general, the more highly textured or fissured the product, the lower the LR value; a smooth, flat white surface will reflect the most light. However, a smooth flat surface also tends to reduce the absorption performance of a porous substrate if the paint is not properly formulated and applied. An effective means of creating such a surface is described in a series of patents by Sensenig et. al [17, 18, 19, 20].

In Table 1, acoustical ceiling products currently being sold in North America, Europe, Asia and Australia are categorized by type of texture, substrate type (slag wool, rock wool or fiberglass), the range of measured noise reduction coefficients, the range of measured light reflectance values, and the range of advertised light reflectance value. All sound absorption properties were measured according to ASTM C423 [21] using an E-400 mounting in a NVLAP accredited facility (*NVLAP lab code 100228-0*); light reflectance values were measured according to ASTM E1477 [6] and are reported as an average of 9 measurements.

Table 1: Noise Reduction Coefficient and Light Reflectance Values

Texture and substrate	Measured NRC range	Measured LR range	Advertised LR values
Smooth, painted veil on slag wool	0.65 – 0.85	0.70 - 0.90	0.89, 0.90, Up to 0.90
Smooth, painted veil on fiberglass, rock wool, or mixtures of wool types	0.80 – 0.95	0.81 – 0.90	0.85, 0.87, 0.88, 0.90, Up to 0.85
Sand-like or dimpled on slag wool (low absorbing)	0.10 – 0.40	0.83 – 0.89	0.87, Approx. 0.87, Up to 0.90
Sand-like or dimpled on slag wool (standard absorption)	0.50 – 0.55	0.82 – 0.83	0.83, 0.84, 0.86, 0.88, 0.89
Sand-like or dimpled on slag wool (highly absorbing)	0.60	0.85	0.85
Sand-like or dimpled on cast mineral wool	0.70	0.77	0.81
Textured or embossed on slag wool	0.55 – 0.70	0.80 – 0.87	0.82, 0.83, 0.84, 0.86
Fissured and punched slag wool	0.30 – 0.70	0.79 – 0.90	0.82, 0.84, 0.85, > 0.75, \geq 0.80, Approx. 0.85, Approx. 0.88, Up to 0.90

The data in Table 1 show a wide variety in light reflectance values for similar acoustical absorption and appearance. Therefore, whenever possible, specifiers should choose the product with the highest measured light reflectance value in order to lower the energy associated with lighting.

Light reflectance is also an attribute for metal, wood and fabric covered ceilings. In Table 2, the light reflectance of white metal ceilings are compared as a function of the percent open area created by round holes punched into the surface. The panels all have a fiberglass veil on the back, and have an NRC value of 0.65, so this is a case where aesthetics are driving the specification of the ceiling panel. The white paint is matched by the manufacturer to a standard colour specification. The percent open area of the samples was determined using image analysis performed with ImagePro™ software.

As shown, the light reflectance decreases in a linear fashion as the amount of open area is increased. Also note that when a white veil is used to back the panel, the LR value is increased by 11% to 0.70 from 0.63, for the same perforation pattern; therefore, switching from a black veil to a white veil would likely correspond to an increased energy savings of approximately 10%.

Table 2: Light Reflectance v. Percent Open Area

% open area	Average Light Reflectance
0	0.839 ± 0.005
1.43	0.741 ± 0.003
7.9	0.692 ± 0.004
11.4	0.682 ± 0.009
16.4	0.627 ± 0.004 (black veil)
16.4	0.698 ± 0.004 (white veil)
22.2	0.614 ± 0.039
22.5	0.584 ± 0.002
23.4	0.570 ± 0.199
Black paint	.031 ± 0.0005

Finally, Table 3 shows the impact on color on light reflectance. The five products shown are all wall products, but comparable products are available for use in the ceiling. As the color darkens, the light reflectance value decreases.

Table 3: Effect of Color on Light Reflectance

Sample Type	Average LR	NRC, A mounting
Gray woven fabric on fiberglass board	0.390	0.80
Beige woven fabric on fiberglass board	0.383	0.80
Light blue woven fabric on fiberglass board	0.246	0.80
Maple veneer, microperfed	0.382	0.45
Light cherry veneer, microperfed	0.171	0.45

The data shown in Tables 1, 2 and 3 clearly show that a wide range of light reflectance values is available for acoustical ceilings. In order to optimize both the acoustical absorption and energy usage of the building, specifiers should also consider the light reflectance properties of the product. Whenever possible, the specifier should choose the product with the highest measured light reflectance value in order to have the largest impact on the energy usage associated with lighting.

4 Conclusions

A suspended, white, acoustical ceiling with a high light reflectance value can enhance both the acoustical environment and lighting efficiency in a space. Such reflective ceilings act as critical components in the lighting system, allowing the number of fixtures to be decreased, improving the uniformity of the dispersed light, and directing natural light further into interior spaces. All of these factors act to significantly decrease the energy used to light the space, one of the largest energy uses in any

commercial building. Simultaneously, the high light reflectance helps enhance occupant comfort and productivity. Comparisons of commercially available ceiling products show that for the same acoustical absorption and appearance, the light reflectance can vary widely. Light reflectance should be considered as a critical differentiator in determining total building energy performance and occupant comfort. In order to reduce the energy used to operate the space, the product with the highest light reflectance value should be specified whenever possible.

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