Delamping in Saunders

A proposal by the Sustainable Saunders Energy Team
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As part of the Sustainable Saunders initiative, we've decided to look at potential energy savings of changing the lighting. While lighting is not the largest energy consumer in Saunders hall (that dubious distinction falls to the air conditioning), it does account for about 40% of the overall electricity used. Coupled with the relative ease of changing the lighting compared to changing the air conditioning system, it seemed a good place to start. Upon further investigation, we discovered that the lighting is not only above recommended illumination levels, but also exceeds the legal power per square foot used for lighting allowed by Hawaii's building codes. Encouraged that a change to lighting would not only decrease energy use, but also make the building a better working environment, we set out to determine exactly how to change the lighting and estimate the benefits of the change.

Lighting in Saunders is a fantastic story about the interplay between human behavior and technology. Between the opening of the building in 1973 and a building-wide lighting retrofit in 2006, every office and classroom in Saunders was outfitted with mercury vapor light fixtures that took 20 minutes to fully warm up. As a result, (long-time Saunders occupants can tell you) most people left their lights on 24 hours a day. Indeed, turning off a light upon exiting a classroom was a real "no-no", because it penalized the next instructor with no lights for the first portion of their class period. To make things worse, the mercury vapor lights were very inefficient - typically requiring 400 watts to provide an amount of illumination that could be provided with less than one-fourth as much wattage with today's modern light fixtures.

In 2006, a major retrofit of the lighting fixtures was performed in Saunders, to replace every mercury vapor light fixture with a standard fluorescent fixture. These new fixtures use much less energy, and are more likely to be turned off when not in use since there is no warm up time. In 2001, the last known accurate data for Saunders indicated that the building's electricity load was 3.1 million kWh annually. Based on new meter data that just became available in 2007, we can accurately say that the electrical load for Saunders is now only about 2.3 million kWh annually - a reduction of over 25%.

Saunders is Over-Illuminated

But one important feature of the 2006 lighting retrofits in Saunders is that the new fixtures are substantially brighter than the average preferred or recommended illuminance. In 2001, the energy audit of Saunders [7] noted that the mercury vapor fixtures were providing only

30-50 foot candles (fc) of illumination,[1] and noted erroneously that "IES (Illuminating Engineering Society) [recommends] 75 foot candles" [7, page 16]. It turns out that 30-50 foot candles **IS** the recommended illumination for offices, as indicated in Table 1 below (Several other illumination recommendations are also provided in Table 1, to put these numbers in perspective).

Table 1: Lighting Recommendations of Illuminating Engineering Society of North America

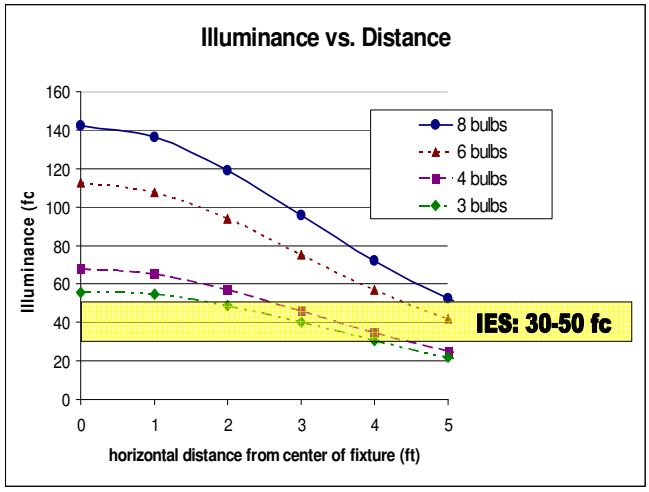
Activity	Recommended Illumination* (foot candles)
Restaurant	5-10
Corridors	10-20
Office	30-50
Classrooms	30-50
Auto Showroom	50-80
Typical Retail Space	50-80
Detailed Manufacturing/Machine Shop	100-150
Hospital Operating Room	100-200

Considering the many word-of-mouth complaints from building occupants that their offices are too bright, we set out to measure the existing illuminance in Saunders. We used standard techniques and equipment to measure the illumination in a typical office in Saunders hall as a function of horizontal distance from the center of the light fixture. Care was taken to allow no external light into the room. Measurements were done with a Lutron LX-1010b light meter, provided by HECO.[2]The results of our measurements are shown in Graph 1 below. We provide two sets of measurements for two kinds of fixtures, because Saunders contains a mixture of 6-bulb and 8-bulb light fixtures in most office spaces.

[1] A unit of measurement of illuminance (or perceived brightness) that is commonly used is the foot candle (abbreviated fc, equal to 10.76 lux), and we use it throughout the rest of the report.

[2] We subsequently verified that the, the LX-1010b was accurate to about +/-10%, based on extensive calibration using an Oriel 91192 Solar Simulator. A Lutron LX-102 meter proved too inaccurate to use, based on our calibration with the Oriel Solar Simulator.

Graph 1: Illuminance at desk level vs. horizontal distance from a typical fixture in a Saunders Hall office for different numbers of installed bulbs



Notes:
1.The IES recommended illuminance (30-50 foot candles) is highlighted in yellow on the graph.
2. The horizontal distance from the center of a fixture is zero when a desk is directly underneath a fixture. So, in Graph 1, if a fixture is directly over a desk and has 8 bulbs, the desk is illuminated with 142 foot candles-between three and five times higher than IES recommended levels.
3. Bulbs were configured within the fixture to uniformly illuminate the workspace as much as possible.
4. The average horizontal distance between workspace and light fixture is 1.67 feet. The maximum distance is 5 feet.

Since the Saunders light fixtures currently have either 6 or 8 bulbs installed (circle and triangle curves above), it is clear from Graph 1 that the typical Saunders office is over-illuminated. Because almost all offices in Saunders are 10 feet wide, almost no workspaces are 5 or more horizontal feet from the nearest light fixture. In fact, the average horizontal distance from a desk to a light fixture in Saunders is 1.67 feet. For example, at a typical desk location of about 2 horizontal feet from the center of the fixture, 8 bulbs provide 120 foot candles, and 6 bulbs provide 96 foot candles. This is well over twice the IES recommended illumination of 30-50 fc (highlighted in yellow on the graph). At the same distance of 2 feet, 4 bulbs provide 58 fc and 3 bulbs provide 50 fc - approximately at the high end of the recommended range if illumination. To put it simply, ***the recommended illumination of a typical office can be met with half of the bulbs.***

There is another way of gauging the amount of electricity used for Saunders lighting. City and County of Honolulu Ordinance (Chapter 32: Building Energy Efficiency Standards, Article 6: Lighting) dictates a limit for the amount of electricity that can be used by a building for lighting, whether for new construction or for lighting retrofits.[3] The DBEDT (Department of Business and Economic Development and Tourism) web site provides software called HILITE[4] which we used to calculate the overall allowable energy use for lighting for the building. We entered the length, width and height of each room as well as its purpose for 95% of the rooms that we were able to access in Saunders. The results showed that the legal limit for Saunders is 63,981 Watts. The amount of electricity used for lighting in the same 95% of the rooms is

[3] It uses the standards set out by ASHRAE (American Society of Heating, Refrigeration and Air-Conditioning Engineers) 90.1-2007 to define this legal limit. It is based on the purpose of each room since different tasks require different lighting levels (refer to Table 2).
[4] at http://www.hawaii.gov/dbedt/info/energy/efficiency/

92,426 Watts. This significant sample indicates that ***Saunders is 44 % over the legal allowable limit dictated by City and County ordinance***. We confirmed with DBEDT that Chapter 32 regulations applied to the 2006 lighting retrofits of buildings.[5]

Over-illumination of offices is not just energy profligacy and is not just a matter of taste. Illumination above recommended levels has been shown to induce some important workplace-related ailments, including eye strain, headaches, and stress. These lighting-induced ailments have significant negative productivity consequences [2,3,8].

Delamping is a Win-Win Solution

So Saunders offices are overly bright - providing illumination more appropriate for a hospital ward than an office. This introduces the possibility that UH could pursue a cost-effective delamping (bulb removal) project to reduce illumination to levels more preferred by Saunders occupants and reduce the energy costs of the building at the same time.

Many private sector and public sector building managers engage in delamping to achieve energy conservation. This energy management technique is so well established and effective at reducing peak power use that HECO subsidizes delamping in commercial buildings through its energy conservation rebate program. If a bulb is verifiably removed in such a way that it cannot be merely replaced, HECO will compensate the customer. In the case of Saunders, HECO would provide five dollars per four foot bulb.[6] The customer benefits with the one-time subsidy as well as lower future energy costs, and HECO benefits by reducing peak power usage and avoiding greater strain on its ability to provide electricity during peak hours.

Removing a bit more than half the bulbs from Saunders light fixtures is the ideal delamping scenario, based on a consideration of recommended illumination, and equipment and bulb longevity. Prior sections demonstrate that delamping to 3 bulbs will reduce illumination down to the upper end of IES recommendations for offices, at the typical horizontal distance between fixture and workspace. Such delamping will also reduce the total wattage of illumination in Saunders to within City and County building code limits. In addition, we researched the light fixtures in Saunders, and learned that each 8 or 6-bulb fixture is powered by a pair of identical ballasts capable of supporting 4 flourescent bulbs each. According to the manufacturer, the ballasts achieve maximum efficiency and provide maximum bulb life when powering 3 bulbs. If a ballast is forced to support 2 bulbs or less, the lifespan of the bulbs is reduced by 50% or more, and there could be a reduction to the lifespan of the ballast.[7] Thus, the

[5] Personal communication with the Institutional Energy Analyst at DBEDT, February 27, 2008.

[6] HECO also provides a $10 per removed bulb rebate if customers concurrently install reflectors above the remaining bulbs. Reflectors diffuse the light and they also tend to make the bulb absence less conspicuous to occupants, but are most appropriate for very old fixtures with limited reflectance. The Saunders light fixtures are all new, so reflectors would provide little benefit.

[7] Personal communications with Advance, Inc. – manufacturer of all the ballasts used for the 2006 Saunders lighting retrofit.

optimal delamping scenario is to remove 3 bulbs from each 6-bulb fixture in a way that completely disengages one of the two ballasts. For eight bulb fixtures, the ideal delamping scenario involves removal of five bulbs, to disengage one ballast and reduce the bulb load on the remaining ballast to 3 bulbs. In all Saunders light fixtures, each ballast powers alternating bulbs so delamping should also remove alternating bulbs. In that way, the fixture remains uniformly lit rather than only one side being illuminated after delamping

Building Residents Enthusiastically Supportive of Delamping

Before advocating wholesale delamping of Saunders, we wanted to consider occupant preferences about their lighting. While the IES recommendations are generally applicable, preferred lighting levels for a particular individual can vary widely [5]. Besides, it seems unwise to threaten productivity or generate a negative workplace sentiment by unilaterally removing bulbs, if occupants don't want it.

As part of the Sustainable Saunders initiative, we surveyed building occupants in spring 2007 about, among other things, their satisfaction with the lighting and the amount of time they spend in their offices [9]. The 2007 survey achieved 70% response rate, so we are reasonably confident of the generalizeability of our findings to every worker in Saunders.

Overall, most people in Saunders (86%) reported in spring 2007 that they were "mostly" or "very" "satisfied" with the lighting in their offices. However, the nature of their satisfaction was not probed fully in our first survey. We hypothesize that a large percentage reported they are "satisfied" not because the lighting level is optimal, but because the lighting is so much better than the old mercury vapor lights. The installation of standard fluorescent fixtures relieved conservation-minded occupants from the cognitive dissonance they must have been experiencing daily, as they were forced to leave the lights on.

Even in our first survey, most people in Saunders dissatisfied with the lighting in their workspaces volunteered that they consider the lighting too bright. That fact led us to the careful documentation of over-illumination we conducted and documented earlier in this report. Given the extreme over-illumination, it seems likely that substantial numbers of people who report being satisfied with their lighting would find lower illuminance preferable, when presented with such an option. In addition, research on lighting preference indicates that people are generally incapable of recognizing illumination reductions less than about 20% [5]. Finally, people are willing to choose dramatically lower illumination levels when they feel they are helping the environment by doing so [1]. When occupants of a typical office building are allowed to set their own lighting level, Moore et. al [6] found "that significant numbers of occupants choose, or at least accept, levels of working plane illuminance below current CIBSE[8] recommendations.

Based on the considerations above, we hypothesized that delamping would be well accepted by the majority of Saunders occupants. To better determine the acceptance of lower lighting levels in Saunders hall, we instituted a delamping pilot project. We asked each of the department chairs to volunteer their offices as well as a few others to be temporarily delamped. In those volunteer offices, we brought all of the 8 and 6 bulb fixtures down to 3 bulbs per fixture and all of the 4 bulb fixtures down to 2 bulbs. We surveyed each person affected by the

[8] The Chartered Institution of Building Services Engineers, a body similar to the IES in the UK

delamping about their satisfaction with the light levels after a period of four weeks. We achieved a 96% response rate among the 26 faculty, staff, and student assistants affected by the delamping pilot.[9]

Our survey of the delamping pilot participants, provides clear evidence that delamping will be accepted and is in fact preferred by the majority of building occupants. For example, not a single respondent reported that they would recommend against delamping for other building occupants (84% recommend delamping, 16% are "not sure", 0% "do not recommend" delamping). As Table 2 makes clear, of 25 survey respondents, 36% reported that they were "mostly" or "very" dissatisfied with their lighting prior to our delamping, while not a single respondent reported any dissatisfaction with their lighting after their fixtures were delamped. That improvement in satisfaction is statistically significant, based on a comparison of means t-test (t=3.9, p=.0002)".

Table 2: Lighting Satisfaction of Saunders Delamping Pilot Participants

Reported workplace lighting satisfaction	BEFORE delamping	AFTER delamping
very dissatisfied	3 (12%)	0
mostly dissatisfied	6 (24%)	0
neutral	4 (16%)	5 (20.8%)
mostly satisfied	8 (32%)	5 (20.8%)
very satisfied	4 (16%)	14 (58.3%)
total	25 (100%)	24 (100%)

In addition to overall satisfaction, we also surveyed delamping pilot participants, to investigate the specific and most likely health consequences of over-illumination: eye strain, headaches, and stress. As Table 3 illustrates, our delamping resulted in noticeable improvements on all three dimensions, though none of the improvements are statistically significant, based on two-sample tests of proportion in this small sample.

Table 3: Lighting Health Outcomes of Saunders Delamping Pilot Participants

Workplace malady	Percent of respondents experiencing the malady		t (p-value)
	BEFORE delamping	AFTER delamping	
Eye strain	28%	16%	1.02 (.15)
Headache	8%	0%	1.44 (.07)
Stress	16%	8%	0.87 (.19)

[9] Because the one participant who did not fill out a survey had specifically requested replacement of all bulbs, we ascribed a survey response for one question, effectively achieving 100% response rate, at least for that item. The question was "Do you want any or all of the bulbs replaced in your office (yes/no)?" [We ascribed the participants response as "yes"]. For all other survey questions, we left the data missing for that respondent.

We received the following open-ended comments from the pilot delamping participants.

Table 4: Open-Ended Summary Comments from Pilot Participants

suprisingly painless - initially looked like it would be hard to get used to and turned out to be easy	*good job on the sustainable project. I would like to see more [programs] to make our island a better place for our future*	*It took a while to get adjusted to less light intensity; the delamping has resulted in a comfortable level of light. If we use fewer light bulbs and save money on electricity we, we should do it!*
good project!	*Thank you, that is a good idea.*	
Please do our whole dept, if staff willing!	*sustainability efforts are greatly appreciated!*	*GREAT IDEA!!!*
Don't notice a change	*I think the delamping project is a great success. It has softened the light in my office considerably, altering my work environment for the better. I recommend that every room in the building be de-lamped!*	*Thanks*
Please do this everywhere. It is sane.		*Great to save energy & money*
I didn't [see] much of a difference		

Significant improvement in overall lighting satisfaction and noticeable health improvements notwithstanding, it is the case the some occupants perceive the delamping of our pilot project as worsening their workplace lighting. Of 26 pilot subjects, 4 (13%, two faculty and two student assistants) requested replacement of some or all of their bulbs. Two of those cases (both part-time student assistants) are difficult to understand, because both of the participants reported that they would recommend this delamping to others. While one student reported a reduction in satisfaction from “very” to “mostly” satisfied, as a result of the delamping, the other reported neutral attitude about the lighting both before and after the delamping. We believe there may have been a coding error by the latter respondent. Two others (both faculty in an older age bracket) requested replacement of bulbs in their fixtures, based on a reported preference for the original (higher) illumination. One faculty requested replacement of all the bulbs and restoration of the original illumination. The other faculty requested return of one bulb, resulting in the provision of 4, rather than 3 bulbs in the fixture. In both cases, we complied with the request, as a part of our delamping pilot.

In the end, delamping is going to be preferred by 80% of Saunders occupants, based on our survey. It will not be preferred by about 10% of Saunders occupants, though we believe task-lighting (perhaps a desk lamp) might be an appropriate remedy in such cases. The remaining 10% of building occupants will have no preference one way or the other about delamping.

Recommendations

We are faced with the question of how to institute the delamping procedure. There are two choices: voluntary or mandatory delamping, both of which have pros and cons. We see the following breakdown for the two possibilities:

Voluntary change

- pros:
  - Maintains current satisfaction level with the lighting for every occupant. Improves satisfaction level for those who choose to participate.
- cons:
  - Requires an extensive, sophisticated, and ongoing coordination of delamping/relamping requests across a large number of offices.
  - Change is more complicated, as some rooms will not be delamped and those that are, may have different numbers of bulbs removed depending on the specific occupant's request.
  - Prohibits rebates, because HECO requires permanent modifications to the fixtures (to prohibit replacement of the bulbs).
  - Only those interested will participate. Many people may ignore the program all together or be too busy to deal with it.
  - We will miss the opportunity to delamp rooms where people would benefit from it but don't volunteer because they aren't aware of how extreme the lighting is.
  - May not bring the building into legal levels of use of power for lighting

Mandatory change

- pros:
  - Realizes greatest electricity savings.
  - Realizes greatest rebate.
  - Logistics are much simpler: all offices are delamped in the same way.
  - Brings the building into legal levels of use of power for lighting.
  - Brings light levels down to IES recommended levels.
  - Allows optimal ballast configuration
- cons:
  - Requires strategic marketing and roll out plan so that most of the community feels it is a benefit
  - May reduce some occupant's satisfaction with the lighting.

To get an idea of savings that could be realized, the Sustainable Sanders Energy Team has calculated the rebate, energy saved, and money saved for a variety of scenarios in Table 5 below. To obtain these numbers, the team used a combination of the lighting blueprints and visual inspection to assemble a detailed inventory of the numbers and types of fixtures on each floor of Saunders Hall. From this count we were able to determine the number of bulbs that could be

removed while maintaining the recommended lighting levels. We assumed that all rooms in Saunders would be delamped. We calculated the energy saved using occupancy data from our representative 2007 survey [1], which showed that office lights were turned on 31 hours a week, 50 weeks a year, on average. The total rebate was calculated using the current $5 per bulb which HECO offers. Money saved was calculated at the university's rate of $0.16/kWh. With these figures, each removed bulb saves $7.94 per year in electricity and generates a one-time $5 per bulb HECO rebate.

Table 5: Delamping Projections for Saunders Hall Delamping

Scenario	Assumed Delamping Rate	bulbs in 4x fixtures	bulbs in 6x fixtures	bulbs in 8x fixtures	HECO Rebate	Energy Saved (kWh/yr)	$/yr Saved @ $0.16/kWh
Voluntary Scenarios							
1	75%	3	3	4	$5,490	54,461	$8,714
2	75%	2	3	4	$6,698	66,439	$10,630
3	75%	2	3	3	$7,121	70,643	$11,303
Mandatory Scenarios							
4	100%	3	3	4	$7,320	72,614	$11,618
5	100%	2	3	4	$8,930	88,586	$14,174
6	100%	2	3	4	$9,495	94,190	$15,070

There are two less obvious benefits of delamping as well. First, the removed bulbs can be stored and used when the currently installed bulbs reach the end of their lives. UH Buildings and Grounds Department has indicated a preliminary willingness to roll delamped bulbs back into their inventory. Because they were new in 2006, each bulb in Saunders has 85% of its lifespan remaining.[10] If the bulbs cost $2.00 each, then restocking of the removed bulbs will create a one-time inventory windfall for Buildings and Grounds of $1.69 per bulb (total $3,209.31 if scenario 6 in Table 5 is implemented). Storage space required for the bulbs is minimal: approximately 48 square feet of storage with the bulbs on the ground or 150 cubic feet of shelf space, though it was necessary to purchase new storage boxes.[11] Second, a delamped Saunders would reduce bulb replacement labor costs. Scenario 6 removes 53% of the fluorescent bulbs in Saunders, and it therefore cuts the bulb replacement labor for Saunders by half, in perpetuity. We have not attempted a valuation of that aspect of our delamping proposal.

Of course, the money saved per year detailed in Table 4 will continue to increase as electricity prices increase. According to a recent HECO forecast [4], the price of electricity will increase by roughly 25% in the next 10 years, at which point each removed bulb would be saving nearly $10 per year.

[10] The currently installed bulbs are Sylvania F032/841ECO, which have an expected lifespan of 20,000 hours. If each bulb has been used 31 hours per week for 100 weeks since purchases, then the bulbs have 85% of their lifespan remaining.

[11] After verifying that neither UHM Facilities nor UHM Buildings and Grounds have been keeping old bulb boxes after installation, we purchased new storage boxes from a local Grainger distributor. If UHM Facilities or Buildings and Grounds choose to keep old bulb boxes after installing new bulbs, they can be recycled for any other delamping projects on campus.

Given the information presented above, we propose to institute mandatory delamping for all rooms in Saunders hall, with an efficient feedback mechanism to allow for quick correction of under-illuminated areas by providing desk lamps. Mandatory delamping will realize all of the benefits outlined above and a quick correction of under-illuminated areas will minimize any negative impact the delamping may have. Given the results of our pilot, we expect very few building occupants to be dissatisfied. Before the delamping we propose to present a condensed version of this report (~1 page) to all occupants of the building so they can see the benefits of the delamping program, both for them in terms of creating healthy lighting levels, and for the school and environment in terms of energy and electricity saved. Overall, this proposal presents UH with the opportunity to accomplish the following with no capital expenditures

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- cut the energy use in Saunders by 94,190 kWh each year (4.1% of the building load)
- improve workplace satisfaction for a significant number of currently dissatisfied employees
- reduce workplace ailments linked to the current lighting fixtures
- generate a one-time revenue windfall through HECO rebates
- generate a one-time light bulb inventory windfall for Buildings and Grounds
- cut the bulb replacement parts and labor costs in half each year.

This is such a good idea that many other workplace sustainability advocates have asked us about the possibility of applying our process to their building (including the Hawaii Department of Education, UH Manoa College of Education, and UH Manoa Sea Grant Office). Primary data for all our analyses, including survey instruments, statistical analyses, and detailed bulb inventory are available at

http://groups.google.com/group/sustainable-saunders-energy

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