The Impact of Occupants' Behaviour on Electric Light Usage

A case study of three Milwaukee, Wisconsin Nature Centers

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ABSTRACT: The application of appropriate lighting controls is part of a successful daylighting design strategy. Lighting literature largely emphasizes on the primacy of automatic controls over manual on/off switches. There has not been adequate research on the effectiveness of the occupant control of lights in high performance buildings. This paper presents measured levels of lighting use in spaces controlled by the occupants along with their attitudes toward manual lighting control. The results indicate that energy savings in the studied buildings with manual light controls are comparable to savings published for well designed automatic daylighting systems. The authors conclude that integrating occupants into the operation of high performance buildings results in a substantial lowering of electric lighting energy without the added cost of expensive dimming or switching technology and, more importantly, increases building occupants' and visitors' awareness of daylit buildings. Indeed, proper staff instruction and daylight design are the key factors in reducing energy use as well as increasing occupant satisfaction.
Keywords: energy, lighting control, occupant impact, manual switch

INTRODUCTION

Occupant control of manual light switches is generally not considered an appropriate daylighting strategy. The United States Green Building Council's LEED rating system does not allow modelling occupant control of lights in the Design Energy Case energy simulation for Energy and Atmosphere Credit 1. The benefits of automatic controls are taken for granted. The energy savings from the occupancy sensor lighting controls vary widely depending on the space and occupant type [4]. Automatic systems that turned lights off when daylight was sufficient were not desired by occupants as the switching lights on and off during partly cloudy days annoyed occupants. Automatic dimming daylight controls have become the standard for many buildings. Lighting levels are imperceptibly ramped up or down in response to exterior illumination levels. Occupants are generally unaware whether lights are being dimmed or not. They assume lights are always on, even in energy efficient buildings. Furthermore, photosensors and controls are costly equipment requiring complicated hardware and software along with regular inspection and calibration [5].

To ensure occupant satisfaction, a combined system of manual and automatic control is suggested [2]. The manual component has even proven to add to the energy savings from automatic controls by 15% [2]. Yet, the literature on the potential savings from full manual systems is scarce. In fact, the occupants' ability to reduce the lighting use is completely undervalued. This paper discusses the importance of occupant training in effective use of daylight and shows that direct occupant control of electric lights can, in well daylit spaces, result in substantially reduced electric consumption for illumination.

The following case study examines occupant controlled lighting in three high performance buildings located in Wisconsin, USA. All three buildings were designed by the same architectural firm, the Kubala Washatko Architects. The Schlitz Audubon Nature Center (SANC), located in Milwaukee County and completed in 2003, was studied in 2003 and 2004. Unpublished work from that study is briefly summarized here along with recent interviews of SANC staff. The Urban Ecology Center (UEC), located in Milwaukee, Wisconsin, was completed in 2004. Lighting in the public spaces of the UEC is controlled by staff and the public. Light quality and use in these public spaces is the main focus of this paper. All staff were interviewed to ascertain attitudes and strategies in their approach to lighting control. The Aldo Leopold Legacy Center (ALLC), located in Baraboo, Wisconsin, was completed in 2007. Models of occupant light control based on experience gained from Schlitz Audubon Nature Center and Urban Ecology Center are discussed and presented with measured light use during the first year of occupancy. The energy consultant for these projects visited the buildings often during the first few months of operation reminding staff of the energy cost of lights that were on when not needed. The training took longer in the Schlitz Audubon Nature Center, the first building completed. It served as an example to staff at the Urban Ecology Center. Those experiences were examples for the Aldo Leopold Foundation staff.

SCHLITZ AUDUBON NATURE CENTER

The 2,785 m² Schlitz Audubon Nature Center is an environmental education facility serving southeast Wisconsin. The building was designed to provide daylighting and natural ventilation to all occupied spaces. Different spaces were provided with different means of lighting control. The entry/exhibit space contains a variety of light sources controlled either manually or with a timer, all controlled by a staff member in the entry space. Educational classrooms are provided with switches containing occupant and light sensors. These switches provided automatic control with manual override by staff educators. The building also has a general office space with two sets of light switches, one controlling one-third of the lamps in two long, linear fixtures, and one controlling the other two-thirds of the lamps in the same linear fixtures. Since the building opened in 2003, staff have developed approaches to manually control lights in the classrooms and office spaces.

Figure 1: The triple level lighting control used in classrooms of Schlitz Audubon Nature Center.

In classrooms, the staff have disabled the automatic switching and control the lights manually. The light controls included an occupant sensor which automatically turned on lights whenever anyone entered the classroom (Fig. 1). The energy consultant recalls not turning lights on when daylight is sufficient as the reason for disabling the control. One of the educators, however, maintained that the staff started to use manual control to save energy by excluding the delay time associated with automatic lighting controls. Both of these accounts could be true and indicate that the occupant control of lights can enhance the energy performance of the building, provided they are well informed of their role. The following chart shows 18 weeks of data for hours of light use in the SANC office. The office is used from 7 A.M. to 5 P.M. and five days per week (50 hours per week).

Table 1: The Average Hours of Office Light Use per Week in Schlits Auduban Nature Center.

	All on	2/3 on	1/3 0n	All off	Light %
Fall 2003	10.2	36.2	11.2	110.4	66.1%
Spring 2004	23.7	29.0	8.9	106.5	74.8%
Summer 2004	13.1	11.6	27.8	115.5	57.2%
Average	15.6	25.6	16.0	110.8	66.6%

The data show a decrease in hours of light use from fall 2003 to summer 2004. The daylight design of the building is an important factor in the reduced light use. The thin cross-section of the building allows for adequate access to daylight in all spaces above grade. In the offices, the circulation area is between windows and desks (Fig. 2). This configuration reduces the glare on the desks, thus the shades are kept open and the daylight is introduced to the office all day long.

Figure2: The office area in Schlitz Audubon Nature Center.

However, there was a conflict between education staff located at the west end of the office and administrative staff located at the east end. There are 48 single lamp 4 foot fixtures in two rows. 32 on the 2/3 switch and 16 on the 1/3 switch. The environmental educators have unscrewed 13 lamps over their offices. Currently, the 2/3 switch is utilized with 13 of those lamps disconnected. Hence, it appears that the SANC staff now use 1/3 of the total lamps (the 2/3 setting with 19 instead of 32 lamps).

URBAN ECOLOGY CENTER

The 1802 m² Urban Ecology Center (UEC) has not participated in the LEED™ certification process. The UEC contains manual switches for all accessible rooms in much the same fashion as residential light controls. The main difference between UEC and the other two buildings studied is that the lights in main spaces are controlled by both the visitors and staff. In other words, the first person who enters the space can turn the lights on. The study of lighting performance in this building includes the evaluation of three components:

1 The duration of the electric light usage in the building
2 Staff's attitude about lights in the spaces
3 The light quality of main spaces under daylight-only and electric light-only conditions.

Electric light usage For the first component, the number of the hours that electric lights were used was monitored by installing some battery-powered data loggers (HOBO Model U12 from Onset Computers) adjacent to light fixtures. The data loggers were adjusted to record the light intensity levels at 5 minute interval and the data were gathered for 130 days in three periods. The main spaces on the first and second floors of Urban Ecology Center have two types of luminaires: spot lights with EXN (50 watt) halogen lamps and linear fixtures with two T8 (32 watt) fluorescents in each. Each light switch is related to one of the two fluorescents in linear light fixtures and there are separate switches for halogen luminaires. Therefore, the possible configurations are as follows: all lights on, all fluorescents on, half of the fluorescents on, only spot lights on, and all lights off. In each floor the switches are also divided for east and west parts of the main areas. By conducting a test at night time, the net light intensities received by data loggers in each of the above configurations were determined. Then, these thresholds were used to clarify how many hours per day each light type was turned on. The center operates from 8 A.M. to 7 P.M. By excluding the night hours, the percentage of the time that each luminaire was used during the daylight hours was determined. Table 2 presents the summary of light use data in Urban Ecology Center in 130 days. This table shows that most of the light usage occurred on the first floor east side where the reception area is located. In that area, half of the fluorescent lights were on most (41.5 to 61.6 percent) of the daytime. On average, occupants used half of the fluorescents in 23.1 percent of the daytime. They used spot lights in 3.4 percent of the time and all fluorescents in 5.8 percent of the time that daylight was available. Most remarkable is the fact that the lights were off in 66.1 percent of the daylight hours.

To encourage the visitors and occupants to consume less energy, one strategy was to print lighting power associated with each light switch on the switch plate (Fig. 3). The goal was to attract the attention of the occupants and visitors to the amount of energy that will be used or saved by their choice of lights. The authors' intention was that seeing the energy levels, individuals would choose the least energy consuming configuration.

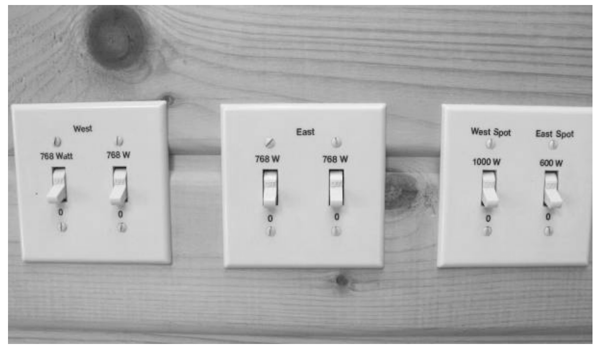

Figure 3: The electric power related to each light switch was printed on the switch plate.

These stickers explicitly showed that spot lights use more energy than the fluorescent. Therefore, this strategy was expected to reduce the use of halogen lights in the building. Table 3 shows the electric power associated with each of the configurations in table 2. To evaluate the results of this tactic, the percentage of light usage before and after attaching the stickers (which was done on June 16, 2008 at noon) is compared. Table 4 shows the average light usage before and after printing the light powers on switch plates.

Table 2: The duration of light use in main areas of UEC. The table provides the number of hours and percentage of the time that lights were on during the daylight hours. (Some of the data failed to be read from the data logger due to technical problems)

Date	Location	All fluorescents on		1/2 fluorescents on		Spot lights on		All on		All off		Any On	
		hours	%	hours	%	hours	%	hours	%	hours	%	hours	%
2/26/08 to 3/26/08 (Daylght hours: 8 A.M. to 5:30 P.M.)	1st floor -East	7	2.3	184	61.6	12	4.2	1	.2	97	32.1	202	67.9
	2nd floor -East	16	5.4	13	4.5	9	3.1	0	0	261	87	38	13
	2nd floor-West	fail	fail	fail	fail	6	2	-	-	-	-	-	-
4/1/08 to 5/19/08 (Daylght hours: 8 A.M. to 6:30 P.M.)	1st floor -East	74	14	220	41.5	53	10	4	0.8	188	35.4	343	64.6
	2nd floor -East	41	7.6	49	9.2	fail	fail	-	-	-	-	-	-
	2nd floor-West	22	4.1	32	6	19	3.5	1	.2	459	86.4	72	13.6
6/4/08 to 7/15/08 (Daylght hours: 8 A.M. to 7:30 P.M.)	1st floor -East	38	7.2	236	44.5	18	3.1	7	1.3	246	46.3	285	53.7
	2nd floor -East	17	2.9	45	7.7	3	0.5	0	0	518	88.9	65	11.1
	2nd floor-West	18	3.1	56	9.6	6	1	2	.4	505	86.6	78	13.4
Average			5.8		23.1		3.4		.4		66.1		33.9

Table 3: the electric power associated with each configuration of lights in main spaces of the Urban Ecology Center.

Location	All fluorescents on	1/2 fluorescents on	Spot lights on	All on
1st floor - East	1152 W	576 W	800 W	1952 W
1st floor - West	1920 W	960 W	500 W	2420 W
2nd floor - East	1536 W	768 W	600 W	2136 W
2ns floor-West	1536 W	768 W	1000 W	2536 W

Table 4: the light usage before and after printing electric power labels on switch plates.

	All fluoresce. on	1/2 fluoresce. on	Spot lights on	All on	All off	Any On
Before	6.7	25.8	3.7	.7	64.5	35.5
After	3.5	16.3	1.2	.4	79.4	20.6

The data in table 4 indicate a reduction in light use after adding the stickers. However, we should bear in mind that the labels were attached in June and measurements after occurred over the summer solistice. The authors did not find any similar approach of posting power demand. However, it was common in the 90's that some government agencies, schools and private offices attached reminder stickers on the light switch plates reading "Turn Me Off". A field study in 1987 showed that this strategy could reduce the electric light energy use by 15% [3]. Therefore, it is not hard to believe that printing the lighting power on the switches can be effective in reducing the light usage.

Occupants' attitude The next step was to interview the educational staff in Urban Ecology Center to learn their vision concerning light quality and consumption patterns in the building. The interviewees were asked to explain how the center has managed to maintain its light usage at such a low rate compared to other public buildings. They were also asked if they felt comfortable with the energy saving policies. The summery of the interviews follows.

The primary mission of the Urban Ecology Center is environmental education. Most of the environmental educators indicated that the center's function and objectives requires the staff to behave as an example for other individuals. "In our employment policy, we have a path that is tuned to ecological role modelling. From recruitment to work training to work, the trainers are expected to incorporate environmental ethic." When the author asked if there are strict rules in the center in terms of light use, interviewees' response was negative. They maintained that "it is not a rule but an expectation to save energy. The building is designed to use less energy, and staff are aware of it." It was also mentioned that it was no specific person's responsibility to turn the lights on or off. Everybody is responsible to turn the lights off when no one is using a room. Some of the staff have trained themselves not to touch the lights unless they are not able to proceed to work. "I only turn the lights on when I can not do what I want to do." However, there were some differences in their behavior depending on the daylight availability or personal preferences: "When I teach in a classroom, I always turn the lights on, because I think daylight is not enough. Kids like the lights to be on." Another educator who worked in a classroom with windows on two walls said that she barely turns the lights on in classroom, because daylight is sufficient. Some liked to use the lights merely for aesthetic reasons: "Sometimes it is beautiful to turn the lights on. I like the lights that bounce from ceiling because they are gentler." However, even those who needed to use the lights usually turned half of them on.

Regarding the daylight quality in space, the educators had quite similar visions. They evaluated the daylight condition in the building as generally good. Almost all of the staff chose the second floor open area as the best place in terms of daylight condition (Fig. 4). The light usage data on second floor absolutely correspond to this point.

Figure 4: The open area in second floor.

One of the trainers depicted it as follows: "I love the windows and a lot of natural light in the building. I love the light that comes into the rooms in the sunset, and in winter when the sun is low. I would love to have my desk next to a window to be connected to outside." (Fig. 5)

Figure 5: Well-designed windows provide pleasant light condition in Urban Ecology Center.

The measurements of light The third part of the study included light measurements in target areas in UEC by means of a light meter (Model LI-189 from LI-COR). The intensity of light at horizontal work surfaces, 0.76 meters (30 inches) above the floor, was measured in selected points indoor and outdoor in both overcast and sunny conditions. The daylight factors were determined and presented in Figures 6 and 7. The same tests were done at night under the electric lights to compare the amount of light available on work surfaces under daylight and electric light (Fig. 8 &9)

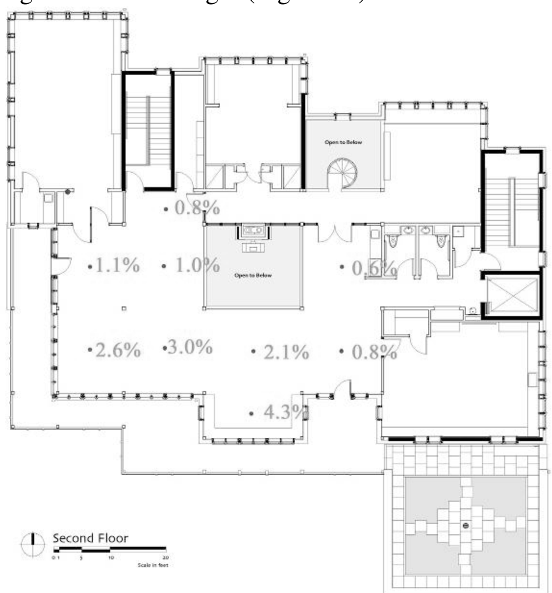

Figure 6: Daylight factors at work level in open area of 2nd floor. (Outdoor illumination: 40 klux clear, 15 klux overcast)

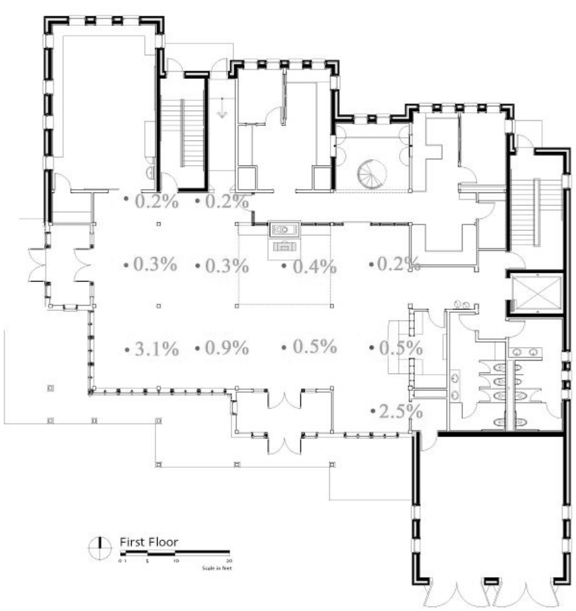

Figure 7: Daylight factors at work level in open area of 1st floor.

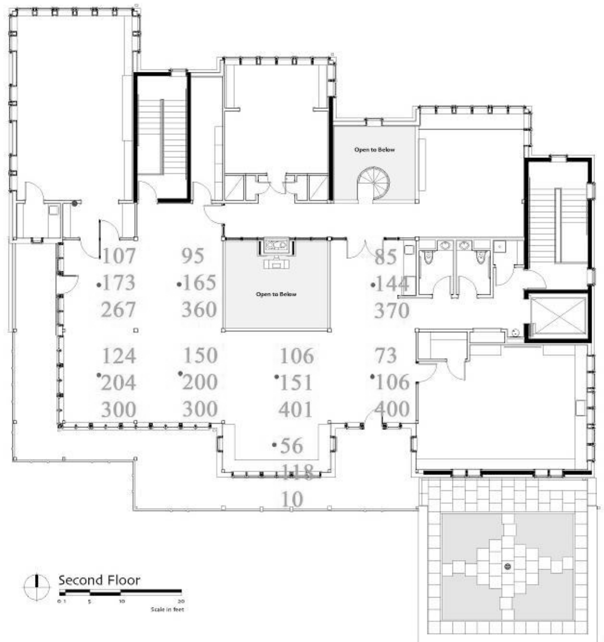

Figure 8: light intensity (Lux) under electric lights in open area of 2nd floor. The three numbers for each point represent the light intensity under half of the fluorescents, all fluorescents, and spot lights respectively from top.

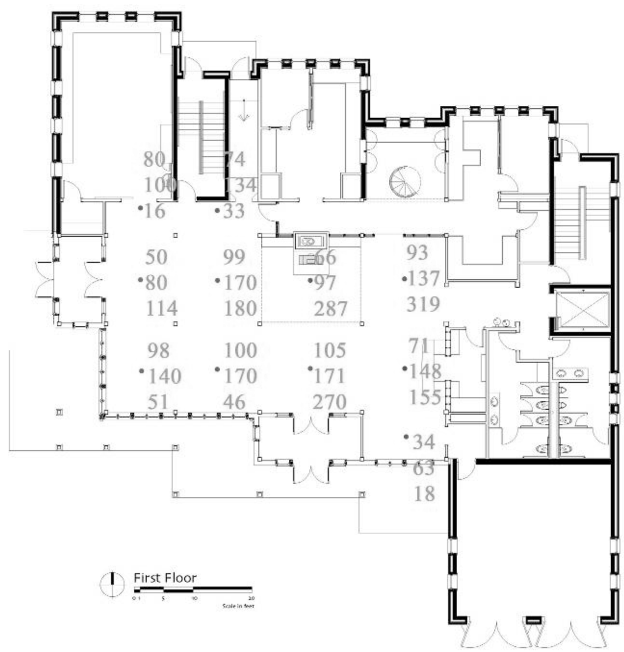

Figure 9: light intensity (Lux) under electric lights in open area of 1st floor. The three numbers for each point represent the light intensity under half of the fluorescents, all fluorescents, and spot lights respectively from top.

These figures show that the daylight factors are not within the acceptable range in all of the points, yet the light usage in UEC is remarkably low.

ALDO LEOPOLD LAGACY CENTER

The primary daylighting controls in the Aldo Leopold Center are manually operated on/off switches. The design team discussed the need to control lights manually. For the Design Energy Case (DEC) simulation, lights controlled by manual switches were assumed to be on at all times during occupancy. A Carbon Neutral Case (CNC) simulation was constructed which modelled occupant operation of manual light switches during occupancy. Electric light use in the conditioned spaces decreased by 39% compared with the DEC model. Occupant control of manual lighting was modelled as a stepped reduction in lighting power as solar radiation levels increased (Table 5).

Table 5: The relationship between solar radiation intensity and light usage in Aldo Leopold Legacy Center.

Global Solar Radiation Intensity	Light Level during Occupancy
0 to 200 Watt per Square Meter	100% on
200 to400 Watt per Square Meter	67% on
400 to600 Watt per Square Meter	34% on
Above 600 Watt per Square Meter	All off

The following data indicate the low actual light level use compared to design estimates in Aldo Leopold Legacy Center.

Table 6: Light energy use in Aldo Leopold Legacy Center based on simulation model

		Light Energy Use
Energy Cost Base Simulation	ASHRAE 90.1	26,638 kWh
Design Energy Case Simulation	no Occupant control	21,818 kWh
Carbon Neutral Case Simulation	Occupant Control	13,399 kWh
Measured Lighting Use Year 1		7,027 kWh

The metered light energy use in the building from October 2007 to October 2008 shows that the actual light energy consumption is roughly 1/3 of the design energy case (All lights on during occupancy). Daylight design of the Aldo Leopold Center includes clerestories on the roof as well as circulation area next to windows to reduce the glare (Fig. 10). Therefore, the daylight levels are comfortable enough to allow the occupants to keep the lights off.

Figure 10: The office area of Aldo Leopold Lagacy Center.

CONCLUSION

The results of the light usage data, interviews, and light measurements explicitly suggest that the occupant control of lights can result in energy savings similar to high performance daylighting systems. But more important is the knowledge and sensitivity that occupants gain of daylighting through their control of lights. Accordingly, the authors conclude that providing comfortable daylight condition along with the proper instruction is the first strategy that every design team should take into account before considering any other lighting solution.

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