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Sustainable Lighting System for University Buildings

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A B S T R A C T

Most of the major universities were constructed at a time when people were not fully aware of the energy efficiency concept. The buildings are old and consume a lot of electrical energy. The most energy consuming category of energy in any university building is lighting, followed by ventilation, then cooling, then heating and then other power equipment. This research paper is investigating a typical university building in Michigan utilizing an old, inefficient lighting system. The study presents several measures a typical university building can take to transform its existing inefficient lighting system into a 100% sustainable lighting system with the least payback time. A sustainable lighting system in a building can easily be achieved by feeding lighting load by any renewable energy generating system however, cutting back the payback time entire relies upon the efficiency of the lighting system. The objective is to reduce the lighting demand load to such a small amount that the payback time is short, and the building can utilize free of cost lighting. This research paper documents several measures which can reduce lighting demand in a university building and identify the implementation of these measures can on the building. In conclusion, the payback time of the proposed efficient lighting system installation is calculated to justify the need for the energy efficient lighting system in buildings.

Keywords: University buildings, Sustainable lighting system, renovation projects, payback time

1. Introduction

There are two main reasons which make lighting system a perfect choice for making sustainable. First, lighting energy use in university buildings is very high. According to National Grid, colleges and universities in the United States spend about $1.10 per ft^2 of their building space and about 31% of which is for lighting only (National Grid, 2003). Lightening being the highest percentage of total power consumption followed by other equipment as already discussed in the abstract section. The second reason relates to the fact that there are three main categories of energy consumption: lighting equipment, HVAC equipment and power equipment and out of these three, the only predictable and stable demand is related to lighting. The lighting system in a building is usually on for a consistent number of hours while HVAC equipment tends to consume a different amount of power every day depending upon daily temperature. Same is validat for power equipment like labs and kitchen appliances, where demands is varying every day. This makes it easy to predict the future demand for lighting equipment almost accurate and data of energy savings and payback time becomes apparent.

A university building comprises of different types of spaces therefore methods to reduce lighting load demand in any area may depend upon the space type. In classrooms, daylighting opportunities can be increased to reduce the need for artificial lights. Installing glass walls and skylights are two way of enhancing daylight opportunities. Corridors are a typical choice for skylights installation since corridors are used by occupants for circulation purposes only and a usual occupant spends less amount of time in corridors hence heat gain due to skylights addition is temporary and does not increase discomfort on a permanent basis. Daylight utilization will result in a reduction of operational hours of artificial lights and hence in reduction of utility bills (ASHRAE's Advanced Energy Design Guide, 2011). In areas where daylight utilization is not possible, the use of automatic lighting controls can reduce the number of lighting operational-hours when space is unoccupied. The proper design should consider the glare and heat

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gain caused by glass walls and skylights which increase the discomfort to the building occupants. Using energy t light fixtures, the building can reduce the lighting energy consumption. A typical T8 light fixture consumes 64 watts of power while a LED light fixture providing similar light quantity consumes 25 – 35 watts per fixture. High traffic areas like faculty offices and washrooms where people keep on coming and leaving but never occupying space for longer time spans, can be controlled by using electronic controls to turn the lights of these areas ON or OFF automatically as needed. Occupancy sensors can reduce almost 40% - 50% light savings as compared to conventional manual switches (Lighting Control Association, 2013). To make lighting system sustainable, the first step is to reduce the electrical load demand of the existing lighting system by increasing daylight opportunities in a building.

2. Literature Review

By achieving efficiency in building lighting system, significant savings can be made in utility bills and these savings can be utilized in providing additional facilities for the students. Efficient lighting design is a significant milestone for attaining overall building efficiency. One such study on lighting efficiency has been done by Dubois and Blomsterberg (2011). The authors conducted a literature review on exploring the possibilities of achieving efficiency in the lighting system of a typical commercial building and proposed several ways by which these buildings can offer potential savings in their lighting load demand. Their focus was on North European office buildings. Another research published in IEEE magazine conducted by Bellido-Outeirino et al. (2012) was inspired by the importance of lighting automation in the buildings and the savings achievable by this. The authors discussed the integration of Digital Addressable Lighting Interface devices in wireless networks. According to Muhammad et al. (2010) quoted in their IEEE magazine research paper "Energy Efficient Lighting System Design for Building" that: "Lighting contributes the highest amount of electricity usage in a building. Generally, lighting will consume from 20% to 50% of electricity consumption." Having this in mind, the authors investigated the energy management system in a building and carried out a study on the energy cost of an efficient lighting system and wastefulness on existing lighting systems. The research concluded with the fact that energy efficient lamps can significantly improve the energy efficiency of a building.

There are several studies which have identified the importance of incorporating daylight in buildings to achieve savings in energy. Bodart, and Herde (2002) published their research "Global Energy Savings in Offices Buildings by the Use of Daylighting" in Science Direct Journal. This article evaluated the effect of lighting energy savings on global energy conservation level in office buildings. The research concluded with the fact that a typical commercial building could save as much as 40% of lighting loads by using daylighting in their buildings. One study done on a similar energy field of lighting load conservation has been done by Ihm, P., Nemn and Krarti (2008) which explored the energy savings estimates by using daylighting. The article name was "Estimation of Lighting Energy Savings from Daylighting". The paper discussed different daylighting methods as a function of the building geometry, window dimensions and type of glazing for different locations within the USA. Moncef et al. (2004) developed a method of simplified calculation for estimating the energy savings resulting due to incorporating daylight inside the building. They develops a methodology to calculate energy savings by using daylight using four different building geometries. Juan and Wang (2009) developed an idea of deciding on a suitable combination of conventional and sustainable energy use for office buildings. The study developed recommendations for improving an optimal use of sustainable energy which justified the cost of its payback. From the above literature review, it is evident that lighting efficiency is a topic of great interest among researchers. In this research paper, the transformation of an existing inefficient lighting system into a sustainable system with minimum payback time is detailed.

3. Research Methodology

The research provides recommendations for transforming a current inefficient lighting system of an old academic building into an efficient and sustainable lighting system with the least payback time. The sustainability will be achieved by using a renewable energy generating power source and payback time reduction will be obtained by the decrease in lighting load and increasing efficiency of the lighting system. The smaller the lighting load is, the shorter the payback time will be. A typical university building will be taken for this study and current lighting efficiency state and sustainability data will be collected. The data includes the lighting technology installed in the building, the associated power rating of existing lighting fixtures, lighting controls used in various spaces, occupancy data for multiple areas, building operational hours, use of sustainable technologies and daylighting opportunities utilized. The current load demand will be calculated by using this data. Then the various ways by which the building under study can utilize for reducing its lighting loads will be investigated and its associated cost will also be calculated. A renewable energy system will be selected for the building. The savings that will be achieved by the energy efficient system will be calculated as well. The payback analysis will be carried out at the end which will show that in how many years, the lighting system will start to sustain itself.

3.1 *Case Study Analysis*

The building considered for the research is Engineering & Technology building of Eastern Michigan University called "Sill Hall" building. The building is situated in Ypsilanti, Michigan, USA. The total floor area of the building under study is 6,762 m2 which are approximately 72,700 ft^2. The building is installed with old fluorescent lamp fixtures. The lighting fixtures have either 2 or 3 T8 florescent lamps inside them, each lamp consuming 40 watts. The lighting fixtures are not adequately maintained which has resulted in loss of illumination level and consequently discomfort. Typically; the classrooms are maintained at 350 LUX level. LUX is Unit of measuring the Illumination level of any lighted space. For comfortable reading environment, a LUX level of 400 – 500 LUX is required, the working plane height is taken to be 2.5 ft above finished floor level. Wall finishes are either white or off-white which is very appropriate for energy efficient design. Lighter finishes require less number of lighting fixtures required as compared to darker finishes due to high light reflectance values (LRV's). The lighting controls of core areas like corridors, washrooms and service rooms is controlled by main switchboard which allows the lights in these areas to keep turned on for whole operation hours. Lighting in classrooms and laboratories is controlled by manual ON/OFF switches but are observed to operate for more than occupancy timings which is 50% of total operational hours averagely. The lights keep turned on from 8:00 am till 8:00pm unless someone remembers to turn them off manually.

The building seems to utilize a few daylighting opportunities. The building has exterior buildings facing all four orientations: East, West, North and South but all orientations seem to be very safe window design as for thermal heat gain avoidance. This minimizes the North and South facing window daylight opportunities which result in less heat gain as compared to East and West facing. There are observed some vertical glazing on North and South portion of the South wing of building which is beneficial for daylight utilization and is a good design practice. The corridor facing South of the courtyard located in the middle of the building is also having a ceiling height glass window for sunlight entrance. However similar opportunities are neglected in other parts of the building. Daylight can only be harvested within 25 ft of facade. The source of electric power for the building is the power plant of Eastern Michigan University which consumes fuel and costs energy. No measures for using renewable energy have been considered for the building. A portion of the existing load can be fed from the renewable energy source. The regular business hours of the building are 8:00 am till 8:00 pm, 12-hour operation from Monday to Friday. All calculations are performed on the same basis. Though the building utilizes power plant fuel, for simplification cost of power consumed on regular rates commercial buildings are being charged from the department of energy is assumed as 10.39 cents per kwatt-hr. Sill Hall has currently approximately 95KW of installed power for lighting only. All areas are lighted for 12 hr unless someone turns the lights off. Sometimes some spaces are turned off manually for a couple of hours. It is assumed that, 10 hr for covered spaces and 12 hr for corridors and washrooms. The building lighting utility bill is calculated to be around $24,212, at a cost of 10.39 cents/ kw-hr. This gives us a watt/square foot of 1.3 and cost per ft^2 of 33 cents which are quite high. Table 1 summarize existing lighting data.

Table1. Building Lighting Operational Data

Installed power (KW)	Operational hours (Hr)	Daily power consumption (KW-hr)	Power consumption KW-hr	Annual Utility cost $	Building area Ft2	Power Density Watt/ft^2	$/SFT $
94.64	*10-12*	*852*	*221520*	*$24,212.14*	*72,700*	*1.30178817*	*$0.33*

3.2 *Exploring Lighting Efficiency Opportunities and Associated Cost*

Adding glass walls is a way for utilizing daylight by which a building can allow sunlight to enter in the building and its occupants can use daylight instead of artificial lights and hence decrease the operating time of artificial lights.

Glass walls are a type of fenestration. The choice of wall fenestration design depends upon the location of the building on the globe. The following map has been taken from ASHRAE – Advanced Energy Design Guide for K-12 School Buildings (2011). ASHRAE has recommended dividing the map of the United States into eight zones as per their climatic characteristics. The case study building exists in Zone 5 as indicated in Figure 1.

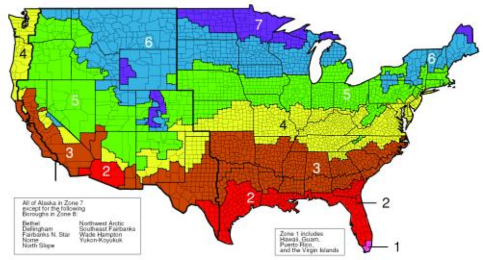

Figure 1. Advanced Energy Design Guide (ASHRAE, 2011)

The building under study is located in Zone 5 of climate zones. Daylight can be harvested using added fenestrations and using solar power for electric supply discussed later. One of the characteristics of Zone 5 (where the case study building is situated) is that it is in the Northern hemisphere and in the Northern hemisphere, North facing fenestrations are preferred. South facing windows and doors are second preference. East and facing fenestrations are highly discouraged. Table 2 is the data provided by an HVAC design firm "Energy Vanguard" about solar heat gain in Michigan (Zone 5) from glass walls for the summer season with different orientations which shows why North & South facing glass walls are preferred.

Table 2. Thermal Gain from Glass Windows in Michigan for different window orientations

Glass Window Orientation	*East*	*West*	*North*	*South*
Heat Gain (BTU/hr/Ft^2)	28.8	28.8	10.2	16.3

The data given in Table 2 shows that the thermal heat gain from East or West facing windows is almost three times as that of North facing. One factor for considering the feasibility of glass walls inclusion in a building is the amount of heat gain due to the glass walls. Solar Heat Gain Coefficient (SHGC) of a glass material is the fraction of heat absorbed in a building which transfers into heat and is a commonly used factor to measure the amount of heat gain. Lower the SHGC, lower is the heat absorbed by the building. In this case, the more heat coming from outside, the lower SHCG kept for glass wall to allow less amount of heat in the building. Below is an extract from ASHRAE guide (et al) which shows that solar heat gain coefficient should be kept lower for East and West facing glass walls as compared to North and South. The recommendation for the case study building is that all areas which have concrete exterior walls facing either North or South be replaced by glass walls. The maximum surface area of the wall that can be utilized for daylighting is the entire wall facing North and South however the final surface area will have to be consulted by professional daylight designer and HVAC engineer to ensure minimum glare and minimum heat gain. Table 3 is the recommended SHGC values for glass walls by ASHRAE while selecting the glass type for glass walls.

Table 3. Recommended Solar Heat Gain Coefficient for different window orientations

Window orientation	*East*	*West*	*North*	*South*
Recommended SHGC	0.42	0.42	0.62	0.75

For finding the cost to be incurred in the installation of wall fenestration, some online supplier databases were explored. The average cost of a glass wall is around \$52-\$55 per ft^2 as per an American brick making company named "AMBRICO". Using AutoCAD software, the length of North and South facing was found to be 260.14 m (~854 ft). Taking wall height as typical 9 ft, it is \$46,970 installation cost. In the case study building, the corridors have end to end connected florescent light fixtures having 2 – 3 fluorescent tubes inside them. These account for almost 453 tubes, of 40 watts each. These lights are observed to be on for whole operation hours and they not only consume electricity but also every watt of these light is resulting in thermal heat gain. When considering skylights, corridors utilized for circulation of occupants is a common choice. The reason is that these areas are not occupied by any occupant for a longer time and hence less discomfort from the additional heat. If the building installs skylights in corridors, a considerable amount of electricity can be saved using daylight in daytime and using artificial lights in evening only.

The primary area of concern while installing skylights is the additional heat gain after installing skylights. The final allowable area covered by skylights will need to be consulted by daylighting designer and HVAC engineer however in this study, the strategy to calculate the skylight area will be that any skylight added will be as a trade-off for replacing artificial lights. That is the heat gain by skylights should not be greater than the heat gain by existing lights. The heat gain data from the same “Energy Vanguard” website resulting from skylights in different orientations is presented in Table 4 and Thermal heat gain data due to existing luminaires is presented in Table 5. The area which has an exposed roof and can be utilized for installing skylights is 2,706 m^2. The thermal heat gain per electric light watt is 3.412 BTU/ Hr. All 453 luminaires of 40 watts result in 18,120 watts and a heat gain of 61,825.44 BTU/ hr.

Table 4. Heat Gain from Skylights in MI for different Skylight orientations by Energy Vanguard

Skylight Orientation	*East*	*West*	*North*	*South*
Heat Gain (BTU/hr/Ft^2)	66.8	66.8	60.1	62.38

Table 5. Thermal heat gain data due to existing luminaires

Thermal Heat Gain per lighting watt BTU/ Hr/ Watt	**The wattage of Lights in area** Watts	**Thermal heat gain due to lights** BTU/ Hr
3.412	18120	61825.44

To keep thermal gain same as previous, thermal heat gain should be limited due to the addition of skylights to 61,825 BTU/ Hr. If the orientation of the corridor is North-South, the only efficient way to install skylights will be East/ West facing. The calculations for skylights will be done on worst case scenario that is East/West facing skylights. As given in Table 4, “ENERGY VANGUARD” data, thermal heat gain value from East/ West facing skylights which is 68.8 BTU/hr/ft^2 for Michigan. Hence to keep HVAC load unaffected by the addition of skylights, it should be calculated that how much area can be converted into skylights. The existing building is already going through some process of HVAC system upgradation, hence the building can tolerate at least 10% more heat gain due to skylights. As summarized in Table 6, after calculations, it was found that to keep HVAC load unaffected, can be converted 3.4%.

Table 6. Allowable Skylight Area Calculation

Thermal Heat Gain per SFT of skylight BTU/Hr/Ft^2	Allowable SFT before C Roof Ft^2	Cool Roof contribution %	Allowable area after C Roof Ft^2	Total area in Yellow Ft^2	%age allowable for skylight %
68.8	898.6	10%	988	29,127	3.40%

To simulate the addition of skylights and how much illumination they add into space, second floor corridor was taken as a specimen and was simulated on a lighting design software called DiaLUX Lighting Software. After running simulations, that with 3.4% area of the roof of the second floor which is 13 skylights of 1 m^2 area; it is achieved that an illumination level of 433 LUX where LUX is the unit of illumination and around 400 LUX provides the very comfortable reading environment. Table 7 gives DiaLUX Daylighting Simulations. The artificial lights will also be present to be utilized when the light level is below required level and will be circuited with photo-sensors. This was the result of peak time sunlight however after peak time, the artificial lights will be turned on by photo-sensor. Material cost for installing 13 m^2 will approximately be $17,500. As a general rule of thumb, to achieve a slope equal to geographical latitude plus 5 to 15 degrees. North latitude of Ypsilanti is 42 degrees hence the recommended slope of skylights is between 47 degrees to 57 degrees. The skylights are recommended to be “Energy Star” rated. To achieve a reduction in energy utilization by lighting, high-performance lights should be used. Light Emitting Diodes have become a very popular choice for new construction. The reason is that old lighting fixtures consume a large amount of energy as compared to modern LED fixtures. The Sill Hall building utilizes Troffers with old T8 florescent lighting fixtures which are very energy consuming. Currently the case study building is using fluorescent light fixtures having 2-3 T8 lamps, each 40 watts. Consider the photometric data of a standard T8 fluorescent light versus conventional LED as given in Table 8.

Table 7. Results of DiaLUX Daylighting Simulations on Second Floor Sill Hall Corridor

Area	**Skylight Area**	**Skylight Area**	**Illumination Level achieved**
m^2	%	m^2	LUX
382	3.40%	12.988	433

Table 8. Comparison of a typical florescent and LED light fixture

	Model #	**CCT**	**CRI**	**Fixture mounting**	**Light Distribution**	**Power (Watts)**	**Luminous Flux (Lumens)**	**Efficacy (Lumens/Watt)**
Typical T8 Florescent	2GR8-232A	3200 K	90+	Surface	Direct	*64*	*3100*	*49*
Typical T8 LED	4WSL-LD4-40-UNV	3000 K	85	Surface	Direct/ Indirect	*35*	*4010*	*114*

A typical measure of a luminaire is using Luminaire Efficacy which is the amount of light per unit power consumed. The unit is Lumens / Watt. From Figure 2, it is clear that the lumens per fixture are 3100 and power per fixture is 2 x 32 = 64 Watts. This gives us a luminaire efficacy of 47 lumen/watt. In contrast, the LED fixture has an efficacy of 114 lumens/ watt; that is almost 2.5 times the T8 fluorescent tube. The same LED T8 fixture is proposed to replace all old T8 florescent tube lights. An experimental evaluation of how many lights will be required shall be examined in a later section. The proposed Light fixture is manufactured by Cooper Lighting and has its lighting calculator. A sufficiently sizeable rectangular area was taken as a typical area to be illuminated at a sufficient illumination level. For a computer-based studying environment, 350 LUX is fine where LUX is the level of illumination. As indicated in Table 9, 400-ft by 400-ft room with 9 ft height was taken and simulated with the proposed LED fixture. The result is that if this light is used, 0.37 watt/ft^2 power density can be achieved as compared to the current 1.3 Watts/ft^2 with T8 fixtures. Since the research is strictly bounded by time, hence these results are extrapolated to the whole building. However; simulating each room individually will give exact results. For this study, all rooms were not simulated and the watt per ft^2 found by light calculation.

Table 9. Results of simulating LED lighting design in a typical room

LED wattage	**Room Dimensions**	**Illumination Level**	**Lighting power density**
(Watts)	LxWxH (ft)	(LUX)	Watt/ft^2
25	400x400x9	509	0.37

As identified in Table 10, simulation data to the whole building, the total wattage of the whole building will be total ft^2 area of the building multiplied by the resultant watt per ft^2 achievable by the proposed LED light fixture. Then, the total power consumption in watts can be divided by the power of individual light fixture to find out the number of LED light fixtures required by the whole building.

Table 10. LED light cost and quantity calculation required for Sill Hall

LPD	**Building Area**	**Total watts**	**Watt/LED**	**Light Qty**	**$/LED**	**Cost of LED**
W/SFT	*SFT*	*(W)*	*(W)*	*Each*	*Dollars*	*Dollars*
0.37	72,700	26899	25	1075.96	$150	161584

The areas which utilize exterior windows for daylight utilization, the lighting fixture layout of those areas should comply with daylighting strategy since daylight can only be utilized within 25 ft of the facade. The lighting fixtures are proposed to be in rows parallel to the side windows and wired separately with a photo-sensor. Since areas away the exterior windows tend to be darker sooner than the areas near windows. Hence when sunset time approaches, the lights away from windows shall be turned on earlier and the ones near the windows will still be using daylight in the early evening. The photo-sensors are suggested to be at a point where actual light utilization is required. Usually it is at 0.75 m from the floor which is a standard table level. This way the photo-sensor will be able to switch on the lights when the task level illumination level reaches below the required level. As an example of implementation, Room 215 from the second floor was taken from case study building and lighting layout with photo-sensors was drawn in Figure 3. It is clear from Figure 3, photo-sensor 1 (PS1) is nearest to the exterior window on the North side of the room and PS4 is farthest from the window. When the sun starts to set, the lighting of the room does not need to be turned on. The lights connected to photo-sensor 4 is turned on first. When the darkness increases, PS3 will be turned on.

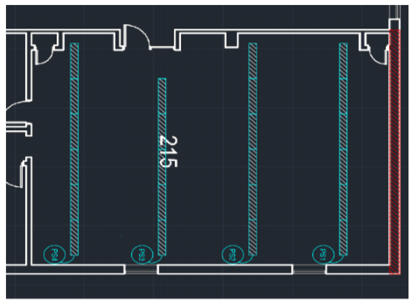

Figure 2. Sample room taken from Case Study Building located on the second floor

The final design and quantity of photo-sensors will depend upon the lighting controls engineer but approximately if areas having access to North or South windows have four rows each, then the total cost of photo-sensors will be $2,500. The occupancy sensor is a device which turns the lights automatically on and off in areas it controls when the area they detect human occupancy. These devices detect either heat or sound waves happening due to human entrance inside an area and respond by turning on and off lights accordingly. As is the case of manual controls, the lights of classrooms and washrooms are on all the time even when the classes are finished unless someone turns off the lights manually. An occupancy sensor can help savings by turning off lights automatically when they are not required.

Table 11. Estimated power savings by using Occupancy sensors as per Lighting Control

Area type	Private Office	Open Office	Classroom
% savings in lighting	*38%*	*35%*	*55%*

According to Table 11, it is recommended that, lights should control of areas outlined in blue by Occupancy Sensors. The reason is that these areas do not have access to exterior walls and hence cannot have exterior windows for daylight utilization. The observation of Sill Hall building provides some insight about the actual occupancy of different areas and they have been observed to be averagely 55% of the time vacant. This gives us occupancy of 45% of total time. A typical occupancy sensor covers 20 ft x 20 ft area ~ 400 ft^2 and the area proposed to be controlled by Occupancy Sensor is 3108 m^2 or 33,455 ft^2. This roughly gives us approximately 84 occupancy sensors required for the proposed area. Now it proceeds with the cost versus benefit analysis as given in Table 12.

Table 12. Savings achieved by using Occupancy Sensors

Area in blue	**LED Lighting Power Density**	**Power consumed in marked area**	**Building Operation hours**	**Occupancy**	**Total KW-hour per day**
ft^2	W/ft^2	KW	Hr	%	KW-hr
33455	0.37	12.37835	12	45%	66.84309

If the cost of a typical occupancy sensor is $50, then the cost of 84 Occupancy sensors will be $4,200. Several ways to reduce the lighting load to a minimum were investigated. The only thing left in this research is to make the lighting load sustainable. Sustainability can be achieved by using renewable energy power generation. Utilizing renewable energy is an efficient way to reduce power consumption inside any building by catering a portion of existing load by renewable energy plant. Renewable energy generation plants have no operating costs except maintenance. Solar panels are generally a common choice for onsite power generation. However; solar panels have high capital costs hence before deciding to go with solar panels should be done carefully. For deciding that in Sill Hall case, would it be beneficial to recommend solar panel installation.

It is generally recommended that Photovoltaic panels should be used only if the solar radiation intensity is either greater than or equal to 1.1 watts/ ft^2/ day. In the map, it is evident that Michigan receives more than 4 watts/ ft^2/ day averagely hence it is advantageous to install solar panels in this case. Solar panels are mounted South facing to make Sill Hall roof to install solar panels. The total footprint of the building is almost 58,000ft^2 and total lighting load after renovation will be 107 KW-hr per day. Lighting load after renovation is suggested to be fed by solar panels. The size of the solar panel system should be designed in such a way that the panels provide for lighting load on a daily basis. However; it is not sunny in Ypsilanti for 356 days per year. So; it is needed to account for those extra days when sunlight is not available and Sill Hall has a sufficient reservoir for dealing with this situation. There are average 180 sunny days in Detroit which is near Ypsilanti so it will be assumed the same for Ypsilanti. This approximately accounts for half of the days per year. On the average Detroit has 6-hr of sunlight daily. With this information, the size of the solar panel system can be calculated as given in Table 13.

Table 13. Solar Power Plant Size Calculations:

Daily Power *KW*	Sunlight available *Hours*	Safety reservoir *KW-hr*	Total requirement *KW*	Solar power rating *KW*
107	6	107	35.66	35

For finding the cost and physical size of panels, supplier websites were investigated and it was found that installation cost of solar panel is $3.36 / watt and size of solar panel system is 15 watts per ft^2. Table 14 gives a few quotes provided in 2015 by Energy Sage company website:

Table 14. Solar Panel quotes:

Wattage	6KW	8KW	10KW
Price	$15,000	$20,000	$25,000

This gives the following data: 35 KW system will cost = cost of 3 systems of 10 KW and one system of 6 kW; hence; Solar panel cost = $15,000 + $25,000 x 3 ~ $90,000. To find the feasibility of solar panel installation, it should be confirmed if it will have sufficient space for solar panels, and to find out the physical space the solar panels will be provided by the total foot print or not. This is a general rule of thumb by solar panel suppliers that 15 ft^2 will be required every 15 Watts of power hence; 35 KW needs 35 x 1000 / 15 is approximately equal to 2,400 ft^2 area which is less than actual footprint of the case study building which is 58,000 ft^2.

3.3 *Payback Analysis*

For payback analysis, it should be calculated that, the cost of installation and the amount of savings it can be achieved from these installations. Generally; contractors are observed to take 2% - 5% of material cost as installation cost, 5% was taken for the following calculation purposes. The payback calculation is summarized in Table 15. The data in the table shows that if the case study building goes with the sustainable lighting system in 2018, the building will start to utilize free of cost lighting energy by 2034.

Table 15. Payback time calculation

Energy Efficiency Item	***Cost ($)***
Glass Walls for daylight	46,970
Skylights	17,500
LED light fixtures	161,584
Electronic controls	6,700
Solar Panels	90,000
Installation cost	16137.7
Total cost	**338,892**
Annual Savings	**21,273.87**
Simple Payback Time	**15.92 years**

4. Conclusion

In conclusion, the above recommendations have proven to save electrical energy demand. There have been several similar cases where schools have implemented these techniques and the result is not only energy savings but also occupant comfort and satisfaction. Marin County Day School, CA, USA maximized on daylighting opportunities by using glazed facades which allowed natural light with the least solar heat gain. This resulted in less use of artificial light when daylight is available and hence the use of electricity was minimized. In addition to glazed facades, the school harvested more daylight through solar chimneys which provided a cooling effect as well and therefore more comfortable reading environment for students. The building used 95 KW solar panel array for catering various building's energy needs and it is interesting to note that this 95 KW solar array was not very costly and accounted for only 1.5% cost of total construction. The motion sensors provided control over electric power consumption time and florescent lights were enabled to be dimmed in coordination with natural light. As a result, the building was able to achieve more than 50% reduction in its energy utilization pattern after implementing these recommendations (ASHRAE Advanced Energy Design Guide, 2011).

Another case study on Richardsville Elementary School, KY, USA was the first school in its locality to use daylighting for its ambient illumination during the daytime. The building used a combination of glazed facades and tubular chimneys for optimizing on daylight harvesting. The building reduced over the excess lighting level and minimized it to 400 LUX and saved project cost. For 95% of teaching hours, daylight was available as the only sufficient means for providing ambient lighting and hence no requirement for using artificial lighting (ASHRAE Advanced Energy Design Guide, 2011).

The above discussion makes it very obvious that though energy efficiency involves high cost of implementation and new equipment, the pros of these installations overpower its cons. The benefits of energy efficient and sustainable lighting design include low energy consumption and hence less dependence on fossil fuels which will not only reduce our electricity bill but also will produce less carbon footprint. Although energy efficient fixtures have higher initial cost but they result in less light pollution.

This installation will result in almost 87% reduction in its utility bills related only to lighting which is a considerable saving as demonstrated in Figure 3. Hence implementing the energy efficiency measures in the case study building will be worth spending the high initial cost of proposed installation if savings in the long term are considered. The research concludes with the statement that the payback time for energy efficient lighting system is not difficult, rather it only required determination.

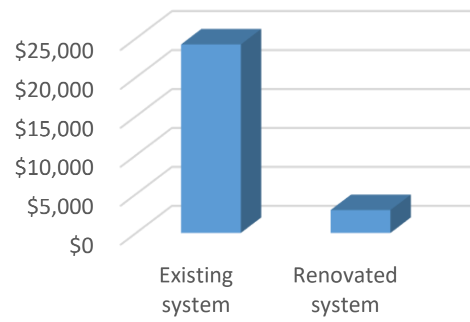

Figure 3. Difference in cost for existing versus energy efficient lighting system

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