P08428 LED Lighting Technologies for a Sustainable Entrepreneurial Venture

System Level Review

February 1, 2008

Presentation Outline

Project #	Project Name	Project Track	Project Family
P08428	LED Lighting	Sustainable Products, Systems, and Technologies Track	Sustainable Technologies for the RIT Campus
Start Term	**Team Guide**	**Project Sponsor**	**Doc. Revision**
072	Dr. Stevens	FMS (unconfirmed)	C

Project Description

Project Background:

RIT is dedicated to environmental issues and sustainability. This project entails developing a product that will conserve electrical energy, and reduce Maintenance costs. It was found from project P07421 that off-the shelf LED light fixtures are inadequate.

Problem Statement:

Current exterior lighting technologies are resource intensive and not electrically cost effective. RIT spends about $6 million per year in electrical costs, which half is due to lighting. RIT also dedicated a large portion of resources in the maintenance of exterior lighting. A newly designed LED replacement kit will be easily implemented in existing light fixtures.

Objectives/Scope:

1. Reduce energy usage.
2. Reduce maintenance costs.
3. Create a marketable end product.
4. Gain experience with LED lighting system design.

Deliverables:

- Scalable lighting product prototype to accept multiple voltage inputs.
- Life cycle report.
- Return on investment.
- Budget.
- Plan for commercialization (Finish in SDII).
- Drawing plan.
- Manufacturing plan.
- Conference paper.
- Technical poster.

Expected Project Benefits:

- Design feasibility has been determined at the end of SDI.
- Prototype and plan for implementation has been accomplished at the end of SDII.
- Expected energy and cost savings to RIT.
- Improve RIT's image by reducing its global footprint.
- RIT gains experience in alternative lighting systems.

Core Team Members:

- Shawn Russell
- Christine Lagree
- Taylor Shivell
- Arthur Deane
- Philip Pietrantoni
- David Eells

Strategy & Approach

Assumptions & Constraints:

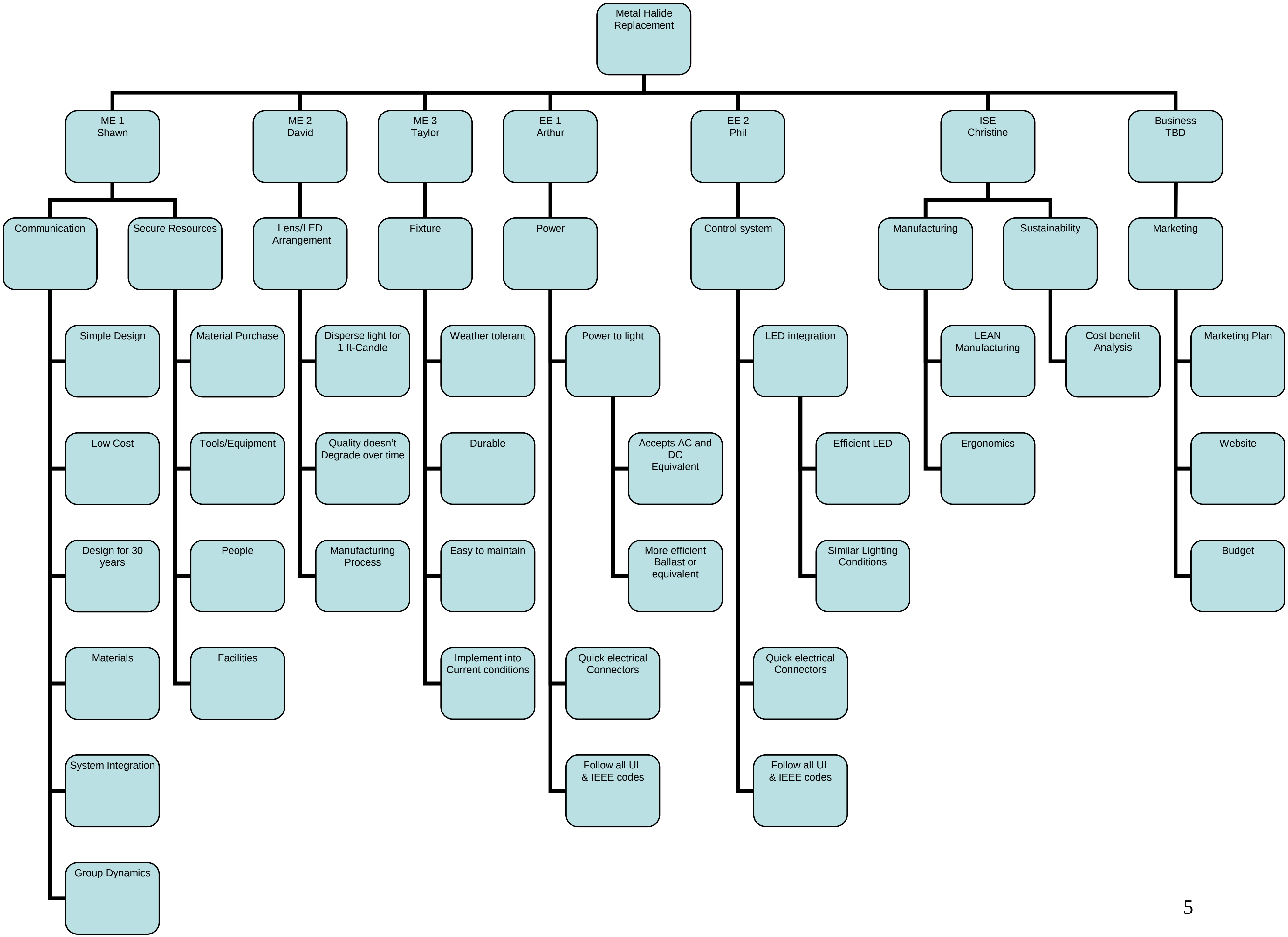
1. Current shoebox fixture will be used.
2. Use of Light Emitting Diodes (LED).
3. LED performance is comparable to current lighting systems.
4. LED's will be more cost effect over its lifetime.
5. Lighting system decreases maintenance costs.
6. The new lighting system will be safe and durable to outdoor conditions.
7. The new lighting system will be compatible with the existing power grid.
8. The light output must be measured at 1-2 a minimum of ft-candles at the ground along walkways.
9. Lighting system conforms to all safety regulations and electrical standards.
10. Easily manufactured.
11. CRI higher than that of HPS lamp.
12. Color temperature is between 3000K and 5400K.
13. Use common parts amongst fixtures.

Issues & Risks:

- Have not obtained funding.
- Adequate light distribution might not be possible with current LED technology.
- Adequate light intensity might not be possible with current LED technology.
- Incoming power might not be easily converted to usable source for LED lighting.
- Design for 30 years could be expensive.
- Cost of materials and manufacturing.
- Product might not be easy to install.
- Timeframe for completion is small.
- Resources might not be available.
- Product may not have a favorable market outlook.
- Environmental considerations (manufacturing and use).
- Systems integration.

Roles & Responsibilities

Name	Project Area of Responsibility	Functional Area of Responsibility	Hardware Area of Responsibility	Role	e-mail	Phone Number
Shawn	Project manager	Mechanical	System Integration	Lead	spr2237@rit.edu	607-351-2777
Arthur	Individual Contributor	Electrical	Power systems/LED integration	Support	ajd8109@rit.edu	347-306-7640
Philip	Individual Contributor	Electrical	Control systems/ LED integration	Support	ppp5425@rit.edu	585-737-4434
David	Individual Contributor	Mechanical	Lens/LED arrangement	Support	dme0759@gmail.com	845-558-8904
Christine	Individual Contributor	Industrial	Systems Integration	Support	CLL3219@rit.edu	716-864-5778
Taylor	Individual Contributor	Mechanical	Fixture Design/Packaging	Support	wts5717@rit.edu	203-623-8028


Metal Halide Replacement
ME 1 Shawn
ME 2 David
ME 3 Taylor
EE 1 Arthur
EE 2 Phil
ISE Christine
Business TBD
Communication
Secure Resources
Lens/LED Arrangement
Fixture
Power
Control system
Manufacturing
Sustainability
Marketing
Simple Design
Low Cost
Design for 30 years
Materials
System Integration
Group Dynamics
Material Purchase
Tools/Equipment
People
Facilities
Disperse light for 1 ft-Candle
Quality doesn't Degrade over time
Manufacturing Process
Weather tolerant
Durable
Easy to maintain
Implement into Current conditions
Power to light
Accepts AC and DC Equivalent
More efficient Ballast or equivalent
Quick electrical Connectors
Follow all UL & IEEE codes
LED integration
Efficient LED
Similar Lighting Conditions
Quick electrical Connectors
Follow all UL & IEEE codes
LEAN Manufacturing
Ergonomics
Cost benefit Analysis
Marketing Plan
Website
Budget

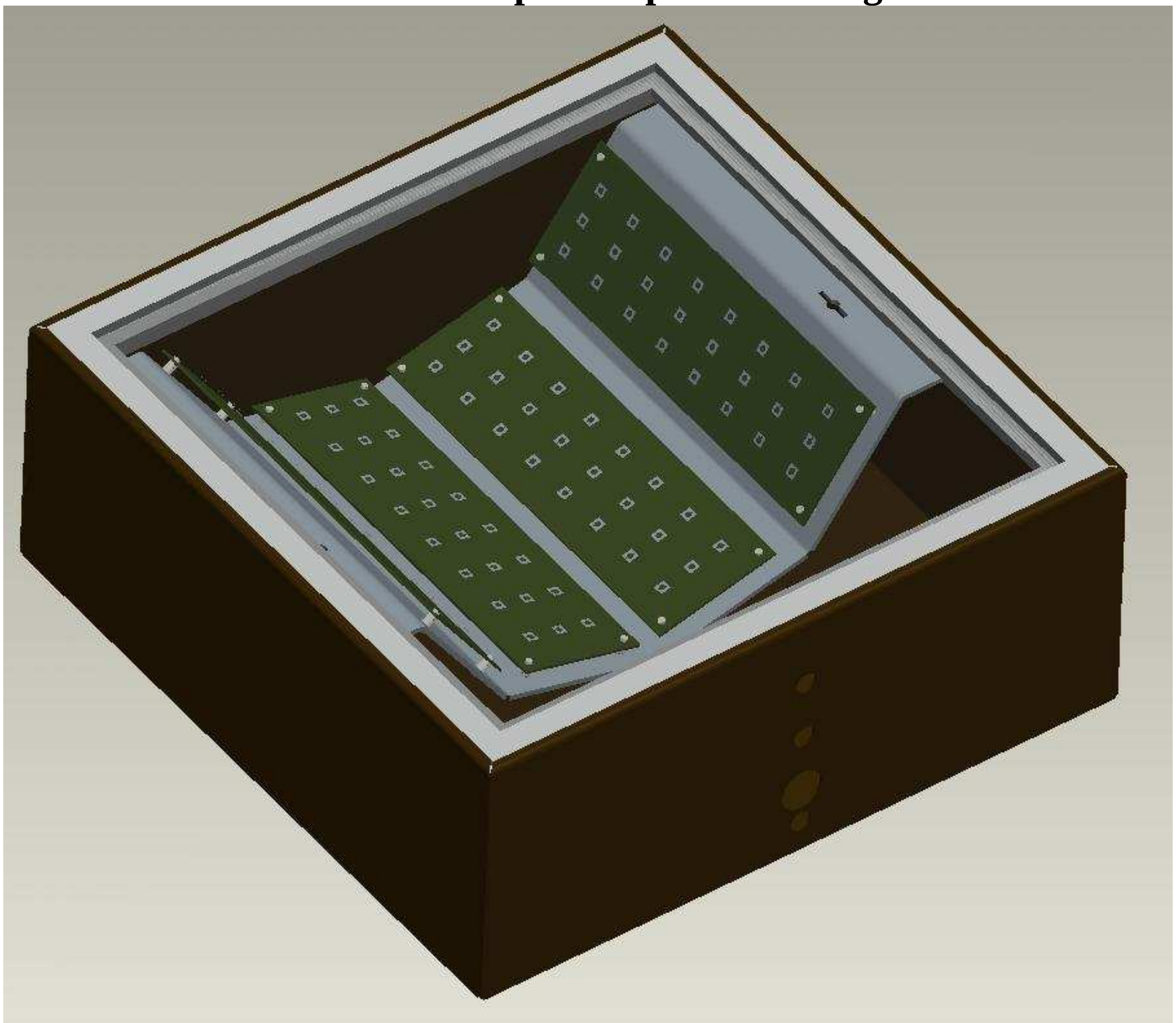
Customer Needs

Need No.	Subsystem	Need	Importance
1	Fixture and light	Conform to regulations put in place by OSHA, IEEE, UL and EPA	9
2	Fixture and light	Use less energy than existing systems	3
3	Fixture	Be recyclable	1
4	Fixture and light	Be sustainable	3
5	Light	Decrease the light pollution that the existing lights create	1
6	Fixture	Standardize parts within the fixtures	9
7	Light	Color Temperature comparable to Metal Halide	9
8	Fixture	Be easy to install and replace lights	3
9	Light	Provide as much light as current systems	9
10	Light	Spread the light out	9
11	Light	CRI higher than that of HPS lamps	9
12	Fixture	Aesthetically pleasing	1
13	Fixture and light	Decrease energy bill	3
14	Fixture	Keep fixture price low	3
15	Fixture and light	Decrease the amount of time and money maintenance spends on the system	9
16	Light	Bulbs are recyclable	1
17	Fixture and light	Provide a product that can be easily manufactured	9
18	Fixture and light	Economically viable	9
19	Fixture	Be vandal resistant	3
20	Fixture	Have a long life span	9
21	Light	Have a long life span	9
22	Fixture	Withstand the elements of the outdoors	9
23	Fixture	Weight	9

Engineering Specifications

Metric No.	Need Nos.	Metric	Imp.	Units	Marginal Value	Ideal Value
1	1	Complies with applicable codes and regulations	9	Binary	Yes	Yes
2	2,4	Power consumption	6	W	<130	<50
3	2,4,9,10	Power efficiency	24	lm/W	>30	>70
4	3,4,16	Percent by weight of product recyclable	5	%	70%	100%
5	4	CO_2 Emissions	3	Pounds	??	??
6	12	Luminance	2	ft-cd	??	??
7	6,8	% of common parts used in fixtures	12	%	>50	>70
8	7, 12	Color Temperature	10	K	3000-5400	4100
9	8,18	Install Time	12	hr	<3	<1
10	8,15,18	Maintenance Time per “ticket”	21	hr	<2	<1
11	8,23	Weight	12	lbs	<50	<30
12	9,10	Light density for entire coverage area	18	ft-cd	0.5-2	1
13	9,10	Light spread (length)	18	ft	30-40	40
14	9,10	Light spread (width)	18	ft	3-5	4
15	7,9,11,12	CRI	28	unit less	>65	>80
16	9,10,12	Aesthetically pleasing (Survey 1-5)	19	unit less	>3	>4
17	13,18	Energy usage	12	kWhr/ month	<65	<18
18	14,18	Fixture cost	6	$	<700	<500
19	4,14,18	Disposal cost	7	$	10-100	50
20	14,17	Manufacturing cost	12	$/unit	<400	<250
21	4,13,18	Pay-back Time	15	years	<15	<7
22	2,4,13,15,18	Total Savings per fixture	27	$/yr	>40	>60
23	19	Pass Drop & Vibration tests	1	Binary	Yes	Yes
24	4,18,20,22	Fixture lifetime	30	years	>25	>30
25	4,18,21	LED lifetime	21	hours	70,000 - 120,000	100,000
26	22	Operating Temperature	9	*F	-10 - 110	-30 - 130
27	??	Maximum Temperature range	9	*F	>140	>150
28		# of maintenance “tickets” in lifetime		unit less	??	??
29		Life-cycle cost				
30		Return on Investment				

Selected Concept – Dispersion of Light



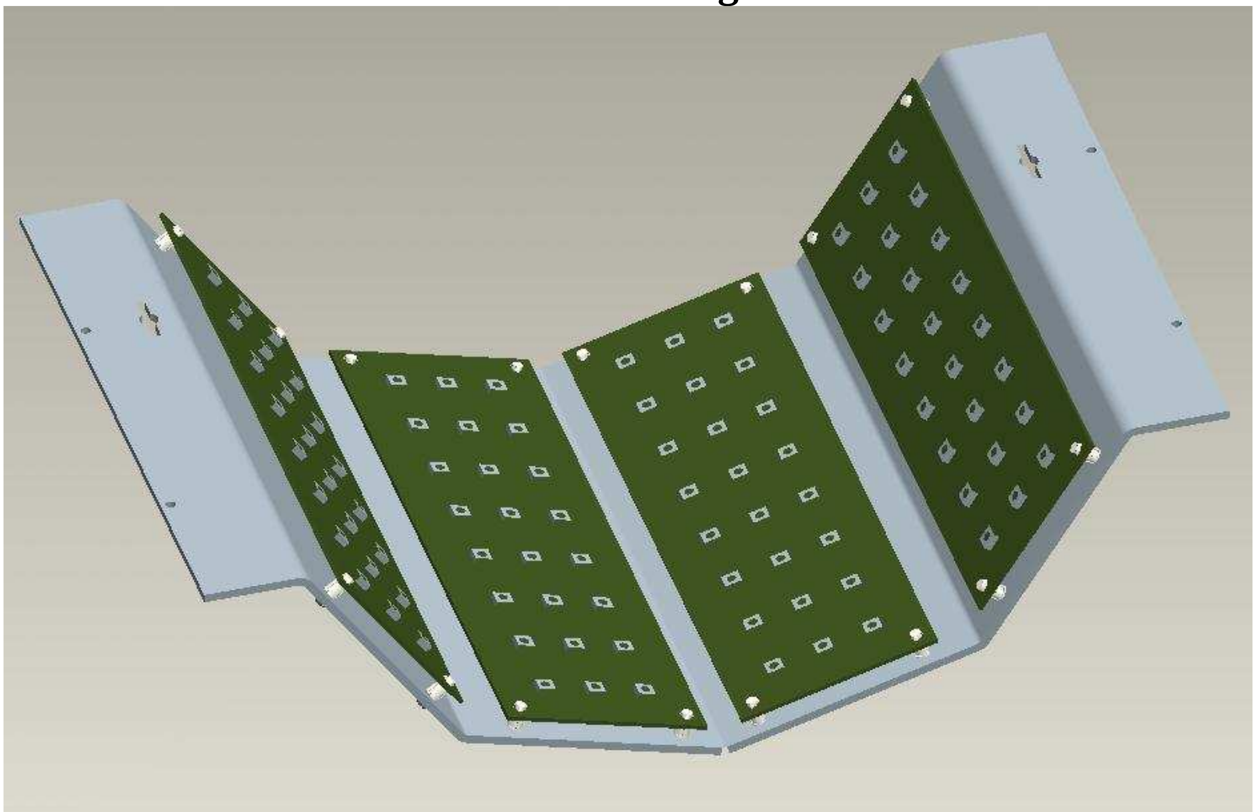
Advantages:

a. LEDs will be positioned to distribute light where needed.
b. Cheaper than current system available (screw in replacement bulbs).
c. With modular design, failure of one part does not lead to failure of the system, unlike the screw in bulb in which when one part fails, the entire system is down.

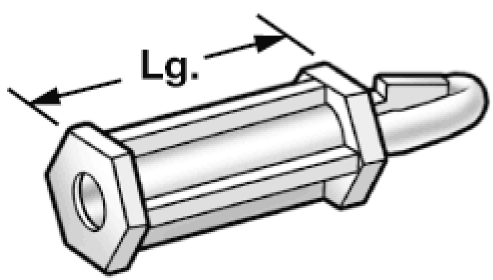
Disadvantages:

a. Initial installation is slightly more time consuming and intricate than screw in bulb replacement.
b. Maintenance requires replacing individual defective boards
c. Requires more parts than the screw in bulb and entire system is not currently in manufacture.

Fixture Design

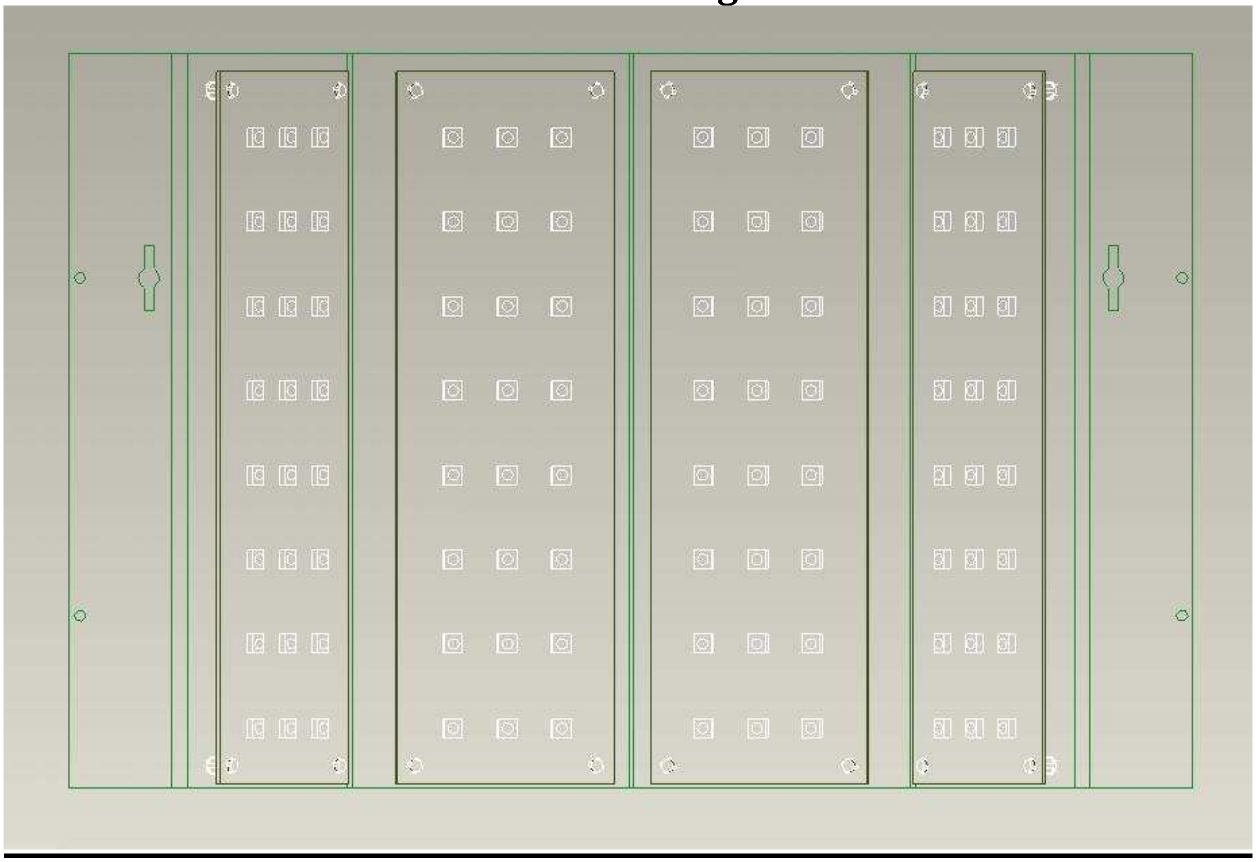


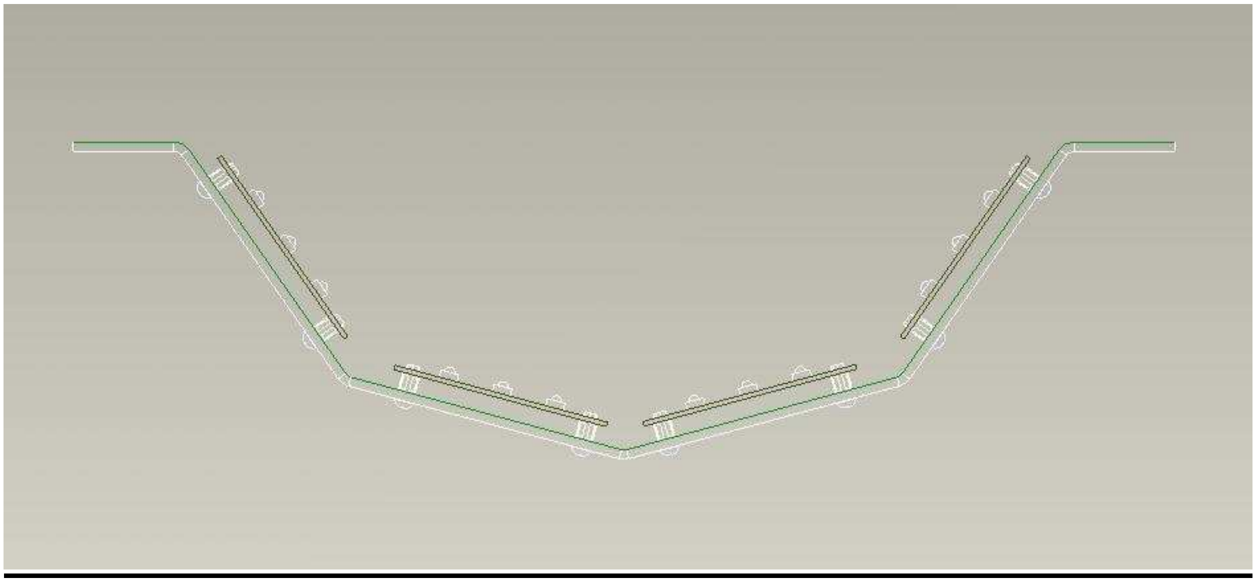
The retrofit assembly consists mainly of a sheet metal base plate. This plate can be easily prototyped by making bends in a flat piece of aluminum or steel. The end product will be manufactured using a stamping process. The thickness is not critical, and is therefore ideal for stamping. The circuit boards (green) mount to the sheet metal base using s plastic standoff with a snap connection. This one sheet metal plate has mounting features to accommodate different fixture housings, and does not need to be modified to fit each housing.



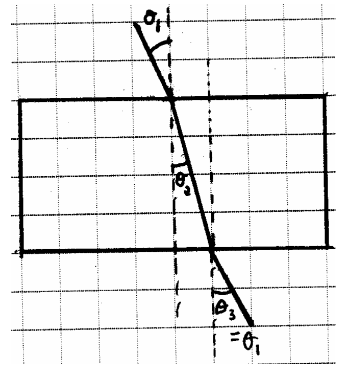
Mechanical connection

Fixture Design





Calculations - Incidence Angle



Incidence Angle

$$n_1 \sin(\theta_1) = n_2 \sin(\theta_2)$$

$$\theta_1 = \theta_3$$

$$\sin\theta_1 = \frac{l}{\sqrt{l^2 + H^2}}$$

$$H = 14\ ft$$

$$l = 10, 40\ ft$$

$$if\ l = 10\ ft, \sin\theta_1 = \frac{10}{\sqrt{10^2+14^2}} = \frac{10}{17.20465} = 0.5812382, \theta_1 \approx 35.5377°$$

$$if\ l = 40\ ft, \sin\theta_1 = \frac{40}{\sqrt{40^2+14^2}} = 0.943858, \theta_1 \approx 70.7099°$$

Ray displacement, d

$$d = \frac{t}{\cos\theta_2} * \sin(\theta_1 - \theta_2)$$

$$ASSUME\ Crown\ Glass, n_2 = 1.52.\ n_1 = 1.00\ (air)$$

$$Multiple\ refractions\ cause \| rays\ (\theta_1 = \theta_3), with\ displacement\ d\ as\ shown.$$

$$\frac{n_1}{n_2} = \frac{1.00}{1.52} = 0.657895$$

$$\theta_2 = \arcsin\left(\frac{n_1}{n_2} * \sin\theta_1\right)$$

$$if\ l = 10\ ft, \theta_2 \approx 22.482°, d \approx 0.2445 * t\ (ft) \approx 2.9337 * t\ (inch)$$

$$if\ l = 40\ ft, \theta_2 \approx 38.386°, d \approx 0.68216 * t\ (ft) \approx 8.1859 * t\ (inch)$$

What this shows us is the minimum angle of incidence of a light ray required to make the full "reach" to the desired distance, as well as the "offset" caused by the refraction inside the glass. To sum up, to reach a 40-ft distance on one side, a light ray must impact the glass at approximately a 71-degree angle, and it will be deflected approximately 8.2**t* inches perpendicular to the ray, where *t* is the thickness of the glass. As we can obtain up to a 67-degree viewing angle on our LEDs, this means that the boards meant to illuminate the far ends of the zone must be at a minimum 4-degree angle.

Calculations - Intensity

Intensity

$$52\,lux * \frac{1\ ft-cnd}{10.76}\,lux = 4.83\ ft-cnd\ @1\ LED\ source$$

$$I = \frac{I_0}{r^2}$$

$$r = 14\ ft,\ r^2 = 196\ ft^2$$

$$\frac{4.83\ ft-cnd}{196\ ft^2} = 24.64\text{x}10^{-3}\,\frac{ft-cnd}{ft^2}$$

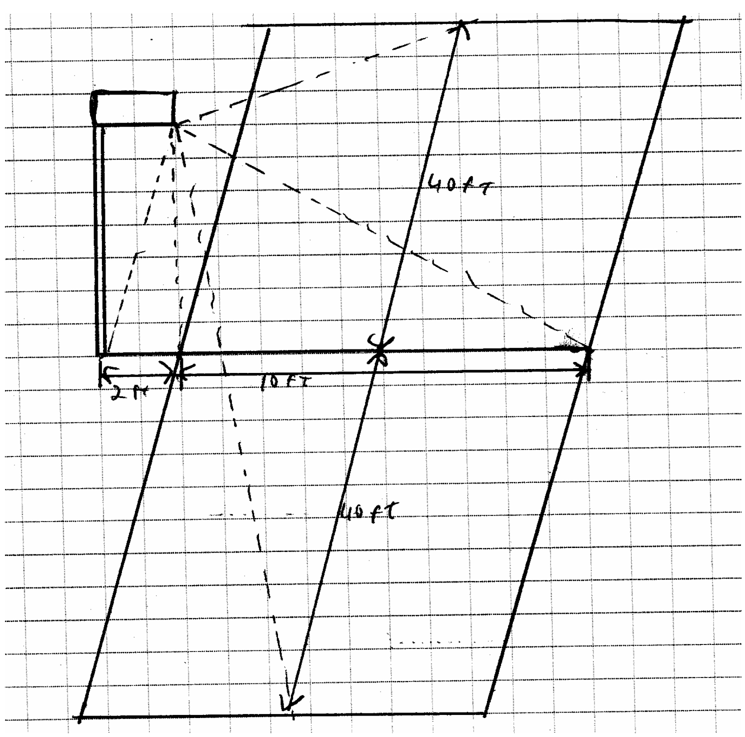
$$24.64\text{x}10^{-3}\,\frac{ft-cnd}{ft^2} * (\pi * (40\ ft)^2)$$

$$REQUIRED: 123.85\ ft-candle\ at\ source.$$

$$1\,\frac{ft-cnd}{ft^2} = \frac{x}{196\ ft^2}$$

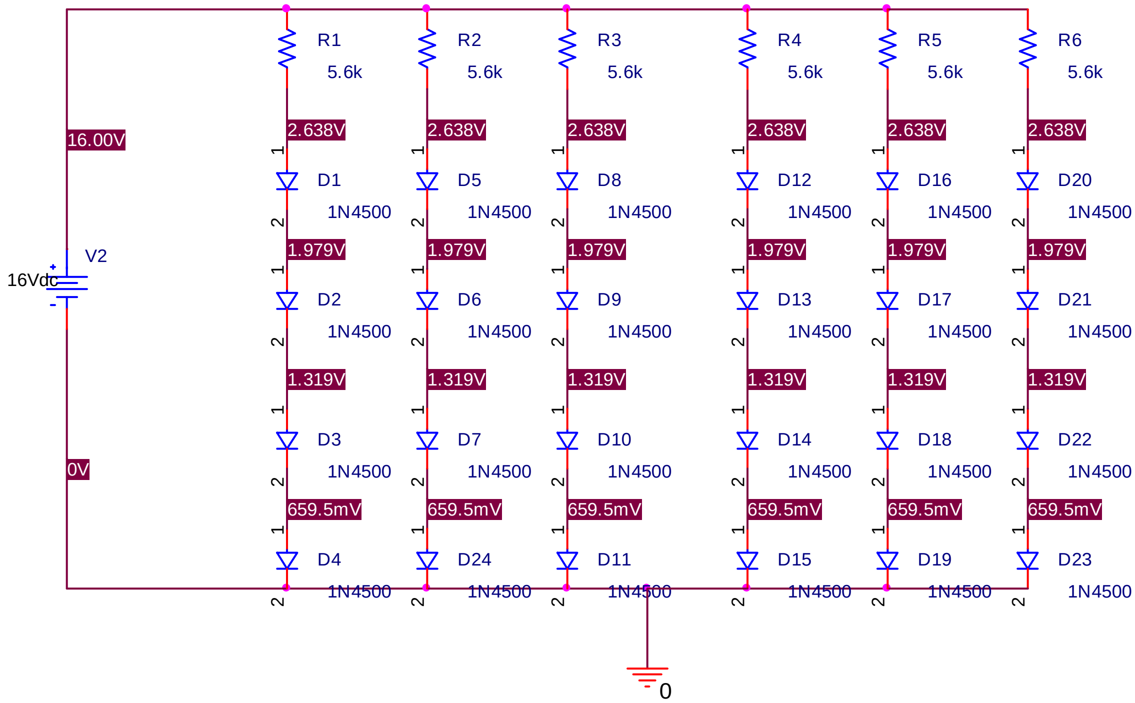
$$x = 196\ ft-cnd$$

$$196\ ft-cnd * \frac{10.76\,lux}{1\ ft-cnd} = 2108.96\,lux * \frac{1}{52\,\frac{lux}{LED}} = 40.56\ LED \approx 41\ LEDs.$$



Light obeys an inverse-square law: as you illuminate an area twice as far away, you need four times the energy, and so forth. Treating foot-candles as an intensity measure, we can find the number of LEDs needed to produce the necessary light density on the walkway. Note: These numbers are preliminary, and may need to be changed based on benchmarking of our test LEDs. Our preliminary calculations show that we will need approximately 41 LEDs to create the needed amount of light.

Circuit Design



This is the circuit design for one LED board. The incoming power can be controlled from the motion sensing circuit (optional). The DC voltage source is representative of the AC line-in to the bridge rectifier circuit.

Specifications:
Each LED is 1watt, 400mA, 3.5VDC drop
Each resistor dissipates ~714mW (~17W loss/system)
40 lms, 4000K

FAIRCHILD SEMICONDUCTOR®

KBU4A - KBU4M

KBU

Features

- High surge current capability.
- Reliable construction technique.
- Ideal for printed circuit board.

Bridge Rectifiers

Absolute Maximum Ratings*

T_A = 25°C unless otherwise noted

Symbol	Parameter	Value							Units
		4A	4B	4D	4G	4J	4K	4M	
V_{RRM}	Maximum Repetitive Reverse Voltage	50	100	200	400	600	800	1000	V
V_{RMS}	Maximum RMS Bridge Input Voltage	35	70	140	280	420	560	700	V
V_R	DC Reverse Voltage (Rated V_R)	50	100	200	400	600	800	1000	V
$I_{F(AV)}$	Average Rectified Forward Current, @ T_A = 50°C	4.0							A
I_{FSM}	Non-repetitive Peak Forward Surge Current	200							A
T_{stg}	Storage Temperature Range	-55 to +150							°C
T_J	Operating Junction Temperature	-55 to +150							°C

*These ratings are limiting values above which the serviceability of any semiconductor device may be impaired.

Thermal Characteristics

Symbol	Parameter	Value	Units
P_D	Power Dissipation	6.6	W
$R_{\theta JA}$	Thermal Resistance, Junction to Ambient,* per leg	19	°C/W
$R_{\theta JL}$	Thermal Resistance, Junction to Lead,* per leg	4.0	°C/W

*Device mounted on PCB with 0.375 " (9.5 mm) lead length and 0.5 x 0.5" (13 x 13 mm) copper pads.

Electrical Characteristics

T_A = 25°C unless otherwise noted

Symbol	Parameter	Device	Units
V_F	Forward Voltage, per bridge @ 4.0 A	1.0	V
I_R	Reverse Current, total bridge @ rated V_R T_A = 25°C T_A = 100°C	5.0 500	µA µA

Connection Design

3-PIN CONNECTOR W/HEADER, .156

Larger Picture Available

3 pins. 0.156" spacing.
CAT# CON-233

Your Price: $1.20 each

In stock, ships within 24-48 hours.

1 Purchase

Connects boards that don't shut off.

5 PIN CONNECTOR W/HEADER, .156

Larger Picture Available

5 pins. 0.156" spacing.
CAT# CON-235

Your Price: $1.95 each

In stock, ships within 24-48 hours.

Connects to boards that shut off**.**

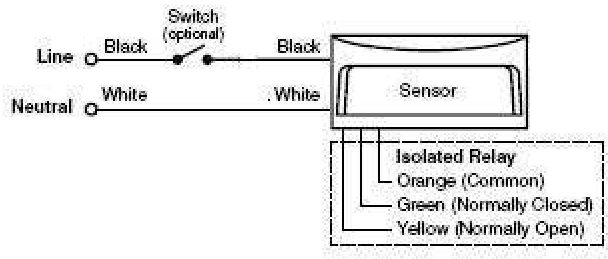
Advantages:

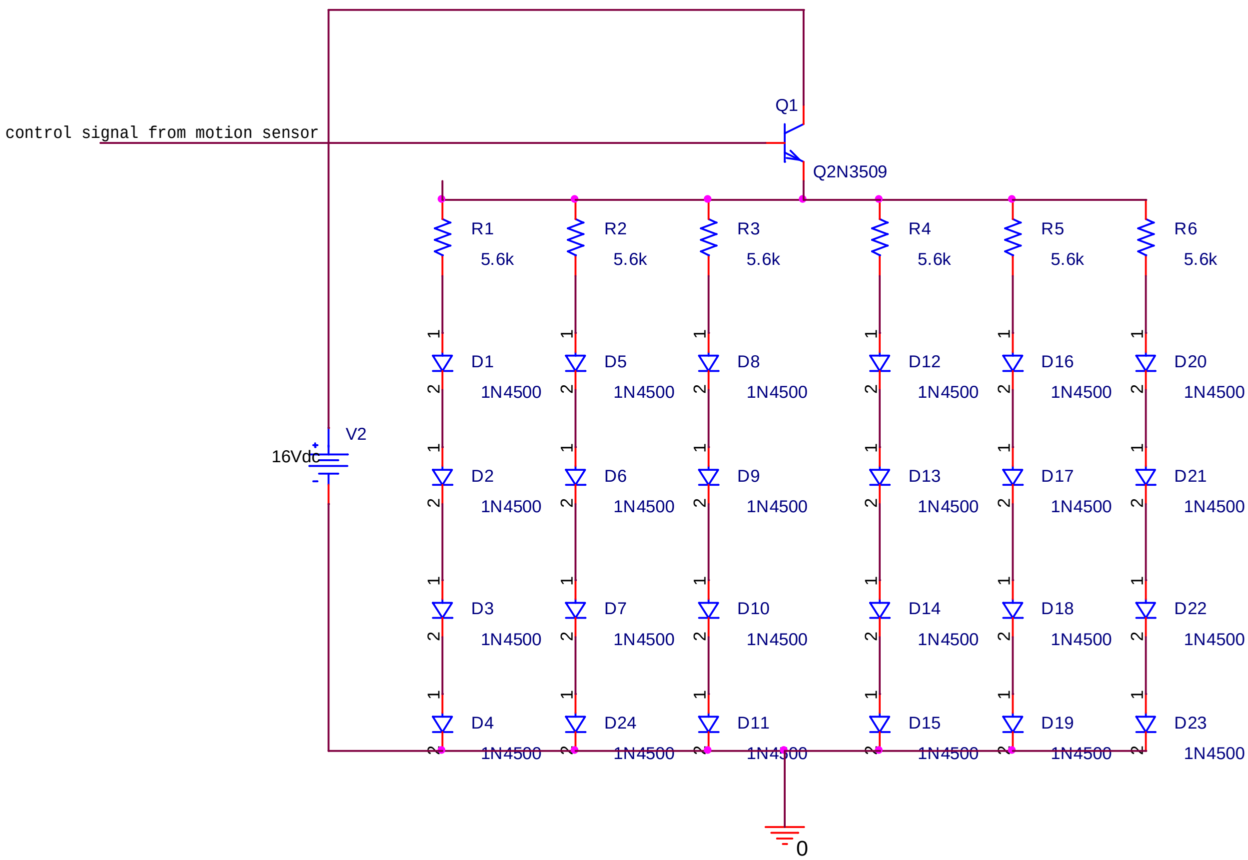
a. Fairly inexpensive.
b. Quick and easy to connect.

Disadvantages:

a. No screw holes.
b. Need 4 connecters per fixture.
c. Need 4 wire connector for dimming switch

Sensor Design





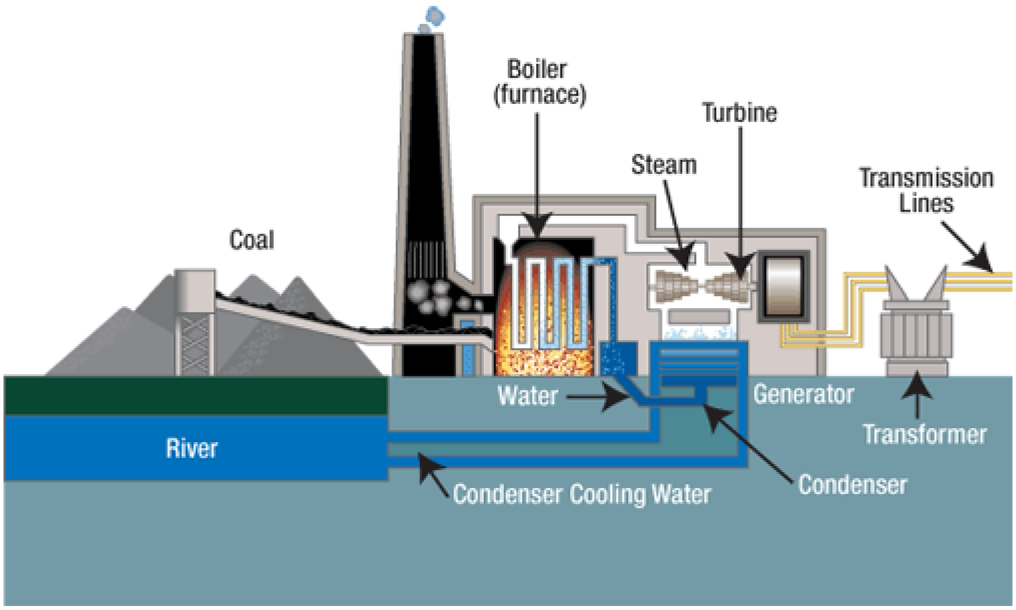
Advantages:

a. Motion sensors will lead to energy savings with potential decreased light output when area has low activity.
b. Uses existing photoeye zone.

Disadvantages:

a. Each individual motion sensor must be installed and replaced directly.
b. Failure may lead to dead spots in detection area.

Power Supply



Courtesy of Tennessee Valley Authority www.tva.gov

Advantages:

a. Uses readily available electricity with no additional setup.
b. No external parts that may fail or break.

Disadvantages:

a. Not as environmentally friendly as solar/thermo-electric/wind.
b. Susceptible to rising energy costs.

Energy Cost Comparisons

*calculations per fixture

Materials, Costs, and Usage

LED Materials

Description	Price/Part	Quantity	Subtotal
Sheet Metal	$30.00	1	$30.00
Boards	$60.00	4	$240.00
Replacement Boards	$20.00	4	$80.00
Resistors	$0.40	24	$9.60
Mechanical Connectors	$0.10	16	$1.60
Electrical Connectors	$2.00	4	$8.00
Fasteners	$0.05	4	$0.20
Sensing Device	$10.00	1	$10.00
Switching Device	$4.00	1	$4.00
Bridge Rectifier	$4.00	1	$4.00
LEDs	$4.00	96	$384.00

Metal Halide Materials

Description	Price/Part	Quantity	Subtotal
Metal Halide Lamp	$30.00	1	$30.00
Ballast	$70.00	1	$70.00

Labor

Description	# employees	Hours	Labor Cost	Subtotal
Replacement	1	1	$26.00	$26.00
Retrofit	1	2	$26.00	$52.00

Hours per day in use	12
Days per year	365
Electricity cost (cents/kw-hr)	0.06

Power (LED System, watts)	96
Power (MH System, watts)	165

LED Cost Calculations

Price per lamp	$473.60
Cost of material to retrofit fixture	$217.80
Labor cost to retrofit (per fixture)	$52.00
Investment to upgrade site	$743.40

Price per lamp	$473.60
Spot relamping labor cost ($ per lamp)	$26.00

Total Replacement Costs	$499.60

Energy Cost Calculations

Energy Cost = (watts*electricity cost *hours/use*days/year)/1000

Total Annual Energy Cost (LED)	$25.23
Total Annual Energy Cost (MH System)	$43.36
Total Annual Energy Savings	$18.13

Simple Payback on Energy Savings

P = I/A

P	payback period (years)	**41.00**
I	incremental investment (dollars)	$743.40
A	incremental annual cash flow (savings)	$18.13

Simple Rate of Return on Energy Savings

ROR = A/I

ROR	rate of return	**0.0244**
I	incremental investment (dollars)	$743.40
A	incremental annual cash flow (savings)	$18.13

Simple Cost of Light Analysis

Annual Operating hrs.	4380
Electricity cost (**cents** per kwh)	6

Lamp Information	Existing	Alternate 1
Lamp designation		
No. of fixtures	1	1
No. of lamps per fixture	1	1
Price per lamp ($)	$30.00	$473.60
Lamp rated life	20,000	60,000
Spot relamping labor cost ($ per lamp)	$26.00	$26.00
Ballast Information		
Ballast description		
No. of ballasts per fixture	1	0
Price per ballast ($)	$70.00	$0.00
Input watts per fixture	165	96
Cost of material to retrofit fixture	0	$217.80
Labor cost to retrofit (per fixture)		$52.00
Investment Calculation		
Total no. of lamps at site	1	1
Total price of lamps	$30.00	$473.60
Total no. of ballasts at site	1	0
Total price of ballasts	$70.00	$0.00
Total Cost of Material to Retrofit Fixture		$217.80
Total retrofit labor cost		$52.00
Investment to upgrade site		$743.40
Cost Calculation	**Annual Operating Costs**	
Annual electricity costs	$43.36	$25.23
No. of lamps replaced annually	0.2190	0.0730
Annual cost of replacement lamps	$6.57	$34.57
Labor costs for relamping	$5.69	$1.90
Annual cost of light (averaged out)	$55.63	$61.70
Savings Calculation		**Estimated savings from upgrade**
Annual Savings (compared to existing)		**-$6.07**
Payback (years)		**-122.40**
Simple ROI		**-1%**
Energy $ saved per year		$18.13
Energy $ saved over lamp life		$248.40
Life Cycle savings (over 15 yr. system life)		-$91.10

Please Note: This is a simple Cost of Light calculation for estimating purposes only. It uses a "straight line" mortality curve instead of the actual lamp mortality curve and ignores impact on A/C systems, environmental savings, benefits of group relamping and other quality of light considerations. Please consult GE's Value*Light software for a comprehensive analysis.

References

Metal Halide Reference	LED Reference	Ballast Reference
150 W Metal Halide Bulb	1 W Natural White LED	150 W Metal Halide Ballast Kit
prolighting.com	mouser.com	prolighting.com
MCH150-U-M-4K	889-S11190	MH-150-QUAD

http://www.gelighting.com/na/business_lighting/lighting_applications/pop_formulas.htm
http://www.westcoastlighting.com

Testing

Reliability tests:

1. Drop Test – Fixture dropped from different heights to simulate impacts
2. Climatic conditioning Test – Temperature, Humidity
3. Corrosion Testing – Salt spray
4. Accelerated Lifetime test (Board and LED's)
5. Vibrations testing – ASTME testing method

Performance Tests:

1. Power Consumption – Record current and voltage over a length of time
2. Light pollution – "Brightness" or Luminance = Illuminance*%reflectance
3. Replacement time of LED units – Time required to replace LED units safety
4. Light spread (density) – Light meter
5. Ease of Installation – Time required and ergonomic issues
6. Aesthetically pleasing – Survey with a scale of 1-5 where 5 is best

<u>Concerns/Issues & Risks</u>

1. Ability to model LED light.

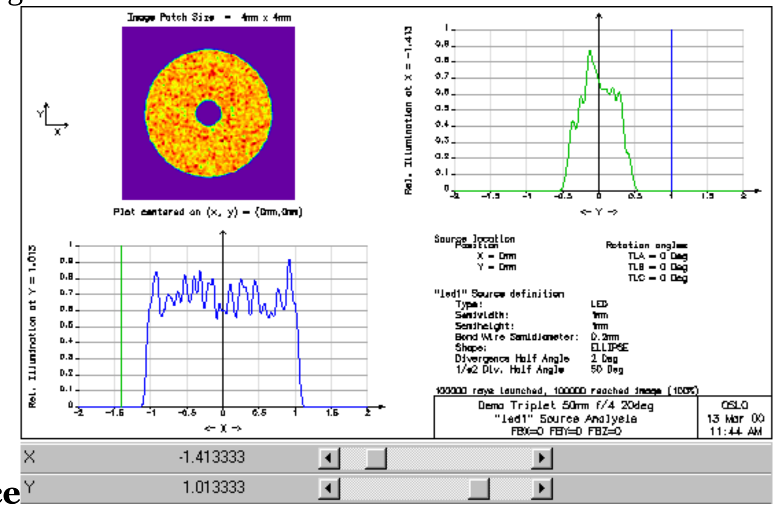


Image of a LED source

2. LED viewing angles. Testing is needed to optimize the selection of viewing angles.

3. Applying heat to LED's changed appearance of the LED's.

4. Displacement of the light due to refraction.

Next Steps

1. Finalize drawings and Schematics:
   - **a.** Fixture and circuit board implementation
   - **b.** Power conditioning circuit design
   - **c.** Sensing circuits
   - **d.** Modeling light to find optimum system

2. Benchmark LED prototype board
3. Preliminary Test plan
4. Identify all long lead time order items

Notes