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Energy Use Comparison of Fluorescent Fixtures with Standard Ballasts and Daylight Harvesting Ballasts

Prepared for

Kentucky Office of Energy Policy
Jefferson County Public Schools

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UNIVERSITY of LOUISVILLE

TABLE OF CONTENTS

EXECUTIVE SUMMARY

The Kentucky Pollution Prevention Center (KPPC) performed testing of daylight harvesting (DH) ballasts as part of the Technology Diffusion Initiative (TDI). The purpose of TDI is to help the Commonwealth of Kentucky adopt energy efficiency (E2) solutions that are commercially available but have not achieved widespread market penetration. Organizations need pilot demonstrations of technologies and technology education assistance to create E2 technology awareness and promote understanding of technical principles. Funds from the E2 and Bio-based Product Outreach Demonstration Project grant provided by the Kentucky Office of Energy Policy (KOEP) were used to complete this project.

A DH ballast is a special type of electronic dimming ballast in fluorescent fixtures that adjusts the light output from lamps depending on the daylight that enters the room through windows and skylights. Use of DH ballasts can result in energy and cost savings. A standard ballast is an ordinary ballast that does not have this feature.

KPPC conducted tests at the following three locations of Jefferson County Public Schools (JCPS):

1. Coleridge Taylor Montessori Elementary School (Coleridge Taylor)-Library
2. Coleridge Taylor-Stairwell
3. Whitney Young Elementary School (Whitney Young)-Library

These locations were retrofitted from standard ballasts to DH ballasts and where necessary, lamps were also changed. These locations were selected due to an abundance of natural light in the areas. At Coleridge Taylor-Library, fluorescent fixtures using four T12, 34W lamps were replaced with two T8, 32W lamps with DH ballasts. At Coleridge Taylor-Stairwell, fluorescent fixtures using two T12, 34W lamps were replaced with two T8, 32W lamps with a DH ballast reduced to 40% light output. At Whitney Young-Library, where the existing lighting was fluorescent fixtures with four T8, 32W lamps, the ballasts were the only component replaced. The lighting level in this library was intentionally reduced to 40% of the previous level using dip-switches on the new ballasts, because this library was illuminated much more than the recommended level of 50 footcandles.

The energy consumption of the DH ballasts and standard ballasts were measured using clamp-on data loggers. Light levels at the workspace were also collected to ensure that Illuminating Engineering Society of North America's (IESNA) standard for schools of 50 footcandles was met at all times, independent of outside light conditions. For the libraries, measurements were collected on 11 days at Coleridge Taylor, 12 days at Whitney Young. For lights in the stairwell of Coleridge Taylor, measurements were taken for only two days on August 3rd and 5th in the afternoon..

The energy savings are based on 200 school days/year for 8 hrs/day for the libraries and 365 days/year for 12 hrs/day for stairwells. The cost savings are based on an average electric cost of $0.06381/kWh for Coleridge Taylor (General Service) and $0.02417/kWh for energy and $11.14/kW for demand (Large Commercial Secondary) for Whitney Young.

For a typical school, if 100 four-lamp T8 fixtures with standard ballasts were replaced with DH ballasts, energy savings of **9,300 kWh/yr** can be achieved with a reduction in emissions of **8.8 tons of carbon-dioxide, 0.16 pounds of methane and 0.27 pounds of NOx.**

Table 1 shows a summary of savings measured. **Table 2** gives an analysis of the payback for each location, defined as the time required for the energy cost savings to pay for the cost of the project. The tables show that though the energy savings are impressive for classrooms where the lights are only in use 8 hours of the day, the cost per fixture must be reduced in order to have a reasonable payback. KPPC therefore recommends that DH ballasts for classrooms be considered primarily for new construction, where additional cost per fixture will be $25 to $30. The payback for a new construction could be as low as **5.4 years** as discussed in **Section 6**. Thus, this technology is recommended for new construction or facility that has higher annual hours of operation. In the stairwells, the payback time is lowest due to the increase in operating hours of the ballasts.

Table 1: Summary of Energy and Energy Cost Saving

Location	Energy Savings (kWh/yr)	Energy Cost Savings ($/yr)	Demand Savings (kW/yr)	Demand Cost Savings ($/yr)	% Energy Savings
Coleridge Taylor - Library (12 fixtures)	1,074	$69	-	-	52.4%
Coleridge Taylor – Stairwell (16 fixtures)	3,041	$194	-	-	36.5%
Whitney Young – Library (16 fixtures)	1,782	$43	9*	$100	55%

* Demand Savings is estimated based on lowest energy savings of 1,264 kW/yr on August 18, 2005.

Table 2: Simple Payback for Project

Location	Cost Savings ($/yr)	Implement-ation Cost ($)	Cost per Fixture ($)	Simple Payback (yrs)
Coleridge Taylor - Library (12 fixtures)	$69	$984	$82	14.3
Coleridge Taylor – Stairwell (16 fixtures)	$194	$1,312	$82	6.8
Whitney Young – Library (16 fixtures)	$143	$1,407	$88	9.8

1.0 INTRODUCTION

The Kentucky Pollution Prevention Center (KPPC) performed testing of daylight harvesting (DH) ballasts as part of the Technology Diffusion Initiative (TDI). The purpose of TDI is to help the Commonwealth of Kentucky adopt energy efficiency (E2) solutions that are commercially available but have not achieved widespread market penetration. Organizations need pilot demonstrations of technologies and technology education assistance to create E2 technology awareness and promote understanding of technical principles. Funds from the E2 and Bio-based Product Outreach Demonstration Project grant were used to complete this project.

KPPC would like to thank Mr. Mike Mulheirn, Director of Facilities and Transportation and Mr. Kevin Stoltz, Energy Auditor, with Jefferson County Public Schools (JCPS) for providing KPPC their continued support and assistance during the completion of this project.

A daylight harvesting (DH) ballast is a special type of electronic dimming ballast in fluorescent fixtures that adjusts the light output from lamps depending on the daylight that enters the room through windows and skylights. Use of DH ballasts can result in energy and cost savings. The ballast adjusts lighting power automatically to maintain the present minimum light level while using as much daylight as possible.

KPPC conducted tests at the following three locations of JCPS:

1. Coleridge Taylor Montessori Elementary School (Coleridge Taylor)-Library
2. Coleridge Taylor-Stairwells
3. Whitney Young Elementary School (Whitney Young)-Library

These locations were retrofitted from standard ballasts to DH ballasts and where necessary lamps were changed. These locations were selected due to an abundance of natural light in the areas.

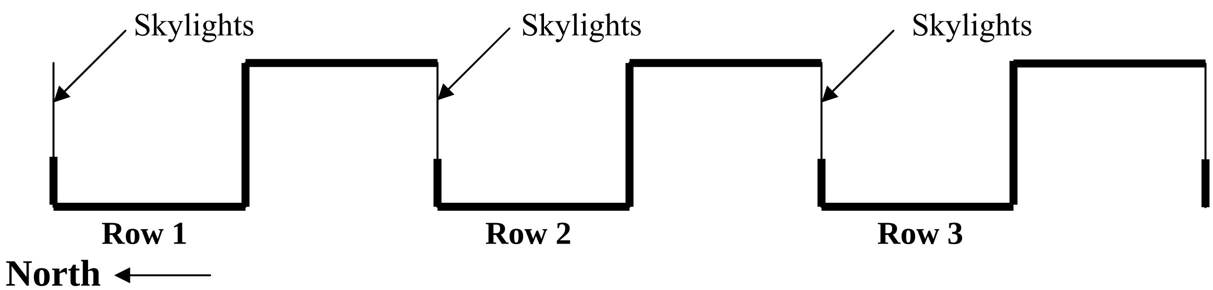
Each ballast consists of a dip switch that can be adjusted manually to allow the light output to be tuned more precisely to the room’s light level. The dip switch can be set to 100% through 40% light output levels in decrements of 10%. This setting dictates the maximum light output from the lamp. Also, a photosensor on each ballast further dims the lamp if outside light entering the room meets the lighting needs. This allows luminaries near the daylight source to dim more than luminaries deeper in the room, and vice-versa. The advantage of this over a single ambient light control photosensor is that the latter must compromise to balance the room dimming levels and may not achieve maximum savings available.

2.0 BACKGROUND

After examining six schools, the libraries of Coleridge Taylor and Whitney Young were identified as potential places for the installation of DH ballasts. The libraries have a similar type of construction. There are four rows of vertical skylights on the roof facing north-south direction. The light levels at workspace height without fluorescent fixtures being turned on ranged from 100 to 120 footcandles during a bright afternoon on mid-June day. The daylight entering the libraries was diffused sunlight and therefore produced no glaring.

Figure 1 gives a schematic front view of the skylights and fluorescent fixtures. At the Coleridge Taylor library, there are three rows of fluorescent fixtures. Each row had six fluorescent fixtures with four 34W, T12 lamps in each fixture. The north row, middle row and south row are numbered 1, 2 and 3 respectively. At the Whitney Young library, each of the three rows had eight fluorescent fixtures with four 32W, T8 lamps in each fixture. There are four stairwells at Coleridge Taylor that have large windows facing north and south. Each stairwell had four 2-lamp 34W, T12 fixtures. Thus, the stairwells have a total of 16 fixtures.

Figure 1: Schematic Setup of Skylights in Libraries



At Coleridge Taylor, 12 fixtures on Rows 1 and 3 were replaced with DH ballasts and two 32W, T8 lamps. The dip switch on the ballasts was set to 100% light output since the fixtures are already delamped from a 4-lamp to 2-lamp fixture. At Whitney Young, for Rows 1 and 3, 16 standard ballasts were replaced with DH ballast, but the dip switch was set to 40% light output. Row 2 at both schools was left alone to compare the performance of daylight harvesting ballast with the existing standard ballasts.

In order to estimate the savings for new construction, a comparison was made between standard T8 ballast and DH ballast set to 100% output level. This was done on February 17, 2006, in the afternoon at Whitney Young. The measured power consumption of the fixture with DH ballast set to 100% light output is about 59W. The measured average power consumption of standard T8 ballast is about 117W. Thus, the estimated energy savings is about **49.6%.**

3.0 DATA ACQUISITION

3.1 Testing Equipment

KPPC measured the current input with the SUPCO LOGIT LCV (LCV) data logger. The LCV data logger is an instrument for recording root mean square (RMS) AC current and voltage. Since the voltage is a known constant of 120 volts for all ballasts, it was not measured. RMS AC current is sampled using a clamp probe that measures the magnitude of the magnetic field generated within the clamp probe. This data is recorded in a data logger to give variation of current with respect to time in the form of a graph. This data can later be retrieved and saved onto a computer for further analysis using the equipment software. The software also has capabilities to export the data from a text file to Microsoft Excel file. The logger can store up to 21,500 sample data points and can be set to collect samples in a user- selectable time interval of 1 second through 6 hours. The measurable current range is 0 – 300 amps. The accuracy is ±5% full scale reading (FSR) with a resolution of 0.1 amps. The operating temperature range is 32ºF to 140ºF.

The light levels were recorded at the workspace by Mannix Digital Light Meter. All light measurements were taken with a limiting range of 200 footcandles at which the accuracy is ±3%. A footcandle is a measure of light intensity at a point defined at a distance from the light source as given below:

$$FC = Lumens/Area$$

Where:

FC = light intensity in footcandles
Lumens = unit of light

For libraries, according to IESNA, the minimum light level that needs to be met at all times is 50 footcandles at the workspace, which in the case of a classroom is the work desk. Generally the height of work desk is two-and-a-half feet. For stairwells, the light level is about 20 foot-candles.

3.2 Measurements

After the installation in mid July 2005, a series of measurements of amperage and light levels were taken by Sri Iyer (KPPC staff) and engineering co-operative students. Because the energy and energy cost savings are a function of the daylight entering the library and stairwell, a day's worth of measurement is insufficient. In order to account for outside light conditions, KPPC staff qualitatively differentiated days as Bright, Cloudy and Dark/Rainy days. The quality of light in morning may also be considerably different during the afternoon. Thus, two sets of measurements were collected during the morning and afternoon for several days.

The energy consumption of the DH ballasts and standard ballasts was measured using clamp-on data loggers. Light levels at the workspace were also taken to ensure that the IESNA standard for schools of 50 footcandles was met at all times independent of outside light conditions **(See Appendix B)**. For the libraries, measurements were taken on 11 days at Coleridge Taylor, 12 days at Whitney Young and two days for the stairwells from the period of July 2005 to December 2005 as shown in **Table 3**.

Table 3: Measurement Schedule				
Dates	Coleridge Taylor		Whitney Young	
	Morning	Afternoon	Morning	Afternoon
07/23/05			×	×
07/27/05			×	×
07/29/05	×	×		
08/03/05	×	×	×	×
08/04/05	×	×	×	×
08/05/05	×	×	×	×
08/15/05	×	×	×	
08/16/05	×	×	×	×
08/18/05	×		×	
10/06/05				×
10/14/05		×		
10/17/05		×		×
10/24/05				×
11/08/05		×		×
12/19/05		×		

3.2.1 Light Level Measurement

The lights were initially switched off, and light levels were measured at workspace height. KPPC walked along the length of rows from one end of the library to the other end to cover the entire library. This measurement gives the light intensity only due to the daylight. These light levels at different areas were then averaged to get a light level that represents the entire library. This was then compared with the light levels with the lights on in this area. The lights were turned on, while the data loggers were measuring the current used in the fixtures, light levels were measured at workspace height walking along the length of rows and between the rows. The light levels along the rows and between rows were averaged to give the light intensities below each row. This allows light levels of the new DH ballasts from fixtures of Row 1 and 3 to be compared to the existing standard ballasts in fixtures of Row 2.

3.2.2 Amperage Measurement

The amperage was measured two different ways with the LCV data logger. From July through the first week of August, measurements were taken right at the fixtures. This was done by attaching a data logger on each fixture of the three rows. From the middle of August for the rest of the measurements, after the schools reopened, the data loggers were connected to the circuits in the breaker panel because attaching to the fixtures with children present was considered both dangerous and distracting to children.

In both cases, the LCV data loggers were set to a sampling rate of one reading every 30 seconds and allowed to record readings for about an hour. If the LCV data loggers were allowed to take measurements for at least 50 minutes, 100 data points would be obtained to analyze with the set sampling rate. The one hour's worth of data taken during morning at anytime between 8AM and 12PM and afternoon at anytime between 12PM and 4PM are assumed to be valid for four hours of morning or afternoon. Thus, the energy savings estimated during morning and afternoon were multiplied by four and added together to get the total energy savings for the school hours from 8AM to 4PM.

For lights in the stairwell of Coleridge Taylor, measurements were taken for only two days on August 3rd and 5th in the afternoon. Savings were estimated based on an average 4 lamp T12 power consumption of 119W. Since light level standards are lower for stairwells and breaker panels were not easily accessible, detailed analysis could not be conducted.

4.0 DATA ANALYSIS

4.1 Data Conditioning

KPPC downloaded the data from the LCV data logger for further analysis. All data samples were exported in a Microsoft Excel file for analysis on a daily basis. During this process, the actual amperage data was rounded to the tenth of decimal place. For certain measurements, the amperage remained constant for the entire logging time and in such cases the data was manually entered up to the one-10,000th decimal. In other cases where the amperage varied with respect to time, the data exported was automatically rounded to one-tenth decimal by the logging software. This rounding off is a limiting factor on the capabilities of the software.

4.2 Data Parameters

A Microsoft Excel template file was created to calculate the estimated energy and energy cost savings from the 100 sample points for morning and afternoon, then added to get the total savings on a particular day.

The performance of DH ballasts and standard ballasts were compared with respect to the following parameters.

Light Levels: The light intensity in footcandles available at the work space. This is a measured parameter.

Power Usage: Power consumed by the fluorescent fixture estimated in watts. For example, one watt consumed over a period of one hour gives an energy consumption of one watt-hour.

Footcandles/Watt: Measure of efficacy of light fixture defined at a distance from the light source, estimated by dividing light levels by power consumed. This parameter signifies daylight harvesting capabilities of the ballast.

5.0 RESULTS

5.1 Coleridge Taylor-Library

Tables 4, 5 and **6** give the measured data and estimated parameters that reflect on the performance of DH ballasts in the library on bright days, cloudy days and dark days.

Tables 7,9,11 and **13** give the estimated energy savings for mornings while **Tables 8, 10, 12 and 14** give the estimated energy savings for afternoons.

Figures 2 and **Figure 3** show the energy savings in kWh/yr. Energy savings ranged from about **1,394 kWh/yr** in August 2005 to **555 kWh/yr** in December 2005. Average energy savings is about **1,154 kWh/yr**, **919 kWh/yr** and **1,064 kWh/yr** for bright, cloudy and dark days respectively. For sample calculations, see **APPENDIX A**. Since the classification of a day is only qualitative and the amount of sunlight entering the library varies with respect to time, the anomalous result can be justified. Although a day could be very bright, measurements could have been taken when clouds passed over, or vice-versa on a cloudy day taking measurements during a break in the clouds. If time permitted, additional measurements for a full year to incorporate all seasonal changes would have been ideal. For schools in this study, an average of 8 hours/day of daylight is assumed, which is reasonable.

Figures 4 and **5** show the average percentage energy savings from installing daylight harvesting ballasts compared to the standard lighting and ballasts. The highest energy savings of **62%** was obtained in July 2005 with the lowest of **32%** in December 2005. As shown in **Figure 5**, bright days had an energy savings of **54%** while cloudy days had a energy savings of **48%.** Contrary to expectations, the average savings on dark days were more than cloudy days at about **53%.**

Figure 6 shows the average efficacy of the system in the library at Coleridge Taylor. As expected, Row 2 shows a much lower average efficacy of approximately **0.8 fc/Watt**, compared to average efficacy of about **1.38 fc/Watt** for Row 1 and **2.00 fc/Watt** for Row 3. The data does not vary significantly based on the type of day. Row 3 has the highest efficacy because the skylights above Row 3 are unobstructed to sunlight compared to other skylights that are blocked by the rows to the south of them (**See Figure 1**).

The calculated savings, separated into morning and afternoon, in **Figure 7** and **Figure 8**. **Tables 13** and **14** show that savings range from **525 kWh/yr** for dark days to **608 kWh/yr** for bright days in mornings and **461 kWh/yr** for cloudy days to **577 kWh/yr** for bright days in the afternoons.

Table 4: Bright Day Averages

Date	Energy Savings (kWh/yr)	Energy Savings (%)	Row 1 Efficacy (fc/W)	Row 2 Efficacy (fc/W)	Row 3 Efficacy (fc/W)	Average Efficacy Difference (fc/W)
7/29/05	1,367	61.9	1.9	0.9	2.8	1.4
8/3/05	1,051	47.6	1.5	0.9	1.8	0.7
8/4/05	1,394	61.1	2.0	0.8	2.5	1.5
8/5/05	1,053	50.1	1.4	0.8	1.7	0.7
10/14/05	1,114	56.6	0.9	0.6	2.0	0.9
10/17/05	946	48.9	0.9	0.7	1.7	0.6
Average	**1,154**	**54.4**	**1.4**	**0.8**	**2.1**	**1.0**

Table 5: Cloudy Day Averages						
Date	Energy Savings (kWh/yr)	Energy Savings (%)	Row 1 Efficacy (fc/W)	Row 2 Efficacy (fc/W)	Row 3 Efficacy (fc/W)	Average Efficacy Difference (fc/W)
8/15/05	1,073	54.6	1.8	1.0	2.8	1.4
11/8/05	1,130	57.5	1.4	0.7	1.7	0.7
12/19/05	555	32.2	0.7	0.6	0.9	1.5
Average	**919**	**48.1**	**1.3**	**0.8**	**1.8**	**1.2**

Table 6: Dark Day Averages						
Date	Energy Savings (kWh/yr)	Energy Savings (%)	Row 1 Efficacy (fc/W)	Row 2 Efficacy (fc/W)	Row 3 Efficacy (fc/W)	Average Efficacy Difference (fc/W)
8/16/05	1,086	53.6	1.5	0.9	2.0	1.4
8/18/05	1,042	52.4	1.1	0.9	2.0	0.7
Average	**1,064**	**53.0**	**1.3**	**0.9**	**2.0**	**1.1**

5.2 Coleridge Taylor-Stairwells

For the stairwells, over the two days measured, the average power consumed by 8 fixtures was 129W. The power consumption, had it been a standard T12 fixture, is estimated to be 476W. Thus, the power savings of 347W for a 12-hour day and a 200-day school year is about **3,041 kWh/yr,** or a **72.9%** savings over standard T12 fixtures

Coleridge Taylor Morning Data

Table 7: Bright Day		
Date	Energy Savings (kWh/yr)	Energy Savings (%)
7/29/05	758	66.8
8/3/05	562	49.9
8/4/05	725	63.6
8/5/05	387	40.4
10/14/05	N/A	N/A
10/17/05	N/A	N/A

Table 9: Cloudy Day		
Date	Energy Savings (kWh/yr)	Energy Savings (%)
8/15/05	533	54.3
11/8/05	N/A	N/A
12/19/05	N/A	N/A

Table 11: Dark Day		
Date	Energy Savings (kWh/yr)	Energy Savings (%)
8/16/05	529	52.9
8/18/05	521	52.4

Table 13: Averages		
Type of Day	Energy Savings (kWh/yr)	Energy Savings (%)
Bright Day	608	55.1
Cloudy Day	533	54.3
Dark Day	525	52.7

Coleridge Taylor Afternoon Data

Table 8: Bright Day		
Date	Energy Savings (kWh/yr)	Energy Savings (%)
7/29/05	609	56.8
8/3/05	489	45.1
8/4/05	670	58.7
8/5/05	666	58.3
10/14/05	557	56.6
10/17/05	473	48.9

Table 10: Cloudy Day		
Date	Energy Savings (kWh/yr)	Energy Savings (%)
8/15/05	540	55.0
11/8/05	565	57.5
12/19/05	278	32.2

Table 12: Dark Day		
Date	Energy Savings (kWh/yr)	Energy Savings (%)
8/16/05	557	54.4
8/18/05	N/A	N/A

Table 14: Averages		
Type of Day	Energy Savings (kWh/yr)	Energy Savings (%)
Bright Day	577	54.1
Cloudy Day	461	48.2
Dark Day	557	54.4

Figure 2:
Coleridge Taylor Energy Savings (kWh/yr)

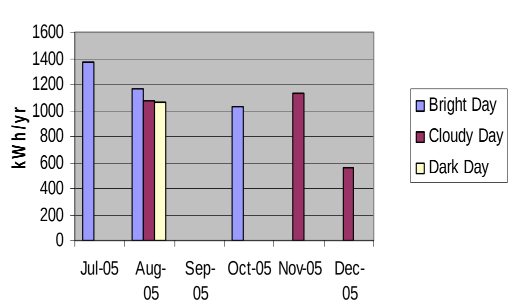
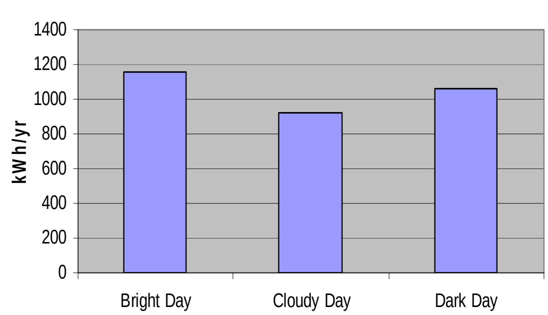


Figure 3:
Coleridge Taylor Energy Savings (kWh/yr)



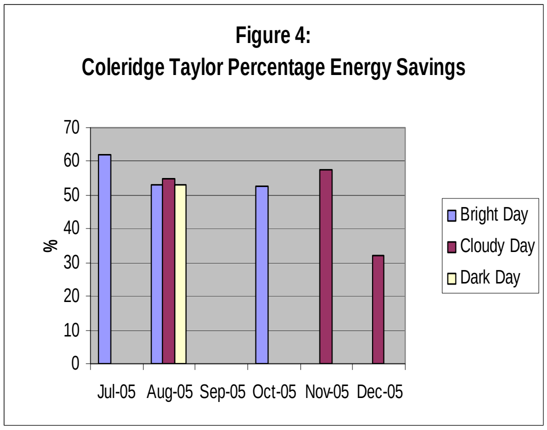


Figure 4:
Coleridge Taylor Percentage Energy Savings
%
Jul-05 Aug-05 Sep-05 Oct-05 Nov-05 Dec-05
Bright Day
Cloudy Day
Dark Day

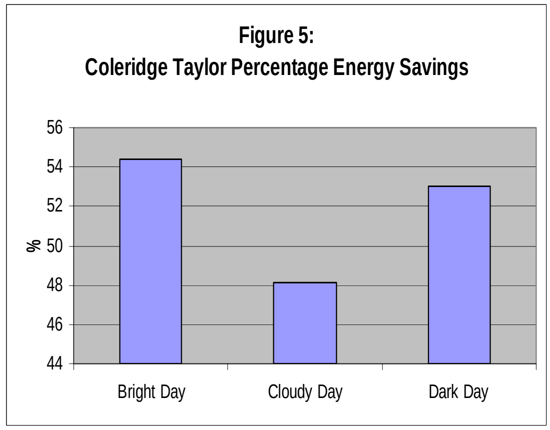


Figure 5:
Coleridge Taylor Percentage Energy Savings
%
Bright Day
Cloudy Day
Dark Day

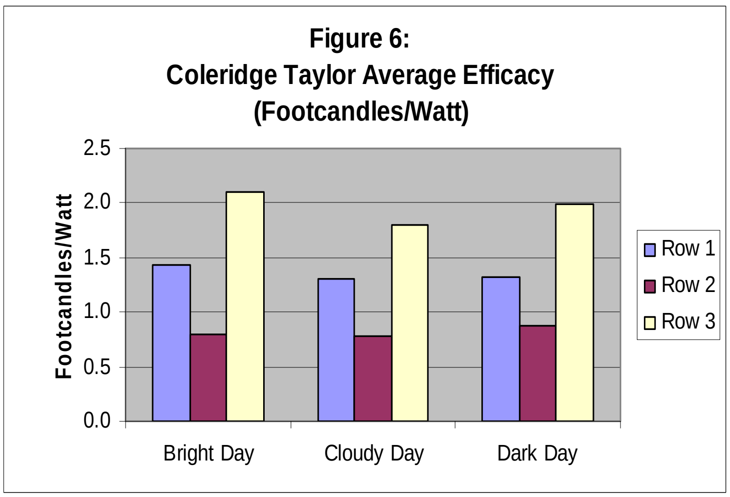


Figure 6:
Coleridge Taylor Average Efficacy
(Footcandles/Watt)
Footcandles/Watt
Bright Day
Cloudy Day
Dark Day
Row 1
Row 2
Row 3

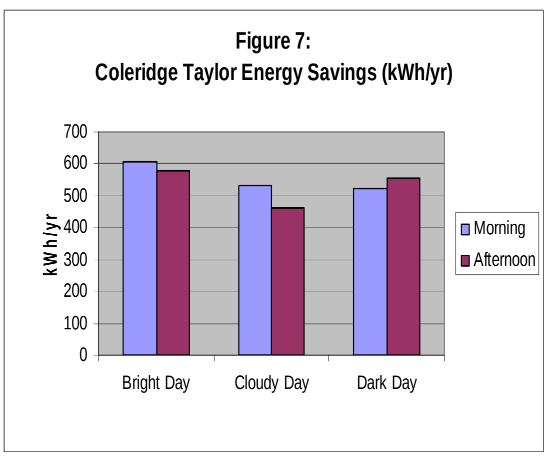


Figure 7:
Coleridge Taylor Energy Savings (kWh/yr)
kWh/yr
Bright Day
Cloudy Day
Dark Day
Morning
Afternoon

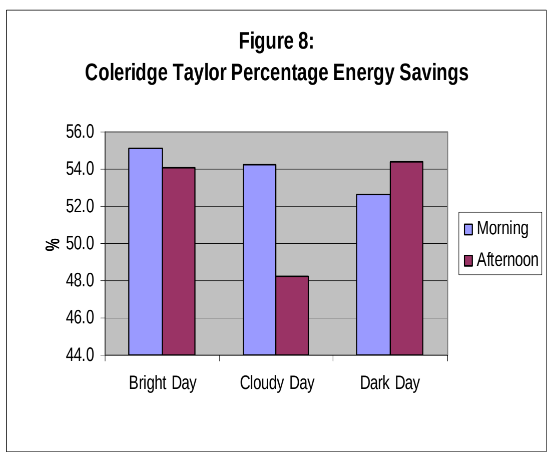


Figure 8:
Coleridge Taylor Percentage Energy Savings
%
Bright Day
Cloudy Day
Dark Day
Morning
Afternoon

5.3 Whitney Young-Library

Tables 15, 16and **17** give the measured data and estimated parameters that reflect the performance of DH ballasts in the library on bright days, cloudy days and dark days. **Tables 18, 20, 22** and **24** give the estimated energy savings for mornings while **Tables 19, 21, 23 and 25** give the estimated energy savings for afternoons.

Savings over the course of the project as shown in **Figure 9** are fairly constant, showing a very slight, steady rise in savings from July to November 2005. This could be attributed to lower elevation angles of sun during winter, thus, resulting in more light entering through the skylights. It should however be noted that the daylight decreases during winter, therefore the overall energy savings per year will be lower in a typical building. For schools in this study, an average of 8 hours/day of daylight is assumed, which is reasonable.

A high of **2,310 kWh/yr** was reached in August 2005 and a low of **1,264 kWh/yr** for the dark days in August 2005. **Figure 10** shows average energy savings from bright days of **1,856 kWh/yr**, to cloudy days of **1,892 kWh/yr**, to dark days of **1,342 kWh/yr**. The high and low percentage energy savings occur at the same time as the energy savings in kWh/yr, with a high in November 2005 of **67%** and a low of **42%** in August 2005 as shown in **Figure 11**. The average percentage savings is highest on a cloudy day at **60%** as shown in **Figure 12**. **Figure 13** gives the average efficacy for three rows for different types of day while **Figure 14** and **Figure 15** give the average energy savings and average percentage energy savings for rows 1 and 2 during different types of the day. For calculations, see **APPENDIX A**.

Table 15: Bright Day Averages

Date	Energy Savings (kWh/yr)	Energy Savings (%)	Row 1 Efficacy (fc/W)	Row 2 Efficacy (fc/W)	Row 3 Efficacy (fc/W)	Average Efficacy Difference (fc/W)
7/23/05	1,634	54.4	1.8	0.8	1.3	0.8
8/3/05	1,393	47.4	1.6	1.0	1.7	0.7
8/4/05	2,310	60.2	1.8	0.8	1.7	0.9
8/5/05	2,069	58.2	1.8	0.8	1.6	0.9
10/6/05	1,904	57.5	1.3	0.7	1.2	0.6
10/17/05	1,827	55.2	1.0	0.6	1.0	0.4
Average	**1,856**	**55.5**	**1.5**	**0.8**	**1.4**	**0.7**

Table 16: Cloudy Day Averages

Date	Energy Savings (kWh/yr)	Energy Savings (%)	Row 1 Efficacy (fc/W)	Row 2 Efficacy (fc/W)	Row 3 Efficacy (fc/W)	Average Efficacy Difference (fc/W)
7/27/05	1,595	53.2	1.8	1.1	2.2	0.8
8/15/05	1,606	53.5	2.0	1.0	1.9	0.9
10/24/05	2,166	66.1	1.4	0.6	1.7	1.0
11/8/05	2,198	67.1	1.2	0.5	1.0	0.6
Average	**1,892**	**60.0**	**1.6**	**0.8**	**1.7**	**0.8**

Table 17: Dark Day Averages						
Date	Energy Savings (kWh/yr)	Energy Savings (%)	Row 1 Efficacy (fc/W)	Row 2 Efficacy (fc/W)	Row 3 Efficacy (fc/W)	Average Efficacy Difference (fc/W)
8/16/05	1,421	45.3	1.1	0.7	1.2	0.4
8/18/05	1,264	42.1	1.0	0.7	1.1	0.3
Average	**1,342**	**43.7**	**1.1**	**0.7**	**1.1**	**0.4**

Whitney Young Morning Data

Table 18: Bright Day		
Date	Energy Savings (kWh/yr)	Energy Savings (%)
7/23/05	851	56.7
8/3/05	734	49.2
8/4/05	1,049	57.8
8/5/05	1,022	57.48
10/6/05	N/A	N/A
10/17/05	N/A	N/A

Table 20: Cloudy Day		
Date	Energy Savings (kWh/yr)	Energy Savings (%)
7/27/05	748	49.9
8/15/05	803	53.5
10/24/05	N/A	N/A
11/8/05	N/A	N/A

Table 22: Dark Day		
Date	Energy Savings (kWh/yr)	Energy Savings (%)
8/16/05	589	39.2
8/18/05	632	42.1

Table 24: Averages		
Type of Day	Energy Savings (kWh/yr)	Energy Savings (%)
Bright Day	914	55.3
Cloudy Day	776	51.7
Dark Day	610	40.7

Whitney Young Afternoon Data

Table 19: Bright Day		
Date	Energy Savings (kWh/yr)	Energy Savings (%)
7/23/05	782	52.1
8/3/05	658	45.6
8/4/05	1,262	62.4
8/5/05	1,046	58.9
10/6/05	952	57.5
10/17/05	914	55.2

Table 21: Cloudy Day		
Date	Energy Savings (kWh/yr)	Energy Savings (%)
7/27/05	847	56.5
8/15/05	N/A	N/A
10/24/05	1,083	66.1
11/8/05	1,099	67.1

Table 23: Dark Day		
Date	Energy Savings (kWh/yr)	Energy Savings (%)
8/16/05	832	50.8
8/18/05	N/A	N/A

Table 25: Averages		
Type of Day	Energy Savings (kWh/yr)	Energy Savings (%)
Bright Day	936	55.3
Cloudy Day	1,010	63.2
Dark Day	832	50.8

Figure 9:
Whitney Young Energy Savings (kWh/yr)

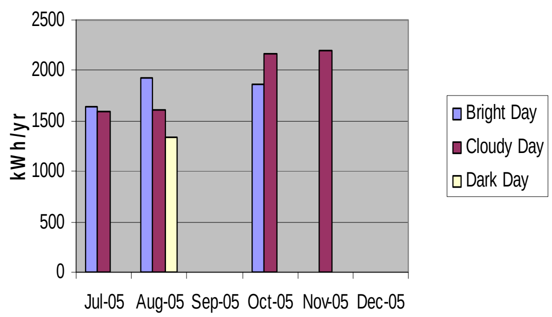


Figure 10:
Whitney Young Energy Savings (kWh/yr)

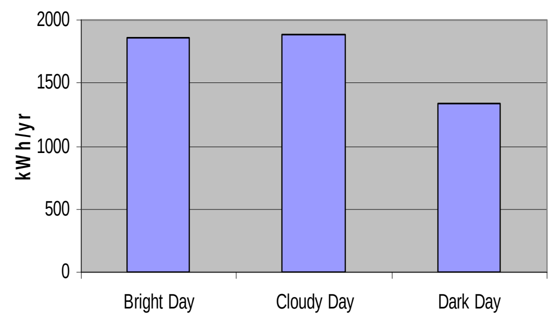


Figure 11:
Whitney Young Percentage Energy Savings

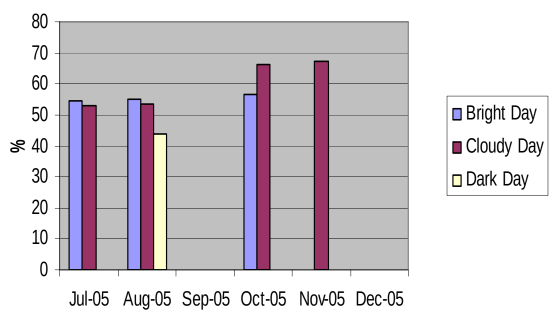


Figure 12:
Whitney Young Percentage Energy Savings

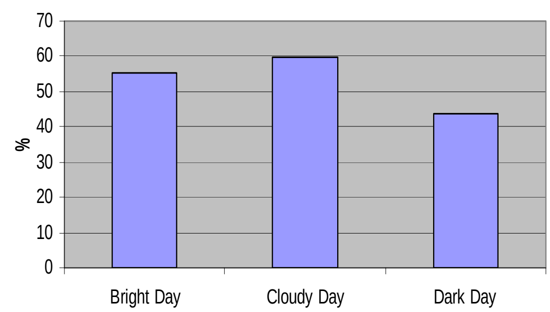
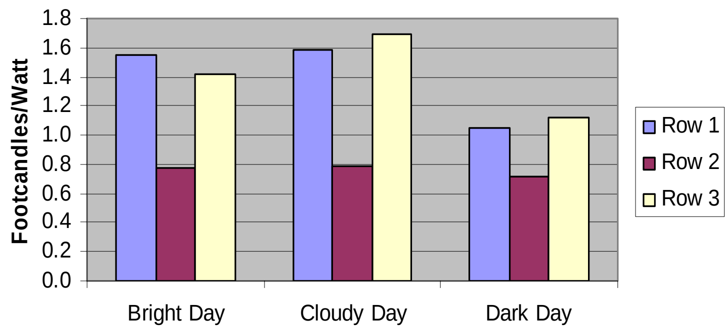
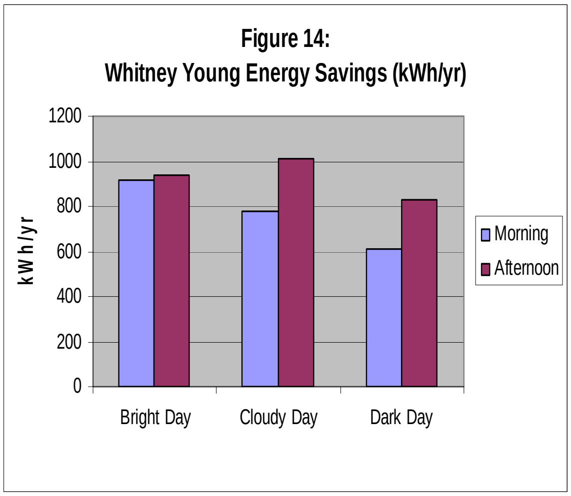
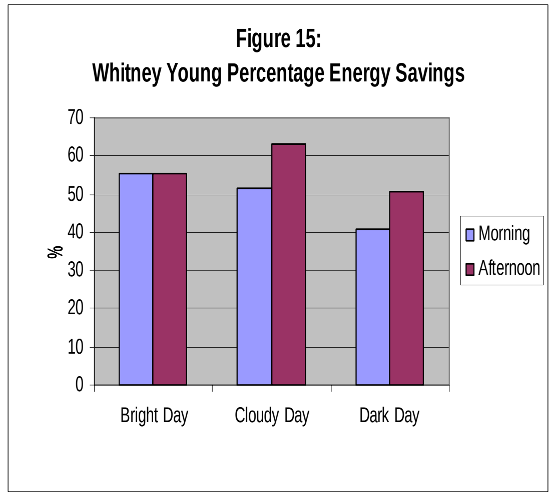


Figure 13:
Whitney Young Average Efficacy
(Footcandles/Watt)







5.4 Overall Result

The energy savings are based on 200 school days/year for 8 hrs/day for the libraries and 365 days/year for 12 hrs/day for stairwells. The cost savings are based on an average electric cost of \$0.06381/kWh for Coleridge Taylor (General Service) and \$0.02417/kWh for energy and \$11.14/kW for demand (Large Commercial Secondary) for Whitney Young.

For a typical school, if 100 four-lamp standard T8 fixtures were replaced with DH ballasts, energy savings of **9,300 kWh/yr** can be achieved with a reduction in emissions of **8.8 tons of carbon-dioxide, 0.16 pounds of methane and 0.27 pounds of NOx.**

Table 26 shows a summary of the resulting savings measured. **Table 27** gives an analysis of the payback for each location, defined as the time required for the energy cost savings to pay for the cost of the project. These two tables show that, though the energy savings are impressive, for classrooms, where the lights are only in use 8 hours of the day, the cost per fixture must be reduced in order to have a reasonable payback. KPPC therefore recommends that DH ballasts for classrooms be considered primarily for new construction, where additional cost per fixture will be \$25 to \$30. The payback for a new construction could be as low as **5.4 years** as discussed in **Section 6**. Thus, this technology is recommended for new construction or facility that has higher annual hours of operation.

In the stairwells, the payback time is lowest due to the increase in operating hours of the ballasts.

Table 26: Summary of Energy and Energy Cost Saving					
Location	Energy Savings (kWh/yr)	Energy Cost Savings ($/yr)	Demand Savings (kW/yr)	Demand Cost Savings ($/yr)	% Energy Savings
Coleridge Taylor - Library (12 fixtures)	1,074	$69	-	-	52.4%
Coleridge Taylor – Stairwells (16 fixtures)	3,041	$194	-	-	36.5%
Whitney Young – Library (16 fixtures)	1,782	$43	9*	$100	55%

* Demand Savings is estimated based on lowest energy savings of 1,264 kW/yr on August 18, 2005.

Table 27: Simple Payback for Project				
Location	Cost Savings ($/yr)	Implement-ation Cost ($)	Cost per Fixture ($)	Simple Payback (yrs)
Coleridge Taylor - Library (12 fixtures)	$69	$984	$82	14.3
Coleridge Taylor – Stairwells (16 fixtures)	$194	$1,312	$82	6.8
Whitney Young – Library (16 fixtures)	$143	$1,407	$88	9.8

6.0 NEW CONSTRUCTION

From **Tables 26** and **27,** though the percentage savings are impressive, due to low annual operating hours in schools, the payback varies from 6.8 to 14.3 years. Thus, KPPC recommends that DH Ballasts be used only for new construction which would achieve lower payback of the order of **5.4 years**. The extra cost incurred would be only the cost differential between the DH ballast and a standard T8 ballast that varies from $25-$30.

In order to estimate the savings for new construction, a comparison was made between standard T8 ballast and DH ballast set to 100% output level. This was done on February 17, 2006, in the afternoon at Whitney Young. The measured power consumption of the fixture with DH ballast set to 100% light output is about 59W. The measured average power consumption of standard T8 ballast is about 117W. Thus, the estimated energy savings is about 93 kWh/yr per fixture (based on operating hours of 8 hours/day and 200 days/year). At an average energy cost of $0.06/kWh (for a typical school), the cost savings is $5.60/yr for each fixture. The cost differential of about $30/fixture would be paid back in about **5.4 years.** The payback for stairwells in schools or other commercial buildings with higher annual operating hours should be lower than five years.

7.0 ENVIRONMENTAL IMPACTS

The following are statistics about greenhouse gas (GHG) emissions for a coal power plant from combustion of coal, assuming a power plant efficiency of 35%:

- One ton of carbondioxide is released by generating 1,060 kWh of electricity
- One ton of methane is released by generating 114 GWh of electricity
- One ton of NO_x is released by generating 68 GWh of electricity

For a typical school, if 100 4-lamp standard T8 fixtures were replaced with DH ballasts, energy savings of **9,300 kWh/yr** can be achieved with a reduction in emissions of **8.8 tons of carbondioxide, 0.16 pounds of methane and 0.27 pounds of NOx.**

Source:

Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2003

8.0 PROBLEMS ENCOUNTERED

Although the DH ballasts are reliable and KPPC did not encounter problems with the operation of the ballasts, two ballasts became non-functional when an attempt was made to remove the lamps from fixtures to change the dip switch settings on the ballast at Whitney Young school. The ballasts were replaced immediately, and the non-functional ballasts have been sent to the laboratory to investigate the cause for this malfunction. Results of the investigation are yet to be received.

9.0 CONCLUSION AND RECOMMENDATION

The energy saving capabilities of the DH ballast is impressive. However as discussed previously, since the payback is longer than most of the other energy efficiency improvement technologies, this technology is recommended for new construction or a facility that has higher annual hours of operation.

Any questions, concerns or information about the project may be forwarded to

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APPENDIX A: SAMPLE CALCULATIONS

The following are the formulas and selected sample calculations for the values shown in the tables and bar graphs on the previous pages.

$$P = V \times I$$

Where:

P = RMS input power in Watts
V = RMS input voltage, 120 Volts
I = measured RMS input current in Amps

$$PS_x = n \times (R_2 - R_x)$$

Where:

PS_x = Average power savings for morning or afternoon of row x, where x designates row 1 or row 3, Watts
n = Number of fixtures per row, 6 for Coleridge Taylor, 8 for Whitney Young
R_2 = Measured average power usage in the morning or afternoon for row 2, Watts
R_x = Measured average power usage in the morning or afternoon for row x, Watts

$$ES = \frac{(PS_1 + PS_3) \times h \times d}{c}$$

Where:

ES = Energy savings, kWh/yr
PS_1 = Average power savings for morning or afternoon for row 1, Watts
PS_3 = Average power savings for morning or afternoon for row 3, Watts
h = Amount of time lights are on, 4 hrs/day for morning session, 4 hrs/day for afternoon session
d = Operating days per year, 200 days/yr
c = Conversion factor, 1000 Watts/kW

$$ES_{Total} = ES_M + ES_{AF}$$

Where:

ES_{Total} = Total energy savings for the entire work day, kWh/yr
ES_M = Energy savings for morning, kWh/yr
ES_{AF} = Energy savings for afternoon, kWh/yr

$$ES_{\%} = \frac{ES}{h \times d \times n \times R_2 / c} \times 100$$

Where:

$ES_{\%}$ = Average energy savings for morning or afternoon session, %
ES = Average energy savings for morning or afternoon session, kWh/yr
c = Conversion factor, 1000 Watts/kW

APPENDIX A: SAMPLE CALCULATIONS (Continued)

$$Eff_x = \frac{FC_x}{R_x}$$

Where:

Eff_x = Average efficacy for row x, fc/Watt
FC_x = Average measured foot-candle level for row x, fc
R_x = Average power usage for row x, Watts

The following example calculation uses the data collected from Coleridge Taylor Elementary on July 29, 2005.

Morning values for Coleridge Taylor, July 29, 2005:

R_1 = 39.36 watts FC_1 = 89 fc
R_2 = 118.32 watts FC_2 = 107 fc
R_3 = 39.36 watts FC_3 = 110 fc

$$PS_1 = 6 \times (118.32 - 39.36) \approx \textbf{474 Watts}$$
$$PS_3 = 6 \times (118.32 - 39.36) \approx \textbf{474 Watts}$$

$$ES_{kWh} = \frac{(474 + 474) \times 4 \times 200}{1000} \approx \textbf{758 kWh/yr}$$

$$ES_{M\%} = \frac{758}{4 \times 200 \times 12 \times 118.32 / 1000} \times 100 \approx \textbf{67\%}$$

$$Eff_1 = \frac{89}{39.36} \approx \textbf{2.26 fc/Watt}$$
$$Eff_2 = \frac{107}{118.32} \approx \textbf{0.90 fc/Watt}$$
$$Eff_3 = \frac{110}{39.36} \approx \textbf{2.79 fc/Watt}$$

Afternoon values for Coleridge Taylor, July 29, 2005:

R_1 = 56.91 watts FC_1 = 91 fc
R_2 = 111.6 watts FC_2 = 107 fc
R_3 = 39.36 watts FC_3 = 112 fc

$$PS_1 = 6 \times (111.6 - 56.91) \approx \textbf{328 Watts}$$
$$PS_3 = 6 \times (111.6 - 39.36) \approx \textbf{433 Watts}$$

$$ES_{kWh} = \frac{(328 + 433) \times 4 \times 200}{1000} \approx \textbf{609 kWh/yr}$$

$$ES_{AF\%} = \frac{609}{4 \times 200 \times 12 \times 111.6 / 1000} \times 100 \approx \textbf{57\%}$$

$$Eff_1 = \frac{91}{56.91} \approx \textbf{1.60 fc/Watt}$$

$$Eff_2 = \frac{107}{111.6} \approx \textbf{0.96 fc/Watt}$$

$$Eff_3 = \frac{112}{39.36} \approx \textbf{2.85 fc/Watt}$$

Total and average values for Coleridge Taylor, July 29, 2005:

$$ES_{Total-kWh} = 758.4 + 608.8 \approx \textbf{1367 kWh/yr}$$

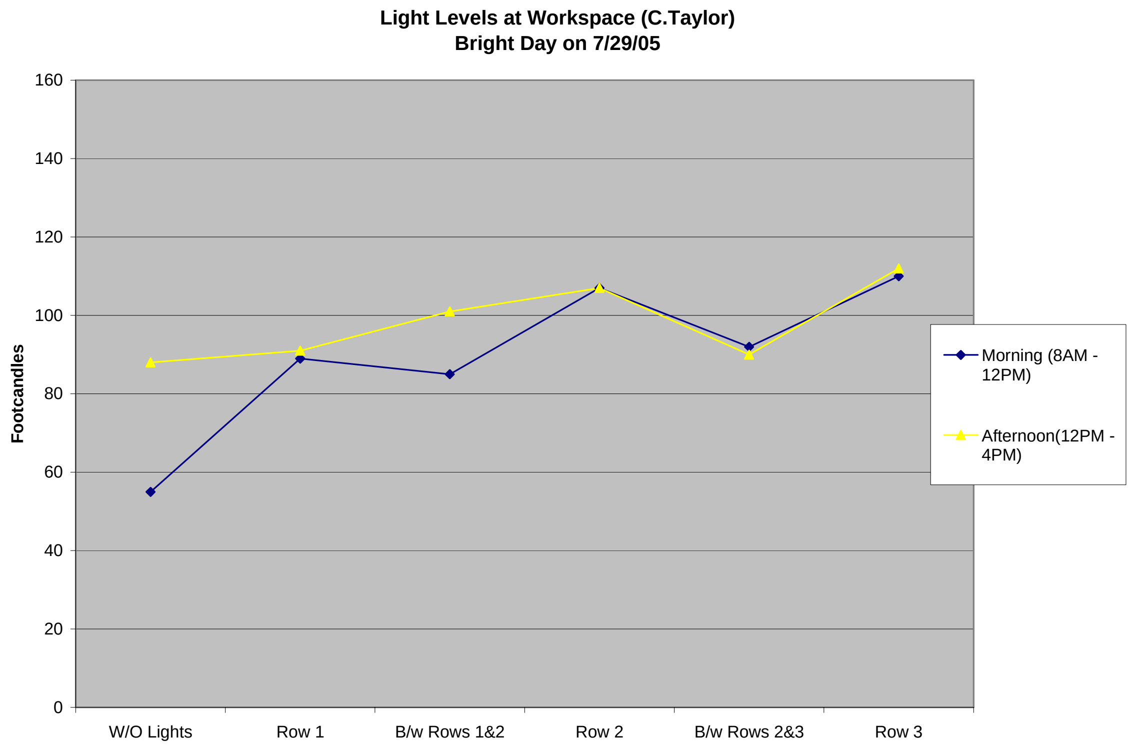
$$ES_{Total\%} = \frac{1367}{8 \times 200 \times 12 \times (\frac{118.32 + 111.6}{2}) / 1000} \times 100 \approx \textbf{62\%}$$

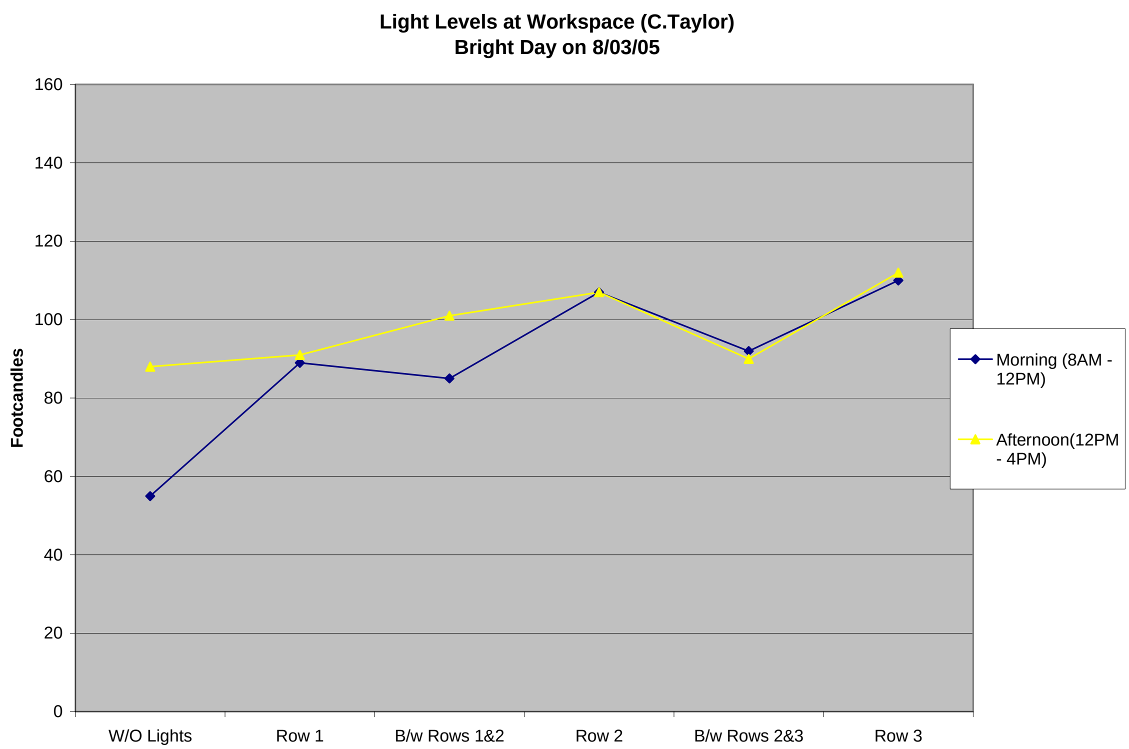
$$Avg\ \ Eff_1 = \frac{2.26 + 1.60}{2} \approx \textbf{1.93 fc/Watt}$$

$$Avg\ \ Eff_2 = \frac{0.90 + 0.96}{2} \approx \textbf{0.93 fc/Watt}$$

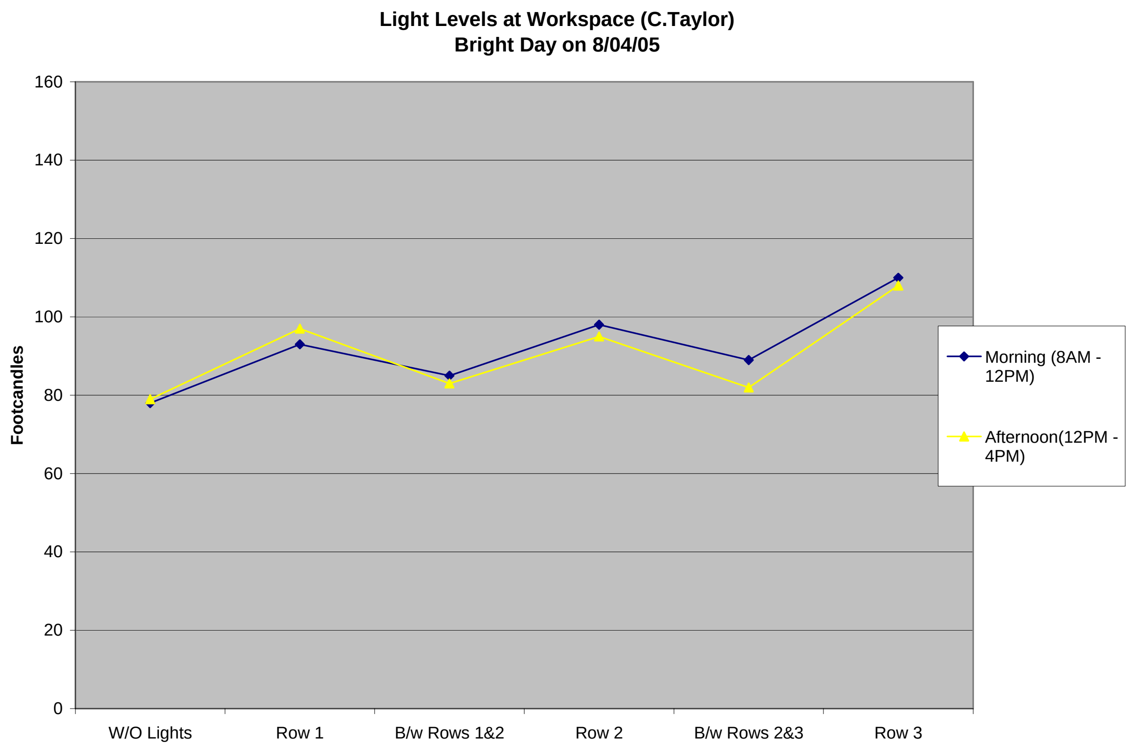
$$Avg\ \ Eff_3 = \frac{2.79 + 2.85}{2} \approx \textbf{2.82 fc/Watt}$$

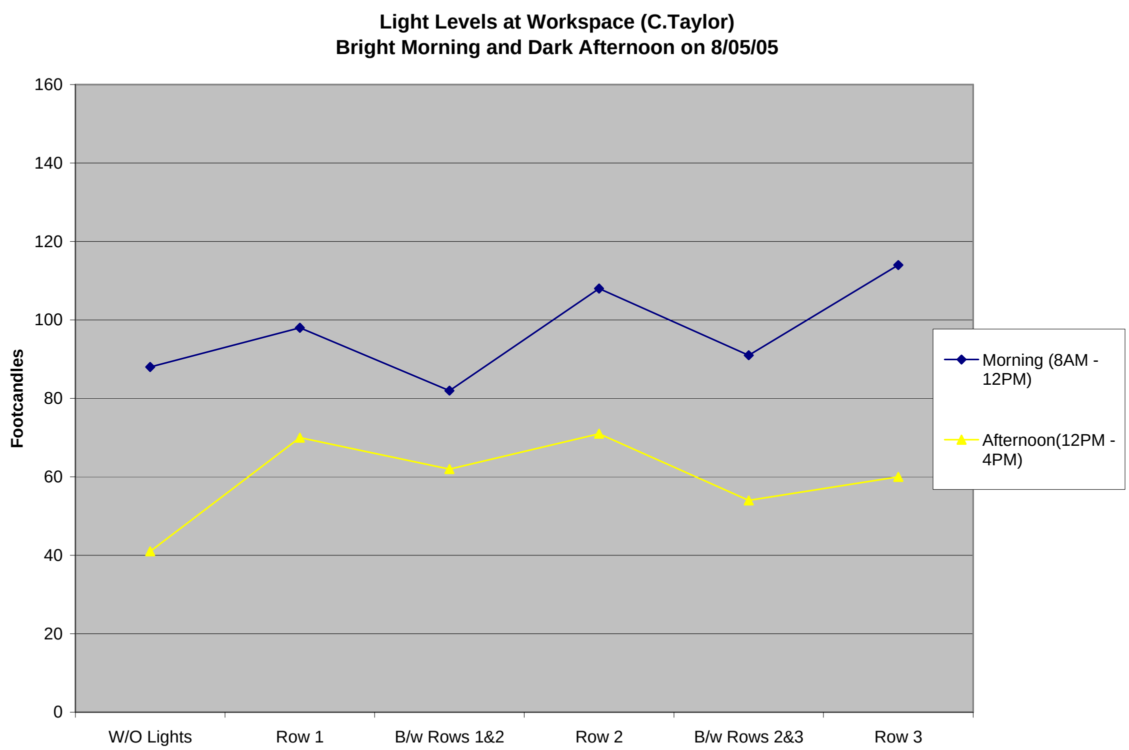
APPENDIX B – LIGHT LEVELS IN LIBRARIES



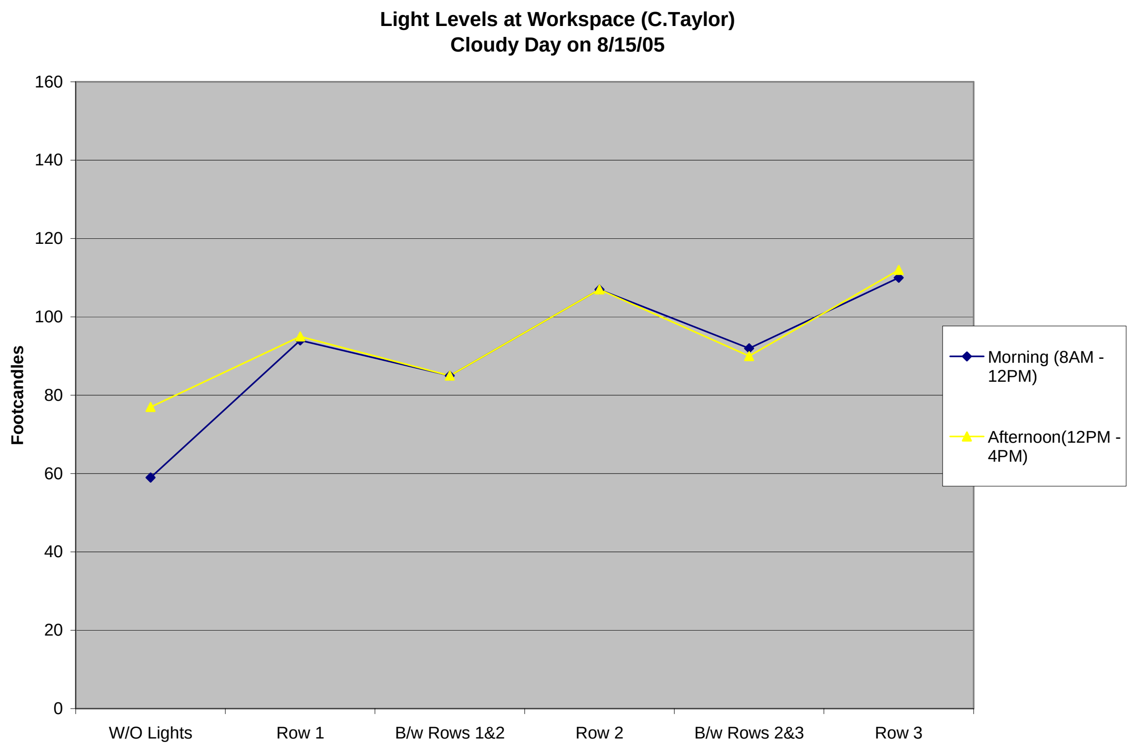


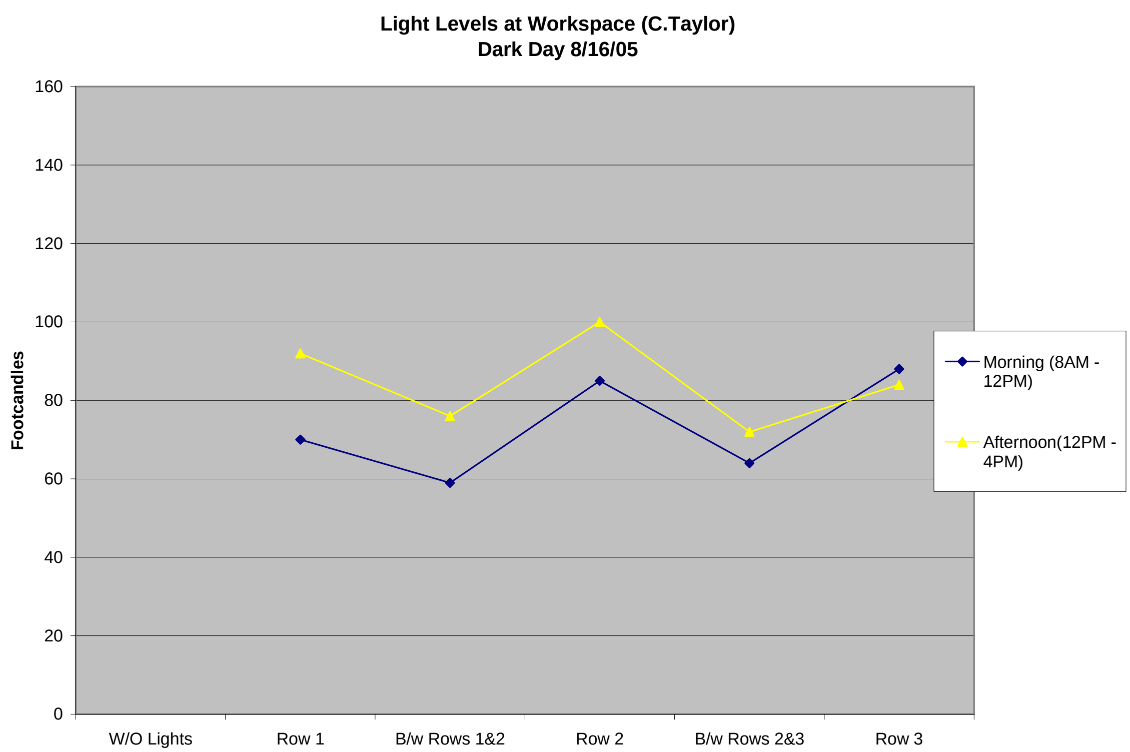
APPENDIX B – LIGHT LEVELS IN LIBRARIES (Continued)



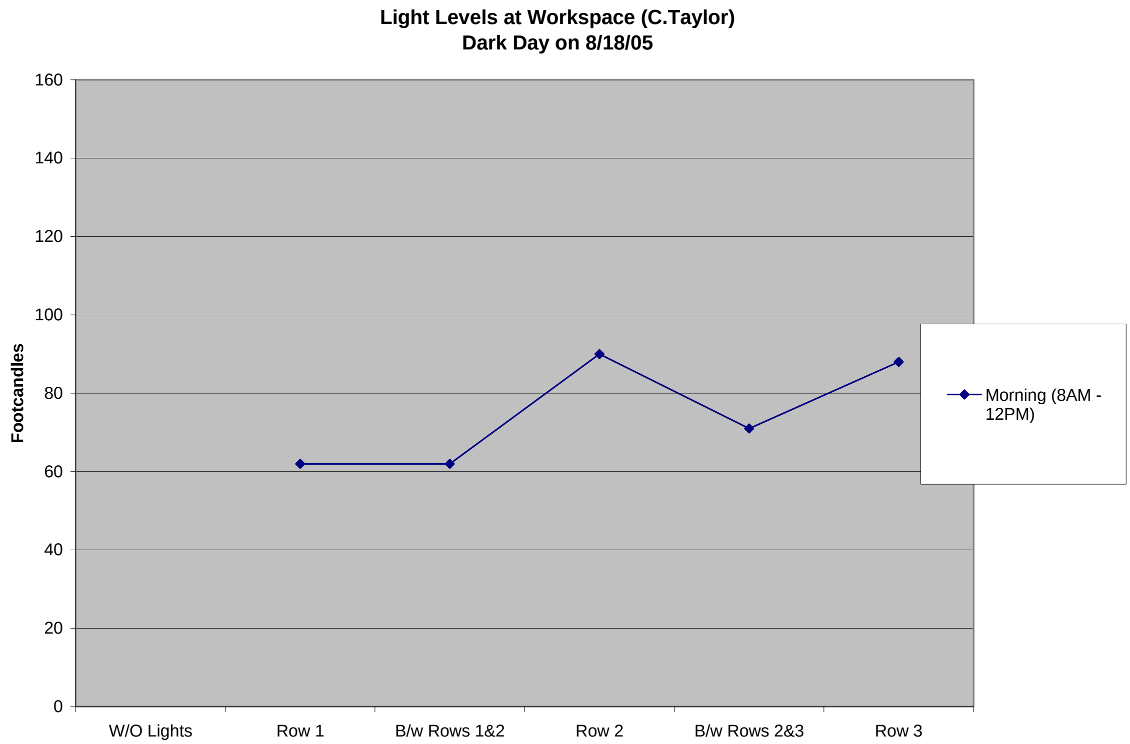


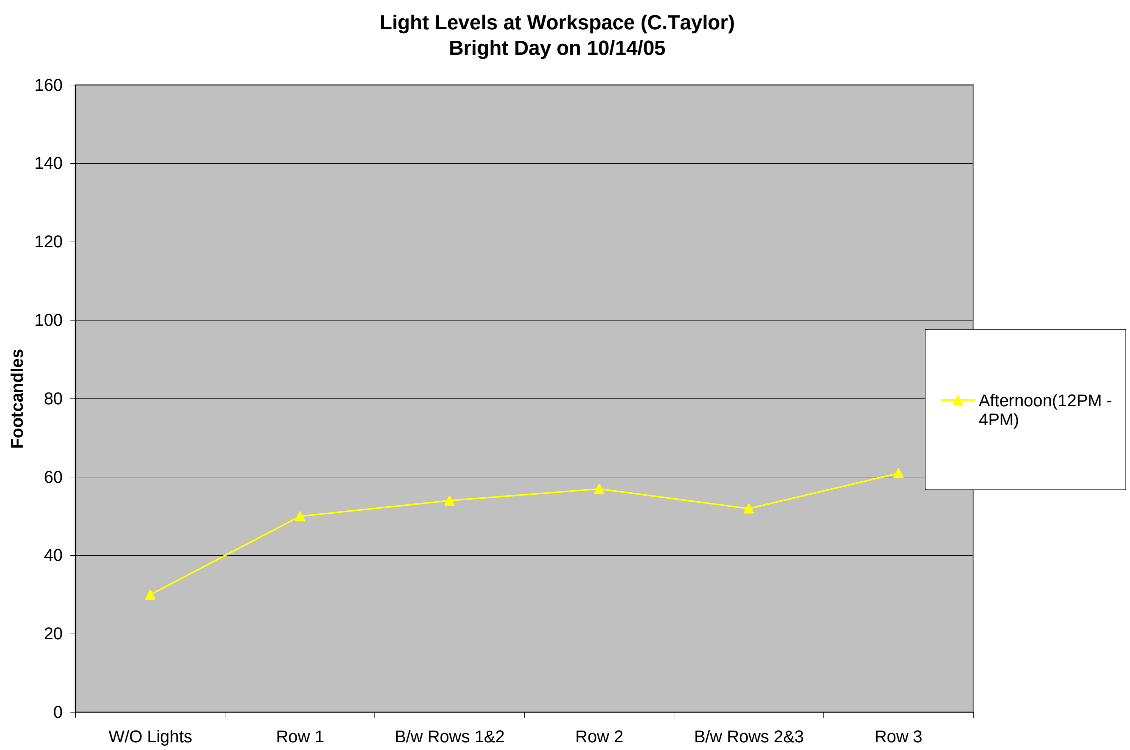
APPENDIX B – LIGHT LEVELS IN LIBRARIES (Continued)



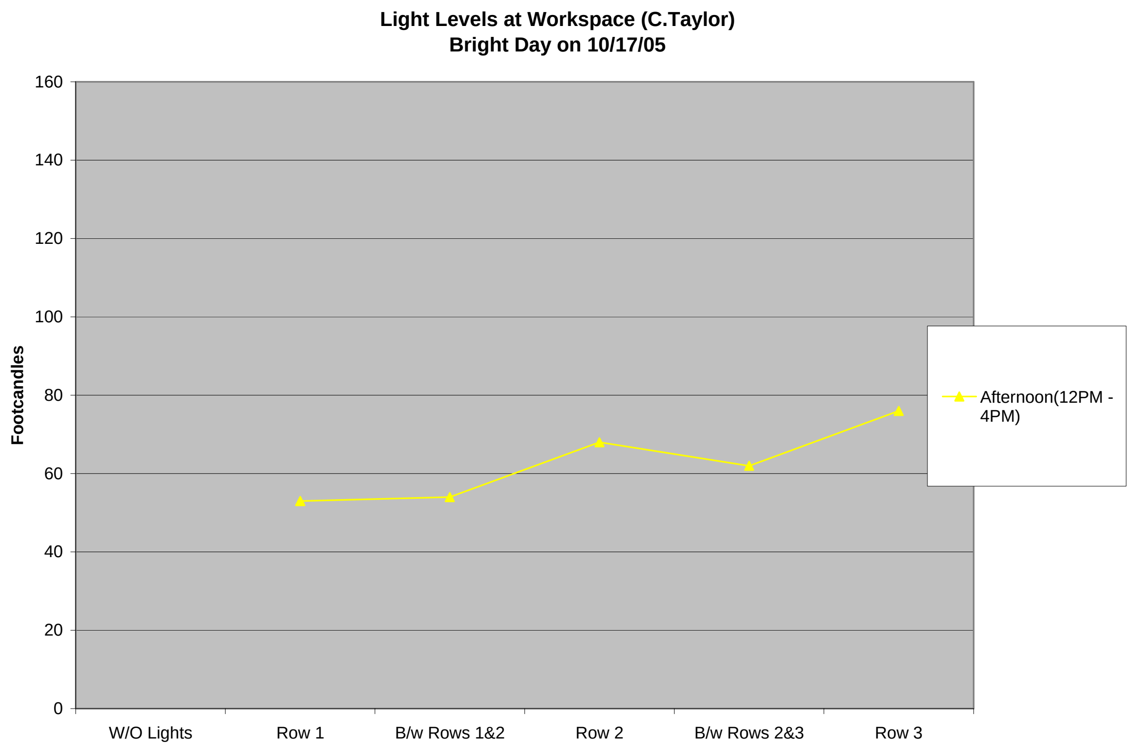


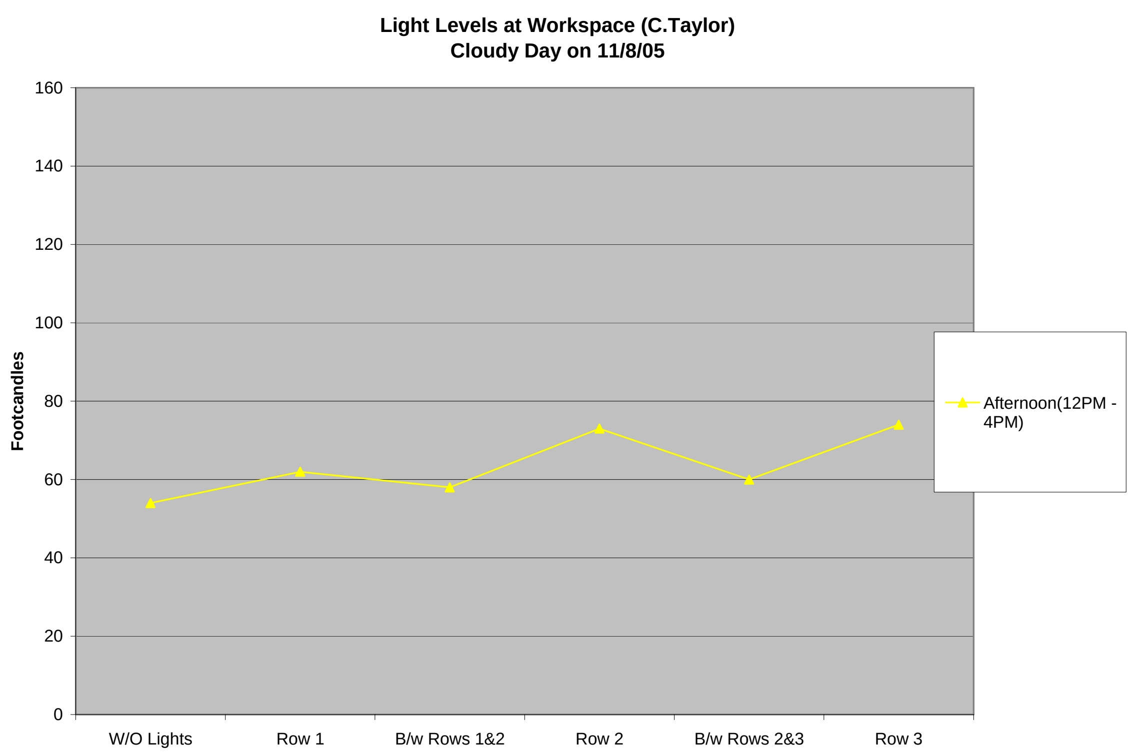
APPENDIX B – LIGHT LEVELS IN LIBRARIES (Continued)





APPENDIX B – LIGHT LEVELS IN LIBRARIES (Continued)





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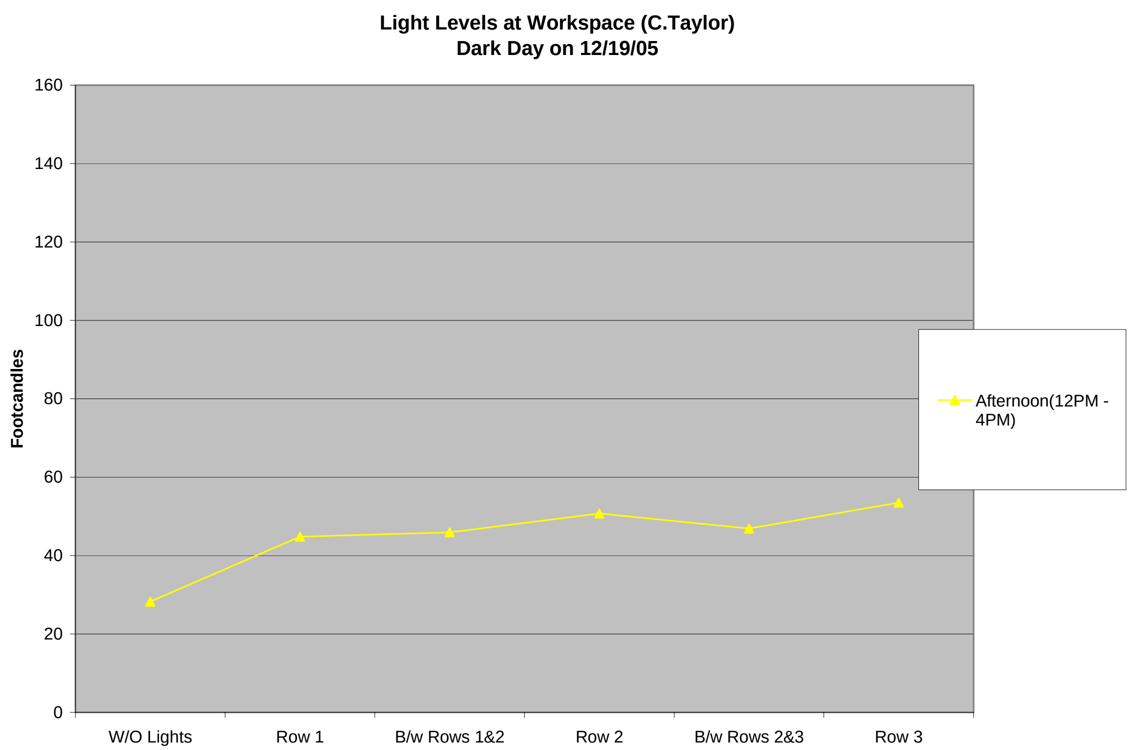

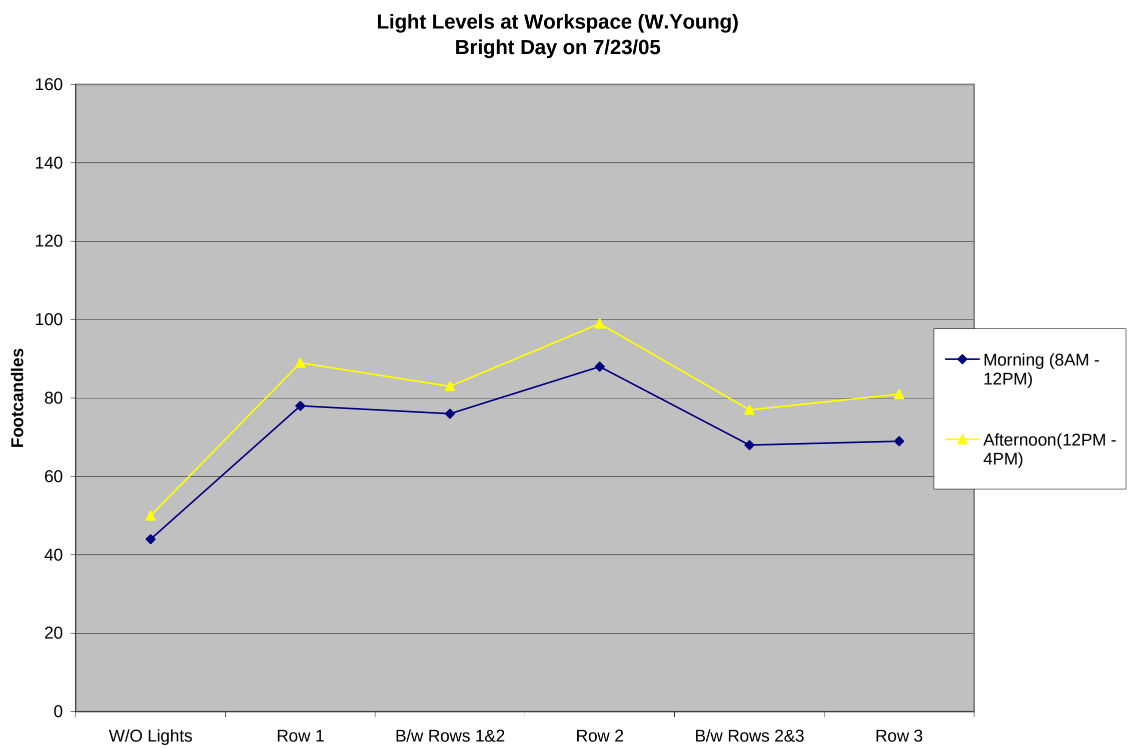

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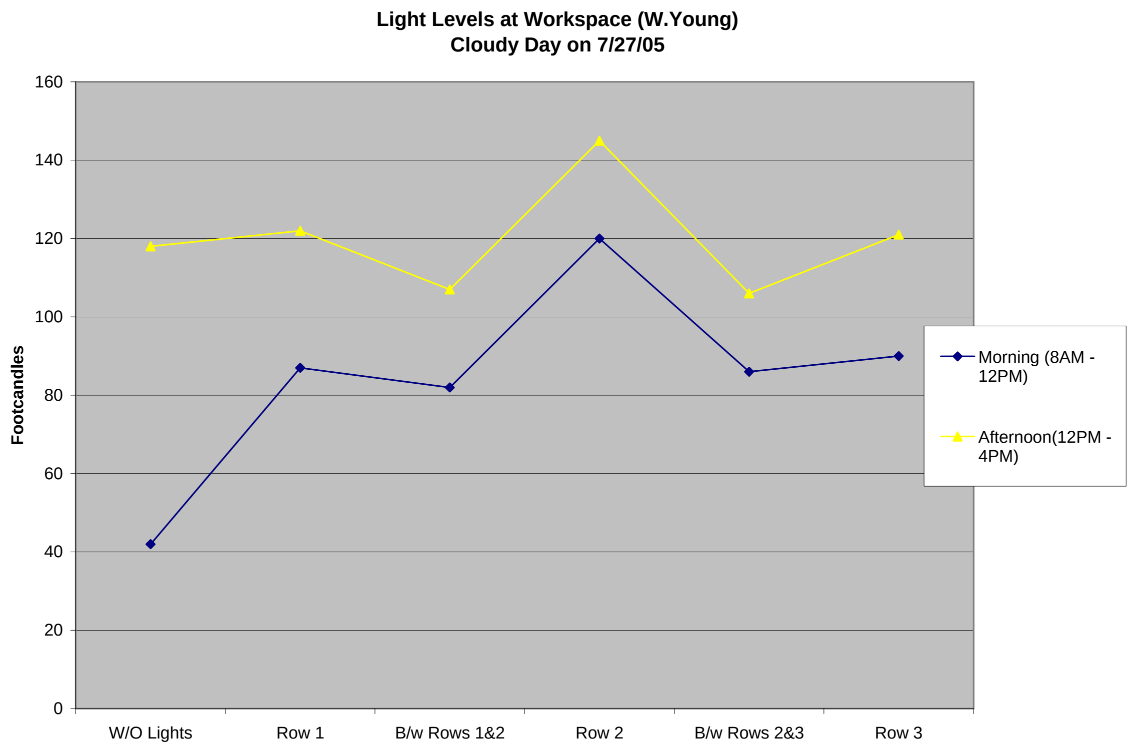

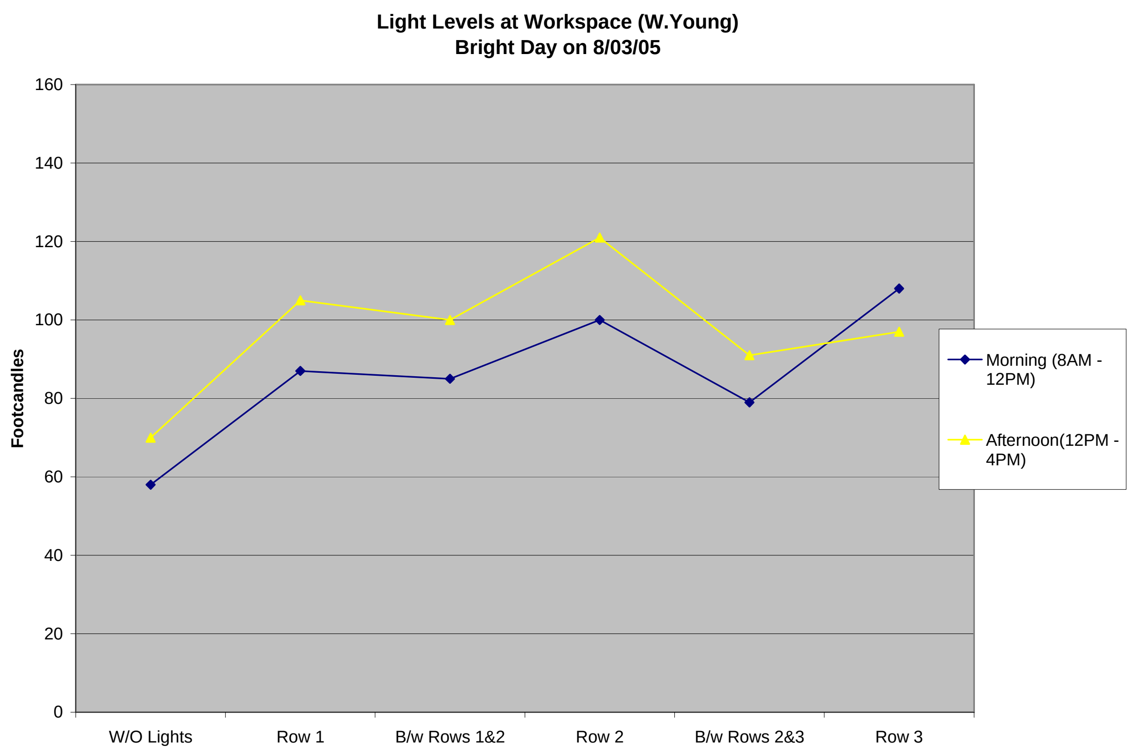

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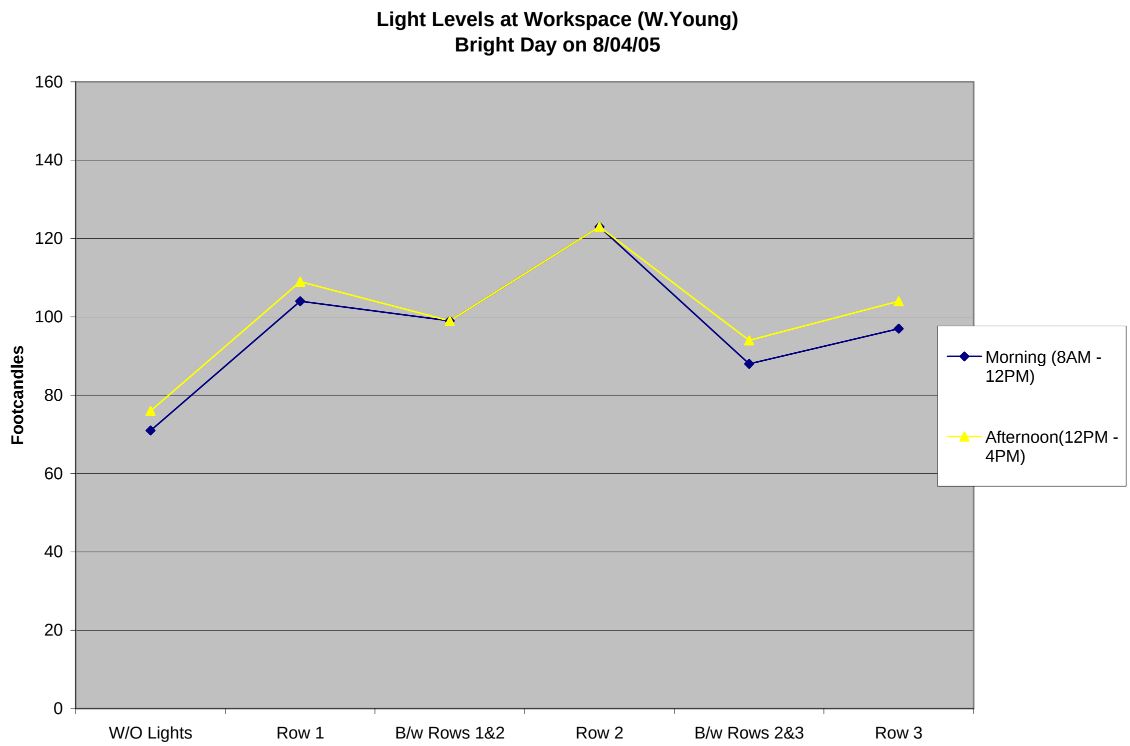

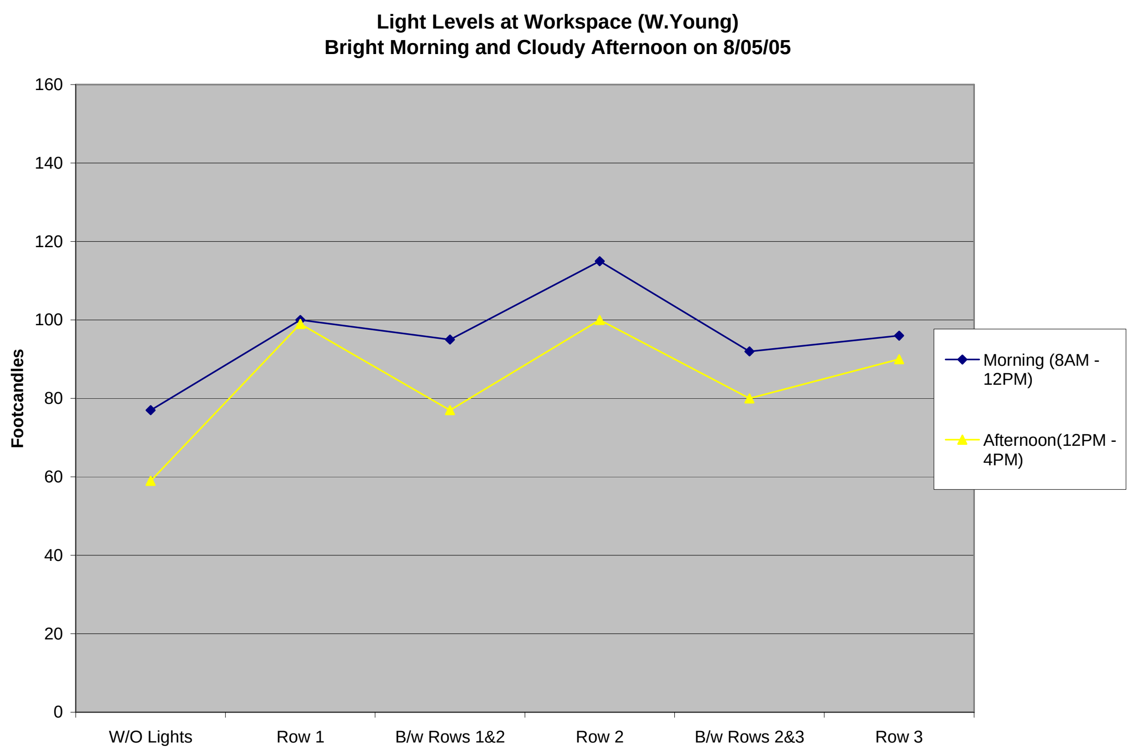

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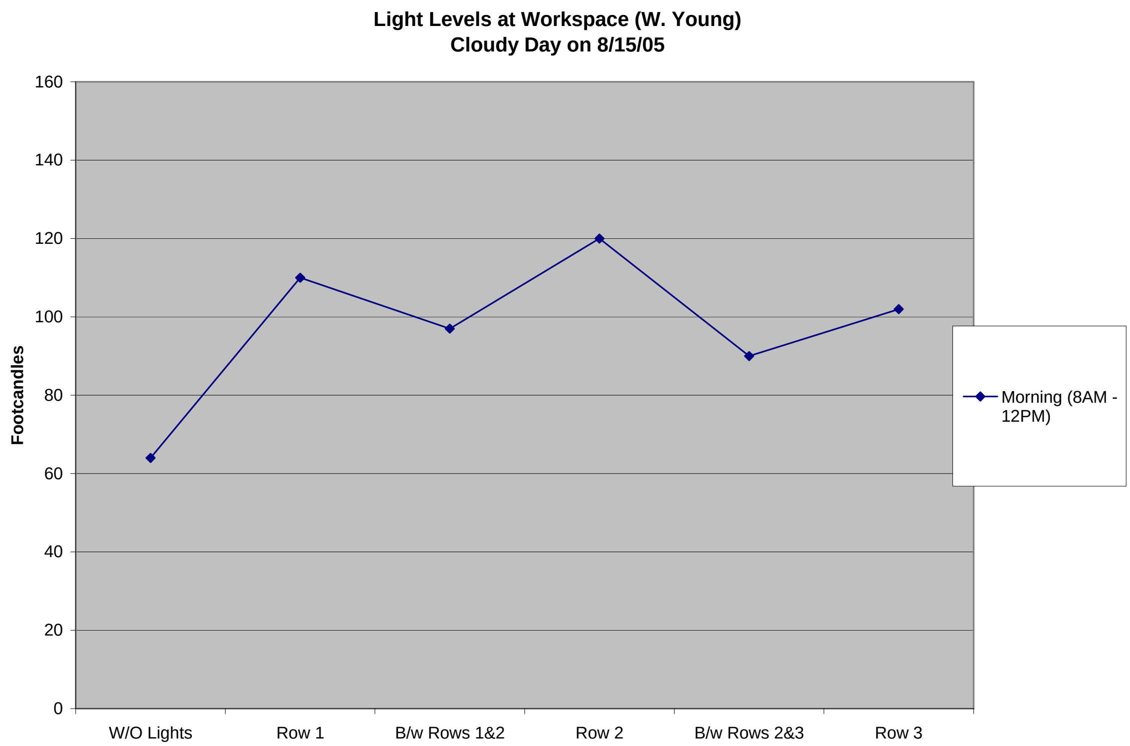

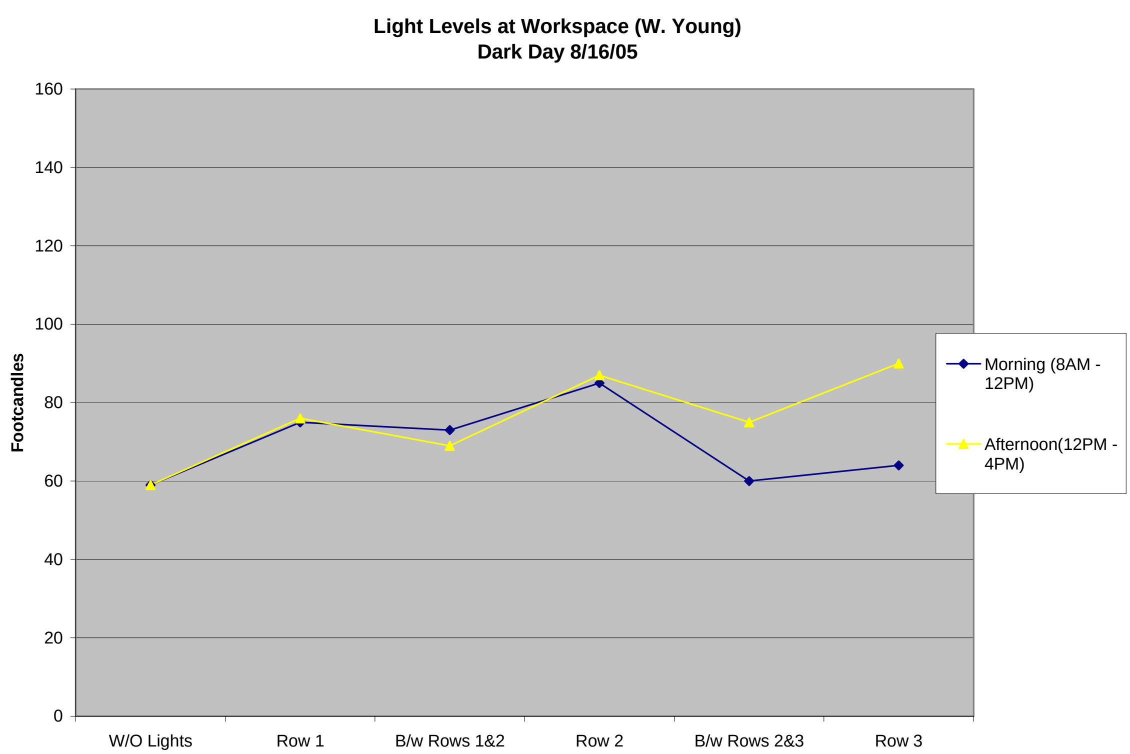

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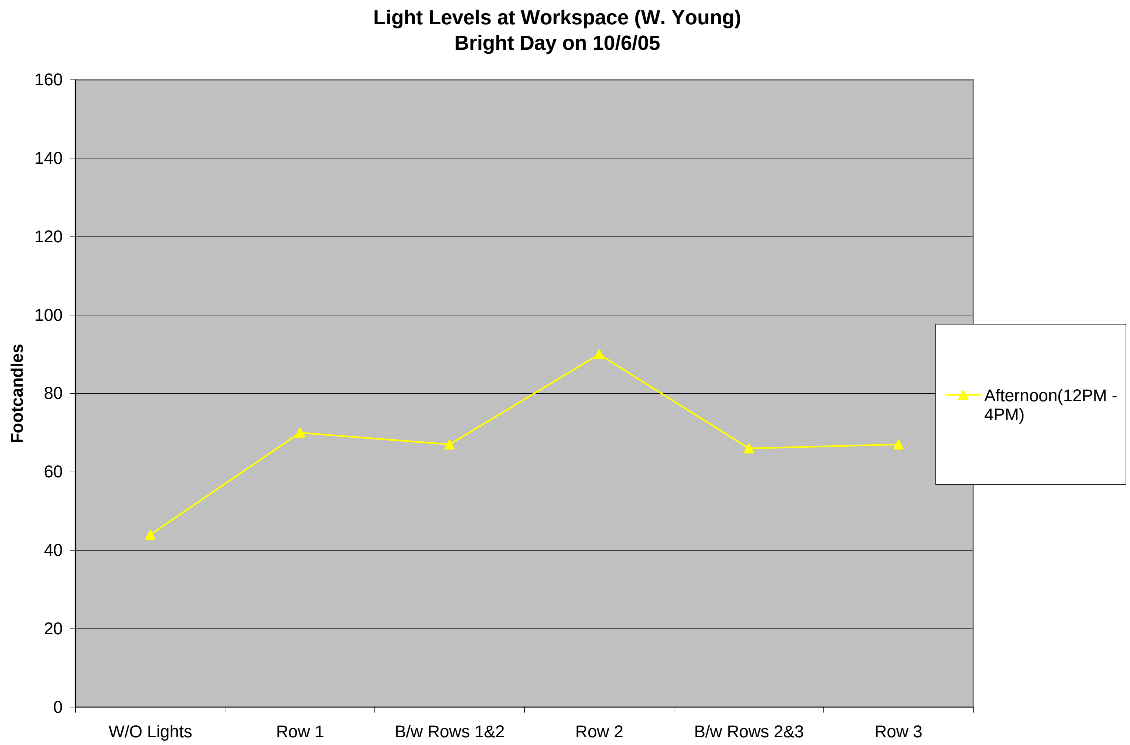

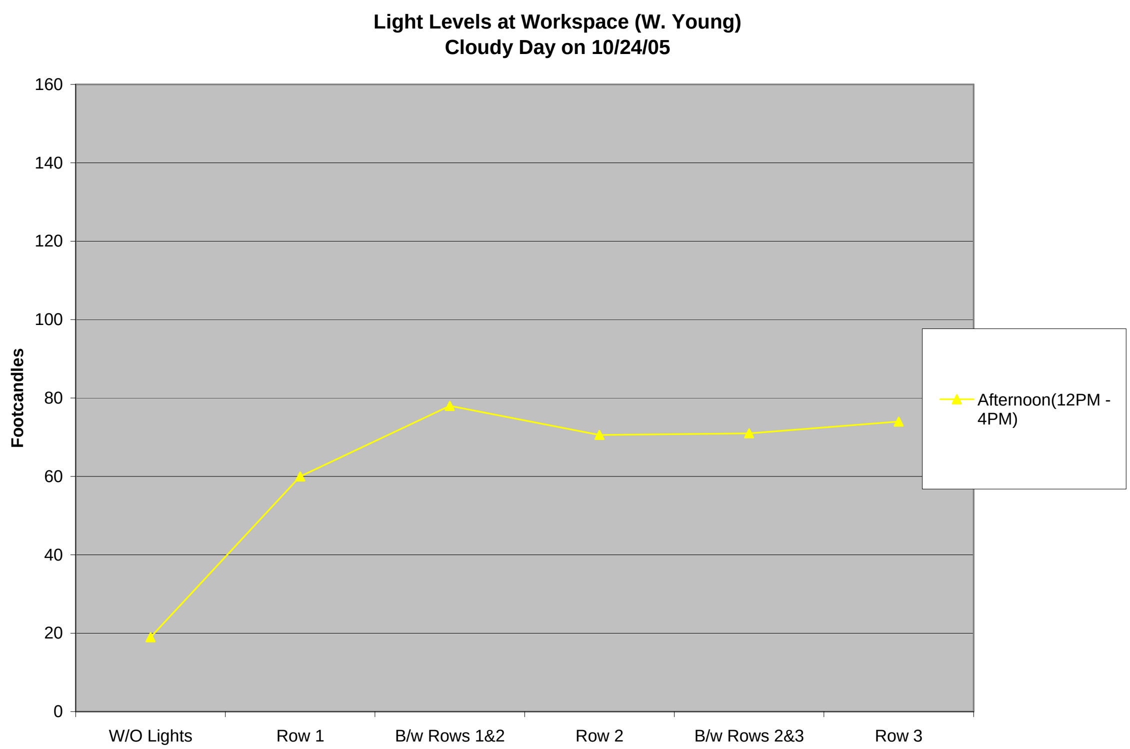

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