

Gold Ridge Elementary School

Circadian Lighting Study

Sacramento Municipal Utility District



October 30, 2018



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1. Executive Summary

1.1 Introduction

Research conducted by the Lighting Research Center (LRC), part of the Rensselaer Polytechnic Institute¹, DOE and others has shown that lighting affects our circadian rhythms, and consequently may have significant impacts upon our health. Specifically, the spectrum and the intensity of the light source, as well as the duration and timing of the exposure affect our sleep patterns. Studies have shown that prolonged sleep deprivation can lead to memory deficits, limited attention spans, poorer balance and higher rates of depression and anxiety. Several other recent studies conducted in Europe suggest that the wavelength and intensity of classroom lighting systems may have an impact upon students as well.

Representatives from the Folsom Cordova Unified School District (Folsom-Cordova) heard about the results of SMUD's previous research projects at the ACC Care Center and Eskaton's Monroe Lodge² and asked us to help them explore potential benefits of tunable-white lighting for children with Autism Spectrum Disorder (ASD).

Although Folsom-Cordova has behavioral experts and teachers with specialized training in ASD, they needed funding and technical lighting expertise to conduct this research. SMUD responded by creating a research project and invited Pacific Northwest National Laboratories (PNNL) to participate. PNNL plans to create two reports for this project under DOE's GATEWAY program. The first report has been completed and is available via the DOE website³.

1.2 Project Objectives

This project included two major segments: (1) installing tunable-white LED lighting in three classrooms, (2) installing tunable-white lighting in the homes of up to 14 students with Autism Spectrum Disorder (ASD). The main objective for this project was to answer the following research questions:

1. Did the new classroom lighting system produce any observable behavioral changes for the students with ASD? Did it produce any observable behavioral changes for the general education students?
2. Did the new classroom lighting system make the teachers' jobs easier? What features did they use? How satisfied were they with the system?

¹ For more information, please visit the Lighting Research Center website: <http://www.lrc.rpi.edu/>

² To learn more about these projects, please download the full reports at <https://www.smud.org/en/Business-Solutions-and-Rebates/Business-Rebates/Advanced-Tech-Solutions>

³ For more information, please visit: <https://www.energy.gov/eere/ssl/articles/report-documents-trial-installation-tunable-led-classroom-lighting>.

3. What are the performance characteristics of the new classroom lighting systems? What are the estimated annual energy (kWh) and cost savings? What is the reduction in electrical demand (kW)?
4. Did the new lighting systems installed in the *homes* of the students with ASD produce any observable behavioral changes? Did it help them sleep better?
5. How easy was the technology to operate? How well did the parents understand it? What information is necessary for other people to fully use the technology?
6. How satisfied are customers with the technology? Would they recommend it to others who have children with ASD?
7. What barriers to market adoption exist? Should SMUD promote the technology? If so, through what programs or channels?

1.3 Results

To answer the research questions listed above, this study included:

- Nearly 4,000 surveys completed by students from the three classrooms. Teachers assisted the students with ASD.
- Interviews with the three teachers in charge of the classrooms.
- Sixteen months of energy monitoring.
- Eight weeks of monitoring the settings of the classroom lighting controls.
- Illumination measurements for the original and new classroom lighting systems.
- Baseline surveys, weekly surveys and final interviews with the two families who chose to participate in the home study.

A high-level summary of the results for this project is presented below:

- Students reported a slight increase in overall feelings of wellness and slightly lower energy levels.
 - Feedback from the teachers was overwhelmingly positive. All of them said the new classroom lighting system helped them teach more effectively.
 - The lighting control modes (aka scenes) used most frequently by the teachers were “General” and the “AV” mode. One teacher used the “Calm” setting on a regular basis.
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- The new classroom lighting system reduced electrical demand by 60 to 74% and energy consumption by 26 to 57%. The energy savings were adversely impacted by high stand-by losses of the lighting controls. Please see the Project Results section for more information.
- The installed cost of the tunable-white classroom lighting system was an estimated 36% higher than a comparable system without tuning.
- Unfortunately, based upon the energy and demand savings alone, the simple financial payback for the classroom lighting system exceeds the rated life of the system. However, further evidence of non-energy benefits (student achievement, less absenteeism, greater teacher retention, etc.) could have a large impact on the economics in the future.
- One of the two families that participated in the home lighting upgrades reported dramatic improvements in the behavior of their child. The other family reported modest behavioral improvements and a dramatic reduction in the amount of time it took their child to fall asleep at night.

1.4 Recommendations

- Based upon the feedback from the teachers and the positive student survey results, school districts should install LED lighting systems that are dimmable and include lighting control scenes such as “General” lighting and “AV” modes.
- School districts should *consider* installing tunable-white LED systems for new classrooms—especially classrooms that will be used during the evening hours or used for teaching students with ASD. Hopefully the cost of tunable-white LED lighting systems will become lower in the future.
- Based upon the improvements experienced by the two families who participated in this project, more research should be done in the homes for students with ASD. Electric utilities should consider partnering with non-profit organizations that provide support to families who have children suffering from ASD.

1.5 Acknowledgements

While many people contributed to this project, we particularly appreciate the cooperation and efforts of:

- David Frankel (Folsom Cordova Unified School District)
 - Tammy Goins (Folsom Cordova Unified School District)
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- Mike Hammond (Folsom Cordova Unified School District)
 - Bethanee Hunnicutt (Folsom Cordova Unified School District)
 - Kevin Smith (Folsom Cordova Unified School District)
 - Teachers at Gold Ridge Elementary School
 - The Gunter Family

 - Brian Pizzi (Cadmus)
 - Emily Shackleton (Cadmus)
 - Sepideh Shahinfard (Cadmus)
 - John Walczyk (Cadmus)

 - Stephen Radovitch (Finelite)
 - Aaron Smith (Finelite)
 - Jane White (Finelite)

 - Robert Davis (Pacific Northwest National Labs)
 - Sarah Safranek (Pacific Northwest National Labs)

 - Mike Corbett (Sacramento Municipal Utility District)
 - Connie Samla (Sacramento Municipal Utility District)
 - Damien Waples (Sacramento Municipal Utility District)
 - Brittany Woodard (Sacramento Municipal Utility District)
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2. Project Description

2.1 Project Scope

This project included two major areas: installing tunable-white LED lighting in three classrooms and installing tunable-white lighting in the homes of up to 14 students with Autism Spectrum Disorder (ASD). The project was organized into three phases:

- Phase 1: Baseline Period. During this phase the project team monitored the energy consumption of the classrooms (fluorescent lighting systems) and developed the student surveys that were used during Phase 2 and Phase 3. At the end of Phase 1, the classroom lights were replaced with tunable-white LED systems (Figure 1).
- Phase 2: LED Lighting Static Mode. During this phase the tunable-white feature was disabled. Teachers could dim the lights and use lighting control scenes (e.g. AV Mode), but the Correlated Color Temperature (CCT) was fixed at 4100K. The project team monitored the energy consumption and administered student surveys throughout this phase. The main purpose of this phase was to establish a clean baseline for assessing the effects of the circadian mode upon student behavior during Phase 3.

During the last two weeks of Phase 2, the project team worked with two families of students with ASD to install tunable-white lighting (mostly light bulbs) in their homes. Although fourteen families were eligible, only two chose to participate.

- Phase 3: LED Lighting Circadian Mode. During this phase of the project, the lights in the classrooms were set to automatically change color temperatures and two new lighting control scenes were made available: “Calm” and “Energize”. During this phase, the project team continued to monitor the energy consumption of the classrooms and administer student surveys. The project team also monitored the lighting control set points for eight weeks to track which control scenes (modes) the teachers used.

The parents of the two families who participated in the home lighting upgrades completed baseline questionnaires and weekly surveys. They were also interviewed at the end of the monitoring period. Complete copies of these surveys can be found in the appendix section of this report.



Figure 1: one of the three classrooms included in the study.

2.2 Research Questions & Methodology

The research questions and methodologies used for obtaining the answers are described below.

- **Questions:** did the new classroom lighting system produce any observable behavioral changes for the students with ASD? Did it produce any observable behavioral changes for the general education students?

Methodology: Folsom-Cordova's Behavioral Specialists developed electronic and paper surveys to assess the overall alertness and energy levels of the 44 students who participated in the study. Thirty of these students were general education students and 14 of them were students with ASD. During this study a total of nearly 4,000 surveys were completed over a period of eight months. A sample survey is shown in Figure 2. Copies of the complete surveys are included in the Appendix section of this report.

Figure 2: sample of one of the student surveys used during this study.

- **Questions:** Did the new classroom lighting system make the teachers' jobs easier? What features did they use? How satisfied were they with the system?

Methodology: At the end of Phase 3, the project team met with the teachers to discuss their experiences with the lighting system. The team also used custom software to track the setpoints used by the teachers during the last eight weeks of Phase 3.

- **Questions:** What are the performance characteristics of the new classroom lighting systems? What are the estimated annual energy (kWh) and cost savings? What is the reduction in electrical demand (kW)?

Methodology: the energy consumption of the classroom lighting systems was monitored at the circuit level throughout the entire project. The project team measured the illumination levels as well. Information regarding the specific types of equipment used during this project may be found in the Appendix section of this report.

- **Questions:** Did the new lighting systems installed in the homes of the students with ASD produce any observable behavioral changes? Did it help them sleep better?

Methodology: The parents of the participating families completed an initial questionnaire followed by weekly surveys. They were also interviewed at the end of

Phase 3. Copies of the initial questionnaire, weekly survey and final interview questions may be found in the Appendix section of this report.

- **Questions:** How easy was the technology to operate? How well did the parents understand it? What information is necessary for other people to fully use the technology? How satisfied are customers with the technology? Would they recommend it to other parents who have children with ASD?

Methodology: The project team interviewed the parents of the participating families at the end of Phase 3.

- **Questions:** What barriers to market adoption exist? Should SMUD promote the technology? If so, through what programs or channels?

Methodology: The project team interviewed teachers, administrators and parents who participated in the project.

2.3 Classroom Lighting Systems

Original Lighting

The original lighting systems consisted of twenty-four, 2 x 4 recessed fluorescent fixtures installed as shown in Figure 3 and Figure 4. The light fixtures included two 4ft. T8 fluorescent lamps (4100K) and electronic ballasts and each consumed 56 Watts of power.

The lights were controlled by two switches located near the door. These switches enabled the teachers to turn off every other fixture. However, the students often had trouble seeing the presentations, so the teachers had to turn off all the lights.

The measured illumination levels with all lights turned on ranged from 57 to 91 foot-candles (fc) at the desk level.

New Lighting

The new lighting system for each classroom included twelve Finelite LED 2 x 2 recessed, tunable-white fixtures and a linear wall-wash fixture installed as shown in Figures 5 & 6. All new lights are dimmable and can be set from 2700K to 6500K. The 2 x 2 fixtures



Figure 3: the original lighting system consisted of 26 fluorescent lights as shown above. Photo credit: PNNL

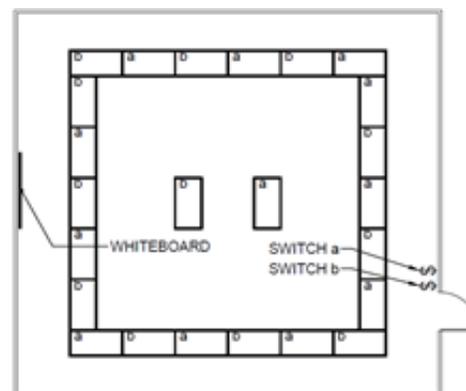


Figure 4: layout for the original lighting system. Credit: PNNL

each consume a maximum of 42 Watts. The wall-wash fixtures consume up to 40 Watts each (Figure 7).

The new lights are controlled via keypads (similar to the one shown in Figure 8). The new controllers feature sliders to control intensity and CCT and five preset scenes. The lighting control scenes described below were programmed in the field during the commissioning process:

1. General: all lights in the room set for 56% of maximum output, CCT: 4397K. The average measured illumination levels were around 36 fc.
2. AV Mode: wall-wash fixture off; recessed lights set for 11% of maximum output. CCT: 3197K.
3. Screen: wall-washer fixture set for 80% of maximum output. Recessed lights set for 21% of maximum. CCT for all lights: 4397K.
4. Calm: wall-wash fixture off; recessed lights set for 6% of maximum output. CCT for all lights: 2997K. The average measured illumination levels were around 3 fc.
5. Energize: wall-wash fixture off; recessed lights set for 62% of maximum output. CCT: 5304K. The average measured illumination levels were around 36 fc.



Figure 7: the new classroom lighting systems included wall wash fixtures that could be controlled independently from the recessed fixtures. This feature was especially helpful during presentations.



Figure 5: the new lighting system for each classroom includes twelve 2 x 2 recessed, tunable-white LED fixtures. Photo credit: PNNL

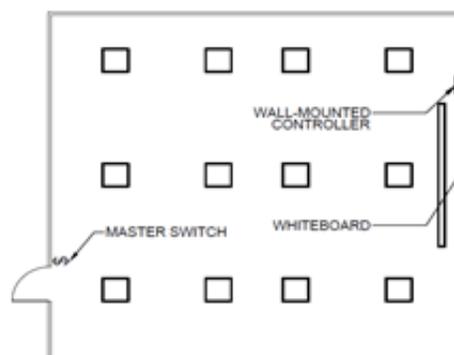


Figure 6: layout for the new LED lighting system. Credit: PNNL.



Figure 8: the new classroom lighting systems were controlled by keypads with slider controls and preset lighting scenes. Photo credit: PNNL.

2.4 Residential Lighting (Homes)

Ultimately, only two families chose to participate in the home lighting portion of the project. At the end of Phase 2, the project team conducted lighting audits and provided recommendations for the new tunable lighting systems. The original lights for the two homes were fairly-typical: recessed downlights, ceiling fans, bathroom vanity lights, table and floor lamps (Figure 9). Many of the original light bulbs were compact fluorescents with CCTs of 2700K.

During the recruiting process, the families were provided with a presentation that included the basics of lighting and circadian lighting principles. After the lighting audits were completed, the families purchased and installed Philips Hue products including:

- White Ambiance A19 LED bulbs
- White and Color Ambiance A19 LED bulbs
- White Ambiance BR30 LED Flood Lights
- Smart Dimmer Switches with Remote
- Smart Motion Sensors
- White Ambiance Wellness Dimmable Smart LED Table Lamp



Figure 9: the original lights for the two homes were fairly-typical and included recessed downlights, ceiling fans, bathroom vanity lights, table lamps and floor lamps.

After the lights were installed and inspected, SMUD provided reimbursements of \$1,500 per family.

3. Project Results

3.1 Classrooms

Hours of Operation

The project team monitored the energy consumption of classrooms D2, F6 and G1. The monthly operating hours are shown in Figure 10. The total annual operating hours ranged from 1,482 to 1,529 hours per year. These hours of operation are typical for elementary school classrooms but much lower than office buildings.

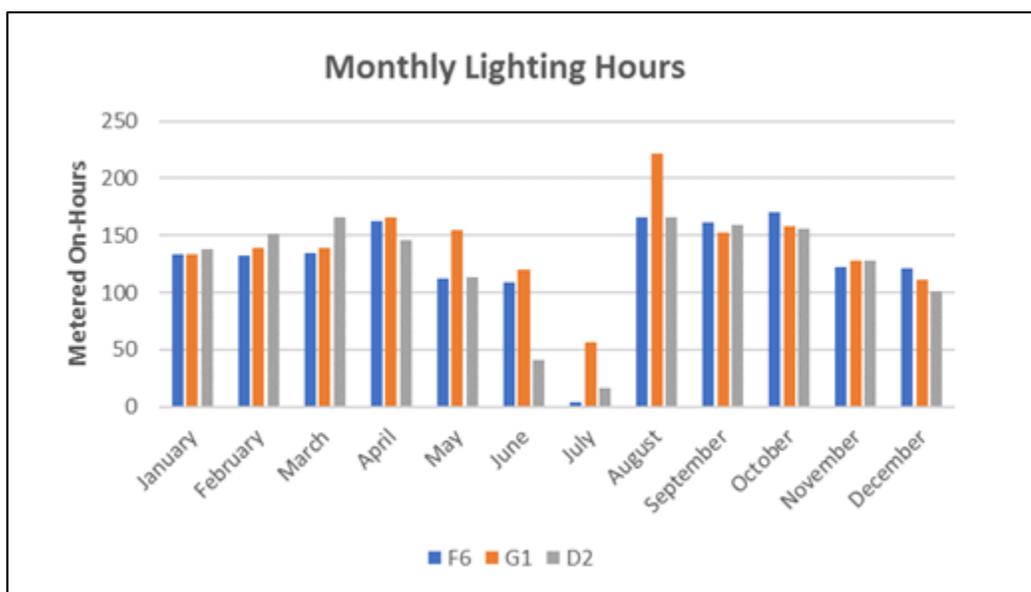


Figure 10: monthly hours of use for the three classrooms at Gold Ridge Elementary School.

Demand Savings

The lighting demand savings are shown in Figure 11. Typical electrical demand profiles for each classroom are shown in Figure 12. The new lighting system reduced the electrical demand by 74% for classroom D2, 73% for classroom F6 and 60% for classroom G1. It is also interesting to note that the maximum measured wattages for the classrooms were around 24% less than the total connected lighting load. This indicates that the teachers consistently dimmed the lights and/or used the lighting control scenes.

Classroom	Lighting kW		Savings	
	original	new	kW	%
D2	1.38	0.35	1.03	74.6%
F6	1.32	0.35	0.97	73.5%
G1	1.38	0.55	0.83	60.1%

Figure 11: electrical demand for the original fluorescent and new LED lighting systems.

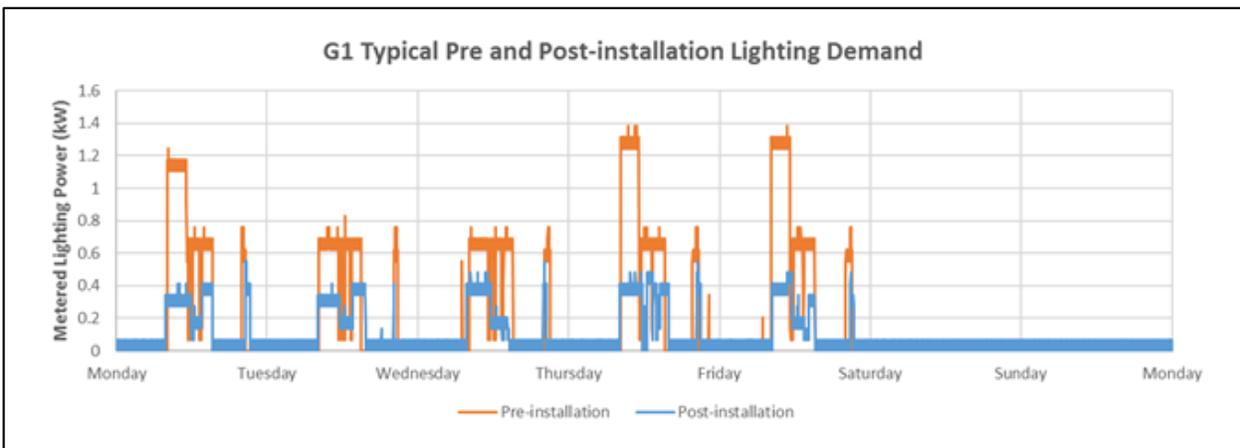
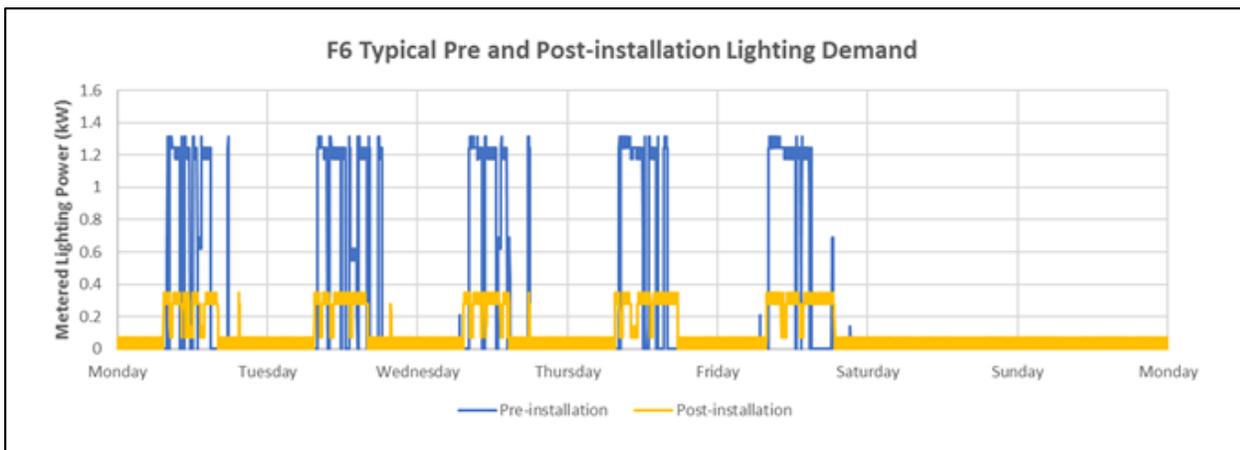
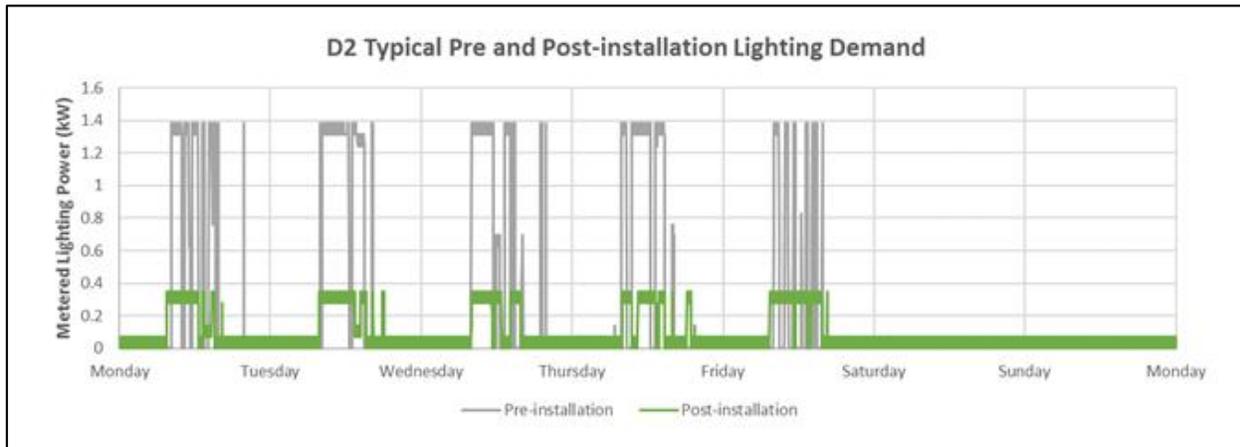


Figure 12: the new classroom lighting systems reduced peak electrical demand from 60 to 74%. It is also interesting to note that the maximum measured wattages for the classrooms were around 24% less than the total connected lighting load—a clear indication that the teachers consistently dimmed the new lights.

Energy Savings

Based upon the monitoring data, the estimated energy savings ranged from 26 to 57.3% (Figure 13). The savings were less for classroom G1 because the teacher frequently turned on only half of the original fluorescent lighting. The energy savings for this project were adversely impacted by standby losses of the lighting controls (Figure 14). Standby losses (or vampire loads) refer to the energy consumed by a device when it is switched off.

Although the standby losses were only between 3-4 Watts per fixture, they collectively accounted for 40% of the overall energy consumption of the LED lighting system. One reason this percentage is so high is that the lighting systems are only used around 1,500 hours per year, whereas the standby loads occur during the remaining 7,260 hours. Fortunately, Finelite has developed options to avoid these losses for future projects.

Classroom	Lighting kWh		Savings	
	original	new	kWh	%
D2	1,816	827	989	54.5%
F6	1,743	744	999	57.3%
G1	1,113	824	289	26.0%

Figure 13: estimated annual energy consumption for the original fluorescent and new LED lighting systems.

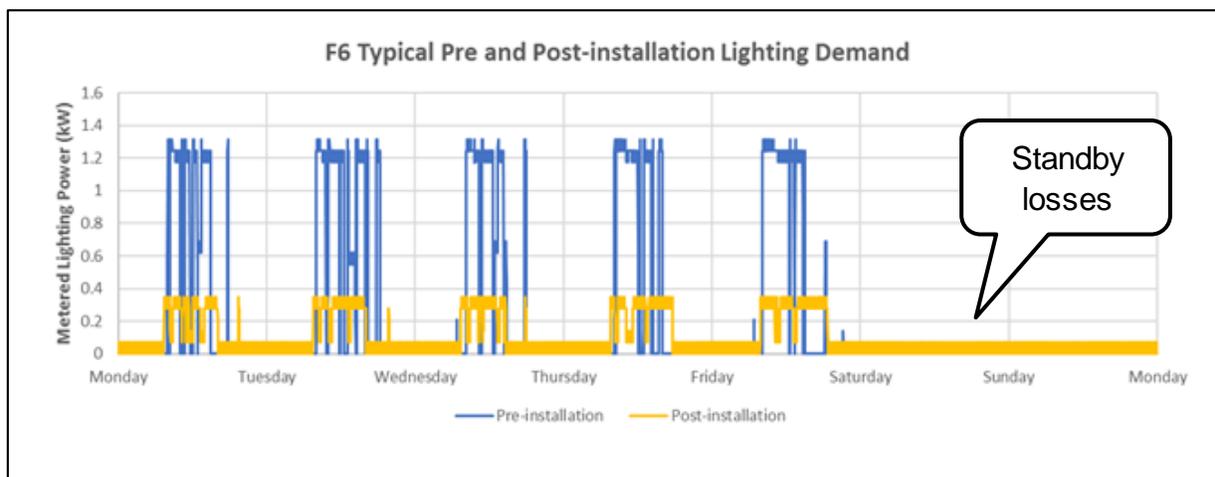


Figure 14: demand graph showing the standby losses due to the DMX lighting controls. Collectively these losses account for 25% of the overall annual energy consumption of the LED lighting system. Fortunately, Finelite has developed options to avoid these losses for future projects.

Illumination levels

The illumination levels for the original fluorescent lighting system ranged from 57- 91 fc. These levels were significantly higher than the current IES recommended level of 30 fc for classrooms. The project team measured the illumination levels for the new LED system with all lights set for the General, Energize and Calm modes. The results are shown in Figure 15. The average illumination levels in the General and Energize modes were still slightly higher than IES recommendations but much closer than the original fluorescent system.

Mode	Max.	Min.	Avg.	Min/Max ratio
General	45.9	25.1	35.9	1.83
Energize	50.2	24.1	36.1	2.08
Calm	4.1	2.0	3.1	2.05

Figure 15: illumination measurements the new lighting system. All values are in foot-candles except the max/min ratios which are unitless. Source: PNNL.

Controller usage patterns

After providing the teachers with an overview of circadian lighting principles and showing them how to use the lighting controls, the project team tracked their choices. Figure 16 shows the results normalized for a four-week period. Before discussing the results, it is important to note that the default for the lighting controls was the “General” setting. Key observations include the following:

- The teacher in classroom F6 switched between "Calm" and "Energize" setting multiple times per day. However, she used the "Calm" mode most of the time. This classroom is used for teaching students with ASD.
- The teacher in classroom G1 frequently used both the preset modes and the slider controls. She mainly chose to use the “General” mode but also used the “Energize” and “A/V” modes. This classroom is used for teaching students with ASD.
- The teacher in classroom D2 experimented with the different control modes but usually left the lights in the “General” (default) mode except during presentations. This classroom was used for general education students.

Control option	Usage counts		
	D2	F6	G1
"Calm" Setting	2	71	5
"Energize" Setting	2	85	75
"Screens" Setting	11	2	10
"A/V" Setting	11	2	39
"General Setting	2	1	33
Slider Adjustments	40	444	1,187

Figure 16: lighting control usage over a typical four-week period.

Feedback from teachers

At the end of this project, the teachers were interviewed in person. The questions and their responses are presented below.

Question 1: Did you regularly use the different “scene” button controls? If so, how did you use them?

- Teacher #1 (teaches general education students in room D2)
 - Mostly used “General” in the morning and would switch to “AV” or the “Screens” setting during presentations.
 - Used the “Energize”, “Calm” and “Screens” settings to get the students’ attention.
- Teacher #2 (teaches students with autism in room F6)
 - Used the “Energize” and “Calm” buttons the most often.
 - After a while, she realized the “Energize” setting was too bright and tried to stick with the warmer settings for the rest of the project.
 - Used the “Calm” setting for transitioning from outside into the classroom or during reading time.
- Teacher #3 (teaches students with autism in room G1)
 - Used the “General” setting the most often.
 - Did not use the “Energize” setting very often because she felt it was too bright. Note: based upon the monitoring data, she used the “Energize” mode frequently at first but must have abruptly discontinued using it after that.
 - Used the “AV” and “Screens” setting during presentations
- Overall the teachers said they enjoyed having the preset buttons (rated this feature at 10/10). They preferred the buttons in the back of the class rather than monitoring it through an IPAD. The children were also trained on adjusting the controls as well.

Question #2: Did you regularly use the up and down slider-bars for dimming controls of the downlights and whiteboard light?

- Teachers #1 & #2 said they rarely used them.
 - Teacher #3 used the slider bars for dimming
-

Question #3: Did you regularly use the up and down slide-bar for color control?

- Teacher #1 (teaches general education students in room D2)
 - Sometimes. The blue light seemed to stimulate the kids while the yellower light quieted the kids down.
 - Tried the different settings each week and had the kids take the survey. He noticed he didn't have to repeat himself on directions for activities.
 - The yellower light seemed to help improve the kids' attentiveness.
- Teacher #2 (teaches students with autism in room F6)
 - Kept the room at the warmer settings after noticing the blue was too much for her eyes as well as the kids.
- Teacher #3 (teaches students with autism in room G1)
 - Used the slider bars for dimming but not for color adjustments.

Question #4: Overall, in what ways did the lighting system help you in your teaching and student engagement? Similarly, in what ways did the lighting hinder you?

- All three teachers made the following comments:
 - They enjoyed the colors, but especially liked the ability to dim the lights.
 - The different color options changed the 'mood' of the classroom. For example, it was great to press one button to calm the kids down after coming in from lunch or recess.
 - It was nice for them to be able to simply press one button and then get back to teaching rather than having to make a lot of adjustments.
 - It would be difficult for them to go back to "regular" lighting. Overall the new lighting system improved their working environment as well as well-being of their students.

Question #5: Do you have any ideas for improvements of the control interface or capabilities? Likes/dislikes?

- A remote control for the lighting options would be nice
-

- They do not recommend using an I-Pad (or smart phone).
- They liked the location of the control pad (which was mounted at the front of the classrooms near the projection screens / whiteboards.
- Said it was nice to use the lighting as a method of getting the students' attention. In the past they used a bell or spoke very loudly. Changing the lighting color is much more effective.

Student surveys

As mentioned earlier this research study was organized into three phases:

1. Baseline period (fluorescent lighting)
2. LED lighting in static mode
3. LED lighting in user-selectable circadian mode

During the Static LED and Circadian phases of this project, students were asked to complete simple survey forms at the beginning (morning) and end of the school day (Figure 17). Some of the surveys were completed in hard copy, but the majority of were completed electronically through Google Forms. Students completed a total of 3,995 surveys:

- Morning survey: students completed 372 hardcopy surveys and 1,855 electronic surveys.
- End-of-day survey: students completed 353 hardcopy surveys and 1,415 electronic surveys

The student surveys included questions such as "Did you sleep well last night?" with the option to answer either "yes" or "no." Another question, "How is my energy level?" had options to answer either "low," "medium," or "high." The survey responses were treated like categorical data (e.g. a response of "medium" is not treated as representing a quantitative difference from an answer of "low" or "high," but simply being categorically between "low," and "high.")

Data are presented as the proportion of respondents that answered in a particular way. For example, in response to the question "Did you sleep well last night?" 88.4% of the student responses in the LED Static condition were "yes." The survey data was analyzed by Folsom's Behavioral Specialist and the results were reviewed by the Project Team. Key findings for the morning surveys include:

- A higher proportion of responses in the Circadian Lighting phase were "Yes" to the question "Did you sleep well?" (93.85% verses 88.44%).
-

- The Circadian Lighting phase had a higher proportion of Smiley and Sad face responses to the question “How am I feeling?” than the Static Lighting phase. There was a smaller proportion of Neutral face responses to the same question in the Circadian Lighting phase compared to the Static Lighting phase (Figure 18).
- In response to the question “How is my energy level?” there was a higher proportion of responses for the answers “Low” and “Medium” in the Circadian Lighting condition and a lower proportion of responses to the answer “High” (Figure 19). The project team believes this may have been linked to the use of the “Calm” setting by some of the teachers.

Morning Student Survey

Did you sleep well last night?

Yes

No

How am I feeling?

How is my energy level?

Low Medium High

Figure 17: students completed nearly 4,000 surveys during this study. These surveys were completed at the start and end of the school day. The form shown above was used for the morning surveys.

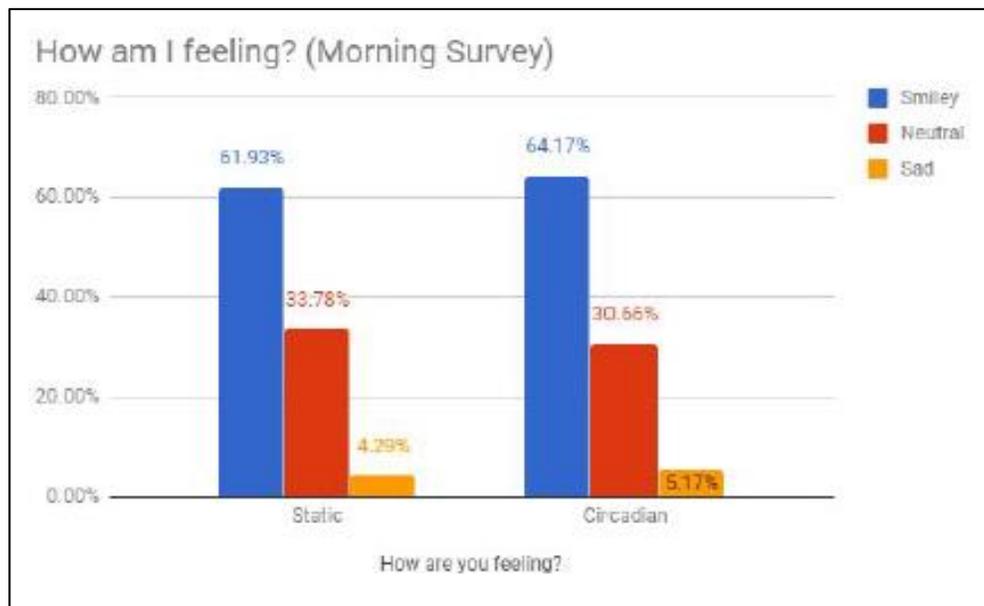


Figure 18: the Circadian Lighting phase had a higher proportion of Smiley and Sad face responses to the question “How am I feeling?” than the Static Lighting phase, and a smaller proportion of Neutral face responses.

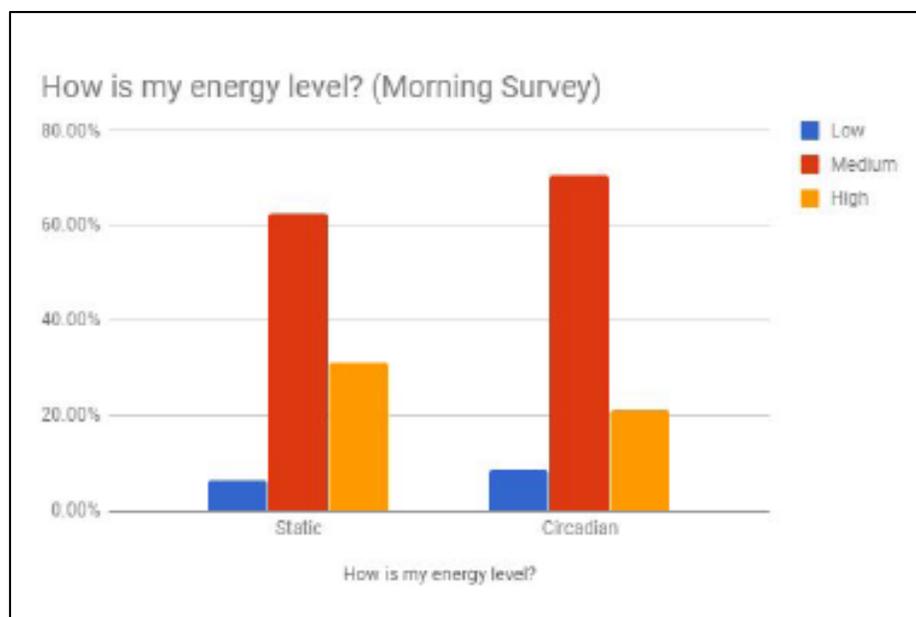


Figure 19: student responses to the question “How is my energy level?” for the morning surveys. Note that the number of respondents who said their energy levels were “Low” and “Medium” increased while the number who said their energy levels were “High” decreased. The project team believes this may have been linked to the use of the “Calm” setting by some of the teachers.

The end-of-day surveys (Figure 20) included two additional, similar questions: “How was my on-task behavior today?” and “How well did I follow classroom expectations today?” After analyzing the data, the project team made the following observations:

- Responses to the question “How am I feeling?” differed slightly across conditions at the end of the day compared to the morning. There was a slightly higher proportion of Smiley face (increase from 73% to 76%) and Neutral face responses in the Circadian Lighting condition at the end of the day compared to the Static Lighting condition and a smaller proportion of Sad face responses (Figure 21).
- Responses to the question “How is my energy level?” (Figure 22) showed the following changes:
 - “High” decreased from 36% to 26%
 - “Medium” increased from 53% to 67%
 - “Low” decreased from 10% to 5.5%

Figure 20: The form shown above was used for the surveys that were completed at the end of the school day.

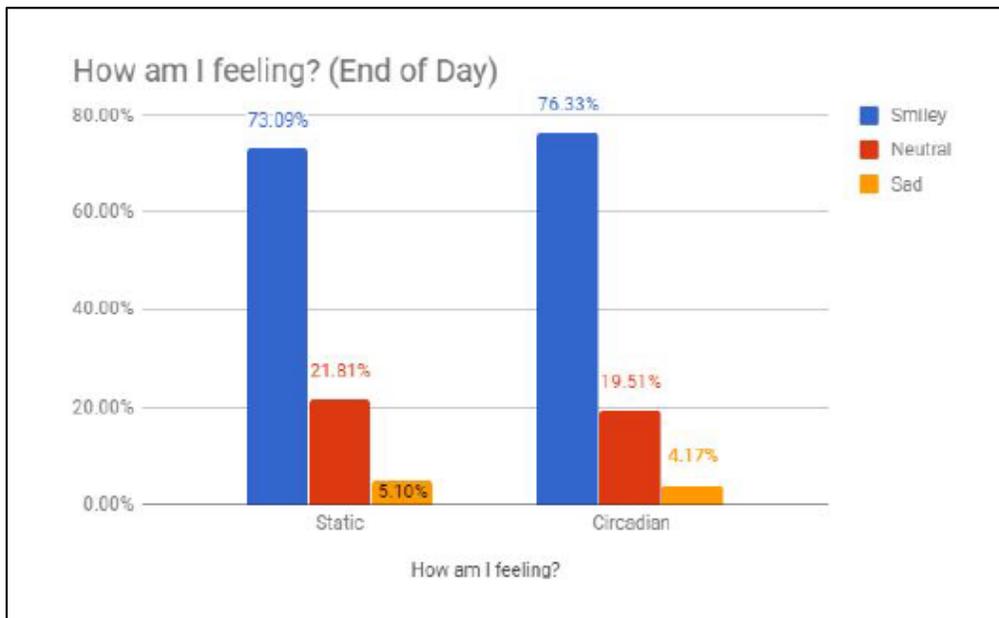


Figure 21: student responses to the question “How am I feeling?” for the End of Day surveys differed slightly across conditions at the end of the day compared to the morning. There was a higher proportion of Smiley face (increase from 73% to 76%) and Neutral face responses in the Circadian Lighting condition at the end of the day compared to the Static Lighting condition, and a smaller proportion of Sad face responses.

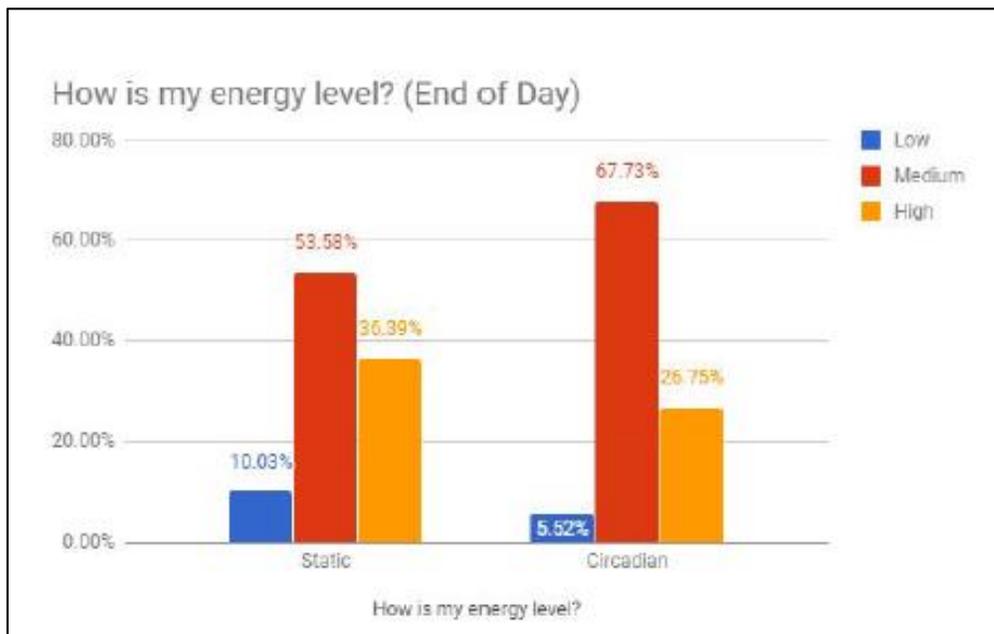


Figure 22: student responses to the question “How is my energy level?” show ed significant changes: The “High” decreased from 36% to 26%. The “Medium” increased from 53% to 67%, and the “Low” decreased from 10% to 5.5%.

- The last two questions in the end-of-day survey had very similar responses - the two questions were probably too similar to each other: “How was my on-task behavior today?” and “How well did I follow classroom expectations today?” However, the similarities across these two questions illustrate that:
 - These students overwhelmingly perceive their own behavior as being “Great.”
 - There were indeed slight increases across lighting conditions to the proportion of responses corresponding with higher levels of self-reported “Great” behavior (Figure 23)

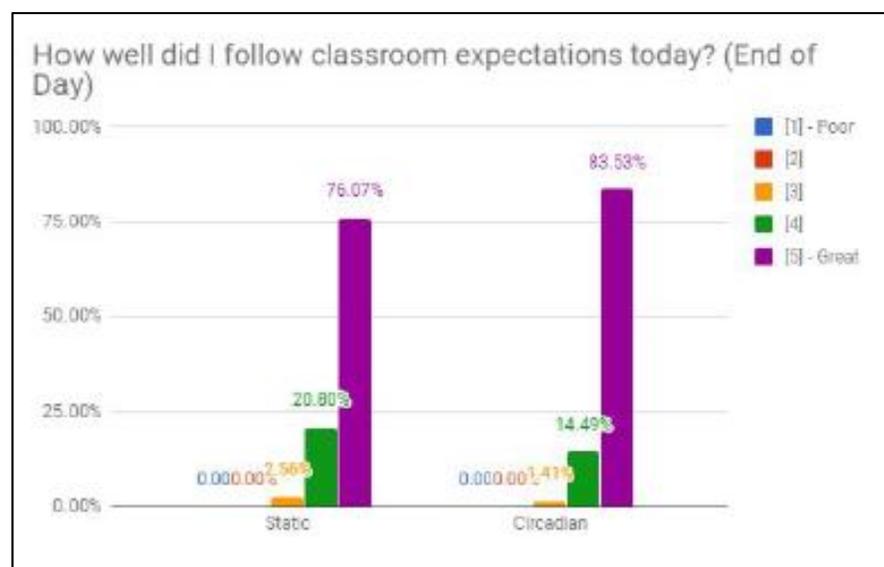
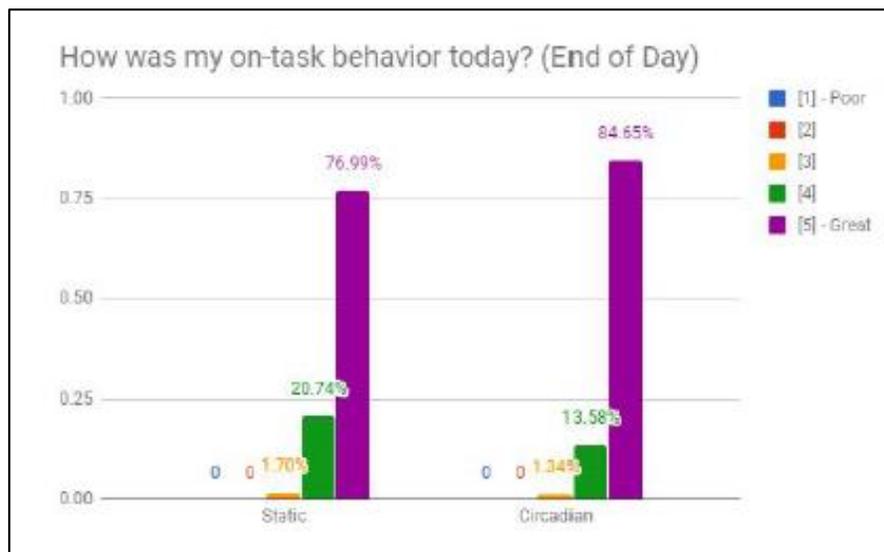


Figure 23: student responses to the question “How is my energy level?” showed significant changes: The “High” decreased from 36% to 26%. The “Medium” increased from 53% to 67%, and the “Low” decreased from 10% to 5.5%.

Survey conclusions

1. The circadian lighting may have had a *positive* effect on:
 - Students' self-reported on-task behavior
 - Students' self-reported sleep quality
 - Students' self-reported mood
2. The circadian lighting might have *some* effect on:
 - Students' self-reported sleep quality by day of the week
 - A small portion of students may be ambiguously impacted by circadian lighting (e.g. proportion of "Sad" responses to the "How am I feeling?" question in the morning). Maybe students just need exposure to the circadian lighting throughout the day to experience the effects - the proportion of "Sad" responses went down from the static to circadian lighting conditions in the end-of-day survey responses.
3. Based upon the responses that were given, the circadian lighting did not demonstrate any negative effects.

Considerations and limitations:

- There are fewer data points for the static lighting condition than the circadian lighting condition.
 - None of the data has thus far been run for statistical significance - this is a plain reporting of the "proportion of responses".
 - Students entered data anonymously, so morning to end-of-day effects couldn't be tracked by student.
 - Many of the hard copy responses did not include a date. That data could not be coded for lighting condition and largely went unused.
 - The progression of the school year coincided with the lighting conditions progressing from the static lighting to the circadian lighting condition. All of the effects observed could simply be students becoming more familiar to the school, classroom routine, teacher and peers, etc.
-

Suggestions for future studies:

- Survey a control class.
- Have a more robust mechanism for surveying teaching staff.
- Consider doing an A-B-A cycle of conditions through the year, and maybe a B-A-B cycle of conditions for a different classroom for comparison. The way this study was structured, all three classrooms went from static LED lighting (condition A) to circadian lighting (condition B), so the study progressed from the A condition to the B condition for all classrooms. A limitation of this approach is that it also coincides with the progression of the school year, changes in weather and other conditions that occur throughout the year.
- Track students anonymously through morning to end-of-day surveys to better explore lighting effects across the school day.

3.2 Families

As mentioned previously, only two families chose to participate in the home portion of this study. At the end of Phase 2, the project team conducted lighting audits and provided recommendations for the new tunable lighting system. After the systems were installed and commissioned, the parents completed an initial questionnaire followed by 14 weekly surveys. These surveys occurred during Phase 3 of the project. At the end of Phase 3, the project team conducted on-site interviews with the parents. Copies of the initial questionnaire, the weekly survey questions, and the final interview questions may be found in the appendix section of this report.

Results for Family #1:

- The child who lives in this home is an 11 year-old boy who would be classified somewhere between low and moderately functioning on the Autism Spectrum Disorder.
 - The results for the weekly surveys did not indicate any changes in sleep patterns that could be attributed to the lighting system. This makes sense since this young man did not have any issues with sleeping before the study began.
 - The mother told us that she and her son used to argue daily about the kitchen lights. Apparently her son thought the lights were too bright and kept switching them off. Since the original lights could not be dimmed and she needed them on in order to cook dinner, their son started to isolate himself. After the tunable lights were installed, they were able to agree upon a certain light level. The son now spends much more time with the family. Understandably, the mother is elated about this development. Furthermore, the behavior specialists said this very important since isolation is not healthy, and once it has become a pattern, is a very hard habit to break.
-
-

- The mother uses the color tuning features of the new lights as a visual cue for different activities. For example, when it is time for her children to do homework (in the afternoon), she switches to color temperature to “cool” (~5000K). When they are done with their homework, she switches the color temperature back to “warm” (~2700K). She said that the lights really help her boys focus on getting their homework done.
- The family uses wireless occupancy sensors to control the lights in the hallways and bathrooms. The lights are programmed to come on at very low levels and warm color temperatures at night.
- During our final interview, the mother offered the following comments:
 - “Overall better lighting quality – we are sleeping better through the night, less waking up at night.”
 - “Our preferred method for programming the lights is the phone app. We tried using a computer but it didn’t work well. It was not finding the lights so we had to enter the serial numbers. The app was much easier to use.”
 - “As far as operating the lights, we like to use the phone app and Google Assistant. Our older son connected the lights to his video games for effect.”
 - “We love the occupancy sensors!”
 - “The main barriers for others adopting this technology are cost and having to leave the old light switches turned on all of the time. We had to buy switch covers to prevent our kids from turning them off.”
 - “We would recommend this system to others. It is very easy to use.”

Results for Family #2:

- The child who lives in this home is a 10 year-old boy who has been diagnosed with Autism Spectrum Disorder (moderate to severe). His parents indicated that he had trouble falling asleep, but once he did, he did not typically wake up during the middle of the night.
 - The weekly surveys indicated a dramatic change in sleep patterns—specifically for the amount of time it took for the young man to fall asleep after being put to bed—from 30 minutes to 5 minutes over a 14 week period (Figure 24). At first, his mother would go in and check on him since he was so quiet—wondering if he had gotten up and went somewhere else, but he was asleep.
-



Figure 24: after the tunable lighting was installed in this home, the time required for this young man to fall asleep after being put to bed was dramatically reduced. Note that no data was available for week 6.

- The mother said that her son’s behavior remained fairly constant during the study with one exception: before the new lights were installed, he used to run upstairs in the dark (which made her nervous). Now her son waits for his parents to turn the upstairs lights on (via the phone app). The lights provide a visual cue to their son that it is time to go upstairs.
- During our final interview, the mother offered the following comments:
 - “The lights keep my son more centered and definitely help him fall asleep much faster.”
 - “We don’t consider ourselves technical but had no problem using the phone to program and operate the lights. We use the phone 90% of the time since it has all the features.”
 - “We prefer using the phone app to program and operate the lights because it puts us in control. If we had a remote, my son would try to change the settings”
 - “The main barriers to other parents adopting this technology are cost, lack of awareness and the complexity of the technologies that are out there.”
 - “The Philips Hue app was easy to use, no big deal to learn.”
 - “I would recommend using this system to anyone.”

3.3 Observations and Lessons Learned

This project provided valuable insights regarding using tunable-white LED lighting in classrooms and homes of students with ASD. Key observations:

- The feedback from the teachers regarding the new lighting system was overwhelmingly positive. All of them said the new system helped them teach more effectively. They loved the presets (e.g. Calm™) that were easily accessed via the keypad. Surprisingly, none of them wanted to use an I-Pad or smartphone to control the lights.
- The student surveys indicated slightly positive results with no negative impacts.
- The LED lighting system reduced the electric demand by 60-74%. However, the overall energy savings were adversely impacted by standby losses from the DMX controls. The standby losses comprised 40% of the total energy consumption of the new system.

In terms of percentage of load, these losses are disproportionately high, because the classroom lighting is only used around 1,500 hours per year, whereas the standby losses occur the remaining 7,260 hours per year. Customers who intend to use this system for future projects should work with the manufacturer to reduce or eliminate these losses.

- Training the teachers is the key to successful engagement. During a previous study conducted by the DOE⁴, the teachers did not actively use the lighting controls on a regular basis. During this project, two out of three teachers in this project actively used the controls because they were provided with an overview of circadian lighting principles and shown how to use the controls.
- The costs of the classroom lighting system were relatively high due to prevailing wages and the wiring of the original lighting system. The tunable-white feature and controls added 36% to the overall cost.
- Recruitment efforts for parents did not work very well. The project team believes that the parents did not believe the potential benefits were worth the effort to change. Working with agencies that provide support to children with ASD would likely have increased the credibility of this project and produced better results.
- The biggest impact from this project came from working with the families in the students' homes. Both families reported very positive results and strongly recommended using tunable-white lighting systems to other parents who have children suffering from ASD.

⁴For more information, please visit:

https://www.energy.gov/sites/prod/files/2017/10/f37/2017_gateway_tuning-classroom_0.pdf

4. Recommendations & Next Steps

- Based upon the feedback from the teachers and the positive student survey results, school districts should install LED lighting systems that are dimmable and include lighting control scenes such as “General” and “AV” mode.
- Schools districts should *consider* installing tunable-white LED systems for new classrooms—especially classrooms that will be used during the evening hours or for teaching students with ASD. Hopefully the cost of tunable-white LED lighting systems will become lower in the future.
- Based upon the dramatic improvements experienced by the two families who participated in this project, more research should be done in the homes for students with ASD.

SMUD’s next project (2019) will include partnering with non-profit organizations that provide support to families who have children with ASD. The new project will include providing circadian lighting systems for 30 families within our service territory. The 2019 study will focus on identifying changes in sleep and behavioral patterns.

Appendices

Appendix A – Morning Student Survey

Morning Student Survey

Did you sleep well last night?

Yes

No

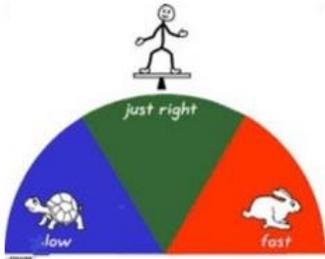
How am I feeling?







How is my energy level?



Low Medium High

Appendix B – End of Day Student Survey

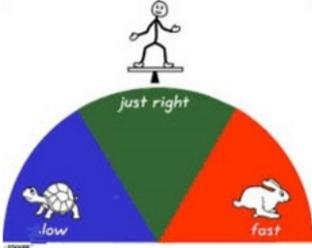
End of Day Student Survey

How am I feeling? How is my energy level?









Low Medium High

How was my on-task behavior today?

Poor 1 2 3 4 5 Great

How well did I follow classroom expectations today?

Poor 1 2 3 4 5 Great

Appendix C – Parent Questionnaire

SMUD Circadian Lighting Project (baseline questions)Date: [Click here to enter a date.](#)1. How old is your child? **(please check one)**

- 5-7 years old
- 8-9 years old
- 9-12 years old

2. What time does your child normally go to bed on **school** nights? **(please check one)**

- 8:00 to 9:00 p.m.
- 9:01 to 10:00 p.m.
- 10:01 to 11:00 p.m.
- After 11:00 pm.

Approximately how long does it take your child to fall asleep after they are in bed?

[Click here to enter text.](#)Comments: [Click here to enter text.](#)3. What time does your child normally wake up on **school** days? **(please check one)**

- 4:00 to 5:00 a.m.
- 5:01 to 6:00 a.m.
- 6:01 to 7:00 a.m.
- 7:01 to 8:00 a.m.
- 8:01 to 9:00 a.m.
- After 9:01 a.m.

Do you wake up your child in the morning on school days? [Click here to enter text.](#)Comments: [Click here to enter text.](#)4. What time does your child normally go to bed on **non-school** nights? **(please check one)**

- 8:00 to 9:00 p.m.
- 9:01 to 10:00 p.m.
- 10:01 to 11:00 p.m.
- After 11:00 pm.

5. Approximately how long does it take your child to fall fully asleep after they are in bed?

[Click here to enter text.](#)

Comments: [Click here to enter text.](#)

6. What time does your child normally wake up on **non-school** days? (please check one)

- 4:00 to 5:00 a.m.
 5:01 to 6:00 a.m.
 6:01 to 7:00 a.m.
 7:01 to 8:00 a.m.
 8:01 to 9:00 a.m.
 After 9:01 a.m.

Do you wake up your child in the morning on **non-school** days? [Click here to enter text.](#)

Comments: [Click here to enter text.](#)

7. **Before** you installed your new lights:

- a) Did your child mention being scared of the dark?

- Regularly
 Rarely
 Never

Comments: [Click here to enter text.](#)

- b) How many times per week did your child normally **wake up** during the night?

- Usually none
 1 time per week
 2-3 times per week
 4-5 times per week
 5-6 times per week
 Every night

Comments: [Click here to enter text.](#)

c) How many times per week did your child normally **get out of bed** during the night?

- Usually none
- 1 time per week
- 2-3 times per week
- 4-5 times per week
- 5-6 times per week
- Every night

Comments: [Click here to enter text.](#)

d) What were the lighting conditions in your child's room? Did your child use windows, blinds or curtains? [Click here to enter text.](#)

8. Are there any environmental cues/routines you use to signal bedtime to your child? If so, please describe them. [Click here to enter text.](#)
9. Please tell us why you decided to participate in this study. [Click here to enter text.](#)
10. What are your desired outcomes for this study? [Click here to enter text.](#)

Thank you for completing this questionnaire. Please send it to dave.bisbee@smud.org. If you have any questions, please feel free to contact me. Thanks!

Appendix D – Weekly Parent Survey Questions

SMUD Circadian Lighting Project: Weekly questions

Start date: [Click here to enter a date.](#)

End date: [Click here to enter a date.](#)

1. How many times per night did your child wake up during the night this week?

- None
- 1 time
- 2-3 times
- 4-5 times
- 5-6 times
- Every night

Comments:

[Click here to enter text.](#)

2. How many times per night did your child get out of bed during the night this week?

- None
- 1 time
- 2-3 times
- 4-5 times
- 5-6 times
- Every night

Comments:

[Click here to enter text.](#)

3. Have you noticed any changes in your child's sleep patterns? ▾

If you answered "yes", please describe:

[Click here to enter text.](#)

4. Have you noticed any changes in your child's behavior? [Choose an item.](#)

If you answered "yes", please describe:

[Click here to enter text.](#)

Appendix E – Parent Interview Questions

Parent Interview

Date: _____

1. Please provide us with an overview of how you are using your lighting system.
 2. Have your lights changed the way you use the spaces in your home?
 3. What is your preferred method of programming your lighting?
 4. What is your preferred method of turning your lights on/off?
 5. What do you see as the potential benefits?
 6. What are the challenges or downsides?
 7. What do you think is the main barrier for people using this system?
 8. Would you recommend this system to other parents?
 9. What changes (if any) have you noticed in your child's sleep patterns?
 10. Have there been any changes in your own sleep patterns?
 11. What changes (if any) have you noticed in your child's behavior? Have you received any interesting feedback from his teacher?
 12. Do you have any feedback or suggestions regarding this project?
-

Appendix F – Monitoring Equipment

Cadmus monitored the classroom lighting energy consumption using current transducers, Wattnode energy meters, pulse adapters, and Hobo RX3000 loggers. The RX3000s provided a cellular connection so all data points were visible from the online portal at Hobolink.com. A summary of installed power metering devices is provided below.

	Device Description	Location (Panel), Service	Quantity
	<p>Magnelab Current Transformers</p>	<p>Panel HD, Classroom D2 Lighting Panel HF, Classroom F6 Lighting Panel HG, Classroom G1 Lighting</p>	<p>1 1 1</p>
	<p>Continental Control Systems WattNode AC Energy Meters</p> <p>Onset S-UCC-M006 Electronic Switch Pulse Input Adapters</p>	<p>Panel HD, Classroom D2 Lighting Panel HF, Classroom F6 Lighting Panel HG, Classroom G1 Lighting</p>	<p>1 1 1</p>
	<p>Hobo RX3000 Remote Monitoring Station Data Loggers</p>	<p>Panel HD, Classroom D2 Lighting Panel HF, Classroom F6 Lighting Panel HG, Classroom G1 Lighting</p>	<p>1 1 1</p>

We monitored the pre-installation classroom light switch usage with on/off loggers and the post-installation keypad controller usage with custom Finelite data logging equipment. A summary of this equipment is provided in the table below.

	Device Description	Service	Quantity
	Onset On/Off Data Loggers	Classroom D2 Lighting Classroom F6 Lighting Classroom G1 Lighting	2 2 3
	Finelite Custom 'FineTune' Control Loggers	Classroom D2 Lighting Classroom F6 Lighting Classroom G1 Lighting	1 1 1