Abstract

Qualitative interviews were used to develop a questionnaire administered to users of supplemental lighting classified by SIC as in Ornamental and Floriculture or Growing Food Under Cover. Even with small number sampling, we find growth in LED use will likely be constrained by lighting being lower than many other organizational priorities which have higher impact. This is compounded by user's perception or actual analysis of LEDS not being economically justified, having a high initial capital expenditure and the belief that the technology is not mature. Most believe LED technology to be as effective as, but not better than, traditional HID or incandescent lighting but the long term operating costs about the same. These factors which slow technology adoption also limit the benefits of industry cost drivers of economies of scale and learning curve effects which would impact user's economic justification.

Method

In order to develop the instrument for quantitative analysis a series of in depth phone interviews was done with large greenhouse operations. Following these the survey was developed which appears in appendix A. The survey was administered electronically with a link being sent to businesses who have identified themselves as being in SIC code associated with Ornamentals and Flouriculture (SIC 0181) and Foods Grown Under Cover (SIC 0182). Using a list supplied by InfoGroup there were 2,208 emails with survey links which went out identifying myself as with Purdue University under a USDA SCRI grant using the survey only for research purposes. Open rates were about 20% with click through rates only around 2%. Potential respondents were emailed only twice if they did not open the first e-mail. Actual completion rate resulted only in 34 completed surveys.

Results

Rank order data is non-parametric and we can make no inference about the sample distribution. Ranks yield less information than an ordinal scale because two parties may rank one of the technologies as most important, but only relative to the other technologies. Even though it might rank as most important to both parties, there may be significant difference between the two parties on the actual impact. The Wilcoxon signed rank test is an alternative to the paired student t test but is used to determine the median of the sample.

The median can be interpreted as a score out of 10 with the results shown in Table 1. Heating, cooling, and watering all appeared to be the most important followed by pesticides and PGR application. Lighting median scores were significantly lower with traditional lighting scoring a 3.5 and LED lighting scoring a 3.0. With overlapping confidence intervals as shown in Figure 1, we cannot say that respondents saw any difference between lighting technologies. However, we can say that respondents find lighting less impactful than water, heat, cooling and other environmental controls.

In table 2 we see the results for reasons why people do not use LED lighting. Data was obtained using a Likert scale ranging from main reason, coded as 3, to not a concern, coded as 0. Many researchers have treated this ordinal data as having equal intervals and as such, used processes which assume a normal distribution (Blaikie 2003). However, we cannot assume that the difference between ‘major’ and ‘minor’ is the same as ‘major’ and ‘main’. Because of this we again use non-parametric methods for an estimate of the medians and associated confidence interval.

With respect to the responses, because the confidence intervals of ‘not priority’, ‘not compatible’, and ‘Radiant heat is necessary, we cannot reject the null hypothesis which says the median is 0, or the issue is not a concern. While the confidence intervals of ‘not economically justified’ and ‘high CapX’ appear to make these the most important issues, the estimated median is equal to the issues associated with the technology being immature and that users are looking for more benefits that just energy savings.

Table 3 represents responses for reasons why users of LEDs chose this technology. Energy savings, life or the product and maintenance all have the highest medians. However, the confidence intervals of the medians are rather broad and overlapping. Unfortunately, sample size of LED users was very small with only 11 observations for most factors and a maximum of 13 which leads to a broader range between upper and lower bounds. Even with small sample sizes, we can reject the null hypothesis that the median is zero; meaning the factor has no impact.

Respondents were asked to rate the efficacy as well as the ease of use for LED systems; the data is represented in Table and Figure 4. Efficacy was asked as two questions, the first as the primary source of lighting, the second question asked was regarding using LEDs as a secondary source. A 7 point likert scale was used which ranged in measurement from ‘Much Better’ (3) to ‘Much Worse’ (-3). Using similar methodology to above, we find the median is predicted as ‘somewhat better’ for primary lighting and we can reject the hypothesis that the median is zero, meaning that LED and traditional lighting perform ‘about the same’. We cannot reject the null hypothesis for LED usage as a secondary light source. With respect to ease of use, we find

the estimated median is ‘better’ with the lower bound of the confidence interval between ‘somewhat better’ and ‘better’.

Users were asked if they ever have gotten a price for LED systems and if they had done any financial analysis on operating costs. A seven point Likert scale was used to rank their price or perception of price from ‘much more’ to ‘much less’ with a similar scale used for ranking the operating costs. We find the estimated median to be between ‘somewhat more’,1, and ‘more’, 2. We reject the hull hypothesis that price or perceived price has a median of zero or ‘about the same’. We cannot reject the null hypothesis for the perception of long term operating costs. Our long term operating cost median confidence interval crosses zero with an estimated median between ‘about the same’ and ‘somewhat more’.

Respondents were asked to rate sources of credible information for LEDs in horticulture applications as seen in Table 6 and Figure 6. A three point Likert scale was used with choices of ‘very credible’ to ‘somewhat credible’ to ‘not credible or biased’. Academics, colleagues and evidence had the highest estimated medians, with academics and evidence having the highest upper bound on the 95% confidence interval for median estimation. Lighting suppliers of only LED systems were seen as the least credible, but with a confidence interval similar to all lighting providers. The confidence intervals allow us to reject the hull hypothesis in each case meaning that all are sources of credible information

Users of LED systems were asked to rank any concerns they have about the systems on a four point Likert scale. The scale was ‘main concern’, ‘major concern’, ‘minor concern’ and ‘not a concern’, with the highest score given to main concern and a score of zero corresponding to

'not a concern'. All concerns listed in the question scored an estimated median which was positive. However, only 'different effects on different cultivars', 'initial cost', and 'ROI' had 95% confidence internals which did not overlap with zero. This is not a very powerful test because of the small number of LED users found in the sample, 8.

Discussion

Because all businesses have limited resources we would anticipate more attention and resources being dedicated to those process or technologies which have the highest impact. Those processes which have less impact on their businesses will get less attention even if there is technological innovation assuming there is room for improvement in each of the categories. With respect to LED technologies and lighting in general, these parts of the business are not thought to be as impactful to the business as things like heating, watering, cooling, environmental controls and pesticides/PGR applicators. Important in the interpretation of the data is that a higher value cannot be interpreted directly because it is only relative rank and not absolute. A business may spend 5% of total expenses on lighting, and 50% on heat but rank them number 3 and 4 respectively.

The lack of importance in lighting compared to other items will likely slow the adoption of LED horticulture lighting. This is a result of two interaction effects. The higher the initial costs of LED versus HID the lower the return on investment (ROI) even though energy savings is large. With a small ROI, changing to LED systems does not raise in relative priority. Slower adoption

leads to less learning curve effects and economies of scale, both of which reduce production costs. Reduction in production costs, increases the ROI assuming prices also come down.

Slow adoption of LED systems can also be seen in the responses to why users do not use LED systems. The highest means are in lack of economic justification, high capital expenditure, and immature technology though the confidence intervals overlap with LEDs lacking evidence and users inability to try before they buy. Interestingly, these align very well with Rogers' belief that the five factors which govern technology adoption are relative advantage, compatibility, complexity (ease of use), trialability and observability (of consumption and benefit) One point to highlight is that economic justification and capital expenditure do correlate but they are different constructs. Users could find economic justification to using LED's however the operation could be undercapitalized or highly leverages and be unable to support the capital expenditure necessary for LED installation.

With respect to why users choose LED systems it would be convenient to say the main factors appear to be energy savings, life of the system and reduced maintenance which all have the highest estimated medians. However, the factors identified have overlapping confidence intervals with one pair exception, so the only thing we can determine is all of the factors have some importance (not zero median) but we cannot statistically identify which one at main drivers. This is most likely due to the sample size of 13 and more respondents would reduce the calculated variance resulting in tighter bands.

Respondents view the effectiveness and ease of use of LED lighting as somewhat better or better (respectively) than traditional sources. Thus, although users may believe the technology

is immature, they believe it to be very effective. Oddly though, the use of LED as a secondary source is rated as “about the same” as HID. This could be due to lack of specificity in the question where the intent was to capture uses such as intracanopy applications.

Non-users of LED systems were asked about the price or perception of price and long term operating costs, responses were given from those who did get pricing or calculate long term operating costs and those who did not. Thus if they did not get pricing they answered the question based on their perception. Respondents ranked price and price perception as ‘more’ but ranked long term operating costs as ‘about the same’. This is not surprising as these are the people non-users. Though not shown, there was no statistical difference mean response when separating those who did price out systems and those who did not or those who did long term operating costs and those who did not. However, small sample size is one probable cause of the lack of differences. Of interest may be that roughly half of the respondents of this question have gotten pricing (8 out of 14) and done economic analysis (6 out of 14). Conversely, the others have not bothered in getting pricing or doing long term cost analysis.

With respect to where people turn for credible information we find LED lighting suppliers and suppliers of all types of lighting, including LED, to be less credible than academics, colleagues or empirical evidence. However, there was no statistical difference between the two types of lighting suppliers. One would expect credibility of LED efficacy to be higher for suppliers who sell all types of lighting. Though the expected median is slightly higher, the upper and lower confidence interval are identical.

For those using LEDs, three concerns appeared relevant with those being the initial cost and actual ROI as well as the effects the LEDs might have on different cultivars. The other concerns of light uniformity, uniformity if grow configuration changes, actual life, obselecence, and lack of evidence cannot be statistically validated even though the expected median is greater than zero though in most cases, not much more than zero.

Table 1

	N	N*	Estimated Median	Lower	Upper
Hydroponics	31	3	3	1	4.5
Cooling Systems	31	3	6	5	7
Watering Systems	31	3	7.5	7	8
Heating Systems	31	3	7.5	6.5	8
Env Control	31	3	5.5	4.5	6.5
Pesticide/PGR	31	3	4.5	4	5.5
Lighting non LED	31	3	3.5	3	4.5
Lighting LED	31	3	3	2	4
Shade/Diffusion	31	3	2.25	1.5	3.5
Proc Automation	31	3	2	1	3

Figure 1

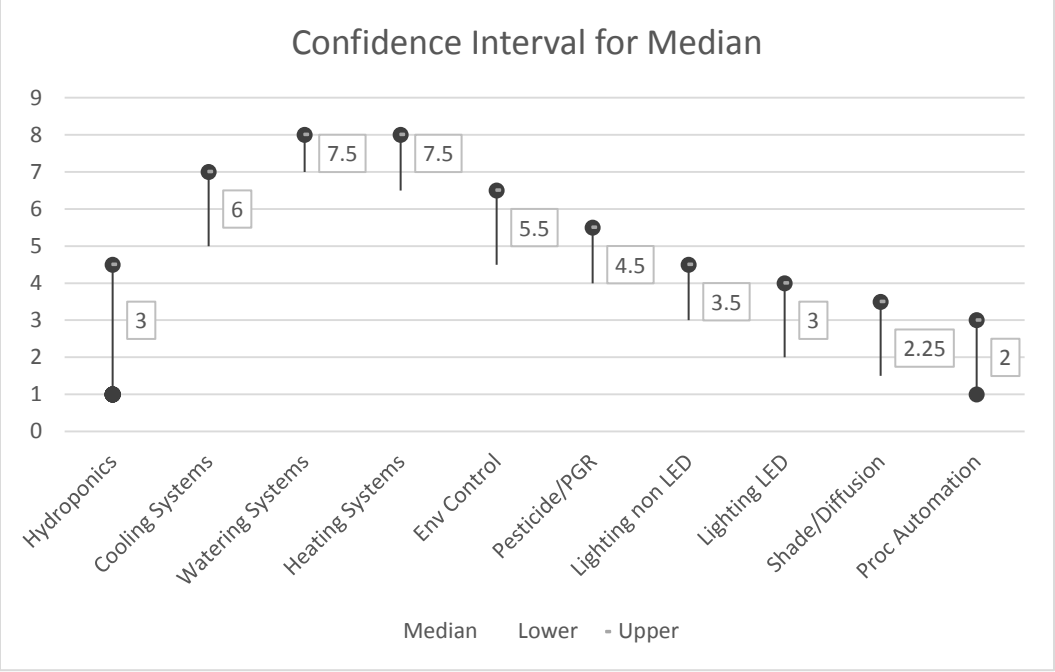


Table 2

	N	N*	Estimated Median	Lower	Upper
Not Econ Just	23	11	1.5	1	2.5
High CapX	24	10	1.5	1	2.5

Not Priority	23	11	0.5	0	1
Lacks Evidence	22	12	1	0.5	1.5
Not Familiar	22	12	0.5	0.5	1
Not Compatible	22	12	0.5	0	1
Info Trust	22	12	1	0.5	1
Not Mature	22	12	1.5	1	2
Cant Try	22	12	1	0.5	1.5
More Benefits	22	12	1.5	0.5	2
Need Radiant	21	13	0.5	0	1

Figures 2

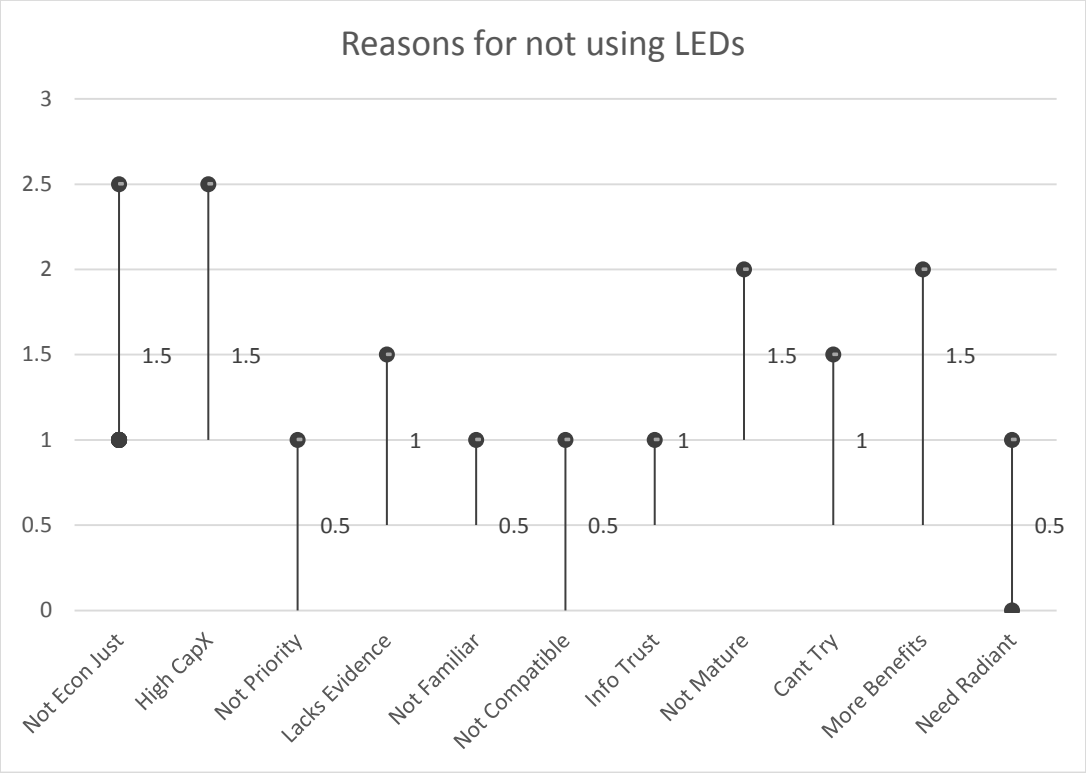


Table 3

	N	N*	Estimated Median	Lower	Upper
Energy Svgs	13	40	2.5	2	3
Cost Avoidance	13	40	2	1.5	2.5
Precise light	11	42	1.5	1	2
Low Heat Load	11	42	1.5	0.5	2.5

Spectrum	11	42	2	1	2.5
Life	11	42	2.5	1.5	3
Maintenance	11	42	2.5	1	3
Light Waste	11	42	1	0.5	2

Figure 3

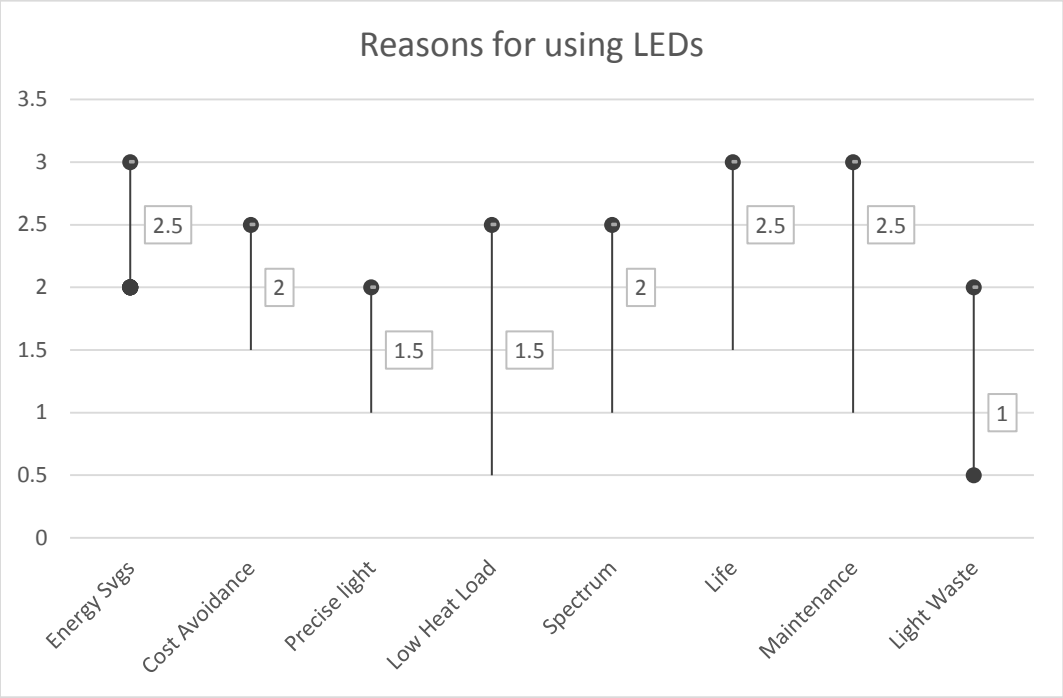


Table X

	Energy Svgs	Cost Avoidance	Precise light	Low Heat Load	Spectrum	Life	Maintenance
Cost Avoidance	0.628						
	(.02)						
Precise light	-0.113	-0.479					
	(.74)	(.14)					
Low Heat Load	-0.352	-0.793	0.828				
	(.29)	(.)	(.)				
Spectrum	-0.216	-0.608	0.935	0.935			
	(.52)	(.05)	(.)	(.)			
Life	-0.113	-0.479	0.817	0.676	0.818		
	(.74)	(.14)	(.)	(.02)	(.)		
Maintenance	-0.186	-0.492	0.891	0.738	0.899	0.966	

	(.58)	(.12)	(.)	(.01)	(.)	(.)	
Light Waste	-0.106	-0.536	0.249	0.49	0.474	0.66	0.55
	(.76)	(.09)	(.46)	(.13)	(.14)	(.03)	(.08)

Table 4

	N	N*	Estimated Median	Inter val Lower	Upper
Primary Efficacy	19	12	0.5	-0.5	1.5
Secondary Efficacy	19	12	1	0	2
Ease of Use	18	13	1	0.5	2

Figure 4

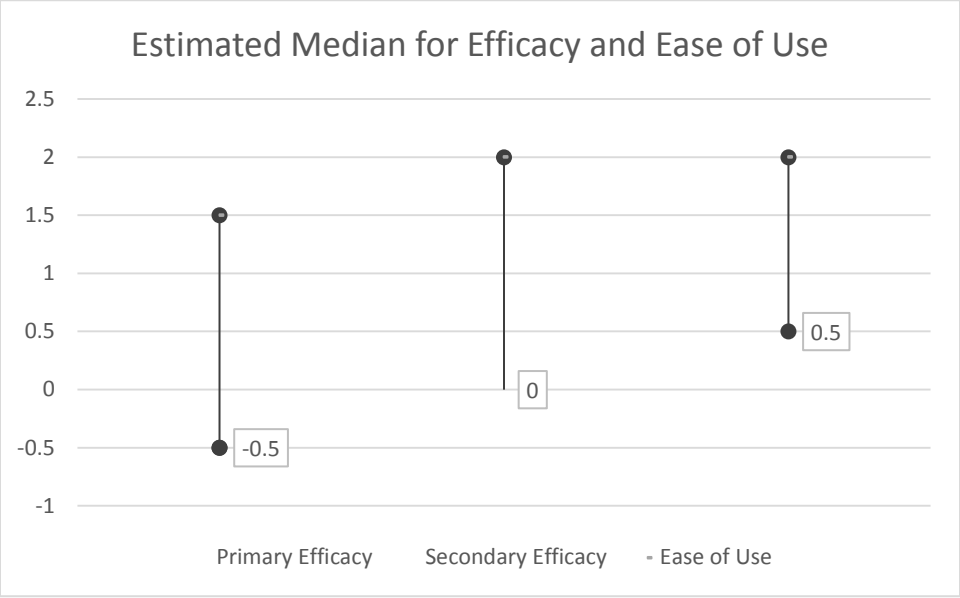


Table 5

	N	N*	Lower	Upper	Estimated Median
Price	14	17	1.00	2.50	1.50
Op Cost	12	19	-0.50	1.00	0.50

Figure 5

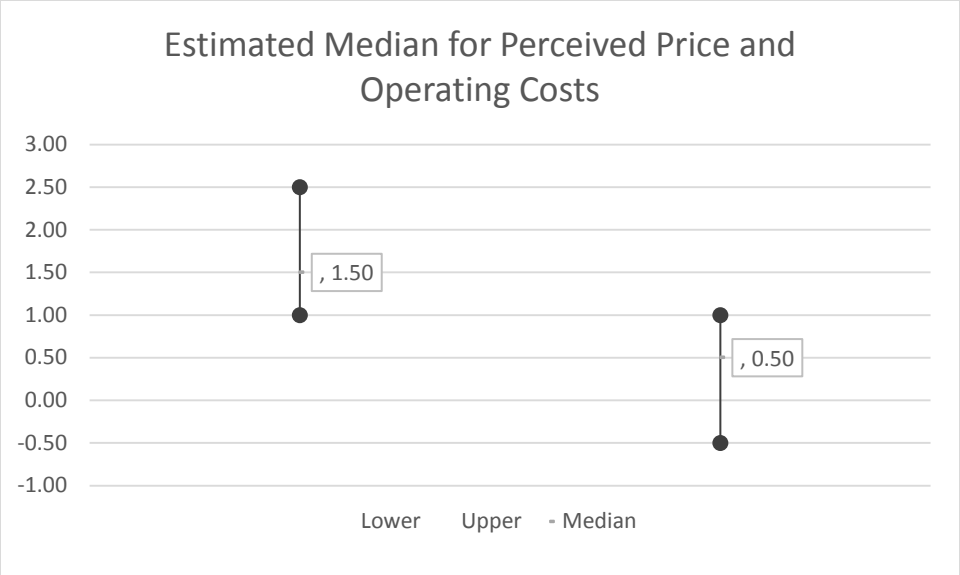


Table 6

	N	N*	Estimated Median	Confidence Interval Lower	Upper
Academics	26	8	1.5	1	2
LED Providers	27	7	0.5	0.5	1
All Lighting Providers	24	10	1	0.5	1
Colleagues	25	9	1.5	1	1.5
Evidence	25	9	1.5	1.5	2

Figure 6

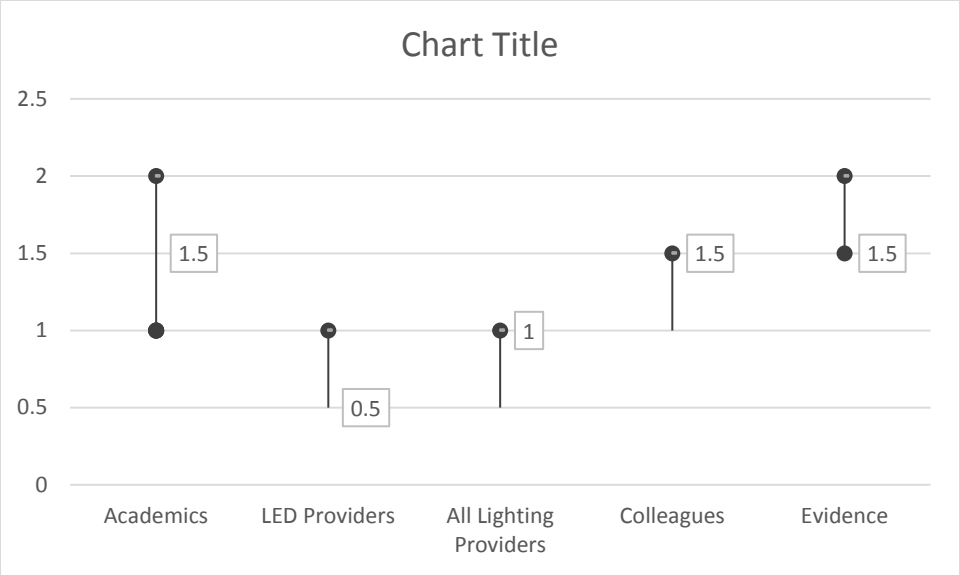
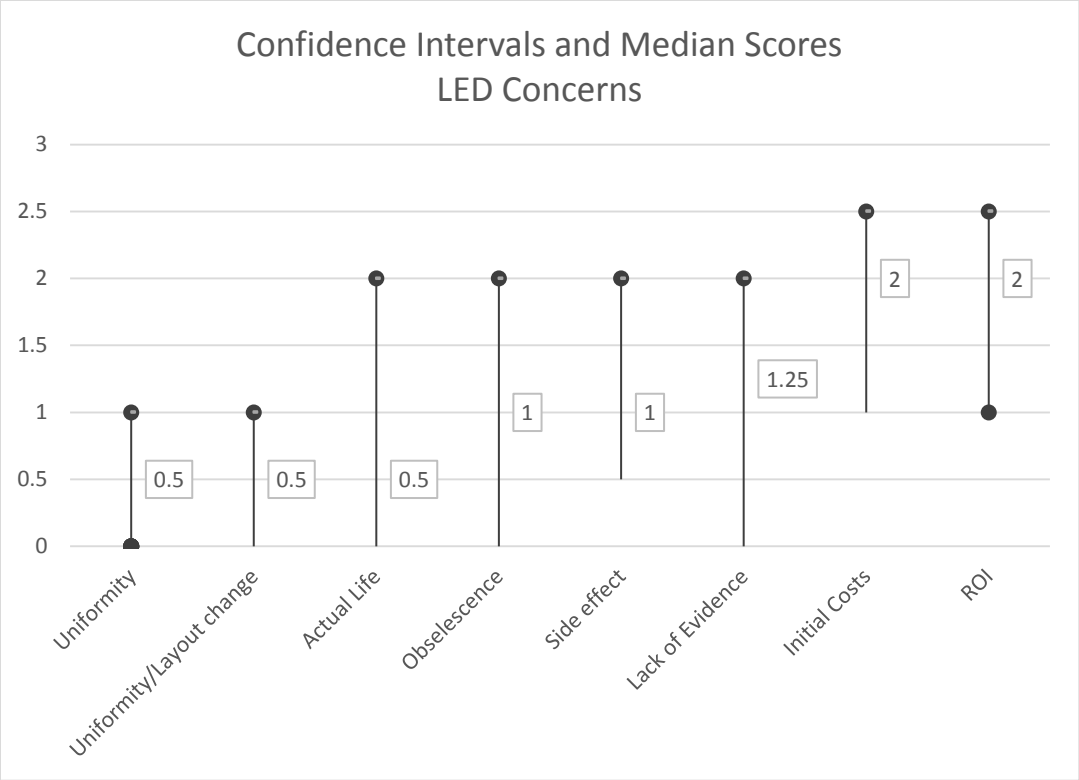


Table 7

	N	N*	Estimated Median	Confidence Interval Lower	Upper
Uniformity	8	23	0.5	0	1
Uniformity/Layout change	7	24	0.5	0	1
Actual Life	7	24	0.5	0	2
Obselescence	7	24	1	0	2
Side effect	7	24	1	0.5	2
Lack of Evidence	7	24	1.25	0	2
Initial Costs	7	24	2	1	2.5
ROI	7	24	2	1	2.5

Figure 7


Confidence Intervals and Median Scores
LED Concerns
3
2.5
2
1.5
1
0.5
0
0.5
0.5
0.5
1
1
1.25
2
2
Uniformity
Uniformity/Layout change
Actual Life
Obselescence
Side effect
Lack of Evidence
Initial Costs
ROI

Appendix A - Questionaire

LEDs in Horticulture

Q1 What type of plants do you grow in your greenhouse? Check all that apply

- ❑ Bedding Plants (1)
- ❑ Vegetables (fruiting) (2)
- ❑ Herbaceous perrennials (3)
- ❑ Plugs. liners and/or transplants (4)
- ❑ Potted flowering plants (5)

Q2 How would you rank the technologies below that impact your business? Rank by dragging the most important to the top, second most important to second place etc.

_____ Hydroponic systems (1)
_____ Cooling Systems (2)
_____ Watering systems (3)
_____ Heating systems (4)
_____ Environmental Control (5)
_____ Pesticide / PGR applicators (6)
_____ Lighting Systems (HID, fluorescent, incandescent) (7)
_____ Lighting Systems (LED) (8)
_____ Automated Shade / Diffusion systems (9)
_____ Process Automation (eg conveyor systems) (10)

Q18 What is the size of the production area under glass and how much of this uses supplementary lighting? Use any convenient units.

Q3 On average, how much supplementary lighting do you use? ie weeks per year, hours/day when used, and intensity

Q4 Do you currently use LED lighting systems in your grow areas?

- ❍ Yes (1)
- ❍ No (2)

Answer If Do you currently use LED lighting systems in your grow areas? No Is Selected

Q5 What are the reasons why you do not use LED technology?

	Main Reason (1)	Major Issue (2)	Minor Issue (3)	Not a concern (4)
Not economically justified (cost / benefit too high) (1)	❍	❍	❍	❍
Capital investment too high (2)	❍	❍	❍	❍
Economically justified but not a priority (3)	❍	❍	❍	❍
Not enough evidence of use in my field (4)	❍	❍	❍	❍
Not familiar enough with the technology (5)	❍	❍	❍	❍
Not compatible with current systems (6)	❍	❍	❍	❍
Do not trust information from LED lighting suppliers (7)	❍	❍	❍	❍
Immature technology / waiting for upgrades (8)	❍	❍	❍	❍
Would like to try before I commit to buying (9)	❍	❍	❍	❍
Looking for more than energy savings (improved growth) (10)	❍	❍	❍	❍
Radiant heat from HID is necessary (12)	❍	❍	❍	❍
Other (if 'other' the next question will ask you to specify) (11)	❍	❍	❍	❍

Answer If What are the reasons why you do not use LED technology? Other (to be specified below) Is Not Empty

Q13 Other concern(s) not listed above

Answer If Do you currently use LED lighting systems in your grow areas? No Is Selected

Q6 Perception of Price

	Your Price or Perception of Price							Cost - Operation	
	Much More (1)	More (2)	Somewhat More (3)	About the Same (4)	Somewhat Less (5)	Less (6)	Much Less (7)	Yes (1)	No (2)
Have you ever gotten a price for LED lighting systems installation? (1)	❍	❍	❍	❍	❍	❍	❍	❍	❍
Have you done an analysis of the long term operating cost of LED systems? (2)	❍	❍	❍	❍	❍	❍	❍	❍	❍

Answer If Do you currently use LED lighting systems in your grow areas? No Is Selected

Q16 Perception of Efficacy and Ease of Use. Primary Supplement means instead of HID, Secondary Supplement means in addition to HID

	Much Better (1)	Better (2)	Somewhat Better (3)	About the Same (4)	Somewhat Worse (5)	Worse (6)	Much Worse (7)
LED vs HID as Primary supplement efficacy (1)	❍	❍	❍	❍	❍	❍	❍
LED vs HID as Secondary supplement efficacy (2)	❍	❍	❍	❍	❍	❍	❍
LED vs HID Ease of Use (3)	❍	❍	❍	❍	❍	❍	❍

Q7 Source of Credibility for Utility/Efficacy of LED use

	Very Credible (1)	Somewhat Credible (2)	Not Credible or Biased (3)
Academics (1)	❍	❍	❍
LED lighting providers (2)	❍	❍	❍
Companies representing both technologies (3)	❍	❍	❍
Friends / Colleagues I know (4)	❍	❍	❍
Evidence in same type of application (5)	❍	❍	❍

Answer If Do you currently use LED lighting systems in your grow areas? Yes Is Selected

Q8 I use LED lighting for:

- ❍ Production (1)
- ❍ Test Basis (2)
- ❍ Multi-Tiered Production (4)
- ❍ Multi-Tiered Test (5)
- ❍ Night Interrupt to regulate flowering (7)
- ❍ Specific Applications (next question will ask to specify) (3)

Answer If I use LED lighting for: Specific Applications Is Selected

Q9 In what specific applications to you use LED lighting?

Answer If Do you currently use LED lighting systems in your grow areas? Yes Is Selected

Q10 Your use of LED lighting is primarily driven by:

	Main Reason for Use (1)	Major Reason (2)	Minor Reason (3)	Not Considered (4)
Energy Savings (1)	❍	❍	❍	❍
Cost avoidance such as power distribution (2)	❍	❍	❍	❍
Precise placement of light (3)	❍	❍	❍	❍
Ability to light with limited heat load (4)	❍	❍	❍	❍
Ability to specify or tailor light spectrum (frequencies) (5)	❍	❍	❍	❍
Anticipated life of product incl. light quality vs. HID (6)	❍	❍	❍	❍
Reduced maintenance vs. HID (7)	❍	❍	❍	❍
Reduced light waste / light pollution (8)	❍	❍	❍	❍

Answer If Do you currently use LED lighting systems in your grow areas? Yes Is Selected

Q11 My LED lighting was (optional)

- ❍ Purchased (1)
- ❍ Leased with term commitment (fixed term of committed payment) (2)
- ❍ Leased with no term commitment (clause included to return if dissatisfied) (3)

Answer If Do you currently use LED lighting systems in your grow areas? Yes Is Selected

Q12 Main concerns / dissatisfiers using LED lighting

	Main Concern (1)	Major Concern (2)	Minor Concern (3)	Not a Concern (4)
Lighting uniformity (general) (1)	❍	❍	❍	❍
Lighting uniformity when grow configuration is changed (2)	❍	❍	❍	❍
Actual life of system (3)	❍	❍	❍	❍
Obsolescence of current technology (4)	❍	❍	❍	❍
May have different effects on different cultivars (5)	❍	❍	❍	❍
Not enough evidence in practice (6)	❍	❍	❍	❍
Other (next question will ask to specify) (7)	❍	❍	❍	❍
Initial cost (initial capital expenditure) (8)	❍	❍	❍	❍
Return on investment (9)	❍	❍	❍	❍

Answer If Main concerns / dissatisfiers using LED lighting Other (next question will ask to specify) Is Not Empty

Q17 Please specify other main concern / dissatisfier

Blaikie N. Analysing Quantitative Data. London: Sage Publications 2003.