Optimal Lighting Decisions

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Abstract - **Arriving at the best decision to light a room is sometimes a tricky one (given the complex calculations that we have no clue about); Our research aims at explaining the effects of different parameters and conveying this to the user via intuitive visual encodings. We focus on calculation of optimal lighting required in a given room taking care of efficiency. In this paper we explain how users, with no prior architectural knowledge, can understand the best alternatives based on their preferences and also get a fair grasp on the complex calculations that go on in the backend. Our initial survey brought out the single most prevalent problem of lack of existing visual solution in this domain and we focus on bridging this gap using an explorable explanation in this research project.**

I. Introduction

According to U.S. Energy Information Administration, 11% of the electricity consumption in houses can be attributed to lighting, which is approximately 150 Billion kilowatt-hours. This accounts for the second highest electricity consumption after space cooling. Thus by using lighting efficiently and optimally, we can conserve a lot of energy. Alongside this, people spend a lot of money over lighting equipment and electricity and this can be reduced by ensuring efficient use of lighting. There is scope to improve this and bring the overall electricity usage to optimal levels. This is the reason our project focuses a lot on making the best lighting decisions for your house based on cost incurred to purchase the different types of bulbs, their yearly operating costs, environmental impact and the optimal placement of these light bulbs. This will ensure that power can be used efficiently and energy consumption can be optimized. The users have the option to choose from four different preferences i.e Low power consumption, Cost saving, Ecofriendly and custom settings. Following this, they can select from three different kinds of bulbs - Tungsten, CFL bulbs and LED bulbs, which best suit the requirement they are looking to fulfill, for example LEDs use 75% less energy than tungsten bulbs but are mostly used for task lighting as they provide harsh and direct light. The US Department of Energy has been recommending to phase out inefficient lighting products and there is no interactive platform or existing solution that nails this message. This explorable explanation aims at allowing user to make choices to light their homes: they will have the opportunity to weigh the performance of their current lighting setup to understand if they are getting enough light in a given room and also compare how different lighting products would work in different scenarios.

As part of our initial pre-work, we ran an online survey that asked questions about the level of knowledge about architecture or civil engineering, whether they care about optimal placement of light, whether they were satisfied with the current lighting arrangements, how they make lighting decisions and if they will be willing to use an application to guide them with optimal placement of lights. The results of the survey were interesting to us and gave us a very good direction to head towards. We received 92 responses on our survey, and one very interesting insight that we could derive is that although 61% of the respondents cared about optimal placements of lights, more than 50% of them were not satisfied with the current lighting arrangements in their house and 58% of them would be willing to use an application that can help them make these decisions. Additionally, 72% of the participants responded that they use personal judgment for making lighting decisions, and this is helps us scope our visualizations to bring in the technical aspect of lighting using intuitive visual encodings. We intend to empower users with all the knowledge they need to make independent decisions, without needing any prior architectural or civil engineering knowledge. In addition to this, we also make an attempt at conveying a strong message about the efficiency of different types of bulbs and the best practices around using them.

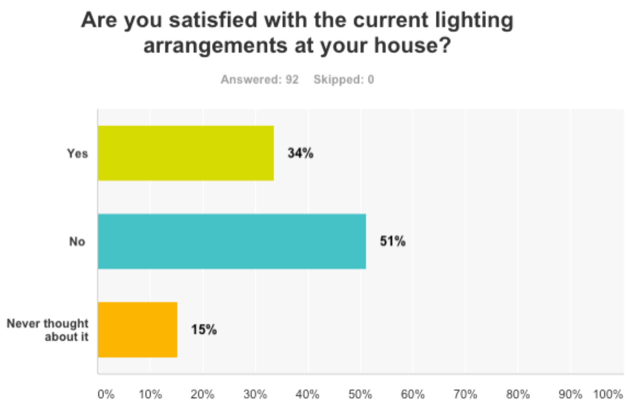

Figure 1. Survey Results

With the results of this survey, we integrated all the feedback received from a diverse set of user groups to create an explorable explanation using HTML, Javascript and D3. The user has the option to select from three different types of bulbs, four different power preferences, enter the dimensions of the room and vary the power of the bulb in use. These values after being retrieved from the user are substituted in a formula through which the total number of bulbs required in that particular room is calculated, the costs incurred to purchase the bulb and the average operating cost per year.

II. RELATED WORK

On conducting background research of relevant work, we found very few applications which allow the user to input parameters and calculate the number of lumens or watts needed and in some cases even the numbers of bulbs required but these do not visually represent this information. Thus leaving the user with a lot complex decisions such as how do the number of Lumens calculated translate to the number of bulbs required and what will be the best way to place them and ensure efficiency (both in terms of lighting and cost). Additionally, the provide no background on the technique used or the calculations happening, and they mostly expect the end user to be an architect or a civil engineer. Our main audience is the common user whom we want to empower with the same decision making ability that an architect or a civil engineer might be in.

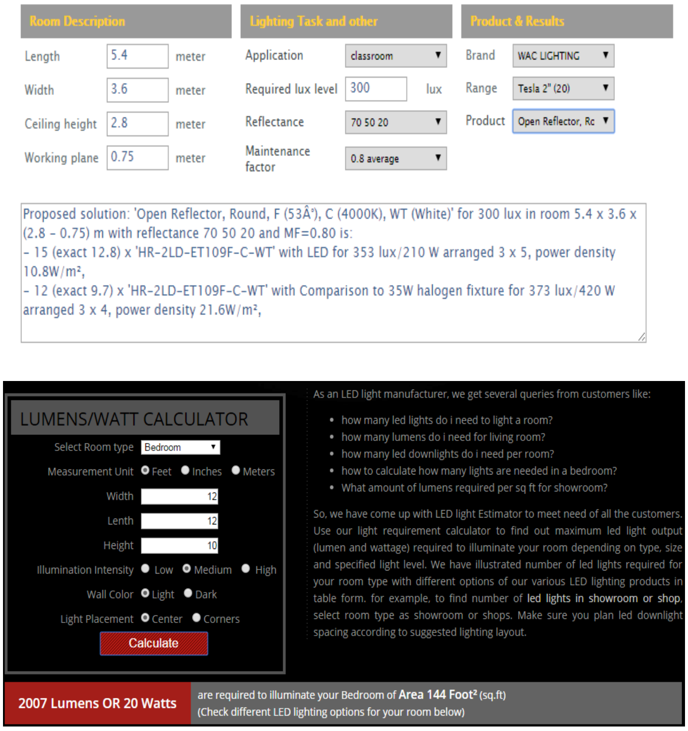

Figure 2. Related work

The bottom-line is that the existing frameworks are too complex to be used by individuals with no architectural knowledge and do not represent anything visually for better understanding in most cases leaving users more confused than they would be even before using the application.

III. METHODOLOGY AND IMPLEMENTED SOLUTION

Setting the right context is extremely important to convey a strong message and we begin by educating the user about the contribution of lighting in the total residential electricity consumption in a given year. This sets the right context and helps the user get a good hang of the bigger picture. We present this data using an interactive visualization that represents the estimated U.S residential electricity consumption as of December 2014, by US Energy Information Administration using a donut chart. Hovering over the donut allows the user to view the split by end use; and we highlight the electricity consumed in lighting in red because that is the most interesting feature to the scope of this explorable explanation.

From the visualization, the importance of efficient lighting is conveyed as 11% of the total electricity consumption goes into lighting, which is the second highest after space cooling. This gives us a great opportunity to fix this gap and bring it further down by helping users make informed decisions to save money and also have optimal visual perception levels.

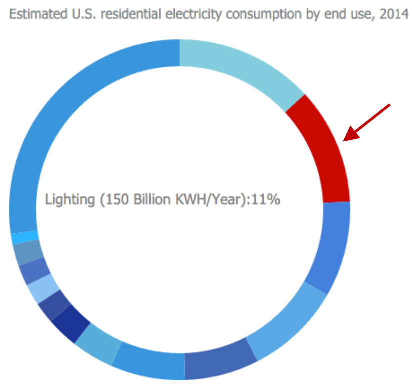

Figure 3. Electricity consumption statistics

Now that we have established a solid base for the user to grasp more information, we then educate the user about the different alternatives available in market for their lighting needs. Most users are not aware about these varieties and their unique selling propositions. Our objective in this section of the explorable explanation is to formulate the user's perception towards different types of bulbs: Incandescent, CFL and LED options. To set perspective, we compare these bulbs based on the 4 critical parameters:

1. Average lifespan (How long do these bulbs last on average before you have to replace them?)
2. Average cost of operating (average per bulb $ cost to operate over one year)
3. Average Efficiency in Lumens (How much light does the bulb emit per watt?)
4. Average Purchasing Cost (average base cost of each equivalent option in $)

Figure 4. Lighting Fixtures convention used

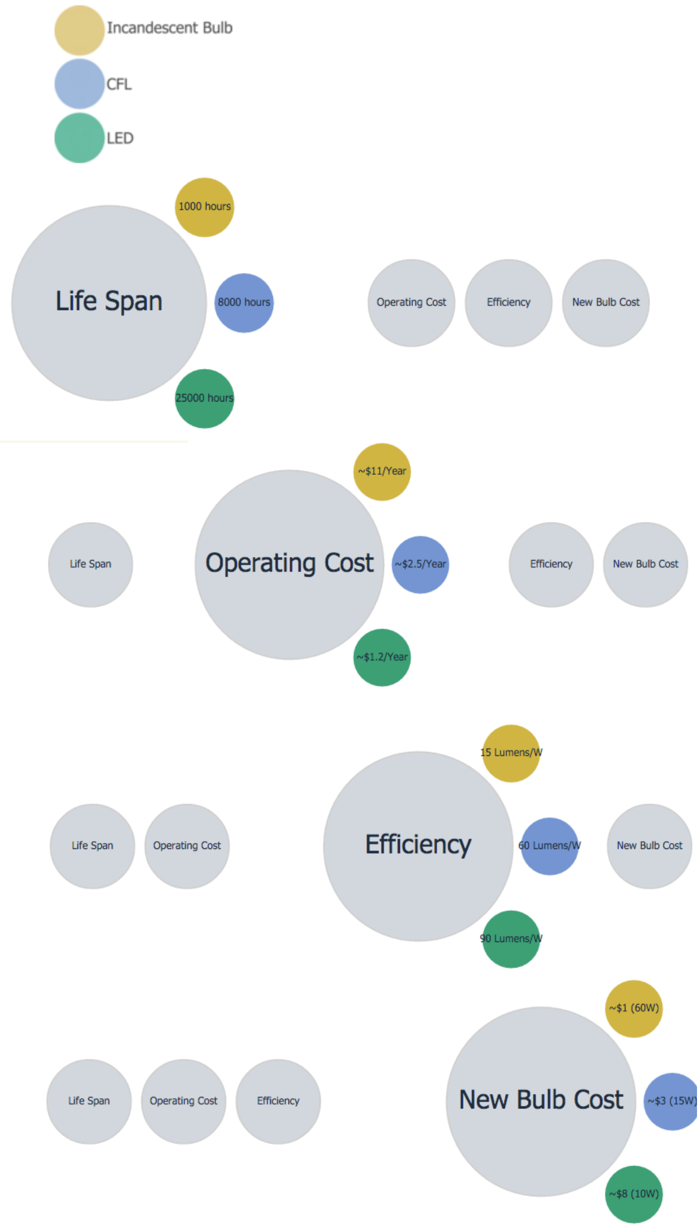

Figure 5. Lighting fixtures comparison

This comparison has been presented using dynamic bubble charts that highlight the attributes of each comparing option on hover. From the visualization we deduce that incandescent bulbs are cheaper upfront, but have a short lifespan and higher cost of operating in a year as compared to its counterparts. LEDs are most expensive, but last longer (much longer) with a low cost of operating. CFLs, sit midway between incandescent bulbs and LEDs.

In the last section of the explorable explanation, we present watch these salient features in action and help users make the best decision that takes care of the optimal lighting for a given room and also the combination of these parameters put together. The idea is to simplify the decision process and empower users with a visual solution to compare these attributes.

The final section of the explorable explanation mainly focuses on combining all the knowledge dispensed in the prior sections to help users make a final strong impression. Setting the prior context is helpful since the user has a good background to be able to interpret the final message and they feel more empowered too. We introduce the users to predefined values that they can pick from based on what they have learned so far, and also they are given an opportunity to modify the suggestions to see the final impact of their input. The following options are presented under user preferences to simplify the decision making process.

1. Low Power Consumption (KWH)
2. Low Cost (Cost of purchasing + operating costs in a year)
3. Eco Friendly (Least emissions)
4. Custom Setting

Figure 6. User preferences icons

The above icons appear as clickable buttons that the user can select to get the corresponding setup. When they select low power consumption, we look at all possible permutations and combinations of bulbs with their power values in watt to come up with the combination that takes up the least energy in a year. For cost saving option, we calculate the sum of cost of buying bulbs upfront, the cost of operating in a year and the overall lifespan for all the permutations of the bulb options and return the best combination. The eco-friendly takes into account the setting that would use the least number of bulbs with the lowest emission rates. This is mostly the LED option that fits best into these criteria. Also, the final option is the custom setting that allows the user to manually make any changes they would like to. Any changes made by the user to our predefined options would automatically navigate them into the custom setting option by default. Also, the default output takes into consideration the average room dimensions, which can be adjusted by the user to fit their own room dimensions in meters.

In addition to the above predefined intuitive options, we also allow the user to make all sorts of changes that fit their needs. The following are the customizable inputs that provide extremely flexible customization options to the user to understand the optimal lighting setup better:

1. Selecting from different types of bulbs
2. Selecting the type of room
3. Input the dimensions of the room
4. Selecting from different types of power preferences

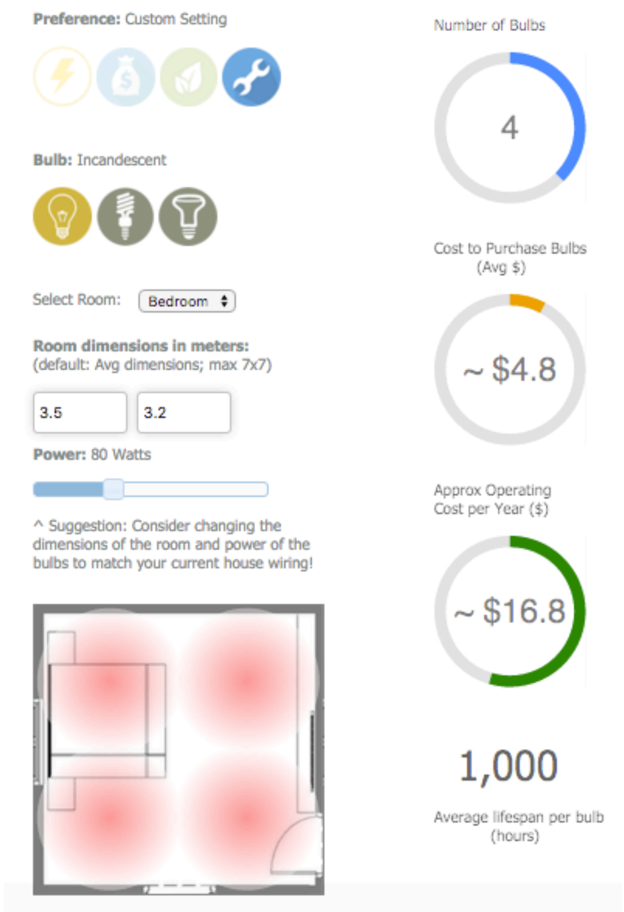

Figure 7. Striking the best combination

The visualization created is extremely intuitive and instantaneously accounts for any changes made by the user to the input. The default values for these parameters are the average standard values as per US convention, and are already fed into the system, in case the users are not sure of the values that they want to enter. The default dimensions for every room are predefined which can be changed by the user and a visualization showing the number of bulbs, the cost and the yearly operating costs, average lifespan of the bulbs and their placement in the room is shown. The idea of showing the bulb placement as a visual map of the room is just to help the user have a picture in mind. But this not set in stone and we understand that rewiring the house may not always be possible. The power of the bulbs in Watts can be changed using the slider to match closest to the number of fixtures available in the user's home.

This design can be taken into consideration while constructing wiring plans for new houses and but may not serve as a placement guide for existing homes. If the suggested number of bulbs do not match the number of current slots in the room, the user can vary the power of the bulb to increase or decrease the number of bulbs accordingly. The formula used to perform these calculations is displayed at the top to help the user gain a better understanding of how these results are obtained ensuring maximum transparency.

The three major calculation techniques used to achieve the desired results are as follows.

A. Lumen method of calculation

In lighting design, the lumen method is a simplified method to calculate the light level in a room. In its simplest form, the lumen method is merely the total number of lumens available in a room divided by the area of the room. In order to perform this calculation, many factors, coefficients, lumen data and other quantities must be gathered. A lumen is a measurement of light, just like watts, which measure the power consumed by the bulb. The brightness of every bulb varies and the amount can be quantified by the lumens value. The higher the lumen rating, the greater the light output. Every room has a different requirement of lighting to perform the tasks at hand.

This is the most widely used method for lighting design to determine a lighting layout to provide luminance on a horizontal plane. The Formula used for the calculation is:

$$\text{Number of Bulbs} = \frac{\text{Avg. Horizontal Illumination (Lux) x Area of the Working plane in sq.m}}{\text{Power x Lamp Lumens x (Utilization Factor x Maintenance Factor)}}$$

Where,

N = Number of bulbs
E = Average horizontal illumination at the working plane in lux
A = Area of working place in square meter
F = lamp lighting design lumens
U = Utilization factor
M = Maintenance factor

Thus the number of bulbs required for a room can be calculated given the area of the room and the lumens required. The lumens are calculated based on the dimensions of the room and the average horizontal illumination at the working plane, Utilization factor and Maintenance factors are constants and in our study we use the values 0.5 and 0.8 for these constants in all our calculations.

B. Prime factorization algorithm for bulb placement

In our explorable explanation, we present the visual map of the rooms for the user's imagination, and we also go ahead and place the bulbs upon calculation. This was a challenging process to come up with the algorithm to distribute the bulbs, as increasing number of bulbs would require some sort of distribution mechanism to govern the placement. After looking at many different alternatives, we finally zeroed down on a prime factorization technique to decide how the bulbs should be grouped together. Again, we want to reinstate the fact that this seems to be the best arrangement, but we have not conducted a scientific to validate the behavior of different placement techniques.

```
function primeFactors(n) {
  var factors = [],
      f;
  while (n > 1) {

// Calling the function for finding the factors
factors.push(f = factor(n));
    n /= f;
  }
  return factors;
}

function factor(n) {

  // Preserving the combination of 4 bulbs
  if (n % 4 === 0) return 4;

  for (var i = 2; i <= n / 2; i++) {
    if (n % i === 0) return i;
  }
  return n;
}
```

Figure 8. Prime factorization algorithm for bulb placement

We group bulbs together in symmetry, we could possibly ensure an even distribution of light throughout the room. Using this technique, we find out the prime factors of the number of bulbs obtained from the calculation and group the bulbs according to the product of prime numbers. For example if a room requires 6 bulbs (N = 6), the prime factors of 6 will be 2 and 3 (2 * 3). Now we form 3 groups having 2 bulbs each and place these in the room ensuring there is symmetry.

C. *Cost of purchase and operating cost per year*

For all our calculations, we use the average cost of each type of bulb in the market to ensure a fair and transparent process. The following are the values we consider for each option:

1. Tungsten – $1.2
2. CFL – $3
3. LED – $8

Based on the number of bulbs suggested to the user, the total cost to purchase is calculated using the following formula:

*Total cost = Number of Bulbs * Average cost of bulb*

Operating cost per year is calculated using the following formula:

$$\frac{(\text{Number of Bulbs} * \text{Power}) * (\text{Hours of use} * 0.12 * 365)}{1000}$$

Where,

0.12 represents the Average residential price of electricity in the U.S. (12.66¢/kWh).

Hours of use = the average number of hours the bulb is used in a day based on the type of room selected. The values are as follows:

1. Bedroom – 1.2 hours
2. Living – 1.7 hours
3. Kitchen – 2.3 hours
4. Bath – 1.2 hours
5. Dining – 1.5 hours

365 = To calculate the yearly cost

IV. RESULTS

The result of this visualization is to help user understand all the steps that go behind making efficient lighting decisions.We start with with making the user understand the importance of efficient lighting, subsequently explaning about the various types of bulbs and empowering them all the knowledge they need to interpret the results. The final visualization is extremely interactive and calculates the number of bulbs required, the placement of these bulbs, the purchasing costs and operating costs involved on the fly. This project takes care of the user needs from start to end and also empowers them with all the information they need at every stage. We present the user options such as Low power consumption, Cost saving and Eco friendly preferences to choose from to make it easy for them to use the explorable explanation to effectively resolve their needs. Every piece is knit with the help of visual messages that are very easy to perceive and clearly understood.

The visualizations our system produces are easy to use and understand by the users. The interactivity element of the visualizations makes it interesting and appealing to the users. On entering the values in the requested field, the visualization is instantly generated and updated, without any need to push a button to be able to view the changes, thus making it extremely smooth and effortless for the users.

V. DISCUSSION

Through this project, the users can dynamically alter the values of different parameters using HTML elements such as dropdowns, sliders and text boxes to create visual charts to aid user' understanding of the various factors to be considered to make lighting decisions. To display the bulbs in the room, they are placed on top of the floor plan of the room selected by the user. Their placement is decided by the prime factorization technique and they visually represented using circles which are denser in the center and their intensity fades as the radius increases. This is to ensure that the user has a rough idea about the area a particular bulb will illuminate and give the users a feel of how these bulbs will light up the entire space or room. The audience is also exposed to different kind of visualizations such as donut chart, bubbles and rings constructed in D3 to give out useful information and statistics to the user and make the application more visually appealing.

VI. SUMMARY

To conclude, this project addresses the issue of complex calculations behind making lighting decisions by individuals. Our main audience is the common users that have very little or no prior knowledge about these terms. Using this, the user can easily assimilate the various factors that come into play in making such decisions and eventually will help them make optimal lighting decisions just by entering the dimensions of the room and selecting the type of bulbs they would like to use and the associated power. On doing this, the users will be able to determine the number of bulbs they should use, the placement of the bulbs and also which arrangement will lead to maximum cost savings and efficiency.

VII. FUTURE WORK

To expand our work in the future, we would like to further improve upon the placements of the bulbs to be more flexible and in accordance to the wiring plans of the user's house. The user may be able to input the number of sockets present in a particular room and the number of bulbs and their power should be consistent with the given information. This way the user does not have to worry about falling short of sockets to achieve efficient lighting arrangements.

Additionally, our design currently does not accommodate for having different types of bulbs in the same room based on the activities performed in the room. For example, if users have a study table in their bedroom, they will require a targeted LED to focus on the table in addition to the other lighting arrangements in the room whereas others might have a dressing table in their room which might have different requirements. Thus we wish to accommodate for such differences and add bulbs based on such needs. We can also extend this work further by adding functionality of changing the color of the light based on the type of bulb selected to help the user differentiate between the different types of bulbs used and make it more visually appealing in the same room.

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