LightLogger: Eco-feedback Design for Sustainable Light Usage

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ABSTRACT
Light pollution, also known as photo pollution is excessive, misdirected obtrusive artificial light. Over-illumination refers to the excessive use of light. Lighting is responsible for one-fourth of all electricity consumption worldwide, and studies have shown that over-illumination results in energy wastage. Previous HCI research has contributed to the design of eco-feedback systems, behavior change for sustainable electricity consumption, and focused on various other environmental behavior changes in general, rather than this specific narrow problem of light pollution. In this paper we explore the design of a system that tries to motivate people towards sustainable light usage. Initially we conducted an online-survey to gather inputs and requirements from the people. Based on the inputs and feedback , we designed a system that could be used by people to visualize their light usage. We then conducted a pilot study of the system and present our findings.

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Eco-feedback Design, Light Pollution, Sustainable Consumption, Light usage.

ACM Classification Keywords
H.5.m. Information Interfaces and Presentation (e.g. HCI): Miscellaneous

INTRODUCTION
Light pollution is a phenomenon that in general occurs in great cities and that are responsible for a huge energy waste. For example, in the United States, the over-illumination is responsible for approximately two million barrels of oil per day in energy wasted [17]. In Canada, lighting accounts for 14% of the total household electricity consumption, second highest after space heating. Though this may not be the highest contributor to the electricity consumption, the inefficiency associated with light usage is pretty high. For example, most of the bathroom lights are on for at least two hours a day, which results in approximately 20Kwh or $20 per year [14].The numbers may not be huge, but we have to note that these numbers are only for one small room(bathroom) in a household. Considering this, on average there are 30 light fixtures per household in canada [3], and the total usage contributes to $131 per year.

Medical research suggests that over-illumination and light pollution can have adverse health effects such as fatigue and increase in anxiety. Hence this problem of over-illumination and light pollution could be brought under control by efficient use of lights and sustainable behavior.

Government policies and rules do have pivotal a role in determining the energy consumption of a geographic location. However, government policies are not always successful in bringing about a behavior change. For example,the 1997 Kyoto protocol did not serve the purpose of conserving world's energy needs as some of the countries rejected the collective international request for conserving resources. Hence eco-feedback design has been one of the prominent research areas in HCI.

Considering a narrow problem about light consumption, we have observed that it is very common for people to use lights inefficiently. Sometimes this is due to negligence and sometimes people forget to switch off the lights. And, these incidents happen occur very frequently. Though the resulting inefficiency and wastage may not be huge or alarming in terms of numbers for one single occurrence of such negligence and forgetfulness, it can be significant when such behavior occurs frequently.

Hence we try to explore a design aimed at this particular problem. Our design is based on the following questions:

- *Does visualizing light usage rather than the electricity usage as a whole bring about a change in the light usage behavior?*
- *Will the popular, tried and tested techniques from motivational psychology such as rewards, goals, social comparison be successful in tackling a narrow problem of light usage? Will they help in promoting behavior change?*

This paper is organized as follows. Firstly, we briefly review the relevant previous work related to eco-feedback designs , energy consumption and water usage. Secondly, we explain how our survey, essential for our design, was conducted. Thirdly, we describe our design, which is classified into four different themes: Light Usage Visualization, Comparison, Goals and Rewards. Fourthly, we briefly illustrate our implementation details and then, we describe our Pilot Study. We then provide, analysis of the collected data, and present the results and implications of our findings. Finally, we comment on some possible future work, limitations of our work and present some conclusions.

RELATED WORK

Our idea is narrow if we compare it with the huge problem of energy consumption or over-illumination. Eco feedback has become a prominent focus of sustainable HCI research exploring areas including electricity consumption, water usage, transit, and waste disposal. HCI researchers have built quite a few eco-feedback systems for monitoring and visualizing energy consumption. A power aware chord is one such design [10] which changes its color based on the consumption. In [16] the researchers have described a system that monitors the residential energy consumption. Researchers have also used various metaphors such as Oak trees for visualizing the carbon foot print of a building [12]. However, these only try to provide feedback and visualization of the energy consumption and dont motivate the user towards sustainable energy use. The eco-feedback design [7] and Transtheoretical Model(TTM) [11] provide exhaustive information of various methods that could be used to bring about a behavioral change towards energy consumption. [8] provides the design and evaluation of the eco-feedback displays for fixture-level water usage. Disaggregated end-use energy sensing [9] surveys the dis aggregation techniques for energy-consumption and highlight significant features that might be used to sense disaggregated data in an easily installed and cost-effective manner.

ONLINE SURVEY

Before we zeroed in on our design, we conducted an online survey to gather requirements from the people and inputs about their general daily energy consumption. The survey was pilot tested on two participants and then it was finally hosted on the popular on-line platform *SurveyMonkey.com*. The survey had 9 questions and the list of questions could be found in Appendix 1. In order to maintain the privacy of the participants we use Respondent(R) to refer directly to the participants.

Survey Respondent Demographics

The survey was sent to all of our friends residing in various parts of the world. The survey link was also posted on one of the Facebook group pages of the University Of Calgary Residence. A total of 15 surveys were completed. Most of the survey respondents(11/15) were graduate students from the University of Calgary which consists of 73.33% of the total participant count. Out of the other 4 participants, 3 responses were from India and one was from the United States of America.

Survey Outline And Data Analysis

As mentioned previously the survey was designed to get information about the general energy consumption habits of the respondents. Out of the 15 respondents 7 participants felt that they were efficient and 6 felt that they were inefficient. The remaining two felt that thought they were efficient they had room for improvement. Out of the 15 participants 12 of them felt the need for conserving energy, which suggests that we had a set of environment friendly participants. Out of the three remaining participants 2 of them did not feel the need because they felt they are efficient, and the remaining one stated that only sometimes he feels the need to conserve energy. Most of the participants(8/15) felt that visualizing the inefficient energy usage would bring about a change in their behaviour. Only 4 felt that it would not have effect on their behaviour and remaining three of them stated that it depends on the visualization. The following response illustrates the response given by one of the three participants who stated that behaviour change depends on the kind of visualization.

“I think for me it wouldn’t change much, I know because I see the bill every month, I think if you could show it in a way that would save people money by showing them their behaviour and ways they could change it to save money, you would reach a lot more people” -R13.

However these numbers change with respect to visualizing daily light usage. 10 of the participants replied that they were willing to care about the light usage, while 2 of them replied saying that it would not make much of difference, one of such replies is shown below.

“Not really since I am in the basement. So lights are needed.”-R7

The three remaining participants said that they would care if it actually showed flaws with respect to their light usage. 10 of the participants (66.66%) felt that goal setting would help them in reducing their energy consumption. 3 of the remaining 5 felt that it would not help, and the other two were unsure if it could make a difference.

With respect to comparing the energy usage with other people in the neighborhood we received many varied responses. One of the participants skipped the question and only two of them felt that it would not make a difference.

“Even though my household is not particularly efficient we are probably on the efficient side of the population so if that turned out different we may be more motivated to make changes. It should be noted that of our electricity bill over half of it is for other charges than energy so this is a huge disincentive to save energy.”-R12

This reply by one of the participants shows that comparison might play a key role in bringing about a behavior change with respect to energy consumption.

Based on the above survey observation we decided to have four themes for our design : Light Usage Visualization, Comparison, Rewards and Goal Setting. The next section describes these themes of our design.

DESIGN

Taking into consideration, the responses we got from the online survey our design is based on the following themes:

- Light Usage Visualization
- Comparison
- Goals
- Rewards

Light Usage Visualization
Light usage visualization refers to showing the information about the daily light usage in a way that could be easily understood by the people. Since cost is one of the factors, as suggested by one of the responses given by the participants, we have included it in the design as well. We have categorized the visualization into three different views.

General Information View

This gives an overview of the light usage. The number of hours in the day the lights have been used. Last time when the light has been switched on. The cost in dollars associated with the usage, the carbon emission and the number of trees needed to be planted in order to offset the carbon emission. Though lights do not contribute to the carbon emission, the generation of electricity that is contributing to the light usage contributes to the carbon emission. Hence by using lights or electricity in general, we indirectly contribute to the carbon emission. The view is shown in Figure 1.

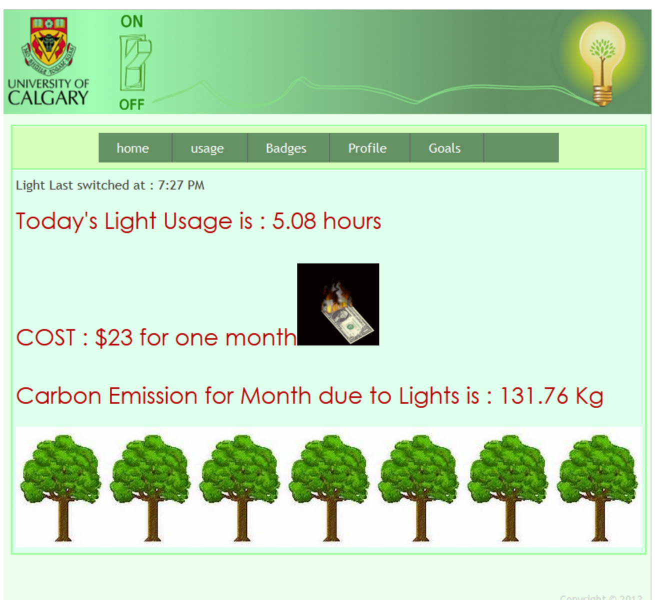

Figure 1. General information view

Room -Level Usage

This particular view shows the light usage across the various rooms in the house. This view could be implemented by having light sensors installed in each and every room. Although we do have some technical challenges of having such a view, our focus here is on the idea of presenting the information on per room basis to the users. The room-level view is shown in Figure 2. As shown in the figure the bar chart represents the number of hours the lights have been switched on in each and every room. The pie chart on the other hand is in the form of an animation which shows the percentage wise light consumption in each of the rooms.

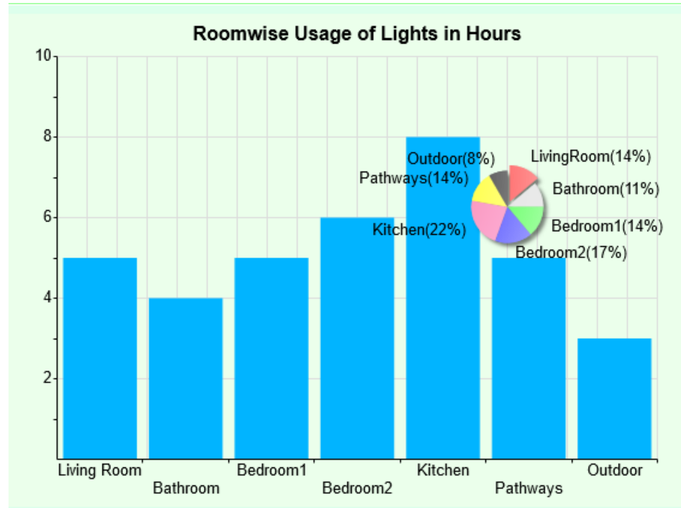

Figure 2. Room wise usage

Week Wise usage

This view shows the usage trends over a five-day period of a given week. This view has been designed with an intention of giving the users a chance to introspect their weekly light usage. The pie chart shown in Figure 3 shows the light usage distribution in percentage over the five-day period.

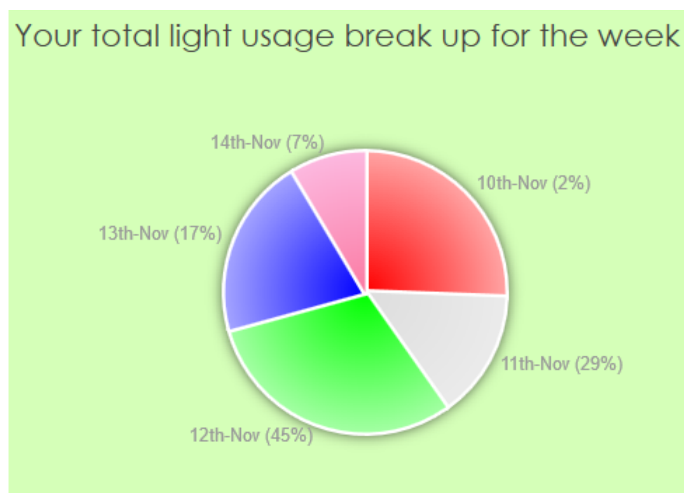

Figure 3. Light Usage Breakup over the week

Comparison
Visualizing information is important but only providing information might not motivate behavior change [4]. Comparing the current energy consumption levels to the energy levels of the neighborhood could bring about cognitive dissonance. This was also supported by the following quote:

"Its human nature to compare ourselves to others and to get cues on out behavior by the actions of others"-R14.

This was one of the responses we got during our online survey when asked about comparison with others in the neighborhood. This has prompted us to include the comparison of light usage of a household with others in the neighborhood. Figure 4 shows the comparison of a household with others in the neighborhood. The two bars associated with a household represent both the daily usage and the average usage over the week. The bar on the left shows the daily usage of the lights and the bar next to it shows the average usage over the week of a particular household.

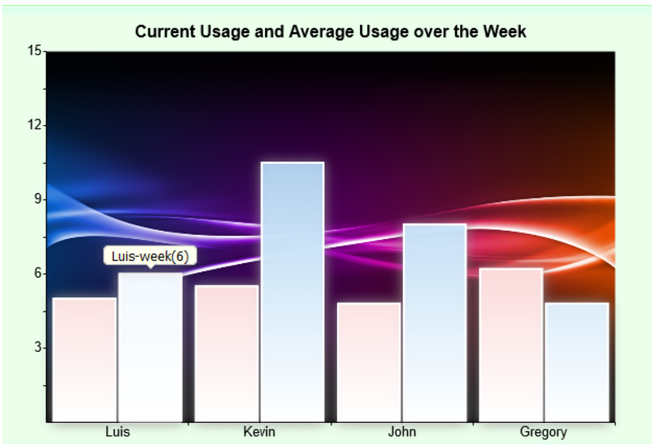

Figure 4. Comparison with others in the neighborhood

Goals

In a study conducted by Houwelingen et.al[13], it was found that goal setting along with daily feedback helped in reducing energy consumption. This was also brought out by one of the participants in our online survey.

"I think small steps and challenges would definitely help"-R13

This was one of the responses we got with respect to goal setting for conserving light and energy conservation. Hence we had incorporated a goal setting in our design. The system sets a goal of maximum of 10 hours in a day. Figure 5 shows the light usage trend of the household for the system set goal of 10 hours.

Rewards

Rewarding people for positive behavior change has been found to be effective [6]. Rewards have been used even in persuasive health technology to bring about a positive response from the participants [5]. Studies also have shown that rewards, even if they are nominal like game points and badges elicit a positive behavior [1].

SOFTWARE

The design LightLogger (an application that logs the light usage data) was implemented with the help of Phidgets Inc Light sensor. A light sensor shown in Figure 7 gives the value of the light present in the room. Based on the values retrieved from the sensor, we get to know if the lights are being used in the room. We check the sensor reading for the ambient light

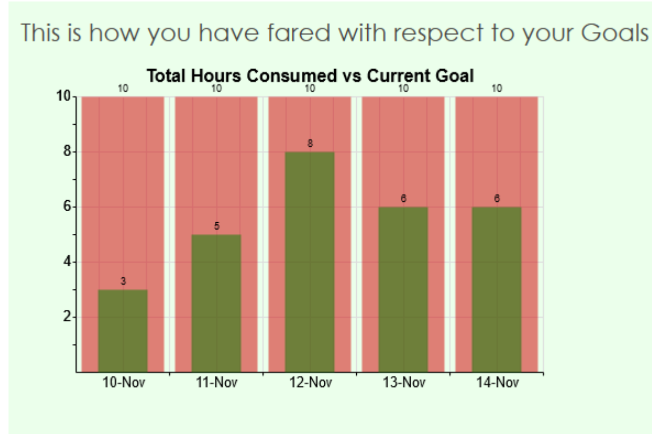

Figure 5. Visualization of the consumption *vs* set goal

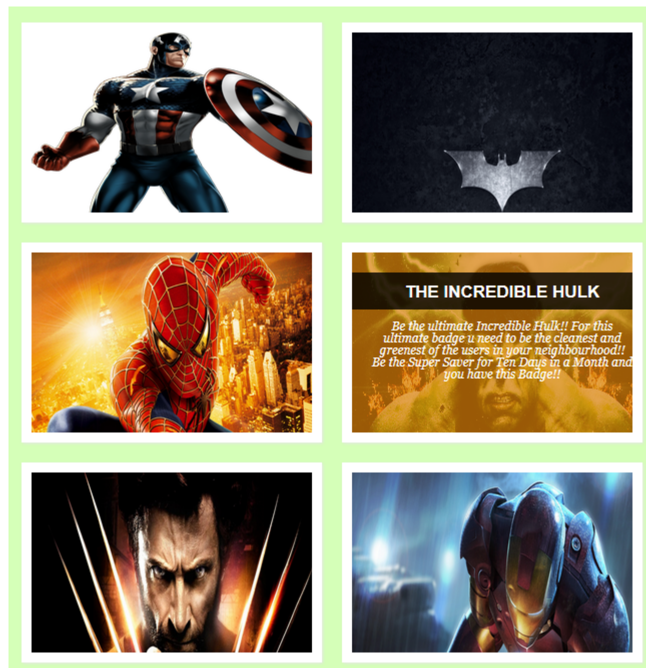

Figure 6. Set of badges used as reward

(the light present in the room when the lights are turned off in the room) initially, and the light present in the room when the lights are switched on. Based on these values the LightLogger gets to know if the lights are used in the room, and logs the time when the lights have been switched on, and the session duration. A "session" refers to the period when the light has been switched on and switched off. We log all this light usage information into an XML file which is read by a web server residing on the local computer, which is connected to the light sensor through USB. Various views described above are then constructed based on this XML file.In order to calculate the cost, we used the Government of Alberta website [2] for retrieving the cost per one Kwh. [15] gave us the information required to map carbon emission in kilograms to the number of trees to be planted to offset the carbon emission.

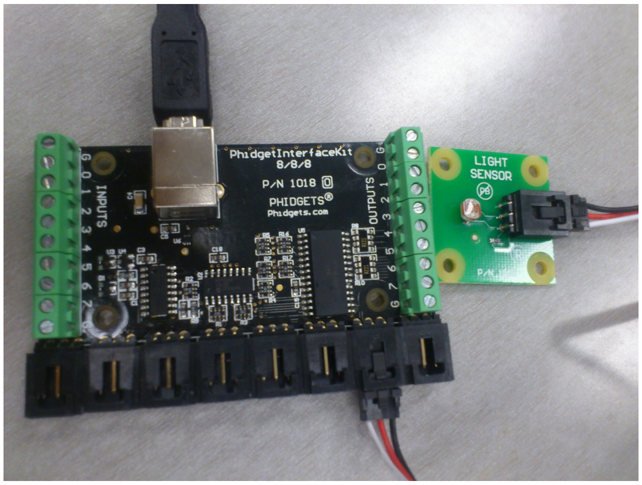

Figure 7. Light Sensor connected to a Phidget Interface Kit

PILOT STUDY

The system was pilot tested on 6 participants, three male and three female. All the participants were graduate students at the University of Calgary. The study was in the form of a semi-structured interviews with the participants. The interviews had two parts. The first part was a brief one, wherein we inquired about the general electricity and light consumption habits of the participants. The participants were provided with a touchscreen tablet which had the light sensor connected. We then explained the whole system to the participants to elicit positive/negative feedback and encourage discussion about how the system could be used in the households. In the end, we asked the participants to select the two views which they would use the most. All the interviews lasted for about 10-15 minutes. All the interviews were audio-recorded for further analysis. We refer to the interviewee(I) to refer to the participants who have participated in the interview. The next section will discuss the study findings.

DISCUSSION

Light Usage Visualization

All the participants were positive about the general information view as it gave broad level information about the light usage and also the cost involved.

“This is good. Generally, sometimes I am lazy but when I see this information I will actually switch off the lights!!” -I3

We observed that cost could be an important factor as was evident from some of the responses in our interviews.

“Having the cost is one of the major things because it allows to view our usage. Even if there are no other views/visualizations, cost alone is an important factor.” - I1

The carbon emission was also important to the participants, as some of them(3/6) were not aware that that light usage indirectly contributed to carbon emission. One of the participants revealed that he did not understand the metaphor behind the trees being displayed, and suggested that we use more alternate metaphors to show the carbon emission.

“I did not get the idea of the trees. How it relates to the usage, maybe you can burn the trees, I was just thinking its just a fancy icon. Maybe you can use the same amount of energy to drive a bus.” - I4.

Implication : After the analysis we found that use of basic metaphors can be more effective than the statistics. All the participants felt that more than the various statistics and numbers presenting the basic information such as the cost, number of trees and other metaphors could be more powerful and intuitive. Although the various statistics can be useful in helping people to analyse their usage, it should be complemented with, showing the usage in very basic terms with common metaphors that people can relate to.

Comparison

Although the on-line survey we conducted had responses that favored comparison our pilot study did not actually support the claim. We did understand that there could be privacy issues when sharing light usage information with others in the neighborhood and inquired participants about the comfort levels in sharing the light usage data. Five of the six(83.33%) were comfortable in sharing the light usage data. Although majority of people are relatively comfortable in sharing, they were skeptical if it could have any effect on their behaviour.

“I might not worry about what the neighbors are doing. I am more concerned about my usage and my own consumption rather than my neighbor’s consumption”-I1.

Implication : Though comparison can bring about change in behaviour care should be taken that the comparison is made among identical entities. For example, in this case of light-usage we have to compare two households that have same number of people or identical light consumption, so that people can relate the light consumption and take the comparison more seriously.

Rewards

As mentioned earlier rewarding people for positive behavior change can be effective in motivating them towards behavior change. We had designed the set of badges and stars for promoting this kind of motivation for behavior change. All the male participants in our pilot study were excited about the various super-hero badges and sharing them on their social networking sites. The female participants on the other hand were not so excited about the choices of badges we designed. This was because they were not interested in super-hero movies and characters. Some of the participants also suggested more rewards, such as more badges and stars for all those households which consistently were among the top-five in conserving light usage.

“More awards and badges should be given to those who are consistently among top-five or top-ten. Apart form the badges maybe those people might be given additional power units as well as rewards. ”-I6

On the other hand, one of the participants brought out an interesting response with respect to integration of social networking.

"The badges are interesting but after some time people might get bored, as it happens with most of the games. I would not use social networking this way, to share badges etc. Even if someone posted such badges I would not pay attention to it and would only consider it as a spam"-I2

The above response shows how social networking can become more of an overdose. In the current age of growing social media and networking there are a huge number of applications and services which try to use the social media and hence care should be taken that this kind of social sharing doesn't become another "spam".

Implication : Although badges are attractive and exciting initially, people might get bored of it. Hence when we design such eco-feedback systems, care should be taken that the users might not get bored of it. This could be done by designing easily achievable targets.Also the badges/rewards maybe designed in such a way that the genre is changed on a regular basis. For example, initially the users might unlock superhero badges and after sometime, they can unlock super-villains and then maybe cartoon characters, so that the users are constantly engaged in unlocking badges of different genres. The badges/rewards we designed did not appeal or excite the female participants, another way of countering this could be is to, present users with a set of different genres so that they can earn badges with respect to genres which they like the most.

Goals

Goals have been designed to motivate people towards reducing their light usage. In our design the goal has been set to 10 hours currently. The participants were positive about the goal setting, and preferred the goal-based visualization, where they could see the trend over the five-day period with respect to the set goal. One of the participants also suggested that the users should be able to set their own goals rather than the system setting the goals. The participants also suggested for continuous motivation for achieving goals they have set.

"I would like to set my own goals rather than the system set goals with me."-I6

"A recommendation system and current status with my goals so that i can know where I stand. I would like to have continuous motivation but if i get a notification every hour then i will be very annoyed "-I3

Implication: Goal system can be very helpful in motivating behavior change but however care should be taken that they could be set by the users themselves. Recommendation and the set of actions to be taken for achieving a goal are necessary but there should be a balance maintained so that the motivation doesn't become coercion.

FUTURE WORK

Currently our work is limited by the robustness of the sensors. Future work could include use of more sophisticated sensors and installation of such sensors in all the rooms in a household. We have only conducted a pilot study, future work could include more elaborate study in real time settings, where in the system could be installed in the households for considerable amount of time, maybe for a period of 3-4 weeks so that various other factors such as fatigue, could be studied and analyzed. Future work could also have more sophisticated visualizations such as providing more time related granularity in data, where in the users can have access to the light usage for a particular date, and time of a given month. With respect to comparison, a more sophisticated comparison could be made based on the similarities between the households. For example, a comparison could be between households which have same number of people and similar number of rooms and lights (two bedrooms, hall, kitchen, etc). Such a comparison could bring about more introspection in people and bring about more intense competition and comparison with respect to conservation. Currently the system has a default system goal set for 10 hours a day. Future work includes a more sophisticated goal setting, giving users the ability to set their own goals and recommendations based on the set goals. Currently we have focused only on house-hold light usage, future work could include designing for office spaces, because there is excessive and inefficient light usage. Another possible area for future work is to make this as a smart phone application so that people can see their light usage on the go.

LIMITATIONS

One limitation of our research is that our study population, both for the online survey and pilot test were skewed towards an environment friendly population. Most of our participants were from the University of Calgary and North America. This could change with a different geographic location as the consumption varies from country to country and from region to region based on various other factors such as climate, culture etc. Also since our pilot had only 6 participants, all from the university of Calgary and similar age group, the results cannot be generalized to a much larger population.

CONCLUSION

The problem we have tried to tackle is a very narrow one compared to the energy and electricity consumption in general. There are lots of applications and designs that provide feedback about electricity consumption but however most of them do not address the issue of light pollution. We have tried to explore a set of design techniques that have been proven to be effective in bringing about behavior change and applying those to the problem of inefficient light usage. By conducting an on-line survey we have been able to get valuable information which has been helpful in our design. By the design of various bar charts and pie charts we have been able to provide a basic insight into the light usage. We then conducted a pilot test, to get the feedback and opinions from the people. Further enhancements which we have mentioned in the future work section and a more elaborate study could help us in achieving more concrete results.

REFERENCES

1. Bang, M., Gustafsson, A., and Katzeff, C. Promoting new patterns in household energy consumption with pervasive learning games. In *Proceedings of the 2nd international conference on Persuasive technology*,

PERSUASIVE'07, Springer-Verlag (Berlin, Heidelberg, 2007), 55–63.

2. Calgary, L. C. I. Light usage cost in calgary, http://www.ucahelps.alberta.ca/enmax-power-regulated.aspx, last accessed: November 2013.

3. Canada, I. L. I. Light usage in canada, http://oee.nrcan.gc.ca/equipment/lighting/46, last accessed: November 2013.

4. Cialdini, R., Kallgren, C., and Reno, R. *A Focus Theory of Normative Conduct: A Theoretical Refinement and Reevaluation of the Role of Norms in Human Behavior*, vol. 24 of *Advances in Experimental Social Psychology*. Elsevier, 1991, 201–234.

5. Consolvo, S., McDonald, D. W., Toscos, T., Chen, M. Y., Froehlich, J., Harrison, B., Klasnja, P., LaMarca, A., LeGrand, L., Libby, R., Smith, I., and Landay, J. A. Activity sensing in the wild: a field trial of ubifit garden. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, CHI '08, ACM (New York, NY, USA, 2008), 1797–1806.

6. Dietz, T., and Paul C. Stern, Editors, C. o. t. H. D. o. G. C. N. R. C. *New Tools for Environmental Protection:Education, Information, and Voluntary Measures*. The National Academies Press, 2002.

7. Froehlich, J., Findlater, L., and Landay, J. The design of eco-feedback technology. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, ACM (2010), 1999–2008.

8. Froehlich, J., Findlater, L., Ostergren, M., Ramanathan, S., Peterson, J., Wragg, I., Larson, E., Fu, F., Bai, M., Patel, S., and Landay, J. A. The design and evaluation of prototype eco-feedback displays for fixture-level water usage data. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, CHI '12, ACM (New York, NY, USA, 2012), 2367–2376.

9. Froehlich, J., Larson, E., Gupta, S., Cohn, G., Reynolds, M., and Patel, S. Disaggregated end-use energy sensing for the smart grid. *Pervasive Computing, IEEE 10*, 1 (2011), 28–39.

10. Gustafsson, A., and Gyllenswärd, M. The power-aware cord: energy awareness through ambient information display. In *CHI '05 Extended Abstracts on Human Factors in Computing Systems*, CHI EA '05, ACM (New York, NY, USA, 2005), 1423–1426.

11. He, H. A., Greenberg, S., and Huang, E. M. One size does not fit all: applying the transtheoretical model to energy feedback technology design. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, CHI '10, ACM (New York, NY, USA, 2010), 927–936.

12. Holmes, T. G. Eco-visualization: combining art and technology to reduce energy consumption. In *Proceedings of the 6th ACM SIGCHI conference on Creativity & cognition*, C&C '07, ACM (New York, NY, USA, 2007), 153–162.

13. Houwelingen, J. H. v., and Raaij, W. F. v. The effect of goal-setting and daily electronic feedback on in-home energy use. *Journal of Consumer Research 16*, 1 (1989), pp. 98–105.

14. in Canada, L. U. Light usage in canada, http://oee.nrcan.gc.ca/equipment/manufacturers/6793, last accessed: November 2013.

15. on The Lamp, L. C. B. Light usage cost, http://selene-ny.org/lightcost/index.php, last accessed: November 2013.

16. Petersen, D., Steele, J., and Wilkerson, J. Wattbot: a residential electricity monitoring and feedback system. In *CHI '09 Extended Abstracts on Human Factors in Computing Systems*, CHI EA '09, ACM (New York, NY, USA, 2009), 2847–2852.

17. Pollution, L. Light pollution, http://en.wikipedia.org/wiki/lightpollution, last accessed: November 2013.