Awareness on Lighting Energy Saving and User Satisfaction in Residential and Office Buildings

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***Abstract*—**Energy saving in buildings not only saves money and also helps protect the natural resources and environment. As a result of this, present day building systems are required to satisfy the dual aim of minimum energy consumption and maximum occupant comfort. When designed and operated effectively, energy efficient lighting and automated lighting systems such as dimming, lighting control panels, occupancy sensors and Building Management Systems can help achieve this aim. The objective of this paper is to present the results of the research study conducted to investigate the awareness levels on lighting energy saving and the associated user satisfaction. The analysis is done on energy awareness from the perspectives of light sources, active participation and user satisfaction. The following emerged as key findings: packaging and energy rating information of light sources, personalized information on products and solutions, addressing the barriers to adoption and demonstrating the cost effectiveness.

***Keywords*—** energy awareness**,** energy behavior**,** lighting energy, lighting system, user satisfaction.

I. Introduction

BUILDINGS consume a bulk of energy in urban and semi-urban cities. People spend much of their life at offices or at their residences. In the case of office buildings, the productivity of the employee is of paramount importance to the employer and negative impacts of the work environment cannot be tolerated [1]. The same is true for occupants of residential buildings also as a comfortable environment enhances the physical, psychological and mental well-being of the occupants. Energy saving in buildings not only saves money and also helps protect the natural resources and environment. As a result of this, present day building systems are required to satisfy the dual aim of minimum energy consumption and maximum occupant comfort. The governments are allocating and spending huge amounts of money in making their citizens aware of their energy consumption and thereby helping them make responsible choices.

Lighting is one of the key areas into which these efforts are being channelized. Energy efficient lighting systems have been aggressively promoted and projected to have long life and quick payback against the high initial cost incurred by the users. With the capital costs of these systems reducing at a rapid rate, it is likely that these systems are utilized more in future. Printing lamp output in lumens, energy wattage and average lifetime on the packaging of lamps enable the users to be aware of the lighting products. Equipping the users with necessary information is critical to and often, the first step in energy conservation efforts. Bridging the gap between available lighting technology and consumer knowledge is a significant challenge [2]. The successful inclusion of a community into environmental policy brings with it a need to develop both environmental awareness within the community and capacity building within a nation's human resources [3].

These days, users can choose from a wide variety of lighting systems such as LED, daylighting and lighting controls which include some of the innovative methodologies that help reduce the energy impact on environment and future generations. Various control mechanisms embedded in lighting systems help adjust the lighting levels automatically according to the available light levels and occupancy, function of space and the time of day. The knowledge about the type of visual task that is going to be done in a given space and the electricity rates at various times of the day help the designers and users in deciding a particular control mechanism. These intelligent and automated lighting can take several forms such as dimming, lighting control panels, occupancy sensors and Building Management Systems (BMS).

The corresponding author, in her earlier work, had noted that major developers, in Dubai, see the automation in lighting as a selling feature to promote their properties and this is the biggest driving force [4]. The satisfaction and comfort index analysis done on the general public who has been given the personal control option can also throw light on the need to develop and bench mark the design criteria, which could be region specific [4]. The research described in this paper was motivated by the authors' observation that there is a need to focus on the user awareness about energy saving and satisfaction associated with lighting systems in residential and office buildings of Dubai. There are tremendous opportunities in the behavioral approach to energy conservation by engaging users with issues such as attitudes, knowledge, awareness and skills [5]. The objective of this paper therefore is to present the results of the research study conducted to investigate the

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awareness levels and satisfaction of users. From the study, we report some key findings that are specific to this region and in the process, also identify some difficulties associated with creating more awareness among the diverse population.

II. Related Work

Studies on energy awareness and satisfaction on lighting systems have been reported in the literature. From the study jointly done by the author, R. G. Bhavani with M. A. Khan, the following emerged as the demand drivers for automated lighting control: Meeting the requirements of the property developers, incorporating personal control for increased satisfaction, convenience and productivity, flexibility in controlling the floor area, willingness to embrace new technologies such as Digital Addressable Lighting Interface (DALI) and energy savings [6]. Energy unaware behavior can add one-third to a building's designed energy performance [7]. Through a comprehensive survey, the article determined the most valuable activities and behaviors and their impact on energy saving potential for each of the three main subsystems, namely HVAC, light, and plug loads. Ref. [8] introduced the Conceptual Model of Energy Awareness Development Process (CMEADP) as a guide for facilities and energy managers to raise energy awareness and improve energy-use behavior among the building's users in a Malaysian university. The paper focused on the transferor dominated segment which play an essential role in creating energy awareness and lead to energy saving. Ref. [9] presented an ecological feedback technique called EnergyLife that harnessed the ubiquitous nature of mobile devices to address energy awareness by helping users understand how their energy-consumption habits contribute to or degrade environmental health. By providing a shared awareness of energy consumption, real-time feedback, and a gaming environment that helps sustain interaction, EnergyLife overcomes many of the problems encountered in other energy-awareness system designs [9]. Ref. [10] proposed an intelligent household LED lighting system, considering energy efficiency and user satisfaction. The proposed LED lighting system reduces total power consumption of the test bed up to 21.9% [10]. Occupants' preferences of office buildings and their contribution to the building energy conservation was the focus of study of the article [11] in which the impact of different types of information on occupant's energy related behavior was presented.

III. The Research Study

In our research study, user awareness about energy saving and satisfaction with the lighting systems they use are investigated. In a city where users can get preoccupied with the daily tasks at homes and offices, we focus on their energy-efficient behavior such as switching off lights that are not in use or using energy efficient lights such as LED along with the ability to maintain the required user satisfaction. In the study, users were occupants of buildings that were equipped with a wide variety of energy related facilities, i.e., the ones that had to do with simple measures such as replacing lamps and fixtures and relamping incandescent by fluorescent fixtures to housing sophisticated systems such as daylighting or Building Management Systems. By data collection through the web and interaction with the construction industry, the buildings were classified as residential or commercial buildings. Villas, apartments and staff accommodation were classified as residential buildings whereas schools, universities, banks, shopping malls, offices, restaurants and hospitals were considered as commercial buildings. E-mail messages and reminder mails were sent to the occupants of these buildings. Table I and Table II summarize the professions and age of participants respectively.

TABLE I
Professions of Participants

Profession	No. of Participants
Students	31
University professors/ teachers	20
Engineers/ Energy Consultants	14
Managers/ Supervisors	10
Sales Professionals	22
Accountants	11
Housewives	5
Service/ health Care	7
TOTAL	120

Depending on the answers provided on a particular category, follow-up questions were asked. The results of the study are presented in the next section.

TABLE II
Age Category of Participants

Age Category	Percentage of Participants (%)
16-25	37
26-35	28
36-45	18
46 and above	17

IV. Results

A. Light Sources

The participants responded as given in Table III for the primary light source used in their offices and homes. The participants could choose more than one option.

TABLE III
Light Source Used

Category	Percentage of Participants (%)
Ordinary Incandescent Bulb	25
Compact Fluorescent Lamp	65
LED	19
T5/T8/ Slim Fluorescent Tube	66
Halogen & Others	8

LEDs were mainly used in office buildings, under counters, in stair cases and hall ways. Few residential buildings had them as concentrated arrays in rooms. Offices, kitchens,

corridors and car parks were popular spaces for T5/T8 lights. The participants were asked to rate the life span of the source they use and their satisfaction associated with it. Table IV provides the details.

TABLE IV
LIFE SPAN OF LIGHT SOURCE USED

Life Span	Percentage of Participants (%)
Up to Six Months	16
Six Months to Two Years	65
Two Years and More	19

The majority of participants indicated that they replace the lamps in six months to two years as the source seems to be CFL, T5/ T8 lamps. The incandescent lamp was to be replaced in less than six months and LEDs had about a three-year life span even though the manufacturers' claims far exceed this figure. Table V presents the results when the participants were asked as to which specification they checked the most while buying the lamps. Lighting output in lumens and wattage are the primary specifications that have to be checked while choosing lamps. The unusually high level of awareness among the participants about lumens and energy efficiency category is due to the presence of students and professors of energy and engineering in universities and facility managers and energy consultant group.

TABLE V
LIGHT SOURCE PACKAGING INFORMATION

Specification	Percentage of Participants (%)
Electricity Consumption (Watts)	51
Luminous Flux (Lumens)	21
Energy Efficiency Category (A to G)	15
Average Life Span (Hours)	9
Dimmabilty/ Color Temperature	4

B. Energy Awareness

Energy awareness starts from home. If present day parents become role models, the energy scenario of future generation will be in safe hands. But cultivating energy-efficient behavior in a big and diverse community is not only about educating the people; it goes beyond informing people about the need to conserve energy and the methods to adopt. Any successful energy awareness campaign should address the barriers to adoption and the suggested behaviors should be socially and culturally acceptable, convenient and easy. The participants were asked as to what would motivate them to participate in an energy awareness campaign. The results are summarized in Table VI. The results were along the expected lines; people look forward to specific suggestions to improve their energy-related behavior and hence the high percentage of respondents voted for personalized information as opposed to being addressed in meetings or receiving information through media. One participant remarked that when a group of students were reassured that adopting energy related practices would not necessarily translate into reduced comfort, they became open to change. The campaigns should target removing such misgivings about reduced thermal and visual comfort of daylighting systems and on the contrary, should highlight the positive aspects such as general well being when exposed to natural daylight and having more control over the occupants' environment, both locally and globally.

TABLE VI
MOTIVATION TO PARTICIPATE IN ENERGY AWARENESS CAMPAIGN

Reasons	Percentage of Participants (%)
Personalized Information	51
Competition	20
Incentives and Rewards	23
Sense of Participation and Well Being	6

The participants when asked about the kind of energy awareness campaign they came across recently, they responded with the usual answers: surveys, training videos, TV, radio and newspaper advertisements, company newsletters, booklets received at shopping malls, posters, stickers (such as the ones above light switches), website information, e-mail messages, interviews, discussion forums and group meetings. The participants were asked about the most pertinent question: do they know their monthly energy bills. The participants responded as given in Table VII. Most people knew the kind of energy usage their households have or the equipments they use at offices. 15% of the users confessed that they are not aware of their energy information and there is a potential to tap this group into developing a commitment and action plan.

TABLE VII
ENERGY USAGE

Category	Percentage of Participants (%)
I am a high energy user due to the type of equipment I use/ the time I have the equipment running for	4
I am a moderate energy user	81
I do not know my level of energy use	15

Among the population that knows their energy bills, the respondents were asked about their knowledge of wastage of energy. A majority of participants revealed that they know where it is wasted though few wanted to have more information about the kind of equipment they use.

C. Active Participation

The buildings chosen were fitted with a wide variety of control mechanisms such as occupancy and light level sensors, dimming systems, lighting control panels, energy efficient lamps, power factor controllers, daylighting and Building Management Systems. Having access to technology is one thing and putting them to best use is another. Simple measures such as replacing lamps and fixtures, relamping incandescent by fluorescent fixtures and using natural light instead of artificial light whenever possible can go a long way in translating an individual to an active contributor of a global community. The participants were enquired about the kind of

control measures they adopt in their homes and offices. They could choose more than one option. Table VIII display the results.

TABLE VIII
CONTROL MEASURES IN LIGHTING

Category	Percentage of Participants (%)
I turn off lights and equipments not in use	94
I have occupancy sensors in corridors/ board rooms	24
I have dimming control	41
I use lighting control systems	25
I have Building Management Systems	58

Occupancy sensors were found to be used in corridors and lift lobbies in residential buildings and in conference rooms, boardrooms and car parks in commercial projects. Dimming control was prevalent as architectural control in conference rooms and as stand-alone dimmers in some residential units. Commercial buildings reported a high percentage of dimming (41%). Lighting control systems can help adjust the light level from 1 to 100 % and the panels for the same are housed near the distribution boards and they control the lighting circuitries. All the relays and dimmers are controlled by a common protocol such as EIB (European Installation Bus), C-Bus, PROFIBUS (Process field bus) etc. The respondents indicated that lighting control systems are used in residential and commercial buildings (25%). BMS when interfaced with lighting control facilitate remote monitoring from far off locations, such as to activate lights when on a holiday to keep the burglars away, giving an impression that the home is occupied. BMS also offers flexible solutions, fast expandability and easy adaptation to the needs of the occupants in addition to increased energy efficiency.

The level of participation and commitment to saving energy stems from awareness and willingness to contribute to a larger cause. The participants were queried as to what was the chief motivation behind improving their energy behavior. They indicated their choices as given in Table IX.

TABLE IX
MOTIVATION TO SAVE ENERGY

Reasons	Percentage of Participants (%)
Costs	49
Environmental Reasons	30
Conservation of Resources	4
Moral Reasons	15
More Comfort and Others	2

According to the responses received, saving on energy bills was the prime reason for energy saving. Energy saving literally translates into money saving for most people. Reduction in green house gases and pollution were the reasons cited as environmental benefits. Using systems in energy efficient manner help extend their life, resulting in reduced replacement frequencies and hassle free maintenance. These were grouped under comfort factor as reason for motivation.

D. User Satisfaction

The satisfaction associated with light sources is the focus of this section. Energy efficiency should not be achieved under user discomfort. The benefits of such a scheme would not last long and hence make the users feel deprived. Visual comfort weighs very high on people's agenda and it should not be compromised under any cost. Table X gives the summary when the participants were quizzed about the satisfaction of the light source they use at home.

TABLE X
USER SATISFACTION ON LIGHT SOURCE

Category	Percentage of Participants (%)
Extremely satisfied	12
Mostly satisfied	77
Not satisfied	11

Users along with technology and government complete an important triangle in efficient management of energy resources and saving energy. All these three components play an equally crucial role in making the community energy aware and energy management strategies to be successful. In the final segment of our study, we asked the participants about the role of government in promoting lighting energy savings and making a sustainable future. The participants indicated their choices as given in Table XI.

TABLE XI
ROLE OF GOVERNMENT IN PROMOTING LIGHTING ENERGY SAVING

Category	Percentage of Participants (%)
Make existing information available about packaging, energy rating, technology and solutions	28
Demonstrating cost effectiveness and payback through pilot studies	26
Promote energy efficient systems, design and research	36
Implementing & enforcing energy codes and standards	4
Offering incentives and rewards on compliance	6

The author, R. G. Bhavani in her earlier work had observed that the property developers in Dubai require lighting controls to be installed in their buildings and that the willingness to experiment new ideas cause encouragement among the providers and designers [4]. The UAE government, in line with this expectation, has implemented an energy ratings system for household appliances, air conditioning systems and lighting [12]. This new energy rating system is similar to that used in Australasia, but has been created specifically for the UAE [12]. Such regulation and best practices have to be communicated to all sections of society to be made effective. 28% of the participants felt that the existing information about available technology and energy rating have to be articulated more. A small minority opined that UAE is now in a position to implement and enforce energy codes and standards in its totality.

V. Discussion

The study conducted indicates some crucial findings on awareness and satisfaction of users in residential and office buildings in an expatriate-dominated society like Dubai. The UAE has the world's sixth largest proven oil reserves but a nation with one of the highest rates of energy usage per capita, it has a unique opportunity to take an active role in the development and adoption of alternative and renewable energy technologies [13]. The predominantly expatriate population is very diverse in terms of its culture and practices which get reflected in energy behavior as well. This article throws light on energy awareness of the general public, mainly from the expatriate community, from the perspectives of light sources, active participation and user satisfaction.

The participants when asked about the various light sources they use at homes and offices exhibited adequate awareness levels though the packaging information such as lumens in addition to watts while choosing bulbs have to still reach the grass root levels. In spite of energy efficiency category rating being displayed on light bulbs, more awareness need to be created to make people select appliances based on informed choices. The payback calculations of energy efficient lighting and automated lighting products have to be demonstrated to people to make the energy related practices to be made sustainable over long term. The study also identified that people are likely to stick with a particular behavior on a long run if personalized solutions and strategies are made available to them. There is also a need to reassure the users that they need not compromise on comfort to adopt an energy efficient strategy. For motivation to save energy, the participants responded with the common answer of cutting down costs. The authors feel that when policy participation is coupled with environmental or moral reasons, greater rewards can be reaped. More number of custom-made energy awareness campaigns targeted at different sections of audience can take this goal nearer to its reach.

User satisfaction on lighting depends on visual comfort and financial savings resulting out of adopting energy-effcient practices. Visual comfort weighs very high on people's agenda and it should not be compromised under any circumstances. An enhanced visual comfort translates into greater satisfaction, productivity and sense of well being among the individuals. Visual comfort is a parameter that is very subjective to evaluate and varies widely within people. Lighting quality may be the most-talked-about but least-understood concept in lighting research and lighting design [14]. In fact, visual comfort not only means the quantity of light that is available at the task surface; it is also indicative of many parameters that define the quality of light. These include various glare indices, uniformity, luminance distributions and color characteristics of lighting. The room surfaces, wall and floor color, furniture layout along with the use of space and the user distribution impact the quality of lighting. Measurement of lighting quality becomes a complex phenomenon with so many parameters defining it in a three dimensional space. Under this situation, the user comfort also becomes a complex one to quantify. The personal control option has given users more control of the environment with the preferences of users loaded on their desktops. However, this is true only for office lighting and spaces intended for different activities are governed by different set of design specifications. The dual aim of achieving user comfort and energy saving is an issue that is multi-dimensional and hence would continue to necessitate innovative solutions in the years to come.

VI. Conclusion

Energy management strategies can achieve its intended benefits if people, technology and government work together towards a common and higher goal of sustainability. This article presented a research study on awareness and user satisfaction from the point of view of energy savings on lighting. The following emerged as key findings: More awareness need to be created on packaging and energy rating information of light sources, personalized information on energy efficient products and solutions, addressing the barriers to adoption and demonstrating the cost effectiveness and payback calculations through pilot studies. More emphasis paid to visual comfort would enhance user satisfaction. The above measures would pave the way for better energy-related behavior among the public. More work is continued by the researchers in identifying and evolving a suitable model for quantifying the user preferences to represent energy-efficient behavior.

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References

[1] G. P. Henze, "Building energy management as continuous quality control process," *J. Archit. Eng.* vol.7, pp. 97-106, Dec. 2001. http://dx.doi.org/10.1061/(ASCE)1076-0431(2001)7:4(97)

[2] J. O'Brien, R. Keivani , and J. Glasson, "Towards a new paradigm in environmental policy development in high-income developing countries: The case of Abu Dhabi, United Arab Emirates," *Progress Planning*, vol. 68, pp. 201-256, Nov. 2007. http://dx.doi.org/10.1016/j.progress.2007.09.001

[3] S. W. Sanderson, K, L. Simons, J, L. Walls, and Y. Lai, "Innovation challenges in the lighting industry: From 1990 to 2006," in *Proc. the Conf. on Globalization and Innovation*, New York, 2007.

[4] R. G. Bhavani, and M.A. Khan, "Prevalence and penetration of lighting control systems in Dubai buildings: A pointer to future measures, " J. *Applied. Sci*., vol. 8, pp. 3460-3466, Sep. 2008. http://dx.doi.org/10.3923/jas.2008.3460.3466

[5] V. Vesma,"Power to the People Facilities Management,"*Facilities Mgmt*, vol. 9, pp.26, 2002.

[6] R. G. Bhavani, and M. A. Khan, "Present trends and future direction of lighting control in Dubai," in *Proc. 4th IEEE GCC Conf. 2007*, Manama, Bahrain, 2007, pp.

[7] T. A. Nguyen, and M. Aiello, "Energy intelligent buildings based on user activity: A survey," *Energy Build*., vol. 56, pp. 244–257, 2013. http://dx.doi.org/10.1016/j.enbuild.2012.09.005

[8] C. W.Wai, "The conceptual model of energy awareness development process: the transferor segment," in *Proc. ICEE 2009 3rd Intl. Conf. Energy and Environment*, Malaysia, 2009, pp.306-313.

[9] A. Spagnolli, E. Hoggan, G. Jacucci, C. Katzeff, L. Broms, and L. Jönsson, "Eco-feedback on the go: Motivating energy awareness," *IEEE Comp. Soc.*, pp. 38-45, May 2011.

[10] J. Byun, I. Hong, B. Lee, and S. Park, "Intelligent household LED lighting system considering energy efficiency and user satisfaction," *IEEE Trans. Consum. Electron.*, vol. 59, pp.70-76, Feb. 2013. http://dx.doi.org/10.1109/TCE.2013.6490243

[11] F. Jazizadeh, G. Kavulya, J. Kwak, B. Becerik-Gerber, M. Tambe, and W. Wood, "Human-building interaction for energy conservation in office buildings," in *Proc. Construction Res. Congress*, Indiana, 2012, pp. 1830-1839.

[12] http://www.uaeinteract.com/german/news/default.asp?ID=408

[13] United Arab Emirates @ G20, Clean Energy and Energy Efficiency, White paper,Available http://www.uaeg20.ae/usr/pages/en/Clean%20Energy%20and%20Energy%20Efficiency%20policy.pdf

[14] J. A. Veitch , and G. R. Newsham," Determinants of lighting quality. I: State of the science,"*J. Illum. Eng. Soc.*, vol. 27, pp. 92-106, 1998. http://dx.doi.org/10.1080/00994480.1998.10748215