Factors Affecting Residents’ Adoption of Energy-efficient Lighting in Rural Areas of China

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Abstract. Energy conservation is one of the core topics to address the goals for sustainable development. Approximately 40% of the total energy are consumed by buildings currently [1]. Energy consumed by lighting accounts for about 20% among all the segments in buildings. Therefore, it’s extremely important to improve the energy efficiency of lighting in buildings. However, this process is relatively slow in the rural areas of China, despite the government’s policies and subsidies on lighting efficiency. According to the current study, only about half of the dwellings in the rural areas has adopted energy saving light sources. The aim of current study is to reveal the key factors that affect the adoption of energy-efficient lighting in the rural areas of Fujian province in China, and provide valuable information for addressing the barriers. From the survey data collected from 321 valid responses, it becomes clear that for the residents who lived in the rural area, their personal characteristics, the perceived ease of use, the perceived lighting quality, and the impact of indoor lighting on their health were not associated with the actual use of the energy-efficient light sources at home. On the other hand, social support, awareness of the technology, and the perception of cost effectiveness were identified to be significantly correlated with the acceptance of energy-efficient light sources. A mediation analysis further shows an important causal relationship among these factors. Social support significantly improves the users’ awareness toward energy-efficient lighting designs, which would influence their perception on the cost effectiveness, which in turn would translate into actual adoption of energy-efficient light sources. These findings will pave the way for better understanding of the influencing factors for the acceptance of energy-efficient light sources, and provide the policy makes with valuable information for the formation and implementation of favourable policies and support programs, in order to speed up the spread of energy-efficient light sources in rural areas of China.

1. Introduction
Lighting is one of the segments that consume a significant amount of energy. In China more than 12% of total electricity is consumed by lighting in buildings [1]. A transition from conventional light sources to energy-efficient light sources could cut down this energy consumption considerably. In last two decades, the development of energy-efficient light sources including compact fluorescent lamps and light-emitting diode (LED) bulbs have made significant changes in the light industry. They are more eco-friendly, have longer lifetime and could provide comparable or better quality of lighting. Energy-efficient light sources were shown to reduce the energy consumption up to 43% comparing to conventional light sources [2].
To curb the growing energy demand, a series of policies and programs were provided by the Chinese government to promote the replacement of conventional light sources with energy-efficient ones. Starting from 2009 and revised in 2011, China formulated a roadmap for phasing out incandescent bulbs in several steps [3]. In addition, subsidies were provided to promote the spread of more efficient light sources. Until 2012, these incentives resulted in the installation of more than 680 million energy efficient light bulbs in China [4]. However, despite the benefits of these energy-efficient light sources and various governmental support, the spread of them is still slower than expected in China, especially in the rural areas. The information regarding to the barriers to adoption is very limited. Therefore, this study is aimed to investigate the key factors affecting the acceptance of energy efficient light sources which could provide valuable information in order to accelerate the transition in rural areas of China.

2. Literature review

2.1. Technology acceptance models

Acceptance of new technologies or concepts have been studied in different sectors by many researchers. Different theories or models have been proposed to interpret the users’ intentions and to predict their behaviours.

Fishbein et al. proposed the Theory of Reasoned Action (TRA) originally for sociological and psychological studies in 1975 [5]. In this model, attitudes, social norms, and intentions were considered as three major classes of variables that determined behaviors. Users first formed attitudes from direct observations or prior information available to the individual, which determined users’ behaviour with intention as a fundamental construct that mediates the relation.

Technology Acceptance Model (TAM), derived from the TRA theory, aimed to better model user acceptance at an individual level [6]. This is probably one of the most widely used model for studying technology acceptance in the past decades [7,8]. In addition to the aspects included in the TRA model, TAM also considers the motivation of the users including perceived usefulness, perceived ease of use, and attitude toward use. Perceived usefulness and perceived ease of use were further hypothesized to be the most important determinants for users to accept or reject a new technology or product[6]. For example, Wu’s study demonstrated that these three factors had clear impact on the acceptance of an SMS-based alert system in universities in north America[9]. Moreover, TAM adopts a unidirectional approach with causal relationship, in which environmental constructs determines behaviours with cognitive beliefs and attitudes being key mediators [10,11].

In order to integrate various models into a more complete and simple model, Venkatesh et al. compared the similarities and differences among various models and proposed a Unified Theory of Acceptance and Use of Technology (UTAUT) model [12]. UTAUT identified four significant constructs which are important in determining users’ behavioural intention, including social influence, performance expectancy, effort expectancy, and facilitating conditions. In addition to these major constructs, gender and age were also shown to be significant moderating variables.

2.2. Acceptance of energy-efficient lighting

Numerous studies in literature investigated factors that could potentially influence the adoption of energy-efficient lighting design. A research study conducted by Bhavani et al. in Dubai, UAE found that intelligent and automated lighting control systems were widely used in commercial and hotel buildings [13]. It was mainly due to building owners’ perception that these energy-saving devices improved the image of the buildings or properties. But on the other hand, the use of such systems in residential sectors were limited. Governmental support, incentives, and standards were proposed to help growing the lighting control scheme in the entire region. A following study from the same researchers identified awareness on lighting energy saving as a key factor on the user satisfaction. More awareness can be created on the packaging and personalized information of energy-saving products to demonstrate the cost effectiveness and visual comfort, which will help to address the
barriers of adoption [14]. A study conducted for the residential buildings in Nigeria suggested the awareness of energy saving benefits would increase the likelihood of using compact fluorescence lamps [15]. Another group of researchers from Malaysia also confirmed the importance of awareness on energy-saving behavior and developed the Conceptual Model of Energy Awareness Development Process (CMEADP) which aimed to arouse the awareness towards energy sustainability and improve energy conservation practices in the setting of universities, schools and other education centers [16].

3. Research model

3.1. Conceptual framework

Based on previous developed theoretical models especially TAM and UTAUT, and the work carried out in other sectors, 17 aspects from four constructs including social support, awareness of the technology, perceived performance, and perceived ease of use were scoped out in addition to several known mediators such as gender, age, and education levels. Social support included various public support such as policy support, manufacturer incentives, and convenient access to various informative materials. Awareness of the technology was measured by the familiarity towards the energy-saving designs available to local rural areas. Perceived performance included a wide range of measures including the perceived overall cost, perceived lighting quality, and perceived influence on the physical and psychological health with different types of lighting. Finally, perceived ease of use included perceived ease of installation, operation and maintenance. The social support – awareness – belief – behavior causal chain is adopted in this study. The proposed conceptual framework is demonstrated in Figure 1.

![Figure 1. Conceptual Framework](image)

3.2. Hypothesis

According to the conceptual framework, the following hypotheses were proposed:

- H1. Perceived performance positively influences the acceptance of the technology
- H2. Perceived ease of use positively influences the acceptance of the technology
- H3. Awareness of the technology positively influences users’ perceived performance
- H4. Awareness of the technology positively influences users’ perceived ease of use
- H5. Awareness of the technology positively influences the actual use of the technology
- H6. Social support positively influences users’ perceived performance
- H7. Social support positively influences users’ perceived ease of use
- H8. Social support positively influences users’ awareness of the technology
- H9. Social Support Positively influences the acceptance of the technology
4. Methods

4.1. Participants and surveys
In this research study, participants were occupants of residential dwellings from the rural areas in Fujian Province of China. These dwellings were equipped with a wide variety of lighting facilities, including conventional incandescent bulbs, conventional fluorescent tubes, compact fluorescent lamps, and LED bulbs. The factors which might affect the acceptance of energy-saving lighting sources in rural areas of China were investigated.

The questionnaire was developed based on a literature review. A list of potential influencing factors together with several personal characteristic items were identified and included in the questionnaire. Background information section asked for age, gender, and the education level of the participants. The next section evaluated the factors that might have impacts on participants’ acceptance toward energy-saving lighting designs. These factors were grouped into four constructs including social support, awareness of the technology, perceived performance and perceived ease of use. The last section asked participants about the main type of lighting devices currently used in their home, directly showing the extent of adoption toward energy-saving lighting designs. Other than the background information section, all questions require scores on a 5-point Likert scale from “strongly agree (1)” to “strongly disagree (5)”, covering different occupant perceptions and opinions. It took approximately 10-20 minutes for the participants to complete the survey.

Questionnaires were created using an online tool “Tencent Surveys” and distributed through the most popular mobile phone messaging app in China – “Wechat”, which has a built-in function to collect data and monitor the process. The sampling method adopted in this research is the “convenience sampling”. Data were first collected from some residents of local rural areas or those who were from other parts of Fujian but were close and easy to access. These respondents were asked to help in distributing surveys to other potential participants, until enough samples with reasonable coverage were collected. A total of 321 individuals from the rural areas of all nine prefecture-level divisions in Fujian province of China participated in the survey with valid answers. The survey was conducted during the summer of 2019 (June-August), as part of a larger survey study investigating the lighting design trend in the rural areas of China. There were no incentives for participating in the study.

4.2. Statistical analysis
Since the response for the survey item “actual use of energy-efficient light source” is dichotomous, Kendall’s tau coefficient was employed to analyze the correlation when this item was involved. Other correlations were analyzed with Pearson’s coefficient. The causal relationship was investigated using mediation analysis. IBM SPSS Statistics 24 software was used to conduct the statistical analysis for this study. Mediation analysis was done by using the PROCESS plugin of SPSS written by Hayes [17].

5. Results

5.1. Characteristics of the participants
In 321 respondents, 47.4% (152) were male and 52.6% (169) were female, as shown in Table 1. The age distribution of the participants based on the questionnaire responses were shown in Table 2.

| Gender | Number | Percentage |
|--------|--------|------------|
| Male   | 152    | 47.4%      |
| Female | 169    | 52.6%      |
Table 2. Age distribution of the participants.

| Age    | Number | Percentage |
|--------|--------|------------|
| <20    | 40     | 12.5%      |
| 20-30  | 86     | 26.8%      |
| 30-40  | 91     | 28.3%      |
| 40-50  | 63     | 19.6%      |
| >50    | 41     | 12.8%      |

5.2. Main light sources used in the dwellings

The main light sources used in the dwellings indicated by the participants were summarized in Table 3. Conventional light sources mainly refer to conventional incandescent bulbs and fluorescence tubes, and energy-efficient sources include compact fluorescent lamps and LED bulbs. Slightly less than half of the respondents had adopted energy-efficient light sources as the main light sources at home.

Table 3. Main light sources used in the dwelling.

| Light sources   | Number | Percentage |
|-----------------|--------|------------|
| Conventional    | 165    | 51.4%      |
| Energy-efficient| 156    | 48.6%      |

5.3. Correlation between factors and actual use

In order to identify the key factors affecting the adoption of the energy-efficient light sources, Kendall’s Tau correlation was carried out and the results are summarized in Table 4.

Unlike other previous studies conducted mainly in large cities, all the items in personal characteristics and perceived ease of use in this study were not correlated with the adoption of energy-saving lighting design for the rural areas in Fujian province of China. Therefore, hypothesis H2 was rejected and H4/H7 became irrelevant in the scope of this study. Moreover, interestingly most aspects in perceived performance including perceived lighting quality and perceived impact on physical and psychological health were found to have no statistically significant impact on the acceptance of energy-saving light sources. Perceived cost was identified as the only item in the category that’s correlated with actual use. Thus, hypothesis H1 was partially rejected. Instead, “perceived cost positively influences the actual use of the technology” is confirmed.

All three items in social support category were significantly associated with the acceptance of energy-efficient lighting. Thus, hypothesis H9 was confirmed. In order to evaluate the reliability of the results, Cronbach’s alpha coefficient was employed to show the convergent validity and internal reliability, which is calculated to be 0.807. A Cronbach’s coefficient is generally considered to be acceptable when it falls between 0.7 to 0.9 [18]. As a result, these three items were concluded to be reliable measures and consistent in measuring social support. They were combined to form a new composite variable “social support” for further analysis.

Awareness on the energy-efficient light sources was also found to be significantly correlated with actual use. The more familiar users are with the technology, the more they adopted energy-saving light sources at home. Hypothesis H5 was confirmed.
Table 4. Correlation between factors and main light source used

| Categories                | Survey Items                  | Actual Use (Correlation coefficient) |
|---------------------------|-------------------------------|--------------------------------------|
| Personal Characteristics  | Gender                        | 0.027                                |
|                           | Age groups                    | -0.036                               |
|                           | Education levels              | 0.103                                |
| Perceived Performance     | Perceived of cost             | -0.326**                             |
|                           | Perception of overall lighting quality | 0.067                              |
|                           | Perception of lighting color  | 0.053                                |
|                           | Impact of lighting on the aesthetics | 0.063                        |
|                           | Glare                         | -0.038                               |
|                           | Impact of lighting on mood    | 0.080                                |
|                           | Impact of lighting on headache| 0.053                                |
| Perceived Ease of Use     | Ease of installation          | 0.048                                |
|                           | East of operation             | 0.069                                |
|                           | Ease of maintenance           | 0.065                                |
| Social Support            | Policy support                | 0.321**                              |
|                           | Manufacturer incentives       | 0.375**                              |
|                           | Access to materials           | 0.364**                              |
| Awareness                 | Familiarity with energy-saving lighting | 0.345** |

**: p < 0.005

5.4. Correlation between other factors and perceived cost

As perceived cost is the only item in the perceived performance category showing significant correlation with actual use, it was used for further analysis of H3 and H6 instead of the entire category. The results are shown in Table 5. As can be seen, both social support and awareness were significantly correlated with perceived cost. The negative sign for the correlation coefficient indicates that when the users received more social support and were more familiar with the technology, they showed a more positive view toward the cost effectiveness of the energy-efficient light sources. Revised hypotheses H3 and H6, when replacing “perceived performance” with “perceived cost” only, were confirmed.

Table 5. Correlation between factors and perceived cost

| Perceived Cost | Pearson’s Coefficient | p    |
|----------------|-----------------------|------|
| Social Support | -0.389                | 0.000|
| Awareness      | -0.315                | 0.000|

5.5. Correlation between social support and awareness

The Pearson’s correlation between social support and awareness were calculated to be 0.412 with statistical significance (0.000).
5.6. Mediation analysis

From the analysis above, social support, awareness of the technology, and perceived cost were identified as three main factors influencing the users’ acceptance of the technology. Based on the TAM model and previous studies, a study model for mediation analysis was proposed. The social support was set as the predictor (X), actual use was set as the outcome (Y), awareness and perceived cost were set as the mediators (M).

The techniques for mediated regression analysis were based on the method proposed by Baron and Kenny [19] and further developed by Hayes [17,20]. Traditionally, mediation analysis was done using a causal steps approach consisting of a logical sequence of multiple regression analyses. The effect of X on Y was first calculated (X→Y), followed by the effect of X on M (X→M). Finally, the effect of the X-adjusted M on Y (M→Y; X adjusted) and the effect of the M-adjusted X on Y (X→Y; M adjusted) were determined simultaneously [19]. All these regressions have to be significant to establish the casual relationship. However, as pointed out by Hayes [17], this approach is not ideal both statistically and philosophically. The mediation relationship can exist even when one or more of the regressions are not statistically significant. Therefore, the approach proposed by Hayes and an SPSS tool (PROCESS) created by him is adopted in this study [17].

The result of the mediation analysis using the serial two-mediator model is presented in Figure 2. The statistical model can be presented as three equations containing three consequent variables:

\[ M_1 = i_{M_1} + a_1X + e_{M_1} \]  \hspace{1cm} (1)
\[ M_2 = i_{M_2} + a_2X + d_2M_1 + e_{M_2} \]  \hspace{1cm} (2)
\[ Y = i_Y + c'X + b_1M_1 + b_2M_2 + e_Y \]  \hspace{1cm} (3)

As can be seen from the figure, the effects of the predictor social support (X) on the outcome actual use (Y) is calculated through a process that X causes the first mediator tech awareness (M1), and M1 subsequently causes the second mediator perceived cost (M2), concluding with the outcome Y as the final consequent. The total effect of social support (X) on actual use (Y) partitions into one direct effect \( c' (0.6977) \) and three indirect effects. Each indirect effect is calculated by multiplying the regression weights linking X to Y through at least one M. The indirect effect of X on Y through M1 is \( a_1b_1 \) which equals 0.1622, the indirect effect of X on Y through M2 is \( a_2b_2 \) which equals 0.0952, the indirect effect of X on Y through M1 is \( a_1d_2b_1 \) which equals 0.0658. The sum of all indirect effects is the total indirect effect of X which equals 0.3232.

![Figure 2. Mediated regression analysis. ** p < 0.01](image)

6. Discussion

Constructs derived from the TAM and UTAUT models including social support, awareness of the technology, perceived usefulness, and perceived ease of use were investigated in current study. The questionnaire successfully identified factors that were associated with the acceptance of energy-
efficient light sources as well as factors that had no effect. The significance of the model was validated through regressions. A causal relationship was also established for the influencing factors using the mediation analysis.

The results from this study clearly demonstrated that the adoption of energy-saving light sources in the rural areas was not associated with most of the common measures for perceived performance, including visual quality, visual comfort, glare, impact on mood and health, and so on. In addition, personal characteristics factors including gender, age and education levels were found to have no impact on the actual use of the technology as well. These results are different from previous findings which were mainly conducted in the cities [21–24]. For example, Min et al. suggested that consumers’ choices on light sources mainly based on several bulb characteristics including color and brightness [25]. Back in 1980s, the attempt to introduce fluorescent bulbs in residential areas replacing incandescent bulbs failed, despite their much higher energy efficiency and better durability [26]. This failure was mainly attributed to the users’ perception of the light being too bright and too cold which resulted in reduced visual comfort [27]. Another study conducted in the cities of Malaysia also identified visual quality and the effect on the mood and health as key factors that were associated with the acceptance of energy-efficient light sources [28]. This difference could be attributed to the cultural differences and the differences between residents living in the cities and rural areas.

Perceived ease of use was also found to be insignificant and therefore hypothesis 2 was rejected. When the energy-efficient light sources first introduced to the market years ago, these bulbs were much heavier and bigger than incandescent bulbs. Therefore, they were not compatible with the lighting fixtures at that time. The installation and maintenance was very difficult which made ease of use one of the key factors affecting the adoption [27]. As the technology continues to advance, currently the energy-efficient light sources are very easy to install and operate. There is no significant difference on the perceived ease of use between conventional and energy-efficient light sources, and it’s no longer a determining factor for the adoption, as shown in this study.

Awareness of the technology was demonstrated to be associated with the acceptance in the rural areas. Residents were more likely to use energy-efficient light sources when they were more familiar with the technology, consistent with previous studies. Bhavani et al. showed that the awareness level on lighting energy saving were correlated with users’ satisfaction. Energy-efficient lighting would be better accepted when providing more the energy rating information on the packaging of the products and solutions [14].

Among the factors evaluated in the perceived performance category, the only factor that was found to have significant impact on the acceptance of the energy-efficient light sources is perceived cost. The higher the cost was perceived, the more unlikely the technology was adopted in rural areas. This finding is consistent with previous studies. For example, Wada et al. demonstrated that the acceptance of the energy-efficient light sources was held back by the higher upfront cost comparing to conventional incandescent bulbs, which was the reason why conventional incandescent bulbs were still widely used in many countries [29]. Perceived cost is the only factor identified in this study to link awareness and actual use. As many data have shown, although energy-efficient light sources cost more, they significantly reduced the operating cost due to longer lifetime and lower electricity consumptions. It’s very important to educate the consumers and consider lifetime cost instead of upfront cost. As reported by Min et al., consumers were willing to pay more for bulbs when the increase of the lifetime and the decrease of the electricity cost were successfully demonstrated [25].

The results from current study indicates that social support was a key factor that affected the adoption of energy-efficient light sources in rural areas of China. Three aspects of social support including governmental support, manufactural incentives, other sources that assist in the easy access of materials, were all found to be associated with actual use. On the other hand, social support was also shown to correlate with users’ awareness of the technology, which is consistent with previous studies [2,26].

With the correlations revealed from the results, a mediation analysis was carried out and a causal relationship was confirmed. More social support significantly improves the users’ awareness toward
energy-efficient lighting designs, which would influence their perception on the cost effectiveness of this technology, which in turn would translate into actual adoption of energy-efficient light sources at home. According to this causal chain, in order to accelerate the adoption of energy-efficient lighting in rural areas, government needs to implement support programs and policies, working with the manufacturers to provide targeted information and materials, with the emphasize on demonstrating cost effectiveness rather than lighting quality or visual comfort.

7. Conclusion
Improving adoption of energy-efficient light sources in the rural area would largely rely on addressing the barriers. This study evaluated the factors that influenced the acceptance of energy-saving light sources in the rural areas of China, and developed a theoretical framework to reveal the causal relationships of the identified factors. Visual quality, visual comfort, effect on physical and psychological health were found to have no impact on the adoption of energy-efficient light sources. Instead, social support, awareness of the technology, perception of cost effectiveness were demonstrated to be the key influencing factors. An important causal relationship was identified: social support improves users’ technology awareness, which brings more positive perception towards overall cost, which results in the adoption of the new technology. This study will pave the way for better understanding of the influencing factors for the adoption of energy-efficient light sources, and provide the policy makers with valuable information for the formation and implementation of favorable policies and support programs, in order to speed up the spread of energy-efficient light sources in the rural areas of China.

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