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Energy conservation through smart homes in a smart city: A lesson for Singapore households

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ABSTRACT

Energy saving is a hot topic due to the proliferation of climate changes and energy challenges globally. However, people's perception about using smart technology for energy saving is still in the concept stage. This means that people talk about environmental awareness readily, yet in reality, they accept to pay the given energy bill. Due to the availability of electricity and its integral role, modulating consumers' attitudes towards energy savings can be a challenge. Notably, the gap in today's smart technology design in smart homes is the understanding of consumers' behaviour and the integration of this understanding into the smart technology. As part of the Paris Climate change agreement (2015), it is paramount for Singapore to introduce smart technologies targeted to reduce energy consumption. This paper focused on the perception of Singapore households on smart technology and its usage to save energy. Areas of current research include: (1) energy consumption in Singapore households, (2) public programs and policies in energy savings, (3) use of technology in energy savings, and (4) household perception of energy savings in smart homes. Furthermore, three case studies are reviewed in relation to smart homes and smart technology, while discussing the maturity of existing solutions.

1. Introduction

Climate change is a global challenge. The change in the global climate system is directly caused by human activities, which is giving rise to the highest greenhouse gases (GHG) emissions in human history (Pachauri and Meyer, 2014). Studies have shown that GHG have attributed to extreme weather and changes to natural and human systems (Pachauri and Meyer, 2014). These climate changes include floods, droughts, and interrupted food production, which ultimately force people to migrate to safer areas. Extensive exposure to heat waves also affect people's health negatively, and may even spread diseases across multiple territories (Xu, 2015). According to Pachauri and Meyer (2014), electricity and heat production contributed to 25% of the highest proportion of total global GHG emission. This highlights the importance and urgency of sustainable energy consumption to reduce GHG emissions.

In line with the Paris agreement under the United Nations Framework Convention on Climate Change (UNFCCC) in December 2015 (National Climate Change Secretariat, 2016a), Singapore has pledged to reduce 36% of GHG emissions from year 2005 by 2030. Even as a relatively small country, Singapore is also affected by climate change. Statistics show that Singapore's average temperature has risen from 26.6°C to 27.7 °C from year 1972 to 2014, with the rise in annual sea levels at between 1.2 and 1.7 mm from year 1975 to 2009 (National Climate Change Secretariat, 2016b). Besides making international commitment, Singapore has made conscious efforts to change internally to deal with climate change.

Given the global environmental issues, there is a global trend and demand for energy saving and smart technology to increase the efficiency of energy consumption. According to the Energy Market Authority (EMA; 2015), households account for approximately 15% of electricity consumption in Singapore. Under the Energy Conservation Act (2012), the Mandatory Energy Labelling was introduced for registered goods in Singapore. This means that all electrical appliances (refrigerators, air conditioners, etc.) sold in Singapore must be energy labeled.

The role of smart home technologies to increase energy efficiencies in households is becoming increasingly important. A survey has been conducted on the consumers' perception and awareness towards adapting new technologies, as well as the role of these technologies in saving energy. According to Balta-Ozkan et al. (2014), a smart-home is a home equipped with connected devices, appliances and sensors that can communicate with each other, and can be controlled remotely. These functions provide consumers the flexibility of monitoring its electricity consumption and making lifestyle changes to save electricity. Moreover, Balta-Ozkan et al. (2013) noted that a smart home does not

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only provide benefits of efficient energy management, but also provides benefits such as improved lifestyle, security and safety. Smart metering, appliances and home automation devices are some of the many technologies that can be used to change electricity consumption patterns of households (Paetz, 2011).

This article aims to find out the households' behaviors on energy consumptions; it also attempts to identify the benefits and obstacles on the implementation on smart home technologies, and how it should be done for it to be successful. The paper has been organized into six sections: the first section outlines the topic and the structure of the article; the literature review section discusses the household energy consumption in Singapore, public initiatives on energy conservation in Singapore, technology and energy saving household perceptions of smart homes; the subsequent section describes the aims of the study and methods employed; the following section reviews three case-studies on success stories of energy savings in urban households; the penultimate section discusses the survey findings; and the final section presents conclusions and lessons for practice.

2. Literature review

This section reviews the current knowledge base relevant to the discussion.

2.1. Energy consumption in Singapore households

According to the Singapore Energy Statistics (2015a, 2015b), households are significant users of electricity as they account to approximately 15% of total consumption in Singapore. As of 2014, public housing made up roughly 80% of the total housing units in Singapore, while the remaining 20% are private condominiums, apartments, and landed properties (Latest Data: Households and Housing Statistics, 2015). Public housing occupied approximately 60% of overall consumptions while private properties accounted for about 40%. Air-conditioners, water heaters and refrigerators account for around 76% of total energy consumption in a typical household.

This section outlines research projects conducted with an aim to identify a list of factors behind the changes in energy consumption for the residential sector using quantitative models (i.e., index decomposition analysis). Xu and Ang (2013) identified environment control, household appliances and personal devices as three sub-sectors that account for 49%, 45% and 6% of total consumption respectively. Within these three sub-sectors, population growth is the key contributor to increased electricity consumption, followed by the shift towards larger apartments by the households.

Externalities (noise, pollution, etc.) are major factors that have drawn interest in the field of research. As noted by a recent study (see Agarwal et al., 2016), households would most likely not passively tolerate externalities with the hope that they are limited via government regulations, but to mitigate the issue by "purchased comfort" activities such as closing all windows, doors, and switching on air-conditioning. Besides maintaining their desired standard of living, this also acts as a 'self-protection' mechanism from externalities. The 1800 samples taken from Singapore public housing (i.e., Housing and Development Board; HDB) matched with construction sites, proving an approximate increase of 6% in electricity consumption by households (S$ 9770 per annum per HDB block) that were affected by negative externalities, particularly noises generated from construction sites. In addition, the findings revealed that the affected households' electricity consumptions would persist and would not revert back to pre-externalities level, even after the noise pollutions are over.

The studies drew counter-arguments because of some questionable assumptions. For instance, the assumption of similar consumption behaviors by households (Xu and Ang, 2013) might not be realistic and practical. Individuals tend to make decisions that offer sufficient satisfaction, but not optimal utility; they also assume a limitation on their knowledge capacity, and thus practice satisfice and "might exhibit cognitive errors as known as 'bounded rationality' (Simon, 1957). Therefore, the behavioral and psychological aspects are important to take into considerations. Ho (2015) conducted a practice-based study to identify qualitative factors behind energy consumptions to fill in this gap. She emphasized the importance of social science in predicting energy consumption as individuals' practices are characterized by their social and cultural values to accomplish relevant and meaningful activities. She also concluded that energy consumption could be based on socialized rules and ethics that subjectivities should be taken into account. Therefore, households would not follow or practice energy saving programs or methods that do not harmonize with their own social practices.

He and Kua (2012) adopted three conceptual pillars as framework to explain social and psychological behaviors related to households' energy usage. Firstly, situational factors consist of households' demographic, accessibility to energy saving services, and the relevant knowledge that they possess. Secondly, different psychological factors towards particular behaviors. Thirdly, households' environmental behavioral choices as a result of their values. They included these factors into their research methodologies and questionnaires, and concluded households adopted energy-saving measures depending on how easily they could implement these procedures, possible monetary savings, and environmental concern.

2.2. Public programs and policies on energy savings in households

In 2007, The Ministry of Trade and Industry Singapore (MTI) developed the National Policy Energy framework with a vision to address the importance of energy security and environmental sustainability while maintaining a balance for continued economic growth and competitiveness. The current emphasis is the strategies and policies that are relevant with the residential sector to improve energy efficiency (National Energy Policy Report, 2007).

Firstly, the framework indicated the commitment of the government to promote competition and innovation in the electricity retail market by privatization of firms, while imposing rules and regulations to safeguard the industry. The aim of liberalization is to increase firm efficiency, which could be due to the improved corporate governance demanded by investors. The retail electricity market divides consumers into contestable and non-contestable categories by threshold of usage intensity. Contestable consumers can choose different electricity packages from different retailers, such as Tuas Power Supply, Senoko Energy Supply, Seraya Energy, and Sembcorp Power. In July 2015, EMA lowered the contestability threshold to 2000kWh monthly (Singapore Power Report, 2015a, 2015b). It should persist to liberalize the market to the small consumers, mainly households, so that they could choose whether they opt to buy electricity from retailers or remain at regulated tariffs from SP Services.

Secondly, as of late 2014, conventional thermal contributed approximately 97.6% (around 80% from natural gas and remaining 17.6% from oil) of the total generating capacity, its dependence on other countries to import natural resources has created significant energy risk (Singapore Power Report, 2015a,2015b). The framework provides new energy options including renewable energy to diversify the energy supply, which could consequently encourage healthy competitions that eventually benefit consumers including households.

Thirdly, there were legislations that align to the goal of improving the energy efficiency. For example, legislations like the Mandatory Energy Labelling Scheme, which was introduced in 2008 to ensure that the two of the most mentioned energy-intensive appliances, air-conditioners and refrigerators, have to be tagged with energy labels that contain an energy efficiency rating. This enables consumers to gauge whether a particular appliance meets their standard for energy efficiency. In July 2015, this scheme was extended to include other appliances, like televisions, clothes-dryers, and light bulbs (About