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Modelling the impact of social network on energy savings

Feng Du [a], Jiangfeng Zhang [a,*], Hailong Li [b], Jinyue Yan [b], Stuart Galloway [a], Kwok L. Lo [a]

[a] Department of Electronic and Electric Engineering, University of Strathclyde, Glasgow, United Kingdom
[b] School of Business, Society and Engineering, Mälardalen University, Sweden

HIGHLIGHTS

- Energy saving propagation along a social network is modelled.
- This model consists of a time evolving weighted directed network.
- Network weights and information decay are applied in savings calculation.

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ABSTRACT

It is noted that human behaviour changes can have a significant impact on energy consumption, however, qualitative study on such an impact is still very limited, and it is necessary to develop the corresponding mathematical models to describe how much energy savings can be achieved through human engagement. In this paper a mathematical model of human behavioural dynamic interactions on a social network is derived to calculate energy savings. This model consists of a weighted directed network with time evolving information on each node. Energy savings from the whole network is expressed as mathematical expectation from probability theory. This expected energy savings model includes both direct and indirect energy savings of individuals in the network. The savings model is obtained by network weights and modified by the decay of information. Expected energy savings are calculated for cases where individuals in the social network are treated as a single information source or multiple sources. This model is tested on a social network consisting of 40 people. The results show that the strength of relations between individuals is more important to information diffusion than the number of connections individuals have. The expected energy savings of optimally chosen node can be 25.32% more than randomly chosen nodes at the end of the second month for the case of single information source in the network, and 16.96% more than random nodes for the case of multiple information sources. This illustrates that the model presented in this paper can be used to determine which individuals will have the most influence on the social network, which in turn provides a useful guide to identify targeted customers in energy efficiency technology rollout programmes.

1. Introduction

In the UK, the residential sector accounts for 31% of total energy consumption except non-energy use in 2013 [1]. It is predicted that domestic energy use will increase more than two times in the UK in 2025 comparing to the amount of energy use in 2013 [2]. Thus, residential areas are important targets for energy consumption reduction, and different aspects of residential energy consumption characteristics are investigated. For instance, Ref. [3] studies the relations between residential energy consumption and building characteristics, socio-demographics, occupant heating behaviour, etc. Embodied and controlled energy consumptions of urban areas are studied from network control perspective [4]. A novel 3-level emergetic evaluation framework is presented in [5] to investigate energy efficiency and sustainability of complex biogas systems with the aid of time-series ecological-economic behaviours. Dynamic and embodied energy for water and water for energy are also calculated in the study of energy-water nexus [6]. It is also noted that residents' personal preferences and habits have a strong influence on energy use in residential homes [7–10]. In [8], the result shows that the operational behaviour of domestic hot water supply system can have influence on the energy use efficiency. Ref. [9] studies the impact of compact development on energy consumption by households' consumption behaviour simulation. The results in [10] show that the energy consumption

* Corresponding author.
E-mail address: jiangfeng.zhang@strath.ac.uk (J. Zhang).

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patterns of a building is affected by not only the behaviour of its own occupants, but also by occupants from neighbouring buildings. Previous studies provide evidence that lifestyle changes can lead to savings in overall energy use [11–13]. It is found in [12] that changing the habit to use an electric kettle can save an average of 40 kW h per household per year. Ref. [14] discusses how change and continuity in practices can be understood by applying practice theory in residential energy consumption. Studies in [15] reveal that collective behaviour change, even within a small network, can provide a large amount of energy savings. Note the connections between people in a community, researchers have studied the impact of social network to energy consumption [13,16,17]. Reduction of energy use can be achieved by residents sharing energy efficiency information in a social network. The results in [13] indicate that energy consumption can be reduced by sharing energy efficiency information between families. A Facebook application for energy consumption information sharing is designed in [18] to promote energy savings.

This paper focuses on the influence of social network to human behaviour. In a social network, different individuals usually have direct or indirect connections with each other. The influence of people from direct connected individuals is easy to understand, and the influence from indirect connections is based on the knowledge of small world phenomenon [19–23]. This paper studies how interactions between individuals among social network will influence the energy savings of the whole network. In order to analyse information diffusion within a social network, complex network theory is applied. In a network graph, an individual can be considered as a node, and the connection between two individuals can be seen as node connection.

Fig. 1 is a diagram which shows the impact of interactions between individuals in social network to the mass rollout of energy efficiency technologies. In the mass rollout of energy efficiency products, such as the rollout of solar water heaters in many countries, there are some selected nodes within the social network with earlier installation of efficient products earlier than others for various reasons, say, a positive response to new technologies or free trial provided by suppliers. These nodes will benefit from the new energy efficient products and will therefore spread such information among their friends and relatives. Thus, other nodes within the social network will get to know the energy saving information, and would potentially purchase the new product. These users will further spread the energy saving information along the social network. In this way more energy savings are expected through the interactions of people within the social network. A challenging problem will be qualitatively determining such expected energy savings.

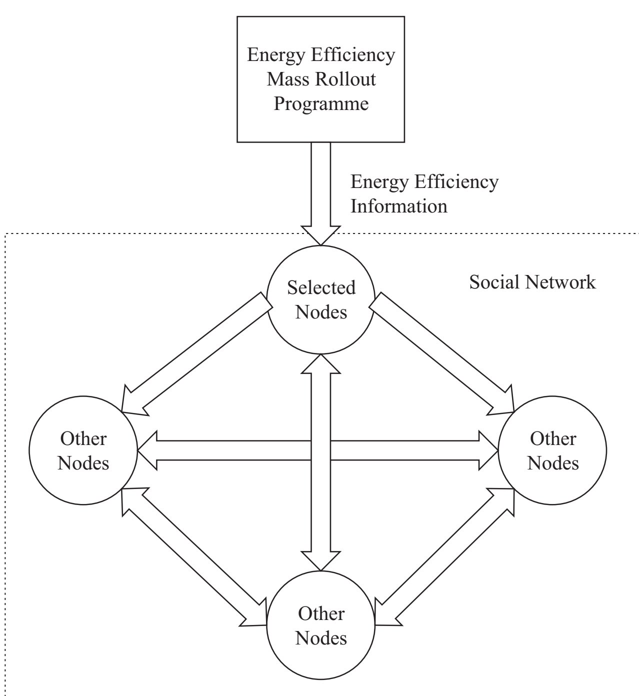

Fig. 1. Impact of interactions of social network to energy efficiency programme.

The connections of a social network are explored in [24,25], where the expected energy savings through interactions under small degree of separation are quantified using information entropy theory. However, the model in [24,25] assumes that an individual has an equal impact to all of his/her friends, neighbours, or family members, and also assumes such an impact does not change against time. The strength of interactions between individuals is considered equal and symmetric in both directions in [26–28]. This paper considers more practical situations where an individual has different and time varying impacts to his contacts. With the aid of weighted directed graph, a mathematical model is developed to calculate the expected energy savings within a social network. Considering data requirement for variable validation in designed model, a survey is designed. This survey investigates the relationship of 40 participants and their response to recommendation of energy saving product within the social network. Then the designed model is further validated by the results collected from the survey.

The remainder of the paper is structured as follows, a mathematical model quantifying energy savings achieved through network interaction and the case study is provided in Section 2, the calculation results from a survey is discussed in Section 3, and some conclusions are made in the last section.

2. Mathematical model

2.1. Weighted social network

Individuals in a social network are represented as nodes in a complex network [19,29], and the connections between people who know each other are represented as edges between nodes.

Consider a weighted directed network with N nodes, assume that node i is connected to k_i neighbours, where $i = 1, \ldots, N$. The weight of an edge in the network is defined as the strength of influence of one node to the other, and this weight is assumed to be an integer between $[0, 5]$ in this paper. A zero value of strength means no effect, while a positive value indicates positive effect between the two nodes.

It is noted that the influence from node i to node j may not be equal to the influence from node j to node i. Thus, this network is generally an unbalanced digraph [30,31] with $W_{ij} \neq W_{ji}$, where W_{ij} is the weight from node i to node j, W_{ji} is the weight from node j to node i [32,33]. In order to represent the dynamic changes of people's relations against time, the weights are assumed to be functions of time t. The weight from node i to node j during time period t is therefore denoted by $W_{ij}(t)$, where $0 \leqslant W_{ij}(t) \leqslant 5$, $t \geqslant 0$. The exact value of $W_{ij}(t)$ depends on the frequency of communications per month between the two nodes.

$$W_{ij}(t) = \begin{cases} 1, & 0 \leqslant f < 1.25; \\ 2, & 1.25 \leqslant f < 2; \\ 3, & 2 \leqslant f < 4; \\ 4, & 4 \leqslant f < 10; \\ 5, & f \geqslant 10; \end{cases} \quad (1)$$