A stochastic model for collective resident activity patterns and energy use: preliminaries

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Abstract

This paper describes the framework for a stochastic model of collective resident activity patterns and consequent energy use. The model is calibrated with a large set of time-use data and produces a probability density distribution of activities with consequent energy use. The complete evaluation of this concept along with the potential prospect of including the complex components involved in interacting individuals is left for future studies.

1. Introduction

High-resolution load profiles for domestic power use are useful for the setup, optimization and evaluation of various kinds of small-scale energy systems in residential buildings. One possibility to estimate theoretical high-resolution load profiles is to use stochastic models, such as for example a Markov-chain model [1,2,4,5]. The model developed in this paper is a purely probabilistic model for determining probability density distributions of resident activities and consequent energy use. The model is calibrated with time-use data (empirical high-resolution activity sequences for residents) along with an assumption that each activity consumes a certain amount of power, much like the Markov-chain model developed in [4,5]. Unlike the Markov-chain model each time-step in this model is independent of previous time-steps which enables more advanced and efficient modelling of independent and dependent collective behaviour. The aim of this paper is to establish the preliminaries for a general stochastic model of this type.

2. The stochastic model

In the first step the model produces an over-time changing distribution of probability for resident activities. The assumption is then, just like in the Markov-chain model [4,5], that each activity has an energy use associated with it. The model is calibrated with time-use data over resident activities in order for the probability distribution over activities to represent a realistic scenario [4,5]. The model prescription is illustrated in Figure 1.

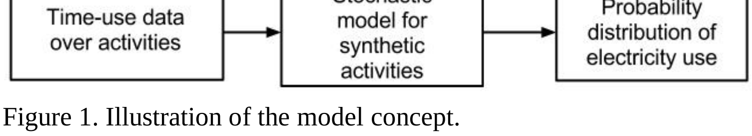

Figure 1. Illustration of the model concept.

A table of activities for the model is presented in Table 1.

2.1 Formal foundation

Assume a set of activities S and the premise that a resident can only be in one activity at a given time as well as the criterion that the resident has to be in one of the activities at any time. From these assumptions we can create a stochastic model based on the probability distribution over activities over time. Let the probability for a resident to occupy a specific activity $S_i \in S$ be $P_i(t)$. A requirement from probability theory is that the normalization criterion holds:

$$\sum_{i \in S} P_i(t) = 1. \qquad (0.1)$$

The probability distributions are calibrated with time-use data and based on the same basic assumptions as the Markov-chain model in [4,5]. However this model is not a Markov-chain model – that is being dependent on the previous time-step – instead it is independent on any of the previous time-steps. Each activity S_i has a power-use Q_i associated with it. With this assumption the expected value of power use can be expressed as follows:

$$\langle Q(t) \rangle = \sum_{i \in S} P_i(t) Q_i(t) \qquad (0.1)$$

2.2 Collective behaviour

Models of collective behaviour are often based on individual level behaviour [3]. In spirit of this assumption our stochastic model for individual behaviour is extended to the collective case. The collective model may be divided up into two different levels of complexity:

(I) Non-interacting collective model
(II) Interacting collective model

The non-interacting collective model is based on the assumption that the probabilities for activities are not dependent on the activities of other residents. This assumption makes the non-interacting collective model perhaps most suitable for simulating an aggregate of single resident households. The interacting model is more general and allows for dependencies between individuals which in turn affect the probability distributions of activities. Stochastic models such as the Markov-chain model developed by Widén [4,5] is by design a non-interacting model but with the addition of certain assumptions the model mimics certain typical interacting features such as shared use of lighting and other appliances [4,5].

2.3 Preliminary setup for a non-interacting collective model

For the single resident case a probability distribution over activities and consequent energy use was given in the previous section. For the non-interacting collective model we consider all individuals to have the same probability distribution over states as in the single resident model. Thus we can define the probability for person j to be in activity i at time t as $P_i(t)$ and the corresponding power use as $Q_i(t)$. Let K be the total amount of activities which may be occupied by a single resident and let N be the number of non-interacting individuals then we have that there are K^N possible configurations in the collection of non-interacting individuals. The probability for each configuration is:

$$P_{ijk...}(t) = P_i(t)P_j(t)P_k(t)... \qquad (0.2)$$

Where $P_i(t), P_j(t), P_k(t),...$ are the probabilities for the activities $i, j, k, ...$. The consequent power use associated with each configuration is then:

$$Q_{ijk...}(t) = Q_i(t) + Q_j(t) + Q_k(t) + ... \qquad (0.3)$$

The total set of probabilities and power for each configuration make up the probability distribution for the power demand. This construction works for the non-interactive model since the residents are considered independent of each other which is perhaps a viable simulation of a collection of single resident households. The more general case involving interacting individuals requires a more advanced theoretical structure and more advanced calibration from the time-use data.

3. Preliminary results

3.1. Single resident case

As an illustration of the over-time changing probability distribution $P_i(t)$ over states a phase-space diagram of the probability distribution for occupying different activities is given in Figure 2. This distribution was obtained from the stochastic model in [5]. In future studies the original time-use data will be used.

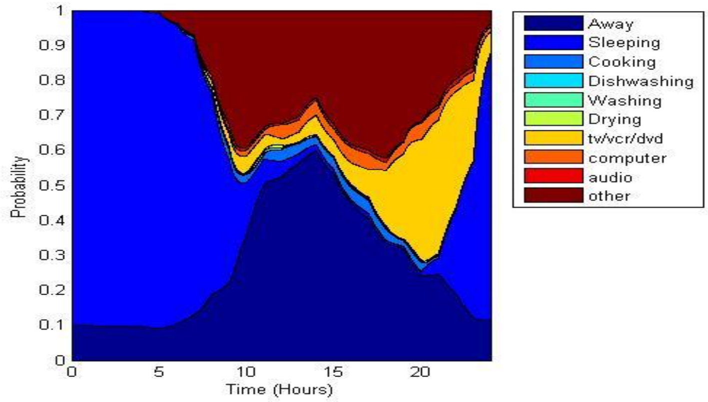

Figure 2. A phase-space plot of the probability distributions of activities over a 24 hour period. The model has minute based resolution.

3.2. Independent collective case

In order to illustrate how to obtain the probability distributions of power from $P_i(t)$ the independent collective case we have assembled a fictitious example with two non-interacting residents. The probability for activity A is $P_A = 0.8$ and the power use associated with it is $Q_A = 100W$. The probability for activity B is $P_B = 0.2$ and its power use is $Q_B = 500W$. See Table 2 for calculations on the probability distribution of power use for this case. See figure 3 for an illustration of the probability distribution of power as a result of this.

Table 2: Probability and power for a fictitious non-interacting two resident case

Combination	AA	AB	BA	BB
Probability	$P_A P_A = 0.64$	$P_A P_B = 0.16$	$P_B P_A = 0.16$	$P_B P_B = 0.04$
Power	$Q_A + Q_A = 200W$	$Q_A + Q_B = 600W$	$Q_B + Q_A = 200W$	$Q_B + Q_B = 1000W$

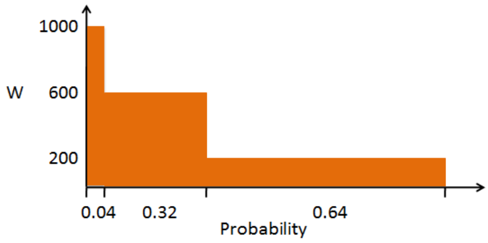

Figure 3. This figure represents the probabilistic power consumption for a fictitious case of two non-interacting individuals. The setup for this can be found in Table 2.

4. Discussion

In this work-in-progress paper a new stochastic model for synthetic activity generation and consequent energy use was investigated. The model is based on the probability distributions of individual activities and calibrated with time-use data. In a second step the individual behaviour was extended to non-interacting collective behaviour and consequent energy use. The possibility of developing a model which involves more complex interactions between residents was also briefly discussed.

5. Acknowledgements

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6. References

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