Energy and Buildings 117 (2016) 332–340

Contents lists available at ScienceDirect

Energy and Buildings

journal homepage: www.elsevier.com/locate/enbuild

A preliminary research on the derivation of typical occupant behavior based on large-scale questionnaire surveys

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ARTICLE INFO

Article history:
Received 1 July 2015
Received in revised form
17 September 2015
Accepted 21 September 2015
Available online 24 October 2015

Keywords:
Occupant behavior
Data mining
Building energy simulation
Questionnaire survey

ABSTRACT

Occupant behavior is a major contributing factor to building energy consumption. Large discrepancies might occur when occupants with diverse types in terms of behavior patterns reside in an identical building. Moreover, it is vital to derive several kinds of typical occupant behavior that represent the assemblage of occupants in a simplified way as the reference for building designers and energy policy makers. This paper presents a preliminary research on occupant behavior categorization through the building energy simulation, where some typical occupant air-conditioning behavior patterns use in Chengdu, China have been derived from a large-scale questionnaire survey based on the energy consumption levels. These typical occupant behavior patterns could be used as the context for an overview of building energy in a community, as well as the evaluation of building energy-saving technology where occupants are involved. Further efforts are required in the algorithm of dividing occupant behavior into typical patterns, the validation of the classification results, and the analysis of other behaviors.

1. Introduction

Occupant behavior is now recognized as a non-negligible factor to building energy consumption. It influences energy use in multiple ways, such as occupancy-based casual gain, operations on appliances, set points of air-conditioning, etc. Al-Mumin et al. [1] surveyed the occupancy patterns and operation schedules of electrical appliances in 30 residences in Kuwaiti and used them as input data of a thermal simulation program. The surveyed occupants left all lights on even rooms were unoccupied, with the AC thermostat set at 22°C. This pattern of occupant behavior led to a 21% of annual electricity consumption compared to the default schedule in the simulation program. In order to study the uncertainty in heating energy consumption caused by occupant behavior, Clevenger and Haymaker [2] studied the different settings regarding behavior schedule and set points in American codes. The simulation revealed that a 150% discrepancy of energy consumption was found between these different settings. Li et al. [3] measured the cooling energy consumption in a residential building during a summer in Beijing, China. The energy consumption of different apartments varied widely, caused by the variance in the durations when air-conditioning was on. Due to its significance, occupant behavior has drawn much attention in building simulation field.

To present occupant behavior in buildings in a quantitative way so as to integrate them into simulation programs, various models have been developed. For example, Nicol and Humphreys [4] studied the use of windows, lighting, heating, etc. with surveys to see how the use of each control varies with outdoor temperature. Andersen et al. [5] measured occupants' window opening behavior, as well as indoor and outdoor environmental conditions, based on which a logit model was developed, describing the probability of an opening or closing event took place. Yasue et al. [6] surveyed the air-conditioner and window use in residential buildings in Japan, and proposed the sigmoid function to describe the probability of operating air-conditioners and windows. These models are generally developed from intensive field surveys or measurements, and correlate behavior with some extrinsic factors like temperatures or daily events.

When it comes to industry such as building design or code formulation, the diversity of occupant behavior becomes more significant than the case studies where the models are developed. Occupant behavior is necessarily simplified to an "average" or several "typical" patterns instead of applying such complicated models. The different composition of occupant behavior patterns in a building may have great influence on the energy consumption. Since determining the parameters in these models often requires intensive measurements, it is temporally and financially consuming to describe each occupant in a large population applying the approach in which models are developed. The researches mentioned above in occupant behavior have focused on the quantitative

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http://dx.doi.org/10.1016/j.enbuild.2015.09.055
0378-7788/

modeling but are not capable of describing the diversity of a large population, which still has a margin from the industrial application of occupant behavior in simulation where the representativeness of diverse occupants is required.

With the development of data collection and analysis technology, there have been more and more researches on date mining of occupant behavior recently to study representative behavior profiles. Yu et al. [7] applied the data mining technique, cluster analysis, in attempt to classify occupants into several categories in terms of context factors (such as climatic conditions) and their behaviors. This study introduced the cluster analysis into data mining in building energy simulation, aiming at predicting the energy consumption level when context factors and occupant behavior related factors were known. D'Oca and Hong [8] applied cluster analysis to categorize window opening and closing behavior in 16 offices according to the influencing factors, durations of the window state, the number of window position changes and the most frequent window degree of opening. Furthermore, the association rules were applied to produce two typical window opening office use profiles. Another study adopted data mining to analyze the space heating performance in residential buildings [9]. Six patterns of the room temperature demand were revealed, associated with the heating energy consumption to predict the performance of heating system.

These studies have introduced new data mining techniques into occupant behavior simulation field, providing new perspectives in behavior pattern categorization. Nevertheless, they are limited to looking into the cases where the measurement was undertaken. Since the patterns are derived from the specific data set, heavily depending on measured cases, they are not convincible to be extrapolated to other occupants or buildings. It is meaningful to conclude behavior patterns and their distribution in large population in terms of energy consumption to be used in energy simulation and technology evaluation. With air-conditioning behavior as an example, this exploratory study proposes a novel approach to categorize occupant behavior into several typical patterns, and to derive the distribution of these typical patterns, from a broad survey, in attempt to narrow the gap between behavior modeling and industrial application where representativeness of occupant behavior is required. The typical patterns could be used to analyze the energy variation with different distributions of occupants in a community.

2. Method

The purpose in this study is to conclude the typical air-conditioning behavior patterns that differentiate energy usage levels. Starting with this, energy consumption is labeled as the index to tell apart behavior patterns. Patterns with similar energy consumption could be represented by a "typical" one. Fig. 1 shows the technical approach of our study.

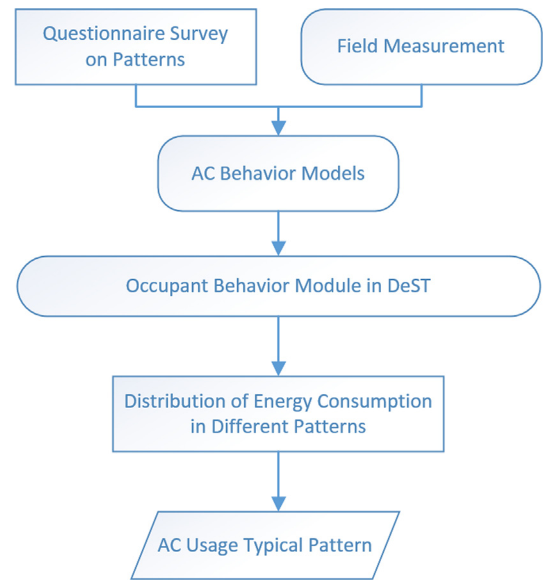

Fig. 1. Technical approach to categorize occupant behavior patterns.

The questionnaire survey was distributed to get the large sample data regarding occupants' air-conditioning behavior patterns. The questionnaire was designed in line with the occupant behavior modeling framework proposed by Wang [10], who had proposed a new approach for the quantitative description from an action-based view. The questionnaire was used to find the influencing factors for occupants to operate various appliances like air-conditioning, lighting, windows, etc, while it was not capable of capturing the quantitative relationship between the factors and the behavior. To overcome this shortcoming, a series of field measurements on indoor environment and behaviors were conducted to build the quantitative behavior model. The patterns were described as conditions under which occupants would turn on/off their air-conditioners, e.g. "turn on when feeling hot", or "turn on when sleeping". Patterns could be combined in the questionnaire survey, which led to a larger amount of patterns than the case when only a single pattern was allowed. After the questionnaire survey, the patterns were input into the simulation program DeST [11], in which a novel occupant presence and behavior module had been developed [12], to simulate the energy consumption with different behavior patterns. From the distribution of the simulated energy consumption, some typical air-conditioning behavior patterns were concluded based on different levels of the air-conditioning energy consumption.

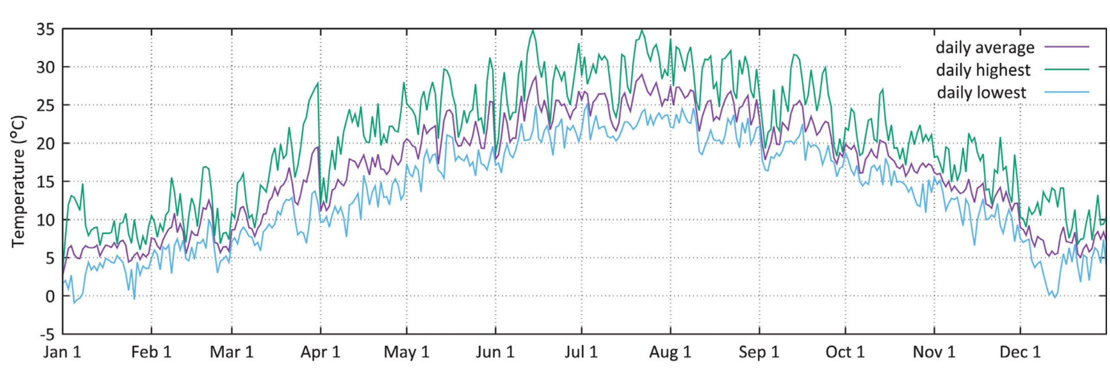

Fig. 2. Daily outdoor temperature of the typical meteorological year in Chengdu.