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ScienceDirect

Procedia Engineering 205 (2017) 1627–1634

Procedia Engineering

www.elsevier.com/locate/procedia

10th International Symposium on Heating, Ventilation and Air Conditioning, ISHVAC2017, 19-22 October 2017, Jinan, China

Indoor environment and adaptive thermal comfort models in residential buildings in Tianjin, China

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Abstract

This paper investigates air-conditioning (AC) usage patterns and adaptive comfort behaviors in a Chinese residential context. Field measurements were conducted in 43 homes in Tianjin from May 14th to November 20th in 2016. Indoor temperatures and AC on/off events were recorded. Occupants' "right-here-right-now" thermal perception and adaptive behaviors were collected. 4,743 AC events and 1,697 online comfort questionnaires were collected. Average duration for AC cooling events in summer was 3.24 hrs per house and the average duration for AC heating events in winter was 0.96 hrs per house. Tianjin residents were less sensitive to indoor air temperature, compared to those in offices. The indoor temperatures corresponding to 80% thermal acceptability ranged from 21.0℃ to 27.3℃. We also derived statistical models to predict the likelihood of adaptive behaviors (i.e. turning on AC, turning on fans and opening windows or doors) with regard to outdoor air temperatures.

Peer-review under responsibility of the scientific committee of the 10th International Symposium on Heating, Ventilation and Air Conditioning.

Keywords: residential; air conditioning; thermal comfort; adaptive behavior

1. Introduction

The internationally applicable ASHRAE 55 [1] standard is originally based on heat balance model and data obtained from experiments conducted in climate chambers. The observation that it cannot predict the thermal

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1877-7058
Peer-review under responsibility of the scientific committee of the 10th International Symposium on Heating, Ventilation and Air Conditioning.
10.1016/j.proeng.2017.10.310

comfort responses in many real world settings has emerged from many field studies [2]. So in 2004 an adaptive model derived from extensive field studies of comfort was first included in the ASHRAE 55 standard for specific application to the indoor thermal environment of naturally ventilated buildings. That global adaptive model [3] was derived from over 21,000 rows of data collected from mainly office buildings in various climate zones around the world [4]. Whether it can be applied directly to residential contexts still remains unclear. In office buildings, occupants' activities are fairly well defined and invariant while their control over the indoor environment is somewhat restricted. In contrast, occupants in their own home have a vastly enlarged palette of adaptive comfort opportunities such as turning on/off AC, opening windows or doors for comfort ventilation, changing their clothing insulation across a wider range, to mention just a few [5]. Meanwhile, occupants' activities in the various rooms of their home tend to be much more diverse in terms of met rate [6]. As a result of these contextual differences the comfort zone in housing may be wider than that in office buildings. These data are useful to the residential building energy simulation community. To get more accurate energy consumption from building simulation software, Nicol et al. [7] suggested a probabilistic method to predict the proportion of adaptive behaviors as a function of temperature variations. In order to investigate thermal environment and use of air conditioner units in Chinese homes, a longitudinal field study was conducted in residential contexts in Tianjin, China.

2. Methods

Forty three householders in apartment buildings in Tianjin urban area were recruited to this study. These homes had installed at least one split system air conditioner. Field observations were carried out from May 14th to November 20th in 2016. A small datalogger called iButton which could record the temperature was installed at the supply air vent of each air conditioner. Meanwhile one iButton was also placed in the middle of the room to detect and record the indoor air temperature of the occupied zone. The measurement interval was set at 15minutes for the duration of this longitudinal study.

During the monitoring period, online questionnaires were sent out to householders' smartphones with a frequency of two-to-three times per week. The "right here right now" questionnaire consisted of questions (1) whether householders are at home; (2) if yes, which room (if no, survey terminated); (3) adaptive behaviors (turning on AC, turning on fans, opening windows or doors); (4) thermal sensation and (5) clothing insulation. The questionnaires were completed only when householders were located in their home. Apart from the online questionnaires, a background questionnaire was completed by householders on the first home visit with the objective of collecting demographic and basic household descriptive information.

This paper specifically analyzed AC usage patterns, thermal environment and thermal sensations in these homes. Meanwhile, in order to better understand occupants' adaptive behaviors in these households, a set of logistic models were derived with the aim of identifying associations between adaptive behaviors and concurrent outdoor air temperatures.

3. Results & discussions

3.1. Background information

The background information on the sample of 43 households is summarized in Table 1.

Table 1. Summary of the households' information.

	Category	Percent（number of people）
Gender	Male	30.3%
	Female	69.7%
Household size	1 person	2.3%（1）
	2 people	7.0%（3）
	3 people	51.2%（22）
	4 people	25.6%（11）
	>4 people	14.0%（6）
Education level of householders	High school	2.3%（1）