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Residential air-conditioner usage in China and efficiency standardization

Jianghong Wu [a,*], Chaopeng Liu [a], Hongqi Li [b], Dong Ouyang [a], Jianhong Cheng [c], Yuanxia Wang [a], Shaofang You [a]

[a] School of Mechanical and Automotive Engineering, South China University of Technology, Guangzhou, Guangdong, 510641, PR China
[b] Refrigeration and Cryogenic Engineering, Beijing University of Technology, Beijing, 519070, PR China
[c] Chinese National Institute of Standardization, Beijing, 610065, PR China

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ABSTRACT

Determining the real energy consumption and usage pattern of a room air-conditioner (RAC) are important issues from the point of view of both RAC design and evaluation of its energy efficiency. An air-conditioner's running time is fundamental data for the calculation of SEER and APF values. Therefore, in 2010, a nationwide investigation of RAC usage was conducted and 400 selected air-conditioning-units were monitored for a full year to obtain data on their cooling and heating usage. Two running time curves (cooling and heating) were obtained for the air-conditioners as a function of outdoor air temperatures using statistical analysis. The results show that the 27–30 °C temperature range accounts for more than 52% of the cooling time. Conversely, the 0–8 °C temperature range is associated with more than 75% of the heating time. The research presented in this paper has significantly contributed to China's new variable-speed RAC efficiency standard (GB21455-2013). It also has far-reaching implications for both the air-conditioner industry and energy policy in China due to its different method of calculating energy efficiency.

1. Introduction

In China, residential air-conditioners account for over 100 billion kWh of electricity consumption each year — they also consume more than 30% of the peak summer electricity load in large and medium cities [1]. Thus, in order to promote energy conservation and mitigate greenhouse gas emission, it is clearly important to reduce energy consumption in the residential air-conditioning sector. Energy efficiency standards are widely accepted as the primary policy tool to effectively reach this goal. Much research has been conducted to evaluate the potential energy savings and environmental impact of new energy efficiency standards.

Mahlia et al. [2–4] assessed the impact of implementing minimum energy efficiency standards for room air-conditioners (RACs) in Malaysia through a series of studies which evaluated the potential CO_2 reduction, electricity savings, and mitigation of emissions. The studies found that new energy efficiency standards for RACs would provide targets to save funds and energy as well as mitigate a significant amount of emissions in this country.

When China announced a new set of minimum energy-efficiency standards for RACs (with the first tier coming into effect on March 1, 2005 and a tighter tier taking effect on January 1, 2009), Lin and Rosenquist performed a life-cycle cost analysis to assess the changes [5]. They found that the new energy-efficiency standards would yield cumulative national energy savings of over 330 billion kWh by 2020, equivalent to a reduction in carbon emissions from power plants of 323 million tons of carbon. However, the existing national standards governing the air-conditioning industry (GB7725-2004 and GB21455-2008) cannot fully meet the demand of energy saving for their excessive heating time and lack of curves showing heating time versus outdoor air temperature, respectively.

Currently, China actively promotes the use of three efficiency measures. The energy efficiency ratio (EER) is used to evaluate the efficiency of fixed frequency air-conditioners, the seasonal energy efficiency ratio (SEER) is used for cooling-only variable-speed air-conditioners, and the annual performance factor (APF) is used to evaluate variable-speed heat-pump air-conditioners. However, the Chinese National Institute of Standardization (CNIS) has decided to

* Corresponding author.
E-mail address: pmjhwu@scut.edu.cn (J. Wu).

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study the possibility of using SEER and APF standards to evaluate cooling-only and variable-speed heat-pump air-conditioners. Curves of the running time versus outdoor air temperature are the fundamental data required for SEER and APF calculations for residential air-conditioners. Therefore, a nationwide investigation of the energy consumption in the Chinese residential air-conditioning sector was conducted in 2010 with the support of CNIS.

2. Over review of the previous research

Over the past few decades, several researchers have published results of surveys relating to the thermal environment indoors and energy use in residential buildings. Work on weather and energy use in buildings has identified climatic factors (e.g. temperature, moisture content, etc.) as key variables influencing the energy consumption in buildings [6]. On delving deeper, many interrelated socioeconomic, cultural, technical, and institutional factors emerge [7–15]. Based on three earlier studies [16–18], Kempton et al. [19] chose to focus their work on the human factors involved: the user's needs, their concepts, and their behavior. They studied the operation of RACs in detail to understand how energy consumption and peak power demand were influenced by these human factors. It was found that many non-economic factors influenced the usage pattern of the RACs. These factors included health, thermal comfort, safety, waste, folk physiological theories, and folk theories about how RACs function, etc.

Recently, more scientists have recognized that the occupants' behavior has a significant effect on the energy consumption of their air-conditioner. To obtain a better understanding of an occupant's behavior in relation to air-conditioning usage, Schweiker and Shukuya [20,21] conducted a series of studies involving a number of international students living in Tokyo. The behavioral patterns of 39 students were first analyzed according to their usage of air-conditioning (AC) units using the logit model introduced by Rijal et al. [22]. The results showed the occupants' climatic background has the same influence on their behavior. In their subsequent study, Schweiker and Shukuya [21] used theoretical and statistical models of AC unit usage behavior to predict the percentage of residential AC units used during the night-time in Japan. The results indicate that the mean outdoor air temperatures on foregoing nights have a major impact on an occupant's behavior during the night in summer. Also, the impact of the individual factors concerned have the same magnitude as the external factors in summer, but bear a higher impact in winter. According to their previous work, preference has to be considered as one of the major factors affecting an occupant's behavior. Thus, Schweiker and Shukuya [23] carried out another study on the effect of air-conditioner usage preference on the pattern of exergy consumption in a building environment. It was found that preference does indeed have an effect on the exergy consumption pattern of air-conditioning usage.

These studies prove that, on the one hand, an occupant's behavior exerts a great effect on air-conditioner usage for obtaining better thermal comfort. On the other hand, thermal conditions also affect an occupant's behavior by influencing their expectation of thermal comfort. In the field of thermal comfort research, thermal adaptation is used to describe this kind of dynamically interactive process. Brager and de Dear [24] have reviewed the topic of thermal adaptation in the built environment. Their results show that occupants are willing to accept a wider range of temperatures in naturally ventilated buildings, whereas there is a narrowing of temperature tolerance in air-conditioned office environments. These results can be explained by thermal adaptation theory. The theory shows that occupants play an instrumental role in creating their own thermal preferences through the way they interact with the environment. They might modify their own behavior, or gradually adapt their expectations, to match the thermal environment.

In China, many researchers have carried out investigations to determine the actual residential energy consumption, as well as its influencing factors, so as to put forward reasonable countermeasures to promote residential energy conservation. In early studies, investigations were mainly focused on the electricity used by air-conditioners in some Chinese cities, such as, Hong Kong [25], Beijing [26], and Shanghai [27]. The investigation areas were subsequently expanded to other parts of China in follow-up studies and the investigated quantities were also further extended to include consumption of coal gas, natural gas, and coal, as well as the energy used for district heating, and so on [28–30].

Wang et al. [31] carried out a field survey of 100 families with air-conditioners in Guangzhou. Their results indicated that, for these 100 families, the relationship between air-conditioner running time and outdoor air temperature is quite different to the curve used by the Chinese air-conditioner energy efficiency standard GB7725-2004. It was, however, most similar to that in the Chinese air-conditioner energy efficiency standard GB21455-2008.

It is undeniable that the results of these studies can be highly valuable for designing low energy consumption systems for individual thermal comfort in China. However, little research has been carried out on the energy consumption of residential air-conditioning on a national scale. This is because it is a difficult task in China due to its diverse climates, multi-ethnic population, cultural differences, etc. Therefore, in this investigation, we aim to provide data for the development of the national standards of energy efficiency for China's domestic air-conditioner industry and to find the air-conditioner usage habits of dwellers in China. Seven typical cities were chosen to represent the different climatic regions of China, namely, Chengdu, Wuhan, Hangzhou, Guangzhou, Beijing, Shanghai, and Qingdao. Overall, 400 air-conditioned families (selected from nearly 1600 questionnaires) were monitored on their energy consumption for a whole year in these seven Chinese cities. The results form a significant database containing a wealth of information. The investigation began in June 2009 and was completed in October 2010. Each air-conditioning unit was monitored for a full year, to obtain the usage pattern including cooling and heating. Large amounts of data were collected. Extensive statistical analysis of the data was carried out and a piece of statistical analysis software was developed to process the bulk of the data. The purpose of the work presented in this paper is to supply the fundamental data (running time versus outdoor air temperature) for revising the energy efficiency standards for fixed frequency air-conditioners (GB/T 7725-2004) and, more importantly, for setting China's new energy efficiency standards for variable-speed air-conditioners (GB/T 21455-2013). The whole investigation process is showed as Fig. 1.

3. Survey methods

The statistic process is shown in the following description. It starts by investigating the habit of using the air-conditioner of each family. The running/stop time of the air-conditioner and the indoor and outdoor temperature are recorded by the monitoring equipment. Moreover, the information of the family with air-conditioner monitored, i.e., the factors that may influence the using time of the air-conditioner, such as family population structure, the orientation of the air-conditioner, family income, the floor area, the installation type and location of the air-conditioner, etc., are obtained from questionnaire. Then the analysis of the factors influencing the using time of the air-conditioner is done according to the results of the measurement of using time and the questionnaire, which determines the weight of each factor on influencing the performance

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