Energy and Buildings 68 (2014) 165–171

Contents lists available at ScienceDirect

Energy and Buildings

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

An experimental investigation of energy saving potentials for room type variable-speed air conditioners in public offices: A case study from Istanbul

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ARTICLE INFO

Article history:
Received 22 April 2013
Accepted 14 September 2013

Keywords:
Air conditioning
Energy efficiency
Inverter AC
EER
SPF

ABSTRACT

This study includes the comparison of constant speed air conditioners (non-inverter AC) and variable speed air conditioners (inverter AC) in two identical public office rooms in terms of the energy consumption by reflecting user comfort conditions as a field test. The period of this field test was totally 64 days from 31st of July to 2nd October 2012 and ACs were operated for 43 days intermittently. After collecting real data, total and operational energy consumptions, weighted average power and energy consumptions of the selected typical days were conducted. As can be derived from the conducted analyses, the energy saving ratio of inverter AC to non-inverter AC varies between 11% and 38%. The second important observation is that the lower cooling loads than minimum rated power results in shifting inverter AC to on/off mode. The last but not the least, usually energy efficiency ratio (EER) is used as an indicator for evaluating cooling efficiencies of ACs and in this field test although both inverter and non-inverter ACs have the similar EER values, their energy consumptions differ from each other. This results in the requirement of a new indicator for better comparison of energy efficiencies of ACs.

1. Introduction

The world primary energy use is almost doubled between 1973 and 2010 [1]. This fact can be regarded as one of the main reasons for the problems in energy supply security, over-usage of energy resources (mainly fossil fuels) and environmental impacts such as climate change. One of the key sectors in terms of the energy consumption is the building sector, constituting residential and commercial buildings. Generally, it can be observed that the share of energy consumption by building sector is in between 20% and 45% in the developed countries [2]. Main reasons observing these ratios can be due to growth in population, greater demand for building services, the need for better comfort levels, and longer duration of occupants spent time inside buildings [3]. On the basis of realized projection studies by various energy related organizations, improving energy efficiency not only in buildings but also in other end-use sectors can be regarded as primary objective for global energy policies and strategies because of inevitable increase in energy demand and prices.

Currently, due to climate change impact and comfort conditions concerns, heating-ventilation-air conditioning (HVAC) systems have started to be widely used in the industry and building sectors. As stated previously, considering energy efficiency strategies, European Energy Performance of Buildings Directive [4] has proposed utilization of high energy efficient HVAC systems. Especially, in buildings equipped with room type air conditioners (ACs), efficient technologies should be taken into consideration, since the usage of individual systems are more consumer oriented, i.e. primary criteria is the comfort rather than efficiency.

In order to optimize the capacity of ACs, variable speed control can be accepted as one of the applicable measures since 1980. Previously, the constant speed ACs (non-inverter AC) have been widely used in the market while now gradually replaced by the variable speed ACs (inverter AC) due to high energy saving potential and providing comfort at the same time [5]. In the literature major studies are related with the improvements of inverter AC technologies [6,7]. Nonetheless Chen et al. [8] studied on a quantitative comparison between the inverter and non-inverter ACs and showing that up to 19% energy savings could be achieved by the inverter technology for the cooling season [8].

In Turkey, between 2007 and 2011, number of room type air conditioners, sold in the national market is approximately 4.75 million, as declared by Turkish Air Conditioning and Refrigeration Manufacturers' Association (ISKID) statistics in 2012 [9]. According to

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0378-7788/$ – see front matter
http://dx.doi.org/10.1016/j.enbuild.2013.09.020

these statistics, in each year, about 1 million ACs have been sold in Turkish market, just for mainly cooling purposes in the summer season. Additionally, according to the same statistics, ratios of inverter technology and ACs with "A" energy class increase from 2.6% to 19.6% and from 29.3% to 87.9% between 2007 and 2011, respectively.

In this study, it is aimed to compare the differences between energy consumptions of room type inverter and non-inverter ACs in the typical public office rooms, located in Istanbul Technical University (ITU), Energy Institute for a period of between 31st of July and 2nd of October 2012. Furthermore, since the study is designed as a field test, reflecting the impacts of actual user behaviours, perceptions and physical conditions of the rooms, the obtained results are discussed by considering user viewpoints.

2. Methods

In this section, first of all designed test fields with a measurement set-up were described and then the conducted analyses on top of the collected data were explained.

2.1. Test field setup

This field test was conducted in Istanbul Technical University (ITU), Energy Institute building in Ayazağa Campus, Sarıyer. In this building, two rooms were selected for the field test. Each of the rooms has an area of 24.5 m^2 and height of 3 m where their windows are facing to the east. Both rooms were equipped with two AC units. One is an inverter model and the other is a non-inverter model as seen in Fig. 1. The non-inverter ACs operate on/off, in contrary to this, the inverter ACs are designed to operate with a variable speed drive. Table 1 shows the cooling capacity (BTU/h and kW), minimum, nominal and maximum rated powers (kW) and energy efficiency ratio (EER) values of the ACs used in this field test. An energy monitoring system was installed with two energy analysers and a digital timer switch. For indoor and outdoor temperature measurements, single temperature logging devices were used.

In this measurement system, the energy analyser was used for collecting data in each room such as date, time, voltage (V), current (I), active (P), reactive (Q) and apparent powers (S). Moreover, a digital timer switch was installed to ensure that if the inverter model is active for one of the rooms at the same time, non-inverter model is made active for the other room. The control schemes are given in Fig. 2.

The energy analysers were set to log the data in 1 min intervals whereas temperature loggers were set to take data in 30 min. It is worth to mention that the set temperatures of each room were freely adjusted according to the user comfort conditions since this study is designed as a field test.

Table 1
The properties of ACs used in the field test.

Type	Cooling capacity		Rated power (kW) Min./nom./max.	EER
	BTU/h	kW		
Inverter AC	11,900	3.2	0.31/0.995/1.43	3.21
Non-inverter AC	12,000	3.52	1.09	3.23

2.2. Analyses methods

After collecting the data, firstly, total energy consumption analysis was conducted in order to determine energy saving ratio of inverter AC to non-inverter AC regardless of the rooms. Additionally, since the test rooms are the public offices, the working hours are usually in between 8:30 and 17:30. For this reason, operational energy consumptions were also calculated. Secondly, weighted average power figures were analyzed to observe the change in energy saving ratio of inverter and non-inverter ACs for each room. Lastly, for reflecting the difference in terms of energy saving obtained by inverter AC over non-inverter AC within a room, energy consumptions of selected typical days, in which the outside temperature patterns are almost the same, were calculated. The following sections are for detailed explanations of each described analyses.

2.2.1. Total and operational energy consumption

By using the power data logged in 1 min interval (P_{ij}) in W, total energy consumption per day (E_{total}) in Wh, operational energy (E_{opr}) consumption within the working hours were calculated by Eqs. (1) and (2), respectively.

$$E_{total} = \frac{1}{60}\sum_{i=1}^{24}\sum_{j=1}^{60} P_{ij} \tag{1}$$

$$E_{opr} = \frac{1}{60}\sum_{i=istart}^{istop} P_i \tag{2}$$

2.2.2. Weighted power analysis

At the beginning, daily average powers (P_{ave}) in W for each day in the analysis period were calculated by using Eq. (3). Afterwards, in order to find weighted average power (P_w) figures, which can be defined as the ratio of total energy consumption to the cumulative

Fig. 1. Test rooms equipped with inverter and non-inverter ACs.