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Field study of thermal environment spatial distribution and passenger local thermal comfort in aircraft cabin

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ABSTRACT

Comfortable aircraft cabin environment is important for civil aviation industry because it means more passengers and profits. In recent years, environment and comfort in aircraft cabin have become a hot topic. The existing investigations provide sufficient results yet still show some weak points. Few studies have concerned the spatial distribution of both environment and thermal comfort in the cabin. Besides, local thermal comfort (LTC) on a real airplane is also unclear.

In present study, we conducted a field survey on 10 aircrafts in China, measuring thermal environment parameters and collecting questionnaires. The results indicated that the spatial distribution in cabin was not as uniform as thought before yet the difference exerted no significant influence on passengers' thermal comfort evaluation perhaps due to their self-adjustment ability. The overall thermal comfort (OTC) evaluation was not so satisfying, with almost 30% passengers complained warm.

Apart from head, back and foot, satisfaction rate of LTC was higher than OTC. The upper body was the most comfortable part with satisfaction percentage over 80% followed by lower body part with 70%–80% passengers satisfied. OTC was significantly influenced by LTC of certain body parts which would vary at different seat positions. Regression model showed that head and back were significant at four seat positions and improved the LTC should be an effective way for better OTC in the cabin. This study only included one aircraft type and in other types the conditions might be completely different which needs further investigations.

1. Introduction

In recent years, with the rapid development of civil aviation industry, the passengers have higher requirement for the comfort in aircraft cabin, which is also a major factor in airline business competition. There are many factors influencing comfort in the cabin such as temperature, humidity, air pressure, noise, vibration and etc. The cabin comfort problem has also attracted the researchers' attention and many investigations have been conducted.

Of all these investigations, only few were performed on board. In 1999, Haghighat et al. [1] measured air temperature, relative humidity and carbon dioxide concentration on 43 commercial flights and calculated the thermal comfort using Predicted Mean Vote (PMV) and Predicted Percent Dissatisfied (PPD) model recommended by ASHRAE Standard 55-2013 [2]. They reported a very low level of humidity and considered this a main reason that caused passengers' dissatisfaction. Similar results were obtained in other literatures [3,4]. Rankin et al. [5] collected about 1560 questionnaires from passengers on 71 flights and reported the passengers' evaluation of overall comfort was 4.7 on a scale from 1 (very poor) to 7 (excellent). They also found that seat comfort was the best predictor of overall comfort and this question was further discussed in a review paper by Brundrett et al. [6]. In recent years, Cui et al. [7,8] reported their field investigation on cabin environment and comfort on 33 aircrafts which revealed that the nonuniform distribution of thermal parameters did exist. Pang et al. [9] collected environment data from 31 aircrafts and found that air temperature and relative humidity in intercontinental flights were generally lower than continental flights.

Due to the difficulty in conducting investigations in real aircraft cabins, researchers turned to laboratory studies in which they could have better control of environment parameters. It is generally accepted that the low relative humidity level in the cabin is an important contributor to discomfort and health related problems. Grün et al. [10] conducted experiments in a simulated aircraft environment and reported the perception of dryness decreased significantly at very low levels of relative humidity around 10%.

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Nagda and Hodgson [11] reviewed laboratory and field studies on low humidity and pointed out that the inability to perceive low humidity or changes in the humidity level was sometimes mistaken for lack of a humidity effect. They also inferred that the effect of low humidity was not noticeable within 3 or 4 h exposure duration. Støm-Tejsen et al. [12] studied the feasibility of increasing humidity level by reducing the supply of fresh air in a simulated aircraft cabin and found that increasing relative humidity in the cabin to 28% by reducing outside flow to 1.4 l/s per person did not reduce the intensity of the symptoms that were typical of the cabin environment, and on the contrary, it intensified complaints of headache, dizziness and claustrophobia, due to the increased level of contaminants. Instead of reducing fresh air, Zhang et al. [13] proposed a new under-aisle air distribution system which could improve the relative humidity from the existent 10%–20% without causing moisture condensation on cabin interior and inducing draught risks for passengers. Zítec et al. [14] explored the possibility of individual ventilation system built into the back of the seat. Some researches were related to physiological factors. Muhm et al. [15] investigated the effect of cabin altitude on passenger discomfort in a 20-h simulated flight and reported a 4% decrease of the oxygen saturation at cabin altitude of 7000–8000 ft, which was insufficient to affect the occurrence of acute mountain sickness but did contribute to the increased frequency of reports of discomfort. Hinninghofen and Enck [16] gave a relatively comprehensive review of passenger well-being in airplanes and discussed almost all the factors that might influence comfort.

Apart from field investigations and laboratory experiments, some researchers are trying to develop new methods for cabin comfort assessment. Cui et al. [17] revised PMV model by adding the influence of cabin air pressure. And Pang et al. [9] proposed another method by combining PMV model with thermal adaptive model to guide the control of the environment control system (ECS).

Thermal comfort is an important part of cabin comfort yet the available literatures provide limited information especially on the passengers' subjective response and its relationship with cabin environment. For example, Haghighat et al. [1] only measured the thermal environment in the cabin without collecting the subjective evaluation of the passengers while Rankin et al. [5] only conducted the questionnaire survey but didn't measure the thermal environment. It is quite necessary to conduct a systematical field study of thermal comfort in aircraft cabin.

Some problems remain to be solved. In most former researches, it was assumed that the thermal environment in the cabin was uniformly distributed so the results of one measure point could represent the entire cabin [1]. Actually, the spatial distribution of thermal environment parameters in cabin is not well understood. Besides, the main way to obtain passengers' evaluation on thermal comfort is through questionnaires but now little data is available especially the data collected on board. Those laboratory experiments [18,19] could not simulate the cabin environment perfectly so whether the results could represent the real conditions in the cabin is not clear.

This study presents a field investigation of cabin thermal comfort, including the spatial distribution of thermal environment parameters such as air temperature, relative humidity, black globe temperature, and air velocity and questionnaire survey for the passengers. In the cabin, passengers' seat or cabin position may influence their thermal comfort. For example, passengers sitting next to window may be influenced by the hot or cold radiation from the window and passengers at high human density area may experience higher temperature. As to the human body, the OTC is influenced by LTC, which has been preliminarily proved by Park et al. [19] in a simulated cabin environment. In this study, we also investigated passengers' OTC and LTC as well as their relationship in real aircraft cabin.

2. Methodologies

Field study was conducted on 10 aircrafts in China from March 8 to 12, 2013. The detailed information is listed in Table 1. A total of five airlines were selected, which were all major airlines in China. Every airline contained a round-trip fight and the starting city was Qingdao in Shandong Province.

To investigate thermal comfort in cabin, thermal environment parameters including air temperature, relative humidity, black globe temperature, cabin wall temperature and air velocity were measured. The cabin space was divided into three parts: front (1–10 row), middle (11–20 row) and back (21–30 row) and in each part one measurement point was set. 1–2 rows belonged to first class and had four seats in each row. 3–30 rows were economy class and had six seats in each row (A–F, left to right). The aisle was in the middle. Since the first class was always empty, most of the investigations were conducted in economy class. The seat locations of the measure points in each flight were listed in the last column of Table 1. Each measure point contained two temperature and humidity sensors fixed on the seat back at passenger's head and foot level respectively for testing vertical temperature difference, one black globe temperature sensor placed on the small table, one infrared thermometer for cabin wall temperature measurement and one hot ball air velocity meter for measuring cabin air velocity. Air temperature, black globe temperature and relative humidity were recorded automatically every 30 s from take off until landing and wall temperature and air velocity were measured manually. The measure points for cabin wall temperature include three parts: the ceiling, side wall and floor. In ascent and descent periods, wall temperature was recorded every 10 min and in cruising period, the

Table 1
Information of measured aircrafts.

Flight number	Airline	Airplane type	Airplane registration number	Time	Attendance	Measure points
SC4631	Qingdao (QD) to Harbin (HA)	B737	B5652	7:35–9:15	120/168	5C/16D/27D
SC4632	Harbin (HA) to Qingdao (QD)	B737		10:30–12:25	140/168	5C/16D/27D
SC4611	Qingdao (QD) to Urumqi (UR)	B737	B5627	11:00–14:33	131/168	4C/16D/27B
SC4612	Urumqi (UR) to Qingdao (QD)	B737		15:40–18:45	123/168	4C/16D/27B
SC4713	Qingdao (QD) to Chengdu (CD)	B737	B5331	18:45–21:30	171/180	4C/16D/30B
SC4714	Chengdu (CD) to Qingdao (QD)	B737		22:50–1:05	180/180	4C/16D/30B
SC4681	Qingdao (QD) to Shenzhen (SZ)	B737	B5333	17:40–20:45	142/168	4C/12D/23C
SC4682	Shenzhen (SZ) to Qingdao (QD)	B737		22:00–0:35	144/180	2C/12D/23C
SC4675	Qingdao (QD) to Guangzhou (GZ)	B737	B5118	17:30–20:30	147/168	4C/16D/27B
SC4676	Guangzhou (GZ) to Qingdao (QD)	B737		21:45–0:35	136/168	4C/16D/27B