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# Experimental investigation of personal air supply nozzle use in aircraft cabins

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ABSTRACT

To study air passengers' use of individual air supply nozzles in aircraft cabins, we constructed an experimental chamber which replicated the interior of a modern passenger aircraft. A series of experiments were conducted at different levels of cabin occupancy. Survey data were collected focused on the reasons for opening the nozzle, adjusting the level of air flow, and changing the direction of the air flow. The results showed that human thermal and draft sensations change over time in an aircraft cabin. The thermal sensation response was highest when the volunteers first entered the cabin and decreased over time until it stablized. Fifty-one percent of volunteers opened the nozzle to alleviate a feeling of stuffiness, and more than 50% adjusted the nozzle to improve upper body comfort. Over the period of the experiment the majority of volunteers chose to adjust their the air flow of their personal system. This confirms airline companies' decisions to install the individual aircraft ventilation systems in their aircraft indicates that personal air systems based on nozzle adjustment are essential for cabin comfort. These results will assist in the design of more efficient air distribution systems within passenger aircraft cabins where there is a need to optimize the air flow in order to efficiently improve aircraft passengers' thermal comfort and reduce energy use.



## 1. Introduction

Increasing numbers of passengers spend more and more time in aircraft cabins (Advisory Council, http://www.acare4europe.org/html/documentation.asp.) and are exposed to environmental conditions artificially created by the aircraft's onboard systems. Since the 1970s, commercial aircraft have been flying at heights of approximately 12 km (ca. 39,000 ft), (Gunnar Grün et al., 2012), with the temperature outside of the aircraft cabins at or below −50 °C, the relative humidity between 20% and 100% above ice (Vaughan G et al., 2005), and the absolute air pressure around 195 hpa (Hinkelbein J et al., 2007). Thus, the environmental control system of an aircraft cabin is critical to both passenger safety and comfort.

The environmental control system of a typical passenger aircraft comprises two parts. The first is the main air distribution system which controls the thermal comfort and air quality of the overall cabin environment (He L, 2010). This main air distribution system cannot however meet the thermal comfort and health demands of every passenger and an individual air system supply is needed to compensate for such limitations. This, the second part of the system, supplies conditioned air directly to each passenger via an individual air supply system. This type of individual supply air system is widely used in the industry. Aircraft manufacturers such as Boeing and Airbus use this type of individual system because of its ease of use and flexibility of its control. It has become an industry standard.

The advantage of the individual air supply system is that each passenger can control both the air flow rate and direction to help achieve their preferred environment. In the past decade, the topic of individualized air supply systems has attracted the attention of several researchers. Jacobs and de Gids (2006) proposed a new concept of aircraft cabin air-conditioning that is built into the seat. Similarly, Zhang and Chen (2007) proposed a personal seatback-

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embedded air supply system that delivers clean air directly to the inhalation regions of a passenger. Based on these studies, Zítek et al. (2010) considered that each seat in a commercial aircraft should be supplied with a separate individual air flow and a separate exhaust, which could help protect passengers against the possible spread of airborne diseases during flights. Zhang et al. (2012) developed a personal air distribution system with air terminals embedded in chair armrests. This was designed and verified using computational fluid dynamics (CFD) simulation and experimental validation. Furthermore, Gao and Niu (2004, 2008) used a CFD model to investigate the personal ventilation of an air supply pipe located in each of the passenger's breathing area and showed that this type of ventilation can improve passenger air quality. Bolashikov et al. (2010) and Melikov et al. (2012) studied thermal comfort and inhaled air quality using a seat headrest system incorporating personalized ventilation.

In these studies of personal air distribution systems in aircraft cabins, the main focus has been on the improvement of the seat position and how this may influence air distribution. Most of these studies only consider the influence on the air quality in the breathing zone rather than the overall effect on passengers' thermal comfort. The innovations proposed by these researchers are however far from complete and the traditional individual nozzle air distribution system remains in active use. Only a few of these studies included experimental investigations, most used CFD numerical simulation as the research method. The disadvantage of such simulations is that the results require further validation due to the simplification of the models and boundary conditions in CFD simulations. In addition, the dummy models used in these studies to simulate human heat dissipation and breathing are not fully representative of actual humans.

Further research was clearly needed. This led to the decision to design and develop an experimental cabin to carry out an experimental investigation of the influence of the traditional individual nozzle air distribution system on human thermal comfort. To simulate the environment of a real airliner cabin, a three-row aircraft cabin was built to the requirements of ASHRAE161 (2007) in a laboratory building of the Faculty of Urban Construction and Environmental Engineering, Chongqing University. This has led to a range of experimental studies. The focus of the research reported in this paper was cabin occupants' use of the personal air supply nozzles, in particularly the analysis of when the research volunteers decided to open or close the air vents, and the direction selected for the air flow. This was investigated based on volunteers' thermal responses to the overall thermal environment.

## 2. Experimental work

### 2.1. Experimental system

The design of the cabin was based on the cross sectional size of the Airbus A320. A cabin sized 4.9 m × 3.9 m × 2.35 m was constructed. From the outside, the cabin structure appeared as a half-cylinder and was made of wood with thermal insulation. The cabin was placed in an air-conditioned room to prevent the influence of the external environment. Fig. 1 shows the main dimensions of the simulation chamber.

The environmental control system comprised both the main air distribution system and the personal air distribution system as shown in Fig. 2. In the design of the system, the main air distribution system followed the requirements of ASHRE161 2007 to create a healthy thermal environment for passengers. The process involved mixing the fresh air and return air before processing it to the set condition. Then, through the pressurization fan, air flowed to the slot outlets on the ceiling of the cabin and into the simulated cabin at a smooth steady speed. The air flowed into the mixer through return air inlets for circulation. The personal air distribution system offered flexible control to meet the individual comfort demands of the volunteers undergoing the experiment. In the system process, after the fresh air from outside and the return air were mixed in the mixer, the air was processed by an air conditioner and flowed into the plenum chamber by a pressurization fan. Then it flowed through pipes to the nozzles above the seats and, when turned on by the occupant of the seat, entered the cabin as a jet flow. The two control systems were independent from each other when the temperature of the air conditioned system ranged from 5 °C to 35 °C with a precision of ±0.5 °C. Common airliner nozzles, with the air supply velocity ranging from 0 m $s^{-1}$ to approximately 25 m $s^{-1}$, were controllable by adjusting the knob and pipeline valve. These were used in the personal air distribution system in the simulated cabin as shown in Fig. 3.

### 2.2. Experimental population

The volunteers in this experiment were healthy college students and were divided into two groups by gender with equal numbers for each group. They were asked to complete forms to provide relevant information, such as gender, age, height, weight, clothing type, etc. The clothing records were based on the clothes worn by the volunteers on the testing day, and volunteers had been informed that they should wear formal summer clothing with a thermal resistance of about 0.6 clo. Specific information relating to the study participants is provided in Table 1.

### 2.3. Experimental conditions and questionnaire

The simulated cabin had a total of 18 seats. These seats were arranged in three rows each with six seats arranged in two blocks of three, separated by a central isle. Passenger comfort is affected by passenger density so the experiment included three different passenger densities, 100%, 67%, and 33% capacity, which meant that the number of volunteers used was either 18, 12, or 6. Each experimental condition was tested four times with equal numbers of male

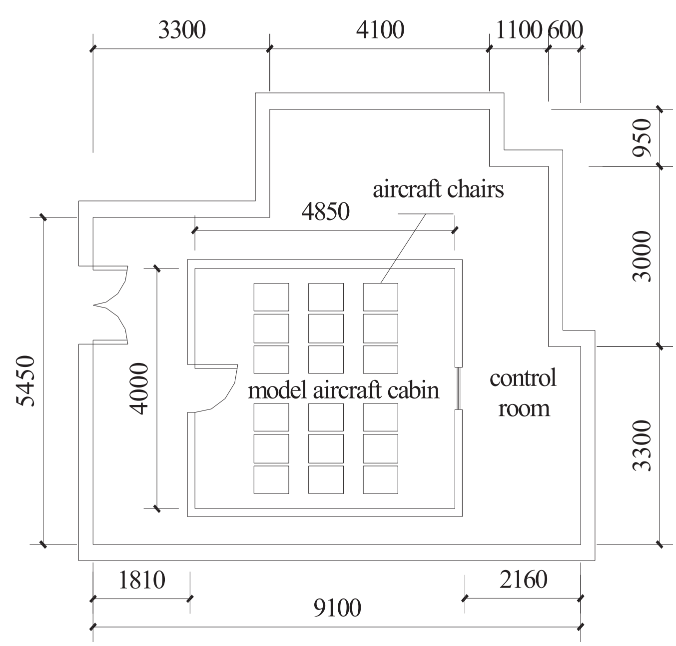


**Fig. 1.** Diagram of the experimental cabin.