
Passengers' Thermal Comfort in Commercial Aircraft Cabins

By **Essam E. Khalil** (ASHRAE Fellow, ASME Fellow and AIAA Fellow), Faculty of Engineering, Cairo University, Giza, Egypt

Abstract

Improving comfortable environmental conditions for passengers has been the focus of airliners in recent decades. This can be achieved by studying air distribution systems and factors impacting this goal inside the cabin to create a healthy and comfortable environment for passengers and the cabin crew. This Research was done using Ansys Fluent 17.0, which has new features that can improve the results. The standard air distribution systems used recently in air cabins are a combination of mixing ventilation and personalized ventilation, and this study will enable simple modification in the ventilation system to improve the ventilation efficiency, thus saving passengers from being infected by each other. Commercial airplane environmental control systems (ECS) currently use mixing air ventilation systems, which are necessary to create a safe, thermally comfortable and healthy cabin environment. The CFD program (Ansys Fluent 17.0) was run after meshing the modeling for more than 7 million mesh element size for both cases that are simulated in the present study. Its modeling techniques solved the equations of energy, momentum, continuity and species transport as well as RNG k-epsilon model equations for turbulence closure. The PMV and PPD indices were used to predict thermal comfort in the present study.

Keywords: CFD, Thermal Comfort, Personalized Ventilation, PMV, PPD

About the Author

Essam Khalil is Professor of Energy in the Mechanical Engineering Department at Cairo University, and may be contacted at khalile1@asme.org

Introduction

In recent decades, travel by aircraft has increased considerably. It is noted that the number of travelers continues to increase every year. Almost two billion people travel by air worldwide every year¹, and this is projected to increase 4.2% over the next two decades². Accordingly, the large number of passengers has to be made comfortable, healthy, safe and free from contracting diseases during their travel. In this Investigation, we have revised the acceptable methods of air distribution inside aircraft cabins to enhance the safety of passengers.

Acceptable indoor air quality means air in which there are no known contaminants in harmful concentrations as determined by cognizant authorities and with which a substantial majority (80% or more) of the people exposed do not express dissatisfaction³. So the Indoor Air Quality (IAQ) plays the main role in achieving the recommended conditions. Modern commercial airplanes cruise at a variable altitude above sea level, where the outdoor environment (pressure, temperature and relative humidity) is extreme. For example, the barometric pressure is only about one-fifth of that at sea level, the temperature is about -55°C (-67°F), the air is nearly dry, and there is a high risk of ozone exposure⁴. Due to extreme difference between indoor and outdoor physical parameters, an Environmental Control System (ECS) is necessary to be equipped in airplanes to keep travelers and cabin crew safe. The ECS consists of two parts. The first one that controls the thermal comfort and air quality of the cabin is called the main air distribution system, which must ensure thermal comfort and healthy environment for each traveler. The second part is the individual air supply system that supplies conditioned air to every traveler directly in the breathing zone. Airbus and Boeing aircraft manufacturers use the individual system in which it is easier to control the air flow and direction by the traveler to achieve the desirable environment.

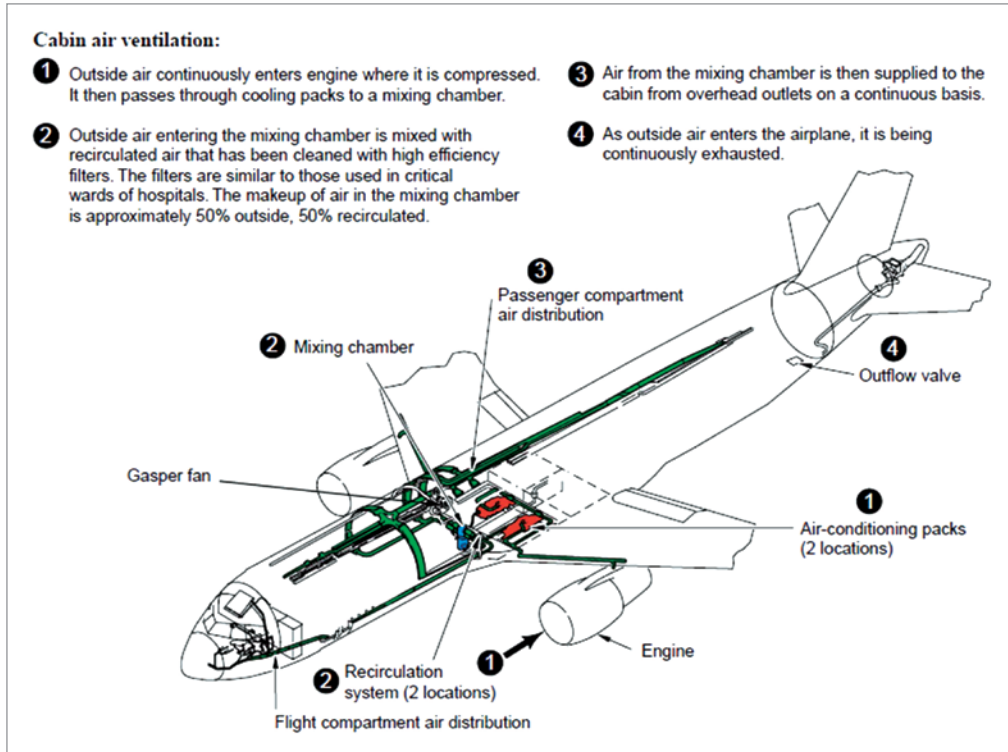


Figure 1: Airplane ventilation system details⁷

Airplane Ventilation System

The cooled conditioned air is supplied to the aircraft cabin through air conditioned packs located under the wing center section. These packs are supplied with equal quantity of outside air from the engine compressor and filtered recirculated air, as shown in Figure 1. The outside air is mixed with filtered recirculated air in a mixing manifold to give almost 20 cfm of air for every passenger, which corresponds to a complete air change every 2 to 3 minutes (i.e., 20 to 30 air changes per hour)⁵. The recirculated air is filtered by high-efficiency particulate air (HEPA) filters before being drawn into the mixing manifold. The recommended thermal comfort condition is in the range between 22.5 and 26°C and 30–60% relative humidity (RH)⁶. The indoor temperature and humidity must be kept within the acceptable range mentioned above. In this investigation, we will study thermal comfort and IAQ by analyzing and providing the best air distribution modes for passengers, using Computational Fluid Dynamics (CFD).

Mathematical Modeling and Governing Equations

The CFD technique uses rigorous fluid flow equations (Navier-Stokes) and conservation principles along with specialized turbulence models:

- k-ε model,
- k-ω model, and
- SST, among others

These models are more accurate and fundamentally more acceptable than empirical ones. The empirical models are approximations, which assemble different phenomena to remove a number of unknown parameters. For this reason, these models are not reliable and therefore should not be generalized.

The CFD models can be divided into two groups:

(i) The Eulerian-Eulerian Model

It considers the gas and solid phases as two interpenetrating continuum flows.

(ii) The Eulerian-Lagrangian Model

It considers the gas as a fluid phase and the solids as a discrete phase.

The Eulerian-Lagrangian model uses Newton's second law in computing the trajectory of each individual particle. The particle interaction in between can be described by the potential energy or the dynamics of collisions. Knowing exactly the particle trajectory and the system variables are the advantages of this method. However, this requires high computational effort, higher still when gas and solid velocity fields are coupled. The present mathematical modeling has been done on Airbus A340-600

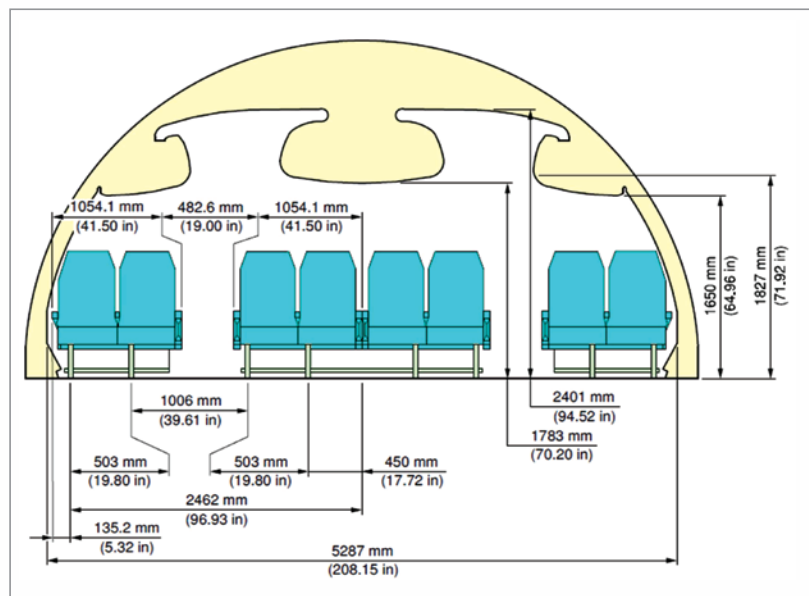


Figure 2: A340-600 aircraft interior design⁸

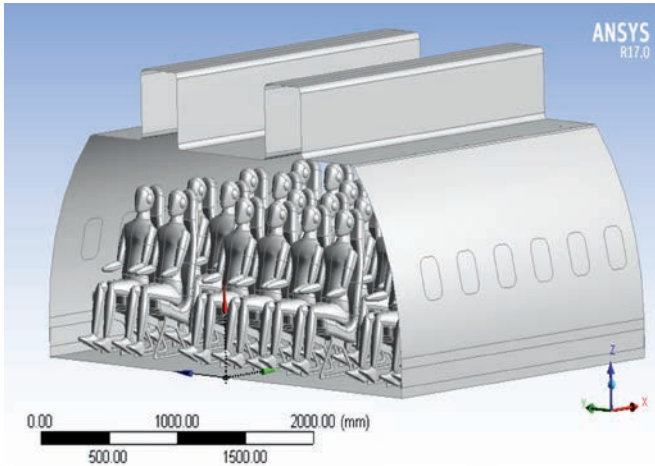


Figure 3: Computational representation of A340-600 aircraft geometry aircraft that are widely used in international transportation and carry a huge number of passengers; hence this study is focused on making the CFD simulation arrive at an optimum design that achieves all parameters for human comfort. In case of airborne diseases in the aircraft being out of control, infection can be transferred rapidly. The aircraft cabin dimensions are 5.29 m width, 4 m length and 2.40 m average height, as shown in Figure 2. It consists of 4 rows, 8 seats for each, and all seats being occupied by passengers. The lighting, composed of two fluorescent lamps, is mounted on the ceiling. The exhaust consists of two outlets that are located in the side wall at the bottom; each exhaust is 0.15 m and the supply air has two main inlets with a width of 0.15 m and a round diffuser for each passenger with a diameter of 0.02 m. The cabin body has double glass windows with the standard dimensions of 0.25 m width and 0.34 m height, as shown in Figure 3.

Case Studies

Ansys Fluent 17.0 was used to simulate the aircraft cabin environment for Airbus A340-600 during the cruise flight. The aim of this research is to arrive at the best comfort environment by modifying the supply and exhaust locations that can

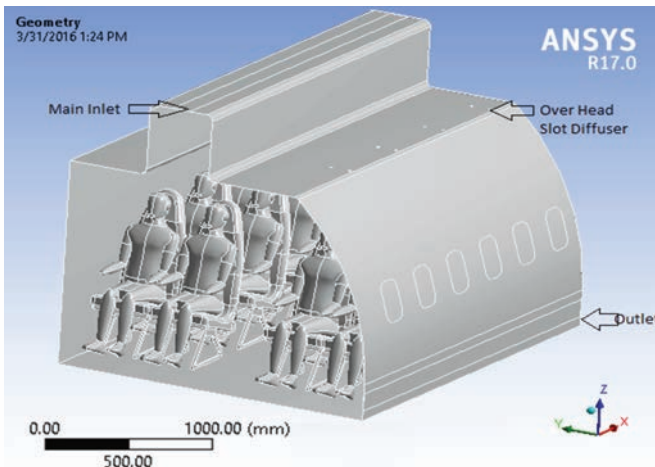


Figure 4: Basic configuration geometry

improve air quality, temperature and humidity, which are the important parameters; compare and analyze the simulated cabin environment with mixing and personalized ventilation systems; and to reach the optimum design to save the occupants against airborne diseases. All the researched air distribution systems simulated prior to this are under-floor displacement ventilation, mixing ventilation and personalized ventilation.

Basic Configuration

This case and the other case consist of two air distribution systems working together. The air distribution systems are mixing ventilation and personalized ventilation systems, as shown in Figure 4. The air in this case is supplied from main inlets in the center of the two corridors and the other inlets are circular diffusers above the passengers. The air is exhausted from two linear slot diffusers at the bottom of the side walls of the cabin that serve the whole aircraft.

Modified Configuration

The air distribution systems are the same as in the first case – a mixing ventilation and personalized ventilation system. The air for this design is supplied from main inlets in the center of the two corridors, and the other inlet is the circular diffuser above the passengers. The air is exhausted from three linear slot diffusers, as shown in Figure 5: two at the bottom of the side wall of the cabin and the third in the middle of the cabin floor. The boundary condition for this case is the same as in the Basic Configuration; only the under-chair outlet is added to improve ventilation.

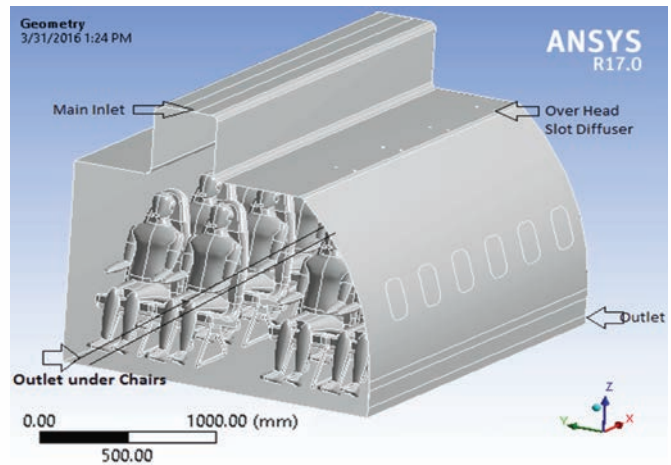


Figure 5: Modified configuration geometry

Results and Discussion

The temperature contours of the Basic Configuration in Figure 6, and the Modified Configuration in Figure 7, show that temperature values are distributed well for the four chairs in the middle of the aircraft and the two chairs on the pathway of the corridors having a temperature within the recommended range⁶ for the four columns, and a temperature between the 21 and 26°C that is comfortable for the passengers. Figure 8 indicates that the velocity contour values are about 0.22 m/s around the passengers, but also indicates air flow dead zones that mean these areas need more ventilation. Figure 9 shows the velocity

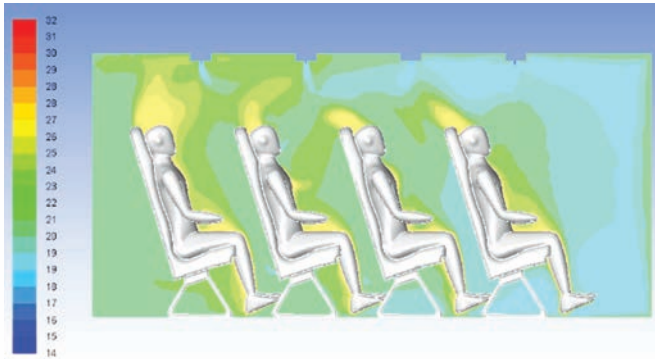


Figure 6: Temperature contours for the second column of Basic Configuration, °C

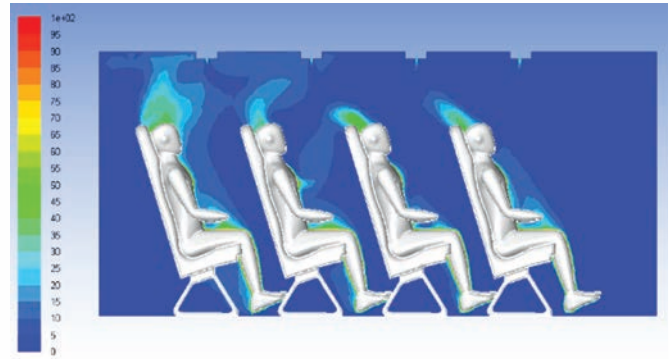


Figure 10: PPD contours for the second column of Basic Configuration

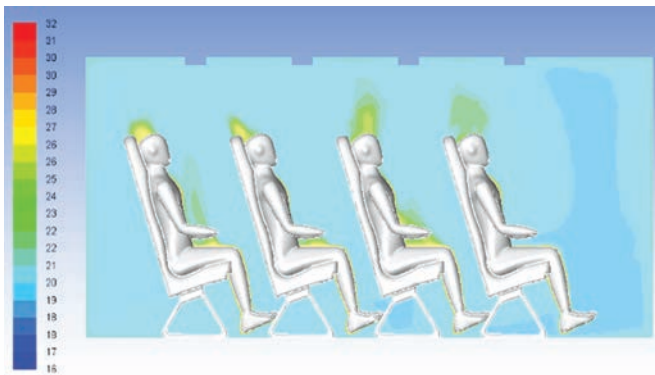


Figure 7: Temperature contours for the second column of Modified Configuration, °C

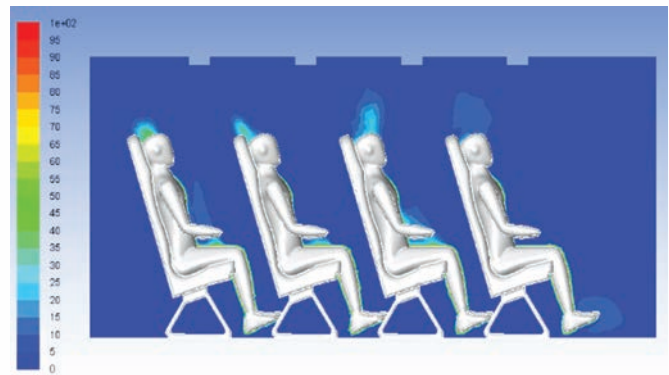


Figure 11: PPD contours for the second column of Modified Configuration

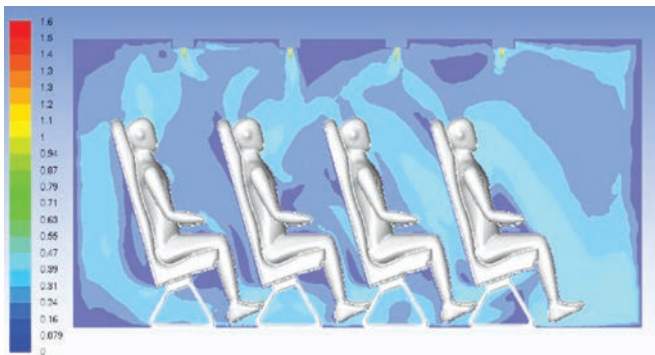


Figure 8: Velocity contours for the second column of Basic Configuration, m/s.

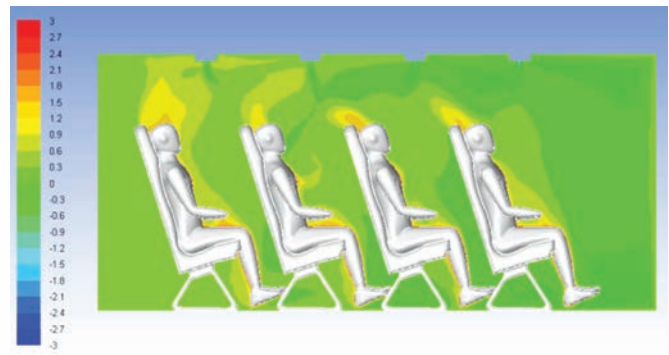


Figure 12: PMV contours for the second column of Basic Configuration



Figure 9: Velocity contours for the second column of Modified Configuration, m/s.

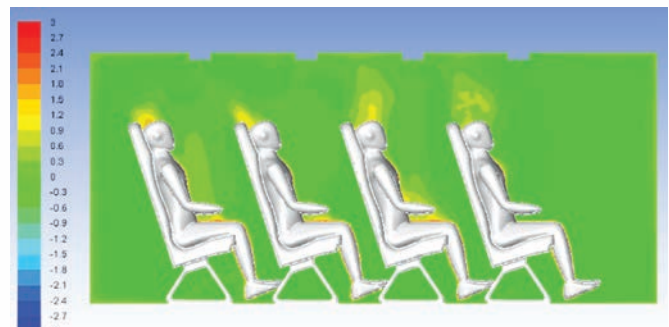


Figure 13: PMV contours for the second column of Modified Configuration

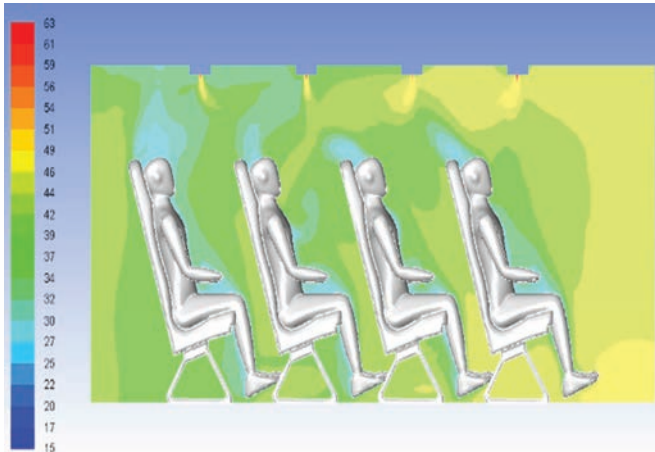


Figure 14: RH contours for the second column of Basic Configuration

contours of the second case also around 0.22 m/s, but both the passengers and other areas are having good ventilation of the cabin and hence guaranteeing passenger safety and comfort^{11,12}.

The contours shown in Figure 10 to 13 indicate the predicted PPD and PMV for the Basic Configuration and the Modified Configuration. The PMV values are well in the range of comfort ($-0.5 \leq \text{PMV} \leq 0.5$) according to ASHRAE 55 (2017).

Figure 14 and 15 show the RH for the second column of the passengers from the window side and it is clear that the Modified Configuration is more comfortable than the Basic Configuration; this shows the huge effect of adding additional exhaust air at the floor of the cabin.

The important parameters here are the dimensions of the exhaust air duct that are calculated, which will reduce the space in the cargo hold and can be discussed with the airliner manufacturer.

Conclusions

1. The air distribution system of the Basic Configuration helped to have velocity values within the recommended range, as referred in ASHRAE 55 (2017), in the cabin. The maximum velocity value in the cabin was about 0.27 m/s.
2. Using the air distribution system of the Modified Configuration provided a good air temperature distribution in the cabin, and the temperature values at the zones between the passengers did not exceed the recommended values 22.5 and 26°C and 30–60% RH6.
3. Combining the mixing air distribution system with a personalized air distribution system creates an efficient ventilation system when providing an additional exhaust outlet.
4. Personalized air distribution systems have many designs but the important point of the design is to direct the fresh air to the breathing zone and to design the suction surface near it to minimize contaminant transportation, as shown in the Modified Configuration.

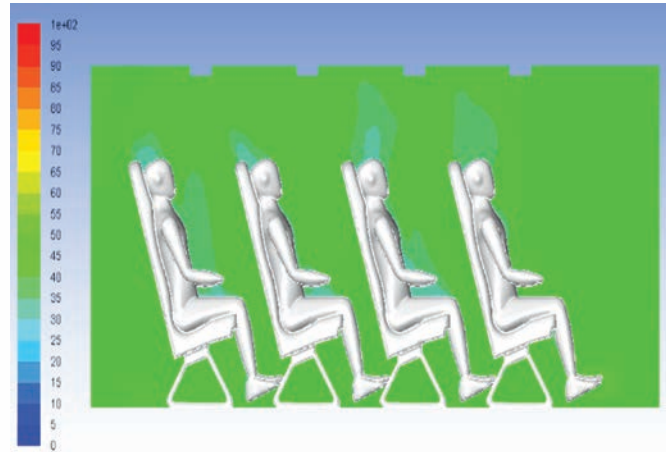


Figure 15: RH contours for the second column of Modified Configuration

5. The Modified Configuration is a simple design modification to the normal ventilation system and does not cost much for improving the ventilation system in the cabin.
6. The Modified Configuration can be modified in the future by adjusting the dimension of the outlet and the velocity of the inlet to reach the optimum design.
7. Air distribution must achieve velocity and temperature balance in the cabin, and this can be done by changing the locations of supply and return air terminals.

References

- 1 Silverman, D., and M. Gendreau. 2009. Medical issues associated with commercial flights. *The Lancet* 373 (9680): 2067–77.
- 2 Boeing Inc., *Current market outlook 2011–2030*. Seattle, WA: Boeing Commercial Airplanes. 2011.
- 3 ASHRAE Standard 62.1, ASHRAE Inc., 2010.
- 4 National Research Council (NRC). 2002. *The airliner cabin environment and the health of passengers and crew*. Washington, DC: National Academy Press.
- 5 Hunt, E., Reid, D. and Tilton. F., 1995. Commercial airliner environmental control system. Aerospace Medical Association Annual Meeting, May 7–11, Anaheim, CA.
- 6 ASHRAE Standard 55, ASHRAE Inc., 2017.
- 7 Hunt Elwood H, Reid Don H, Space David R., Tilton Fred E., *Commercial airliner environmental control system—engineering aspects of cabin air quality*. Boeing web site, 2007.
- 8 www.airbus.com/.../media.../Airbus-AC-A340-500-600-20140101.pdf
- 9 Ansys customer training material. www.ansys.com (Last checked at 2:55 pm, on March 01, 2016).
- 10 Nielsen, P, 1990, *Specification of a two-dimensional test case*, ISSN 0902-7513 R9040, Aalborg University.
- 11 Khalil, E.E., *Air Distribution in Buildings*, Taylor and Francis, CRC Press, 2013.
- 12 Gelgel, M.S., *Numerical investigation of improving air distribution systems in aircrafts Passengers Cabins*, MSc. Thesis, Cairo University, 2016.