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MASTER DEGREE THESIS
ON SPECIALITY
"AVIATION AND ROCKET-SPACE TECHNOLOGIES"

Topic: "Effective Humidification In Aircraft Cabin As A Safety Standard"

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ЗАВДАННЯ

на виконання кваліфікаційної роботи пошукача

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1. Тема роботи **«**Ефективне забезпечення вологості повітря в кабіні літака як стандарт безпеки**»**, затверджена наказом ректора від 05 жовтня 2022 року №1861/ст.

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3. Вихідні дані до роботи: льотно-технічні дані літаків прототипів, нормативні документи по контролю вологості повітря на борту літака.

4. Зміст пояснювальної записки: аналіз впливу вологості повітря на конструкцію літака, дослідження необхідності забезпечення вологості повітря для пасажирів, аванпроект пасажирського літака, розробка рекомендацій по контролю вологості повітря, концепція індивідуальної системи вентиляції, питання охорони праці та навколишнього середовища.

5. Перелік обов’язкового графічного (ілюстративного) матеріалу: презентація Power Point, малюнки та схеми.

6. Календарний план-графік:

№	Завдання	Термін виконання	Відмітка про виконання
1	Огляд літератури про вплив вологості повітря на конструкцію літака, визначення та регулювання її показників	06.10.2022-18.10.2022	
2	Аналіз літаків прототипів, проектування пасажирського літака	19.10.2022-29.10.2022	
3	Аналіз схем вентиляції, систем кондиціонування повітря на борту пасажирських лайнерів	30.10.2022-07.11.2022	
4	Розробка рекомендацій по індивідуальній системі вентиляції на борту лайнера	06.10.2022-31.10.2022	
5	Виконання розділів, присвячених охороні навколишнього середовища та праці	01.11.2022-04.11.2022	
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"___" __________________ 2022

TASK

for the master degree thesis

Liliia Sukhytska

1. Topic: " Effective Humidification In Aircraft Cabin As A Safety Standard ", approved by the Rector’s order № 1861/ст from 05 October 2022 year.

2. Period of work execution: from 05 October 2022 year to 30 November 2022 year.

3. Initial data: flight technical data of prototype aircraft, regulatory documents on air humidity control on board the aircraft.

4. Content: analysis of the influence of air humidity on the structure of the aircraft, research on the need to provide air humidity for passengers, preliminary design of a passenger plane, development of recommendations for air humidity control, the concept of an individual ventilation system, issues of labor and environmental protection.

5. Required material: Power Point Presentation, drawings and diagrams.

6.Thesis schedule:

№	Task	Time limits	Done
1	Review of the literature on the influence of air humidity on the design of the aircraft, definition and regulation of its indicators	06.10.2022-18.10.2022	
2	Analysis of prototypes, passenger aircraft design	19.10.2022-29.10.2022	
3	Analysis of ventilation schemes, air conditioning systems of big airliners	30.10.2022-07.11.2022	
4	Development of recommendations for an individual ventilation system on passenger aircraft	06.10.2022-31.10.2022	
5	Implementation of the parts, devoted to environmental and labor protection	01.11.2022-04.11.2022	
6	Edit and correct the draft, modify the format	05.11.2022-10.11.2022	

7. Special chapter advisers:

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		Task issued	Task received
Labor protection	PhD, associate professor Katerina KAZHAN		
Environmental protection	PhD, professor Lesya PAVLYUKH		

8. Date of issue of the task: 8 September 2022 year.

Supervisor: ____________ Tetiana MASLAK

Student: ____________ Liliia SUKHYTSKA

РЕФЕРАТ

Пояснювальна записка дипломної роботи магістра "Ефективне забезпечення вологості повітря в кабіні літака як стандарт безпеки"

78 с., 21 рис., 4 табл., 41 джерел

Об'єктом дослідження є забезпечення комфортного перебування пасажирів на борту літака, визначення вимог до повітря, до системи вентиляції.

Предметом дослідження є підбір системи вентиляції в пасажирській кабіні, визначення рекомендацій по забезпечення максимально оптимального рівня вологості для здоров’я пасажирів на борту літака та для конструктивних елементів літака та його систем.

Метою магістерської роботи є виконання аванпроекту пасажирського літака, розробка концепції забезпечення необхідного рівня вологості повітря в кабіні, залучення індивідуальної системи вентиляцій з оптимальним рівнем вологості, що створює новий стандарт безпеки для авіаційних пасажирських перевезень.

Методи дослідження та розробки: аналіз літаків прототипів для визначення проектних параметрів, аналіз вимог до системи вентиляції та рівня вологості повітря на борту літака, аналіз літературних джерел про системи вентиляції сучасних лайнерів.

Практична цінність представленої роботи полягає у застосуванні індивідуальної системи вентиляції як одного з перспективних напрямів проектування вентиляційної системи та системи кондиціонування повітря на борту літака для забезпечення комфортного перебування пасажирів при незмінному впливу вологості на корозійну міцність конструкції. Матеріали кваліфікаційної роботи можуть бути використані в авіаційній промисловості та в навчальному процесі.

Пасажирський літак, аванпроект, компонування кабіни, відносна вологість повітря, рециркуляція повітря, вентиляція

ABSTRACT

Master degree thesis «Effective Humidification In Aircraft Cabin As A Safety Standard»

78 pages, 21 figures, 4 tables, 41 references

Object of study is to determine the air requirements and ventilation system requirements to ensure passengers' comfort on board a plane.

The subject of the study is the selection of the ventilation system in the passenger cabin, the determination of recommendations for ensuring the most optimal level of humidity for the health of passengers on board the aircraft and for the structural elements of the aircraft and its systems.

Aim of master degree thesis is to create a preliminary design of an airplane with optimal constant humidity level, which creates a new safety standard for whole aviation industry.

Research and development methods: analysis of prototype aircraft to determine design parameters, analysis of requirements for the ventilation system and air humidity level on board the aircraft, analysis of literary sources on the ventilation systems of modern airliners.

The practical value of the presented work lies in the application of the individual ventilation system as one of the promising directions of designing the ventilation system and the air conditioning system on board the aircraft to ensure the comfortable stay of passengers with the constant influence of humidity on the corrosion strength of the structure. The materials of the qualification work can be used in the aviation industry and in the educational process.

Passenger aircraft, preliminary design, passenger cabin layout, humiditification, relative humidity, moisture, air quality, air recirculation, ventilation

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ABBREVIATIONS

RH - Relative Humidity

SARS - Severe Acute Respiratory Syndrome

CFD - Computational Fluid Dynamics

MV – Mixing Ventilation

DV - Displacement Ventilation

PV - Personalized Ventilation

ESD – Electronic Discharge

EMS - Environmental Management System

INTRODUCTION

The aviation industry has for a very long time ignored the information on the importance of humidification in aircraft cabins though the problem of effective humidification arose a long time ago and remains to this day. Modern aircraft have cabin pressure levels enough high that further improvements to cabin pressure are no longer required. But low air humidity influences the human body to a certain extent that leads to passenger`s and crew`s health, it also has an impact on aircraft structure, electronics, and other onboard instruments.

The key role in the responsibility of humidification leads on the ventilation system. An aircraft ventilation system aims to provide fresh air appropriately and clean up contaminated air towards creating a comfortable, healthy, and safe cabin environment for passengers and crews with no change to flight-essential and flight-critical electronics.

In my work, I analyzed various sources and researches to determine how different ventilation systems affect the level of relative humidity in the plane in order to choose the optimal system. The selected system should supply the freshest and sufficiently humid air to the passengers and not cause corrosive damage to the aircraft structure. The performance of the new system on chosen aircraft in terms of humidity distribution, moisture condensation risk on cabin linings, cabin air quality and thermal comfort, are thoroughly evaluated.

PART 1. EFFECTIVE HUMIDIFICATION IN AIRCRAFT CABIN AS A SAFETY STANDARD

1.1 The role of a humidifier and dehumidifier

Safety and comfort for passengers have always been one of the main goals for aircraft cabin-environmental specialists. It is generally agreed that for the "health" of aircraft, low levels of humidity are the most appropriate conditions for metal structures, for avionics, and for computers. However, low humidity is not comfortable for passengers, as it may cause respiratory problems, skin irritation, eye itching, and so on.

Carnegie Mellon University's Lycos investigated the degree of comfort for the passengers onboard which states that humidity above 60 percent within a temperature of 71-77 degrees F, 80 percent or more of all average dressed persons would feel comfortable [1]. In fact, Lycos states, "We recommend a thermostat setting of 75 degrees F with 20 percent relative humidity, or with a 70 degrees F setting with 80-percent humidity."

First of all, what is a humidifier? A humidifier is an equipment that is used to increase humidity (moisture) in a specified area to ensure that the dry space is comfortable and has enough moisture. The most important parameter for the humidifier is relative humidity (RH). RH is a measure of the actual amount of water vapor in the air compared to the total amount of vapor that can exist in the air at its current temperature, usually expressed in percentage. Different room temperatures can hold a different amount of moisture and Air with low relative humidity (RH) tends to absorb water vapor from the surroundings even from the people inside causing adverse health effects such as discomfort to the nose, eyes, mouth, and throat or even lead to atopic dermatitis and seborrheic dermatitis [2].

Not only human health is in danger, but surrounding materials too. Low humidity can affect furniture causing the wood to shrink, crack and, loose joints pieces. Moreover, in such conditions, it is more common for static electricity discharge. Finally, that may result in destroying semiconductor devices, causing static cling of textiles, and causing dust and small particles to stick stubbornly to electrically charged surfaces [3]. To maintain a specific humidity level an industrial humidifier with a localized spray system is used which prevents static electricity build-up, protects material properties, and also creates a healthy and comfortable environment for workers. The reasons why static electricity build-up is so important are reduction in productivity, safety cases with uncontrolled sparks, a drop-in product quality, and even physical damage to details and equipment. The air must be below 45% RH for friction to produce a static charge. If the air is between 45-55% RH, static will still build-up but at a reduced level as it leaks to the ground through the moisture content of the air. If the air keeps at above 55% RH, static never builds-up [5].

On the other hand, excessive levels of RH are not the best way for people and materials as these promote the growth of dust mites and mold on moist surfaces, on top of that unpleasant smell and the feeling of dampness inside the house also cause discomfort to the occupants. In addition, the high RH causes problems with health that could even lead to hypersensitivity pneumonitis (humidifier lung). That situation is bad for our health as when this happens, it is better to have a dehumidifier to remove the excess moisture from the air. It can be used for household, commercial, or industrial applications.

Dehumidifiers are used in industrial climatic chambers, to reduce relative humidity and the dew point in many industrial applications from waste and fresh water treatment plants to indoor grow rooms where the control of moisture is essential. Typical air conditioning systems combine dehumidification with cooling, by operating cooling coils below the dewpoint and draining away the water that condenses [6].

To use a humidifier or dehumidifier, first of all, is needed to check the current conditions around. The first way, it`s manual calculation.

$$\text{Humidity per hour: } X = \text{Air changes per hour (ACPH)} * M^3 * \text{density of air} * \text{humidity ratio}$$

Humidity per day: X * 24

The air changes per hour (ACPH) ranges wildly based on the next parameters.

Ventilation: Values may be obtained from the HVAC maintainer that routinely (typically every third year or so) tests the ventilation of the residence.

Insulation leakage: Measured with a standard blowout door test.

Cubic meters: The volume of the space.

Density of air: Typically, on ground 1.2 for dry air. Air density, like air pressure, decreases with increasing altitude. It is also depending on atmospheric pressure, temperature and humidity.

Humidity ratio. For example: Current relative humidity: 20% and Humidity needed to reach 55%: 35%, in result Humidity ratio for 35% equal to 0.005.

Manually humidity calculation for special area is in a past, nowadays the automatic control replaces the manual one. A hydrostat or humidistat is used to monitor and control the constant relative humidity conditions.

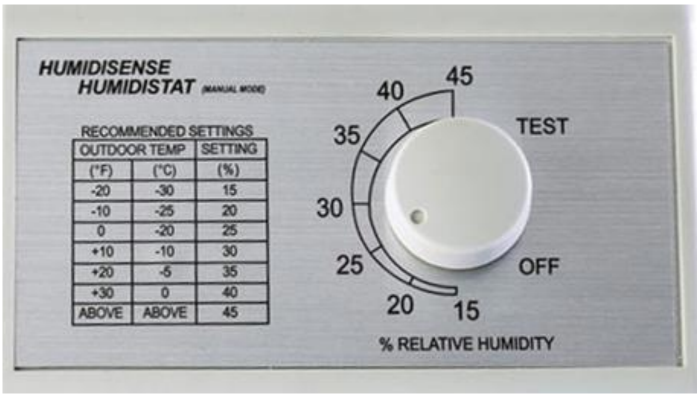

Figure 1.1 – Humidistat (typical)

Humidistat is an electrical device in which two metal conductors serve as a sensing element. Humidity levels are measured by the amount of electrical resistance between these two conductors. A relay amplifier is attached to the sensing element that reads this resistance and turns the humidifier/dehumidifier to add or remove moisture level as needed to control the humidity level inside your indoor area [7].

1.2 Humidity level in the aircraft

Aircraft cabins in commercial airlines are crowded places where the passengers have to seat for long time with an air quality that still an open problem that requires further investigation. Even after a few hours inside an aircraft the eyelids feel like sandpaper, sinuses hurt and you're dreaming of water like an Alaskan malamute on a hot day. The reason for such a bad feeling is aircraft cabin air that is drier than the driest place on our planet. The person cannot survive in an environment where an aircraft usually operates. It means, that it is vital to create an environment inside the aircraft in which everyone would safely travel at high altitudes, where the pressure would otherwise be too low. Nowadays modern aircraft have cabin pressure levels enough high that further improvements to cabin pressure need not be made. But low air humidity influences the human body to a certain extent.

To start with, cabin humidity is the humidity ratio in the aircraft cabin. the aircraft's jet engines pressurize the airplane's cabin air, then the air compress is compressed there. Compression heats the air which has to be cooled, then heated air mixes with air that is recirculating from the cabin while the temperature is adjusted to keep it comfortable for the passengers. Commercial airplanes cruise at a typical altitude of 36,000 feet (11,000 m) where the outside temperature is about −55 °C (−67 °F), the atmospheric pressure is only about one-fifth of that at the sea level and the air is nearly dry [8]. But the plane intakes outside air that at a high altitude has less than 1% humidity. It means that the only humidity source on the aircraft board is the original humidity of the cabin air when the plane took off and the moisture lost by the passengers and crew during breathing and perspiring.

Figure 1.2 – Moisture issue "Rain in the plane"

For high-altitude flights, cabin humidity is too low usually below 10-15%, but often relative humidity drops below 5% for longer flights and even can drop by up to 1%, this is especially observed more commonly in less crowded aircraft. Considering that the humidity rate in living spaces is between 30% and 60%, it is clear how low the aircraft cabin humidity is [9]. Ironically, the problem is most acute in premium cabins, as lower passenger density can result in a drier atmosphere than economy cabins.

A study by the University of Palermo in 2013, which measured relative humidity on different aircraft aboard a large number of short flights, found levels in the range of 1.8-18.5% aboard Boeing 767, Airbus A320 and A340, and DC9 aircraft. The Gobi Desert has an average RH of 23% in May which is the driest month. Chile's Atacama Desert at Maria Elena South is reckoned to be the driest area of the hyper-arid Atacama Desert, where scientists recorded a mean atmospheric RH of 17.3%, for comparison, Mars has the same RH. The only aircraft that has enough high humidity cabin as a selling point is the Boeing 787 with 15% of relative humidity.

The moisture in the air around is essential for our respiratory system, without the humidity it would collapse. The list of things that have a harmful impact on your health is too big, the eyes and skin are irritated, sticky mouth, cracked lips, worst ability to feel taste and smell, the exposed mucous membranes of the body dry out at a faster rate, that could give rise to many problems in result significantly worsen your health.

A cabin with extremely low humidity reduces taste and smell by up to 30%. Mucous membranes in the nose transport odorants to olfactory receptors. Detection of odorants by the brain decreases with drying of the nasal cavity. As olfactory components are lost, flavor components are lost as well [10].

In the air and on the ground, passengers are not as comfortable as they are on the ground. Jet lag, fatigue, and low air humidity result in dry, itchy skin and gritty, irritated eyes as well as a reduced ability to protect against bacteria and viruses. Additionally, such humidity can lead to health problems, such as kidney stones, and exfoliation of the skin if specific irritants are present.

Nowadays, during flights to solve the discomfort such as itching skin can be relieved by the application of a moisturizing lotion or cream on the hands, using lip balm and using drops for itching eyes. But the best solution is not to allow the body to become dehydrated by maintaining a proper level of hydration and electrolytes. It means drinking more than enough water and juices, avoid such common diuretics as sodas, alcohol, and caffeine and skipping the salty snacks. In addition, during the flights, it is recommended to flex muscles when it's possible.

1.3 Aircraft cabin – excellent surrounding for airborne diseases

Among the risks that are often overlooked as minimal is dehydration, but it can be more serious than many people realize. Dehydration occurs when the body loses more fluid than it takes in [11]. There are so many reasons for dehydration from exposure to a high, dry climate to the intake of alcohol or caffeine, or to the use of diuretics or other medications that cause increased urination. Certainly, long hours flights with low RH humidity can be included in the list, especially if added to the others. And older adults and younger children are most often affected by dehydration and of course for most individuals, mild discomfort at worst. The first symptoms include dry skin and mouth, cracked lips, lethargy, less frequent urination, thirst, sunken eyes, headache and rapid heartbeat. At the first signs of dehydration, you need to act and carefully monitor your feelings in the following hours.

Figure 1.3 – Dehydration symptoms

In order to protect our body from infections, our immune system is made up of proteins and cells [12]. Various inner surfaces, such as our respiratory tract and digestive tract, are covered by mucous membranes as part of our complex natural system. Several parts of our body, including the pharynx, larynx, trachea, bronchi, and lungs, have their own mechanisms for self-cleaning and protection against environmental toxic insults [13]. In order for the mucosal immune system to be effective, humidity is essential.

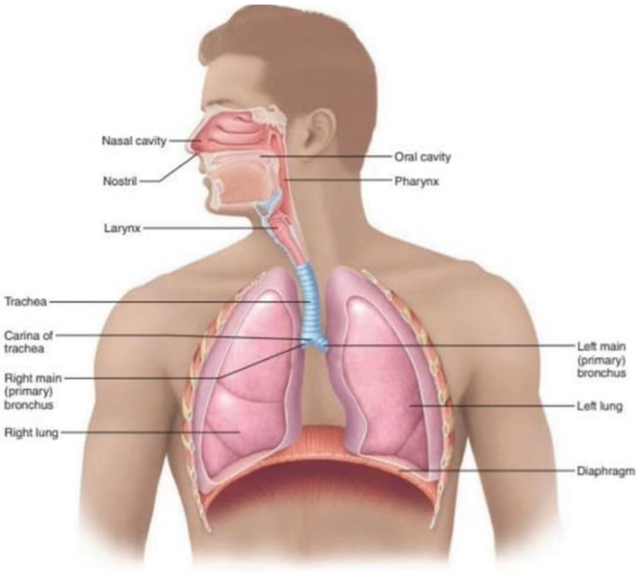

Figure 1.4 – Respiratory system

Mucous membrane antibodies prevent viruses, bacteria, spores, and allergens from penetrating the tissues beneath the mucous membrane, and in turn into the body. As part of mucociliary clearance, infectious agents and other contaminants from the nose and throat are continuously captured in the mucosa and transported to the stomach for digestion. Due to dry air, mucus dries up, thereby weakening the primary defense against infection. Mucus also becomes too thick, resulting in mucociliary clearance problems. Even in some cases to be significantly slowed down, the defense can completely stop working in dry air.

Infectious diseases are consequently more likely to be transmitted through airborne contamination. The low RH also causes droplets to remain airborne longer, increasing infection risks. You may notice that many respiratory virus infections have a seasonal pattern, which is more common during winter partly due to the low humidity in the air during those months.

Special studies were performed to compare different indoor air qualities and levels of RH, the result shows that a virus is five times more infectious in an environment with a RH level of 5% than in an environment with a RH percentage level of 25%. On the other hand, the high levels of RH more than 45-65% could prolong the lifetime of a virus in ambient air [14]. This requests for a controlled and accordingly potentially optimal indoor air quality inside the aircrafts, RH level, amount of ozone and other emissions within a reasonable level. A modern good quality aircraft with appropriate levels of RH could therefore help even to prevent infections.

According to the research, air travel increases the incidence of colds contrasting with people who do not fly. It leads to the conclusion, that the aircraft environment and developed susceptibility to pathogens can be fraught with consequences for the traveler also sometime after travel, for instance, loss of performance and deterioration in the quality of life when ill. In progress, relatives and other people may be infected by an infected passenger [15].

We should not forget that environment inside the aircraft reduces the protection against infection, therefore increases the direct physical transmission of infections, for example, through hands or through the air, since the aircraft cabin is too crowding and the air is mixed between people inside the cabin. By the way, an infected person on the board is a potential danger to people seating two rows in front of and two rows behind.

The choice of seat on board significantly affects the number of bacteria that a passenger may encounter during a flight. For example, choosing an aisle seat gives you more legroom and allows you to get up, but most infected with any infectious viruses that can occur on an airplane. The upper part of aisle seats are likely housing germs from every person who walks by them or holds on for support. Moreover, many of those passing people have just come from the bathroom [16]. The other dirtiest surfaces of the airplanes are bathroom with bathroom handles, seat belts, tray tables, and seat pockets.

1.4 Long flights increase Covid-19 cases

Even before the coronavirus pandemic, medical experts and scientists tried to find out the influence of low and high-hydrated environments on airborne diseases. The most common airborne diseases are: tuberculosis, meningitis, influenza, pneumophilia, measles and severe acute respiratory syndrome (SARS) and so on. The aviation industry has for a very long time ignored vital information that can help prevent infection.

The super-contagious Covid-19 has radically changed the whole world, which made people worry about their health more seriously than before. Long flights not only can lead to the importation of Covid-19 events, but also can provide conditions for unnormal spreader cases. The cause of this is a combination of environmental factors on the airplanes, such as temperature, humidity, and airflow that prolong the presence of SARS-CoV-2 in flight cabins.

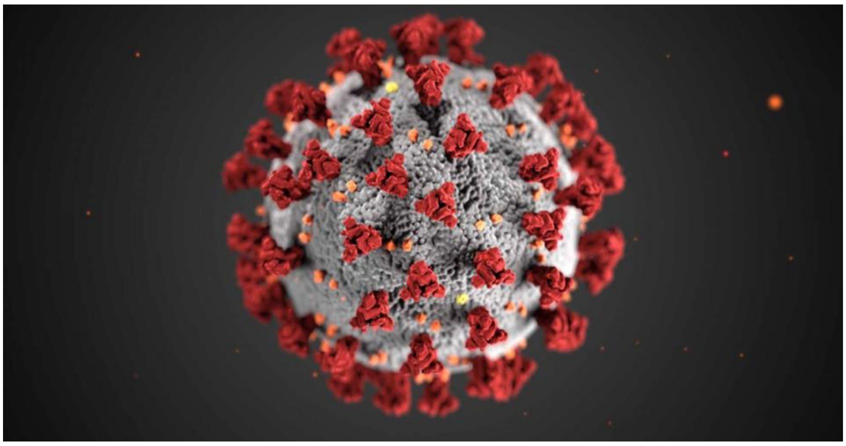

Figure 1.5 – SARS-CoV-2 molecule

The research conducted during the peak of the pandemic focused on the correlation between humidity and transmission of SARS-CoV-2. The aim was to investigate the connection between climatic factors, especially humidity, and cases of coronavirus in different areas in New South Wales, Australia. The investigation was carried out during the southern hemisphere's summer and autumn of 2020, these are exponential and declining phases of the epidemic. In conclusion, the results show that humidity is a climatic factor that is consistent and contributes to the virus spread. Surprisingly, other climatic factors such as temperature, rainfall or wind speed showed no such relationship. In detail, it was demonstrated that even a 1% decrease in RH was related to a 7-8% increase in cases of Covid-19 infections. The investigation precisely proves the critical importance of the humidity in the air that we breathe [17,18].

Conclusion to the part

Combining the scientific point of view and passengers' feedback about feeling during and after the flight lead to the idea that optimal relative humidity in the aircraft can solve a wide list of problems. With an improved ventilation system which could monitor the level of relative humidity to be at optimal level of approximately 20%, lets remind that for good human health and wellbeing RH should be not less than 30% for indoor environment, the goal of comfort and health of passengers and crews could be reached.

What benefits does an airline get from increasing cabin air humidity? In order for the airline to be better than the rest, the airline must offer such conditions that they are no worse than on the ground or even better. The intangible factors such as noise, temperature, drafts and pressurization levels are important in a cabin, especially in a premium cabin, and have largely been addressed. The last critical factor is humidity, if we create humidity like at ground level, this will remove the bad effects of dry air on the body. The result of solving the problem with lack of RH on the cabin is feeling better on reaching destination point for passengers.

With the presence of system that will change the current humidity level on board the aircraft, airlines may not only create a great brand, but also claim passengers that they will be fresh, less dehydrated, relaxed and rested, ready to perform and explore, and surely without strong jet lag after even a long flight. Furthermore, the moister atmosphere improves sense of taste and smell, it means that airlines do not have to dose their in-flight meals with sugar or salt to boost passengers' perception of flavors.

The aim of presented work is making effective humidification in the aircraft cabin with an optimal level of comfort and well-being, which creates a standard for whole aviation industry. The humidity standard is a priority for human health, which will subsequently lead to minimizing the possibility of contracting airborne diseases.

Considering the actuality of the problem, the next tasks will be investigated in the presented work:

- Analyze the different air ventilation systems design to find the one which effect of the relative humidity in a best way for a long-range passenger aircraft.
- Prove that chosen implemented air ventilation will not cause damage to electronic devices, sealants, coatings and welding.

PART 2. PRELIMINARY DESIGN OF LONG-RANGE PASSENGER AIRCRAFT

2.1 The analysis of prototypes and choice of design parameters

Conducting a design study is one of the most significant parts of the master's thesis. To begin, we select the data based on an analysis of the prototypes. The initial information regarding prototypes is presented in table 2.1. For the prototypes of future aircraft, we chose the following aircraft in the long-range class: AN-12, AN-148-100, CRJ-900, and AN-178 which will compete with the designed aircraft in the same class.

Flight performance statistics and some geometric characteristics of prototypes are presented in tables 2.1 and 2.2.

Table 2.1

Technical data of prototypes

Parameter	Prototypes			
	IL-96	B747-400	A380	IL-12
Purpose of the aircraft	passenger	passenger	passenger	passenger
Crew/flight attend. persons	3/9	3/8	3/8	3/4
Maximum payload, kg	58000	60000	83000	53000
Cruise speed., km/h	860	913	945	950
Flight altitude, m	9500	12500	13100	12000
Maximum range, km	10000	9500	15000	3818
Thrust to weight ratio, N/kg	2	2	3	2
Takeoff distance, m	2700	2814	2900	2107
Landing distance, m	1650	1596	1670	1392
Take of weight, kg	265000	341000	560000	230000
Type of engine	4ТРДД	4ТРДД	4ТРДД	4ТВД
Takeoff thrust кN, кVт	160	216	250	140
Pressure ratio	38	46	58	35
Bypass ratio	2	4	4	2

In the next step of the preliminary design, weight estimation, engine selection, and wing loading optimization will be performed. Following the first iteration of mass computation and the conceptual design phase of designing an aircraft, we are able to start the preliminary design for the fuselage, tail, wings, and landing gear. After that, wing loading will be evaluated to determine the area of a wing necessary to generate sufficient lift in all regimes of the V-n diagram.

Table 2.2

Geometrical parameters of the prototypes

Parameter	Aircraft			
	IL-96	B747-400	A380	IL-12
Fuselage cross-section	Circular	Circular	Circular	Circular
Fuselage diameter	6,08	7,13	9,3	5,9
Fineness ratio of the fuselage	9,3	7,6	9,3	8,3
Sweep back angle 1/4 chord	35	36	36	35
Wing aspect ratio	6,54	6,96	7,89	6,9

On the base of prototypes layout, the designed aircraft is a passenger vehicle with four turbofan engines located under the wing on pylons, a low-profile sweep back wing, a classic type of tail unit. It is designed to be operated on long-distance routes, is sufficiently equipped with aero-navigational capabilities, and corresponds to airfields of the class A.

2.2 Aircraft geometry calculation

2.2.1 Wing design

The geometrical parameters of the airplane wing are determined primarily based on the airplane take-off mass m_0 and the specific load applied to the wing surface P_0.

The following formula is used to determine wing area:

$$Sw = \frac{m_0 \times g}{P_0},$$

where m_0 – is a take of mass; g= 9,81 m/s^2- is gravity acceleration; P_0 – is wing specific load during airplane take off.

$$S_{wing} = \frac{m_0 \times g}{P_0} = 576 \text{ m}^2;$$

The following formula is used to determine wing span:

$$l = \sqrt{s_{wing} \times \lambda_w} = 63{,}25\text{m};$$

where λ_w – is a wing aspect ratio.

The following formula is used to determine the tip and root chords of wing:

$$b_o = \frac{2S_w\eta_w}{(1+\eta_w)\times l} = 13{,}86m;$$

where η – is wing taper ratio;

$$b_t = \frac{b_o}{\eta_w} = 4{,}3m;$$

The position of the rear and front spars relative to the leading edge of the wing is chosen according to relative coordinates $\overline{X}_1 = 0{,}2$; $\overline{X}_2 = 0{,}6$.

The following formula is used to determine the root chord relative coordinates:

$$X_1 = \overline{X_1} \times b_0 = 2{,}77m,$$

$$X_2 = \overline{X_2} \times b_0 = 8{,}31m;$$

The following formula is used to determine the tip chord relative coordinates:

$$X_1 = \overline{X_1} \times b_t = 0{,}86m,$$
$$X_2 = \overline{X_2} \times b_t = 2{,}58m;$$

By using the geometrical method, we were able to determine the mean aerodynamic chord of the wing (MAC, bMAC) (figure 2.1). Mean aerodynamic chord is equal to:

$b_{max} = 9{,}9\ m$;

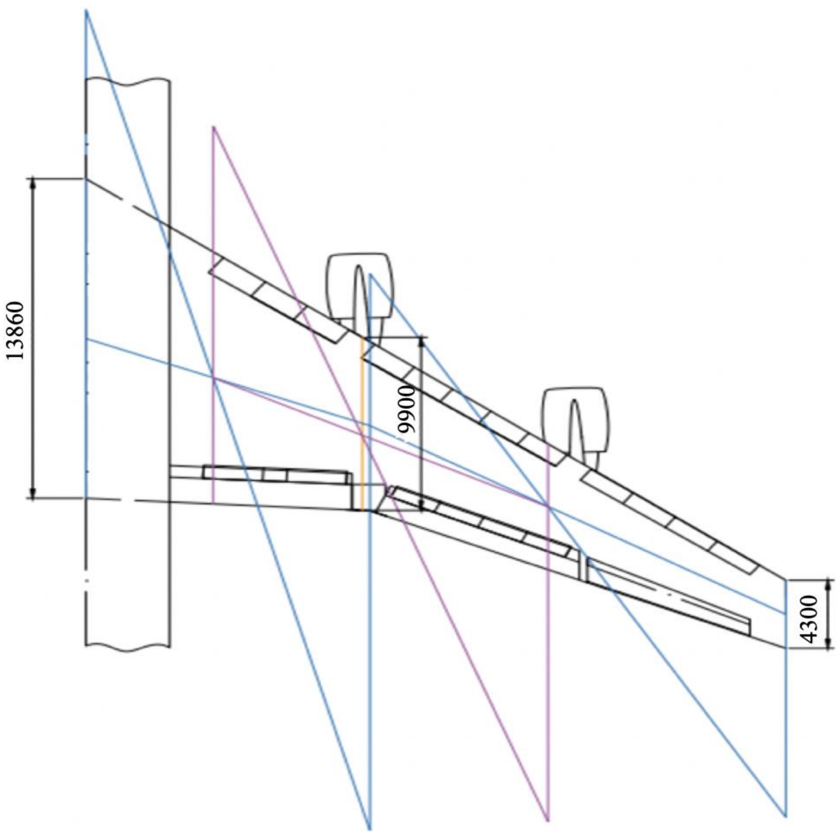

Figure 3.1 – Wing mean aerodynamic chord

Ailerons are designed to provide rolling moment and a sufficient rate of roll.

After determining the geometry of the wing, the aileron geometry and high-lift devices can be calculated.

The following formula is used to determine the ailerons span:

$$l_{aileron} = (0{,}3 \ldots 0{,}4)\frac{l_w}{2} = 0.3 \times \frac{59{,}64}{2} = 9{,}47m\ ;$$

The following formula is used to determine the ailerons chord:

$$b_{aileron} = (0{,}22 \ldots 0{,}26)b = 0{,}25 \times 12{,}77 = 4{,}80m\ ;$$

The following formula is used to determine the aileron area:

$$S_{aileron} = (0,05 \dots 0,08)\frac{S_w}{2} = 0.05 \times \frac{511}{2} = 12{,}77 m^2;$$

Ailerons are equipped by the secondary control surfaces (aerodynamic balance).

The following formula is used to determine the inner axial balance:

$$S_{in\ axial} = (0{,}3 \dots 0{,}31) S_{aileron} = 0{,}28 \times 12{,}77 = 4{,}80 m^2;$$

The following formula is used to determine the area of aileron's trim tab for four engine airplane:

$$S_{trim\ tabs} = 0.05 \cdot S_{aileron} = 0.05 \times 12{,}77 = 0{,}64\ m^2;$$

Increasing $l_{aileron}$ and $b_{aileron}$ even more than the recommended values is irrational.

2.2.2 Fuselage layout

A fuselage layout enables passengers to comfortably travel in the cabin (for passenger aircraft) or cargo to be loaded on pallets or in unit load devices (for cargo aircraft). The standard semi-monocoque structure design is used in the preliminary design of the fuselage structure. Bulkheads (formers and frames), stringers (and longerons) and skin make up the fuselage structure. Formers give the fuselage its shape and hold the stringers with the skin. The formers are parallel to one another, and they are connected with stringers. The main loads are carried by the frames, while concentrated loads are taken on by other parts. At the beginning of the fuselage is the pressurized bulkhead, which seals the cabin. Prior to the auxiliary power unit, the aft pressure bulkhead is located at the rear of the fuselage in order to close the pressurized cabin. Technologically the fuselage is consisting of some parts: front (cockpit compartment), middle (passenger compartment or cargo cabin), rear part (tail unit).

As we select the fuselage parameters, we need to consider the aerodynamic requirements of the streamline and cross section.

Fuselage with circular cross-section is most efficient because they offer the smallest weight and maximum strength. To design an aircraft, meeting strength requirements and reducing weight are key.

The aerodynamic and weight characteristics of the fuselage depend significantly on its shape and dimensions, which are determined by such geometric parameters as the shape of the cross section, the elongation λ_{fus} and the diameter of the fuselage D_{fus}.

The diameter of the fuselage of passenger aircraft is determined mainly by the number of passenger seats located in one transverse row and the cabin class. This is based on the width of the seats with armrests, as well as the width and number of aisles. A preliminary assessment of the diameter of the fuselage should be carried out based on statistical data and parameters of the prototypes.

The following main parameters of the fuselage are selected for calculation:
D_{fus} = 9.26 м; λ_{fus} = 7,78.

For subsonic airplanes wave drag almost may be ignored as it is insignificant so we need to choose value of skin friction drag C_{xf} and parasitic drag C_{xp} from the list of conditions. During the transonic and subsonic flights shape of fuselage nose part affects the value of wave drag C_{xw}. Application of circular shape of fuselage nose part significantly decrease it.

The following formula is used to determine the fuselage nose part for transonic airplanes:

$$l_{nfp} = (2 \ldots 3)D_f = 2{,}5 \times\ 9{,}26 = 23{,}15m;$$

where D_f – is fuselage diameter

In addition to aerodynamics, strength and layout requirements must be considered.

In order to maintain the minimum weight, the most efficient fuselage cross section shape is circular. A minimal amount of fuselage skin is present in this case. A partial case involves combining two or more series of circles vertically or horizontally.

The geometrical parameters that are considered are: fuselage diameter D_f, fuselage length l_f , fineness ratio λ_f, nose part fineness ratio λ_{np}. Based on the aircraft scheme, layout, and peculiarities of the center-of-gravity position, the fuselage length is determined.

The following formula is used to determine the fuselage length:

$$L_f = \lambda_f D_f = 7{,}78 \times 9{,}26 = 72{,}04\ m;$$

The following formula is used to determine the nose part fineness ratio:

$$\lambda_{\mathrm{fnp}} = \frac{\mathrm{l_{fnp}}}{\mathrm{D_f}} = \frac{23{,}15}{9{,}26} = 2.5$$

The rear part fineness ratio is equal to: $\lambda_{\mathrm{frp}} = 3$;

where $\mathrm{l_{fnp}}$ and $\mathrm{l_{frp}}$ - relative length of the nose and rear part of the fuselage.

The following formula is used to determine the length of the fuselage rear part:

$$l_{frp}=\lambda_{\mathrm{frp}}\cdot \mathrm{D_f}=3\times 7{,}78=23{,}3\ \mathrm{m};$$

For mid-range airplanes we may take next parameters: the cabin height h_1=2*m*; passage width b_p=0,6*m*; the distance from the window to the flour h_2=1*m*; luggage space h_3=0,9...1,3*m*.

Round cross sections are the strongest and lightest fuselage designs. However, this shape is not always the most convenient for cargo or passenger location. One of the most efficient ways is to use the double-bubble or oval shape of the fuselage. The oval shape is not suitable for manufacturing, because the upper and lower panels will bend due to extra pressure and will require extra bilge beams.

Step of formers in the fuselage structure is in the range of 360...500 mm. It depends on the fuselage type and class of passenger cabin.

The dimensions of the passenger cabin of the aircraft are determined by the number of passengers with the standard placement of seats. In terms of comfort, we choose an economy-class passenger plane with a small number of business-class passenger seats, which are located in the nose cone part of the fuselage on the lower deck.

To determine the diameter of the fuselage, it is necessary to select the number of seats in one row according to the prototype. In addition, it is necessary to determine the required width of the passenger cabin.

The following formula is used to determine the length of the fuselage cabin:

$$L_{cab} = K_4 + (m \cdot t_w) + 2 \cdot (235 \ldots 250) \text{ мм},$$

$$L_{cab} = 1200 + (45 \cdot 780) + 2 \cdot 250 = 36552 \text{ мм};$$

where t_w - step between chairs; $K_{4.}$ - distance to the partition; m - the number of seats in a row.

After determining the length of the cabin, it is necessary to check the compliance with the requirements for the volume per passenger of the economy class: $\nu_p = V_{cab}/_{n.}$

The layout is mainly one-class with a two-tier passenger cabin and 15 business class seats in the lower bow part of the cabin and 45 rows of 6 and 38 rows of 4 seats in a row - economy class and 18 economy class seats on the upper deck. Passengers should be provided with proper comfort and safety when the cabin is designed.

It is important that the crew cabin takes up as little space as possible while providing them with the most comfortable working and resting conditions.

2.2.3 Luggage compartment

Generally, luggage rooms are located under the cabin floor or on the lower floor of the fuselage. The outer trunk door must meet international standards for loading and unloading luggage and cargo. Planes should be equipped with hatches for accessing trunks.

Given the fact that the unit of load on floor $K = 400 \ldots 600$ kg/m^2.

The following formula is used to determine the cargo compartment volume:

$$D_f \leq 4м\text{-}V_{cargo} = 0{,}20 \ldots 0{,}24;$$

$$V_{cargo} = V_{cargo} \cdot n_p = 0{,}24 \cdot 440 = 105{,}6m^3.$$

2.2.4 Galleys and buffets

International standards provide that if the plane made a mixed layout, be sure to make two dishes. It is recommended that kitchen cupboards have to be located near the door between the cockpit and the passenger cabin. Refreshments and food can`t be placed near the toilet facilities or close to the wardrobe.

The following formula is used to determine the volume of buffets (galleys):

$$V_{galley} = (0{,}1 \ldots 0{,}12) \times n_p = 0{,}12 \cdot 440 = 52{,}8\ m^3;$$

The following formula is used to determine the area of buffets (galleys):

$$S_{galley} = \frac{V_{galley}}{H_{cab}} = \frac{52{,}8}{2} = 26{,}4\ m^3$$

Number of meals per passenger breakfast, lunch and dinner – 0,8 kg; tea and water – 0,4 kg. Passengers are fed every 3.5…4-hour flight. Buffet design is similar to prototype.

2.2.5 Closets

Closets for passenger outerwear are located near the main entrance and exit doors for passengers. Relatively narrow with such a calculation that no more than 2 rows of coats can be hung on hangers suspended on fixed pipes, the width of one row is 500 ... 600 mm, the step of the hangers is 70 ... 80 mm.

The following formula is used to determine the area of closets:

$$S_{cl} = (0{,}035 \ldots 0{,}040) \cdot n_p = 0{,}040 \cdot 440 = 17{,}6m^2;$$

Hats, briefcases and small bags are stored on shelves located on the side along the passenger cabin, the height of the shelves from the floor of the cabin is 1700 ... 1800 mm. Closet design is similar to prototype.

2.2.6 Lavatories

Depending on the number of passengers and flight duration, the number of toilets is determined: t = 2 ... 4 hours and 50 passengers

Based on the number of passengers, the total number of toilets should be 9 toilets.

Area of lavatory: $S_{lav} = 1.5m^2$ with width of lavatory: 1m.

Water and chemical liquid are required in the toilets for one person in accordance with the norms: t = 2 ... 4 hours, q = 1 kg;

Total supply of water and chemical liquid:

$$m_l = q \times n_p = 1{,}0 \times\ 440 = 440\ kg;$$

Toilets design similar to the prototype.

2.2.7 Layout and calculation of basic parameters of tail unit

In the next step, the geometrical parameters of the landing gear will be determined.

Main wheel axis offset is: $e = 0.18 \cdot b_{MAC} = 0.18 \cdot 6.752 = 1.22$ m

The large wheel axial offset complicates the lift-off of the front gear during take-off, whereas the small offset can cause the airplane to strike the ground when loading the back first.

The following formula is used to determine the landing gear wheel base:

$$B = (0{,}3\text{-}0{,}4) \cdot L_f = 0{,}4 \cdot 72{,}04 = 26{,}1m.$$

The following formula is used to determine the front wheel axial offset:

$$d_{ng} = B - e = 17.93 - 1.22 = 16.71m;$$

Wheel track is: T = (0,7 ... 1,2) · B = 0,7 · 26,1 = 15,78 m.

The wheels of the landing gear are selected according to the amount of parking load on the landing gear from the take-off weight of the aircraft.

Depending on the runway surface (balloon, half balloon, arched), the type and pressure of pneumatics will be required. Breaks have been installed on the main wheel and the front wheel.

The following formula is used to determine the nose wheel load:

$$P_{NLG} = \frac{e \cdot m_0 \cdot 9{,}81 \cdot K_g}{B \cdot z} = \frac{1{,}3 \cdot 341\ 568 \cdot 9{,}81 \cdot 1{,}9}{21{,}7 \cdot 2} = 190\ 701N;$$

K_g = 1.5...2.0 – dynamics coefficient.

The following formula is used to determine the main wheel load is equal:

$$P_m = \frac{(B - e) \cdot m_0 \cdot 9{,}81}{B \cdot n \cdot z} = \frac{(17{,}93 - 1{,}22) \cdot 341\ 568 \cdot 9{,}81}{21{,}7 \cdot 4 \cdot 4} = 196\ 877N;$$

According to the calculated value of the load on the wheels P_{NLG} and P_m and the value of the take-off $V_{take\ off}$ and landing V_{land} speeds are selected from the catalog of pneumatics, fulfilling the conditions: $P_c > P_{NLG}$; $P_c > P_m$; $V_{c\ take\ off} > V_{take\ off}$; $V_{c\ land} > V_{land}$.

According to the table, we choose the following wheels:

Main landing gear - 1350 x 450 – high pressure tires with brakes;

Nose landing gear - 1350 x 450 – high pressure tires.

After determining the parameters of the aircraft and drawing on graph paper the view of the aircraft from the side and front, graphically determine other parameters of the chassis.

Following conditions must be met when installing the chassis:

$\varphi_0 > \alpha_{land} - \alpha_{inst} - \alpha_{park};$

$\varphi > 10 ... 18°$ - tail roll angle;

$\gamma_1 > \varphi + (1 ... 2°)$ - the angle of departure of the main legs of the landing gear;

$\gamma_2 > 90°$ - the condition of overturning on the nose support.

2.3 Tail unit design

When calculating the aerodynamic layout, the main goal is to find the location of the tail empennage. An airplane's center of gravity needs to be located at its front focus to provide longitudinal stability.

We can evaluate the longitudinal stability and balance arm between aerodynamic center of tail surface and center of gravity located at mean aerodynamic chord (MAC), based on the following equation:

$$m_x^{Cy} = \bar{x}_T - \bar{x}_F < 0$$

where m^{Cy}_x coefficient of moment, $x_{T.}$,x_F, - airplane center of gravity and focus. The airplanes have neutral longitudinal static stability if m^{Cy}_x equals to 0.

Analyzing prototype airplane statistics, we have the following results:

$$S_{HTU} = (0,3 ... 0,4) \cdot S_h = 0,30 \cdot 123 = 47,07м^2;$$

$$S_{VTU} = (0,35 ... 0,45) \cdot S_v = 0,40 \cdot 91,58 = 36,63м^2.$$

There is a relationship between the length of horizontal and vertical stabilizers and the length of tail and nose parts, wing location, sweep back angle, stability, and aircraft controls. In first iteration, we may take it like the next $L_{HTU} \approx L_{VTU}$.

The following formula is used to determine the elevator area:

$$S_{el} = 0,3 \cdot S_{HTU} = 14,12 \text{ m}^2.$$

The following formula is used to determine the rudder area:

$$S_{rud} = 0{,}22 \cdot S_{VTU} = 14{,}12 \text{ m}^2.$$

The tail unit span and wing span are usually connected by the static data of aircraft.

$$L_{HTU}=(0{,}32\ldots0{,}5)\ l_W= 0{,}4\times63{,}25 = 21{,}56\text{m}.$$

As shown in this dependence, the lower limit corresponds to turbojet aircraft with all-moving stabilization. According to the location of the engines, the vertical TU h_{vtu} is determined. Taking it into consideration low wing aircraft M<1, we assume:

$$h_{vtu}=(0.14..0.2)\ l_w= 0{,}18 \cdot 63{,}25 = 10{,}7\text{m}.$$

Tapper ratio of horizontal and vertical TU for low wing aircraft M<1:

η_h =2,5 and η_v= 2,5; λ_h = 4,0 and λ_v = 1,0.

The following formulas is used to determine the determination of TU chords b_{end}, b_{CAX}, b_{root}:

$$b_{tip\ h} = \frac{2S_{htu}}{(\eta_{htu}+1)l_{htu}} = \frac{2\times 92}{(2{,}5+1)23{,}85} = 2{,}2m;$$

$$b_{tip\ v} = \frac{2S_{vtu}}{(\eta_{vtu}+1)l_{vtu}} = \frac{2\times 61{,}3}{(2{,}5+1)10{,}7} = 3{,}27m;$$

$$b_{mac\ h} = 0.66\frac{\eta_{htu}^2+\eta_{htu}+1}{\eta_{htu}+1}\cdot b_{htu\ tip} = 0.66\frac{6{,}25+2{,}25+1}{2{,}5+1}\cdot 2{,}2 = 4{,}05m;$$

$$b_{mac\ v} = 0.66\frac{\eta_{vtu}^2+\eta_{vtu}+1}{\eta_{vtu}+1}\cdot b_{vtu\ tip} - 0.66\frac{6{,}25+2{,}25+1}{2{,}5+1}\cdot 3{,}27 = 6{,}01m;$$

$$b_{root\,h} = b_{tip} \cdot \eta_{htu} = 2{,}2 \times 2{,}5 = 5{,}5\ m;$$

$$b_{root\,v} = b_{tip} \cdot \eta_{vtu} = 3{,}27 \times 2{,}5 = 8{,}17\ m;$$

2.4 Selection of engine for designing airplane

Required power of one engine in cruising mode:

$$R_{VN} = \frac{\bar{R}_{VN} \times m_0}{n} = \frac{2{,}79 \times 340135}{4} = 224{,}3kN;$$

where n – number of engines; $\bar{R}_{VN}$ - the corresponding energy armament of the designed aircraft. On the basis of the required power and parameters of the power plant, selected earlier in the initial data, we select a two-circuit turbofan engine RB211-524 (figure 2.2), the main characteristics of such engine are shown in the table 2.3.

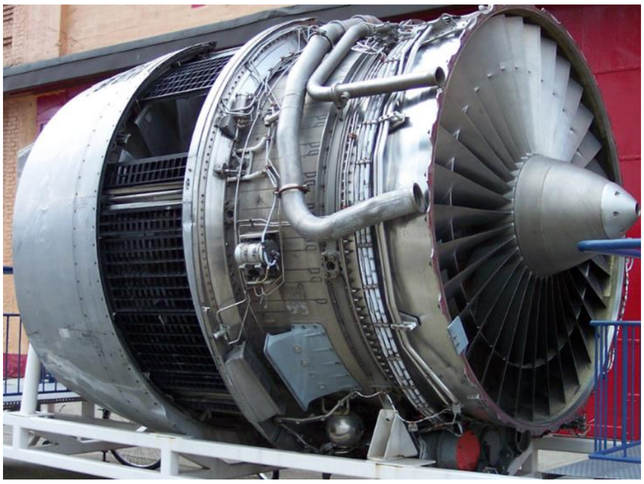

Figure 2.2 – Engine RB211-524

Table 2.3

Engine characteristics

Thrust	Length	Diameter	Weight	Bypass Ratio
224,3 kN	3,175 m	2,15 m	4,472 kg	4,1

Conclusion to the part

The preliminary design of a long-range passenger airplane interregional air lines of the Boeing747SP prototype, which carries 440 passengers per flight with a cruising speed of 850 km/h. at an altitude of 11,200 meters was designed in this part. In the calculation part, the geometric parameters of the aircraft were calculated. When calculating the work, knowledge from other subjects was used, in addition, this design deepened the knowledge of a specific material part and its maintenance. In order to provide the required thrust for different regimes of flight, it was chosen RB211-524 engine. This engine has enough thrust-to-weight ratio, low fuel consumption, and low noise and emissions levels.

The final part is the construction of a drawing of the general appearance of the aircraft in three projections based on the results of the calculation.

PART 3. CONCEPTUAL DESIGN OF THE VENTILATION SYSTEM TO PROVIDE EFFECTIVE HUMIDIFICATION IN THE AIRCRAFT

3.1 Analysis of various types of ventilation in the passenger cabin

The cabins of passenger aircraft experience one of the most complex indoor environments among all other means of mass public transportation. A critical survey of key studies performed mainly in the last decades will be used in this review article to discuss various ventilation strategies (existing and proposed) used aboard commercial aircraft. The research methodologies adopted by these studies, including numerical simulations, will also be analyzed in a systematic manner. A review of the literature is conducted to identify best practices for aircraft ventilation research.

Globalization would not be possible without air travel. But, without proper measures, the cabin environment inside a commercial aircraft can become fertile ground for deteriorating air quality, disease transmission, and infection spread. In this closed space, the occupant density is high, there is a wide range of passenger activity, and passengers are unable to leave.

In this presented work present studies concerned with air quality, contaminant management, relative humidity aboard aircraft are investigated with implementation of the personalized ventilation system. Additionally, recommendations are provided for controlling nuisance moisture in commercial airplanes and controlling of humidity level on the aerospace manufacturing facility.

A variety of ventilation strategies have been investigated as a means of preventing infection transmitted via airborne routes and other contaminants commonly found in aircraft cabins. Efficiency is primarily determined by the efficiency of the ventilation system. The ventilation effectiveness of aircraft cabins is determined by the proportion of outside fresh air reaching the occupants' breathing zones. The major ventilation systems are mixing, displacement, and personalized ventilation, which are shown in Figure 3.1

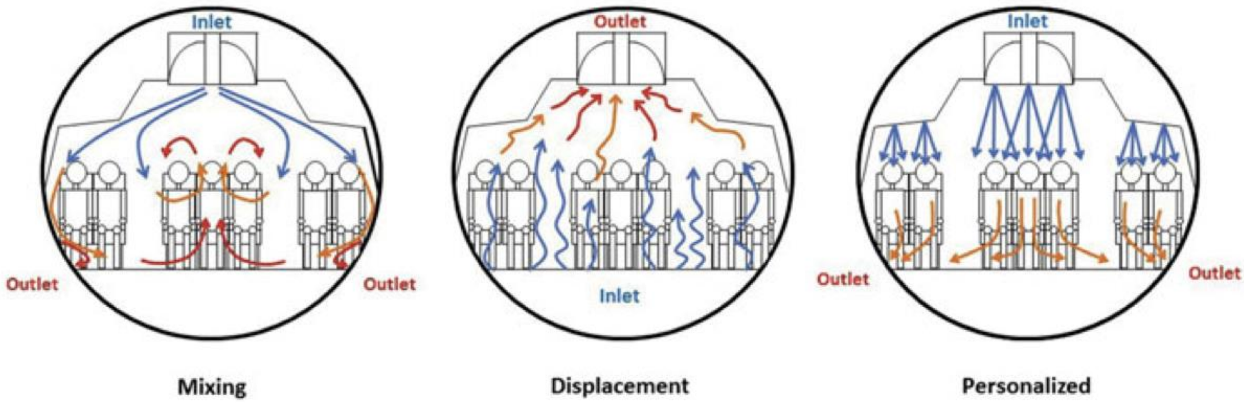

Figure 3.1 – Main Ventilation Systems on Board

The mixing ventilation (MV) principle in aircraft involves mixing the supplied air with the ambient air within an enclosure. A large vortex flow produces local air stagnation in the cabin due to the mixing system. Hazardous pollutants, such as virus-laden aerosols, can't be removed by MV since clean air is supplied from diffusers located far away from occupants, where it mixes with polluted ambient air before inhalation.

Displacement ventilation (DV) systems remove contaminants more effectively than MV. By using these strategies, airborne infectious disease viruses can be reduced and cabin air quality can be improved. In Schmidt and Müller's study [19], they found a high draft risk with an MV system, while overheating could occur with a DV system. The purpose of Zhang's work was to improve relative humidity from 10% to 20% by distributing air under the aisle [20].

Personal ventilating (PV) is a relatively new development in the field of air distribution for buildings, but has already made its mark in the automotive industry [21, 22, 23]. The main aim of PV is to provide clean, fresh air and a sufficient level of relative humidity near the face of occupant. In addition, it gives the user some control over this microenvironment to enhance their comfort. In crowded environments, such as aircraft, PV systems may serve as protective shields. PV combined with MV offers superior protection against airborne infection than systems relying solely on MV. The relative humidity (RH) of the air plays an important role in the transmission of airborne diseases, so an individual ventilation circuit could also include a local humidification solution adapted to the needs of each occupant. Furthermore, Gao and Niu analyzed humidifying the PV to 40-50% moisture. According to their findings, only the area around the face exhibited significant moisture content, while the rest remained without any moisture [24].

Reducing the distance between the occupant and PV diffuser improves PV performance. As a result, PV flow rates can be reduced to as little as 0.5 L/s, resulting in 90% clean air inhalation. This approach is also affected by the initial velocity and equivalent diameter of the diffuser. If air is diffused in proximity of an occupant's face, the inserted flow should not affect the body's thermal sensation. Local discomfort is likely if the initial velocity is high [25].

3.2 Analysis of ventilation system for designing aircraft

Designing aircraft has 3 air-conditioning packs under the cabin floor that distribute fresh and recirculated cabin air to each zone (compartment) [26]. The air-conditioning system has two modes: regular and high airflow. In normal operation, the ratio of outside air to recirculated air is approximately 1:1. For each zone, in normal mode, fresh air is exchanged approximately 10 times per hour, except for the Flight Deck, which exchanges 50 times per hour to prevent the crew from becoming sleepy. When the ventilation mode is high, the fan stops. In this mode, recirculated air is half of the normal mode, and fresh air is 1.5 times that.

A primary measure of air quality is CO_2 concentration (not oxygen availability), according to ANSI-ASHRAE Standard 62-1989: Ventilation for Acceptable Indoor Air Quality can be calculated by [27].

$$\dot{V}_{air} = \frac{\dot{V}_{CO2,gen}}{X_{CO2,cabin} - X_{CO2,outside}} = \frac{4\% \times \left(\frac{0{,}5L}{breath}\right) \times \left(\frac{1breath}{3s}\right)}{(2{,}5+1)23{,}85} = 5\frac{L}{s \times pax};$$

To change all air in the wide body aircraft cabin is need just a few minutes.

$$T_{renew} = \frac{V_{cabin}}{pax \times \dot{V}_{air}} = \frac{886}{500 \times 0{,}005} = 350s;$$

Calculating humidity requires referencing Clapeyron's equation of liquid-vapor equilibrium of a pure substance for the vapor pressure of a pure substance, p_v^*:

$$\frac{d\,\dot{p}_v}{dT}\int_{LVE} = \frac{h_{LV}}{Tv_{LV}} \rightarrow ln\,\frac{\dot{p}_v \times (T)}{\dot{p}_{v,a}} = \frac{-h_{LV}}{R_v}\left(\frac{1}{T} - \frac{1}{T_0}\right);$$

where $p_{v,0}^*$=0.6 kPa for T_0=0 degrees Celsius; h_{LV}=2.5 MJ/kg, and R_V=462 J/(kg·K)) Liquid-vapor equilibrium of an ideal binary mixture according to Raoult:

$$\frac{x_{v,LVE}}{x_{l,LVE}} = \frac{\dot{p}_v(T)}{p} \rightarrow p_{v,LVE} = x_{v,LVE}p = \dot{p}_v(T);$$

In this calculation, x_v is the molar fraction of water in the vapor phase and x_l is the molar fraction of water in the liquid phase (the latter assumed unity due to the poor solubility of air in water) and $p_v \equiv x_v\,p$ is the partial pressure of water in the vapor phase.

Relative humidity, φ, is defined as:

$$\phi \equiv \frac{x_v}{x_{v,LVE}} = \frac{p_v}{p_{v,LVE}} = \frac{p_v}{\dot{p}_v};$$

Let's calculate the cabin humidity at cruise, for an air renewal of 5L/(s·pax), 30 g/(h·pax).

$$w = m_{w,gen/}m_{out} = (0.03/3600)/0.005 = 1.7 \text{ g/kg};$$

$$\varphi = 1.7/16 = 11\ \%\ \text{RH}.$$

In order to choose the most optimal ventilation system for the already calculated aircraft prototype, the results of previous studies were compared, namely the effect on the level of humidity. According to calculation for the RH at cruise, the optimal level should be 11-13% on board. When calculating the inhaled moisture content, was assumed that passengers do not inhale the moisture released by their self.

Firstly, the Zhang's work with CFD was applied to investigate the performance of the new under floor displacement ventilation system. On the basis of this work let's compare the MV system, that implemented almost in all aircraft, with the proposed DV system in terms of relative humidity on five vertical poles for the passengers seated in one side of the passenger cabin.

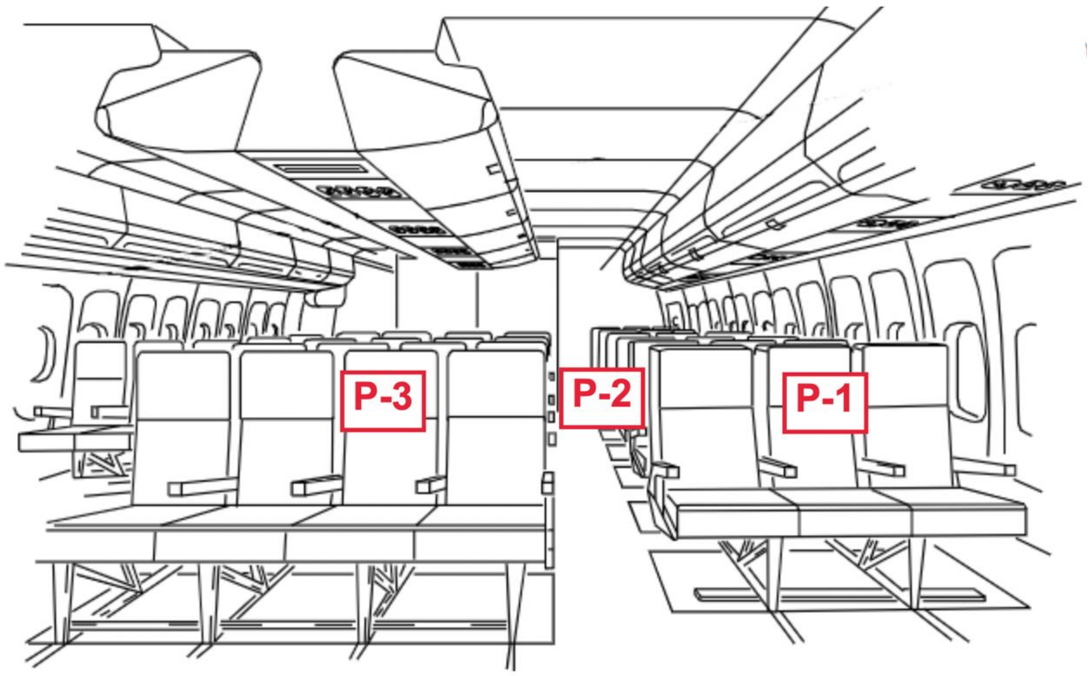

Figure 3.2 - Cross-section plane where the relative humidity will be considered

Generally, the results show that the mixing ventilation system holds uniform relative humidity of around 10% for all locations, while DV proposed system boosting the relative humidity from 10% to 20%, greater results surely in the aisle area near the air source.

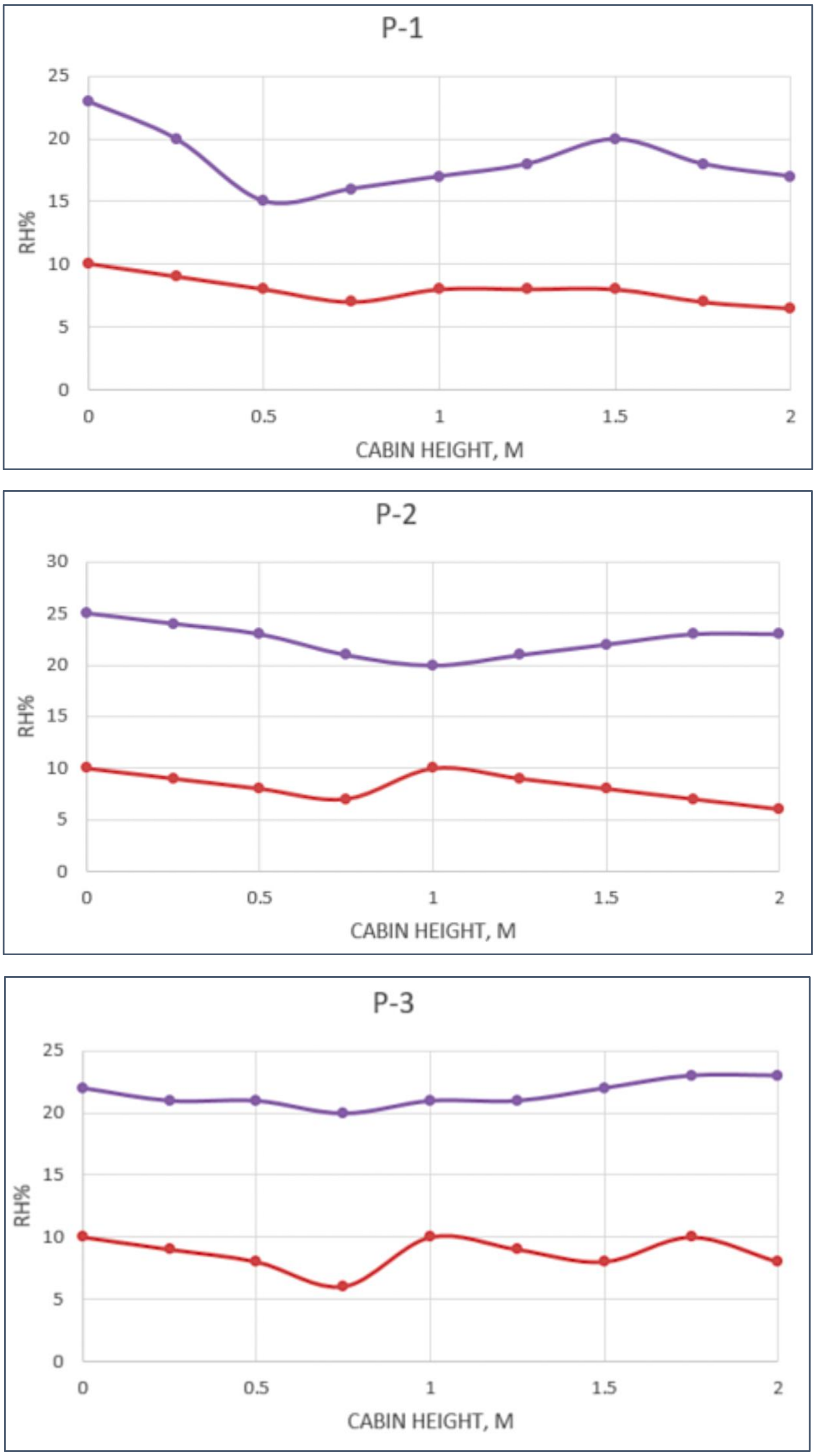

Figure 3.3 – Comparison of inhaled water vapor content (in terms of relative humidity) between the displacement system – violet solid lines and the mixing system – red lines for zones P1, P2, P3

In addition, lessen the inhaled CO_2 concentration by 30% as compared with the current mixing air system. There should be no condensation on cabin interior linings because of the elevation of cabin side temperature with warm air running through the channel passage, and the dry air supplied from the both channels also helps prevent condensation. The draught risks are minimal on benefit of conditioned air supply from both under aisles and weak air motion created inside the cabin.

It only has one disadvantage; contaminants are trapped in a thick layer close to the ceiling unmoved by fresh air waves until the next one blows. It reduces the number of pollutants in the cabin air significantly, but the contaminants trapped in the upper air layer are close to the level of occupants' breathing.

Secondly, personalized ventilation is also associated with better air quality and contamination protection when used in conjunction with ceiling supply mixing and/or displacement systems. Let's compare the PV combined with the MV system and the PV combined with the DV system in terms of relative humidity on five vertical poles. This was done for passengers seated on one side of the cabin as in our last analysis. Both of these systems have inlets located on the back of the seats (directly above the abdomen) in front of the passenger, but PV coupled with the MV system has outlets placed on the floor (in front of the feet) and PV coupled with the DV system has outlets located on the ceiling and channel outlets. The analysis was carried out on the basis on research with CFD for B767, aiming to keep thermal comfort in commercial aircraft cabins [28].

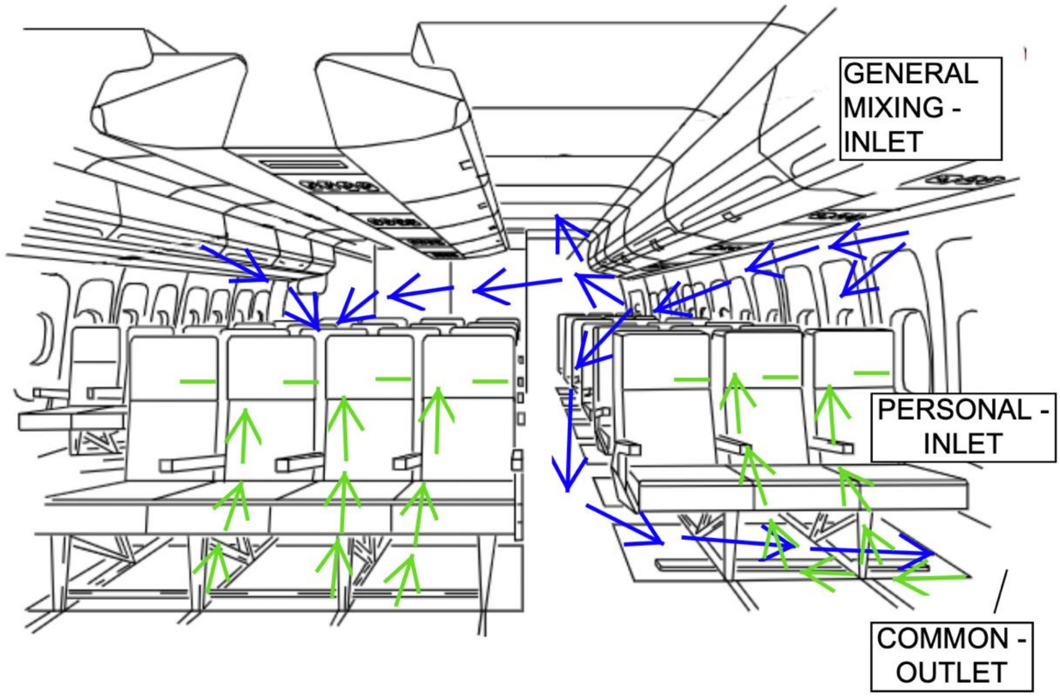

Figure 3.4 – Personalized Ventilation System combined with Mixing Ventilation System

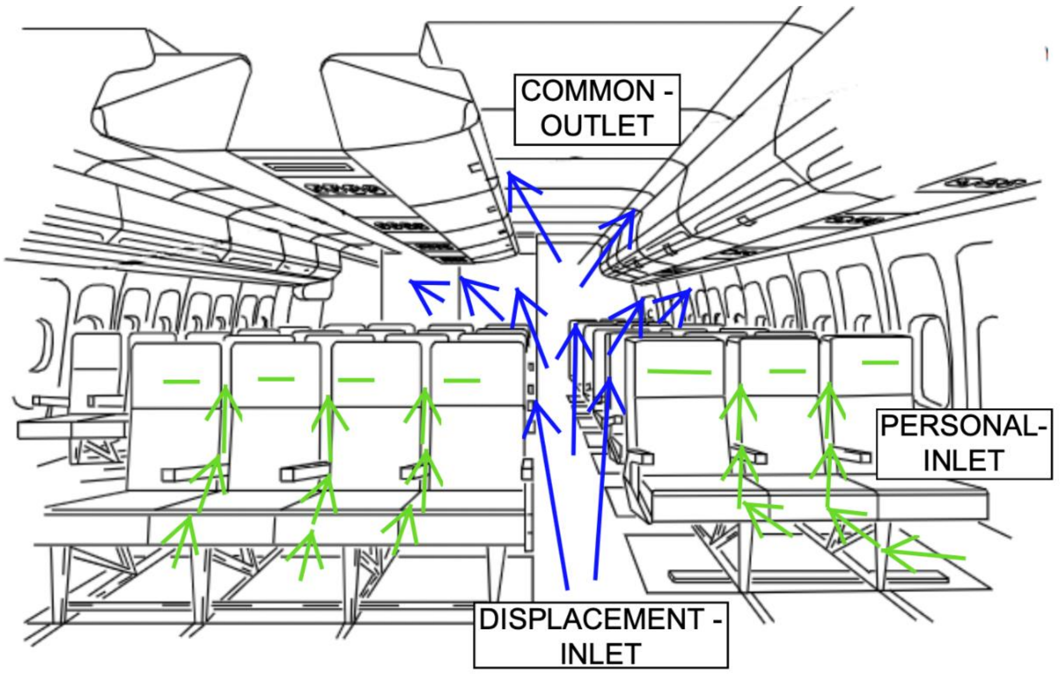

Figure 3.5 – Personalized Ventilation System combined with Displacement Ventilation System

With PV and DV systems combined, relative humidity is about 10%-14% in cruise, which is in line with calculated humidity level values for our prototype aircraft. In the passenger breathing region, the relative humidity ranges from 8% to 12% since both underside aisles and a personal inlet in front of passengers supply humid air. PV with MV system ensures a constant relative humidity distribution between 5% and 8%, resulting in a dry environment, refer to figure 3.6.

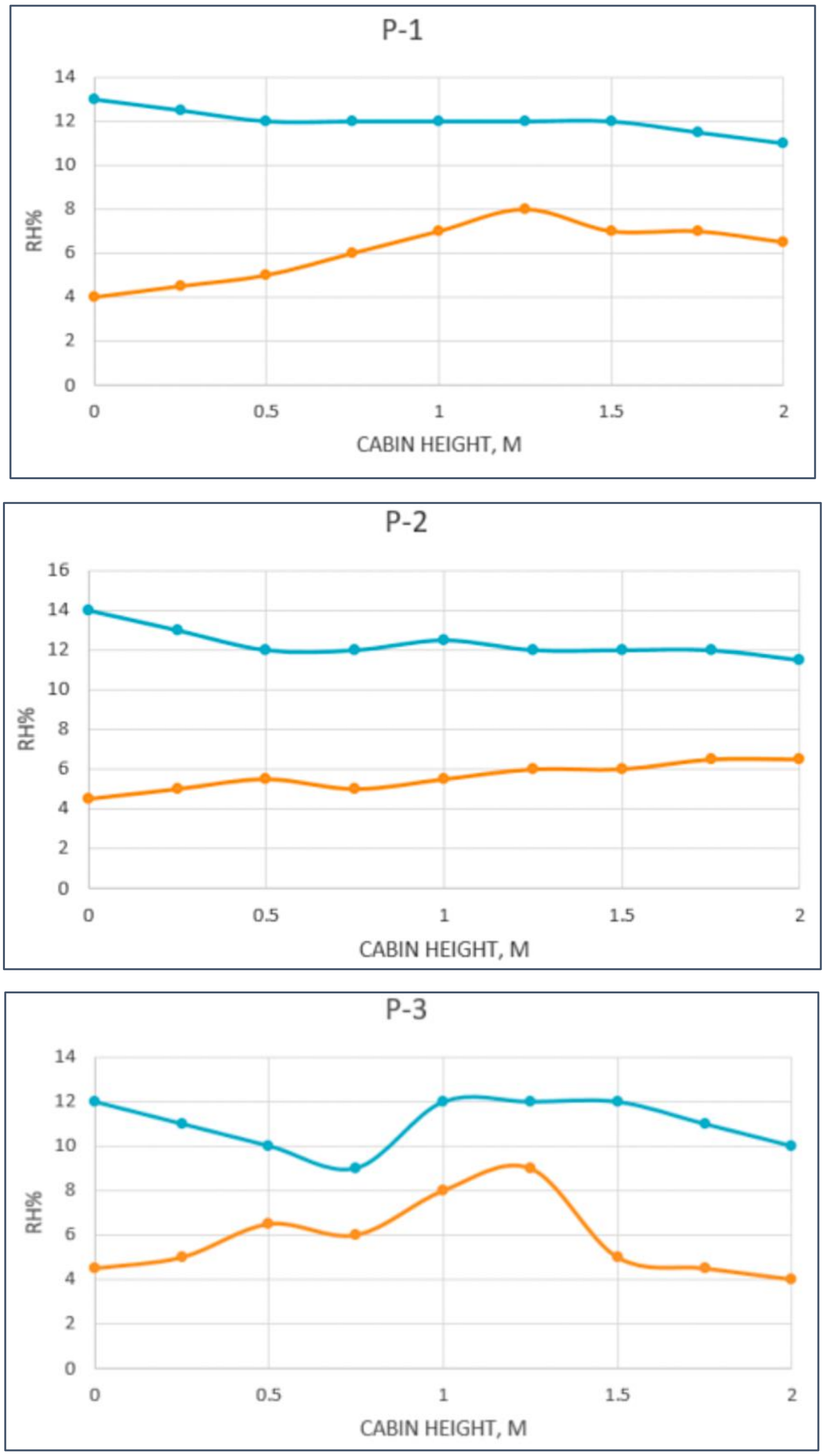

Figure 3.6 – Comparison of inhaled water vapor content (in terms of relative humidity) between the PV combined with the MV – orange dashed lines and PV combined with the DV – blue lines

Compared to PV with DV, the relative humidity is around 10 % higher. Research suggests raising air humidity by 5–10% on aircraft to minimize dryness-related symptoms and argues that such an increase in humidity will not lead to microbial development since there is no moisture concentration. PV and DV are therefore capable of humidifying aircraft cabins efficiently.

3.3 Humidity in the cabin environment and its impact on aircraft design

3.3.1 Control of moisture related problems on the aircraft

In the last 40 years, all commercial airlines have reported moisture-related problems. Passenger compartments, electrical equipment compartments, and wet insulation blankets are expected to have the most problems. Different operators have different problems, depending on how airplanes are used. The purpose of the present study is to provide recommendations for minimizing moisture problems in long-range passenger aircraft.

Relative humidity (RH) is a big question for the aviation sphere both in the sky and on the ground. It is well known that temperatures plummet outside the aircraft body. If the air temperature on the ground equals 20 degrees Celsius, the air temperature would be around 54 degrees Celsius below zero at 35,000 feet (10 700 m). In cold air, contact with the metal of an aircraft causes gaseous water to accumulate rapidly, condense, and cool until droplets are formed. The droplets remain until the airplane reaches a warm enough environment to cause the droplets to melt and allow the water to flow. Furthermore, the water may gather in puddles, then it can overflow while the aircraft changes the attitude during the climb. It is due to the decrease in the external temperature and the rise in the internal temperature that the engine and wings exhibit a decrease in performance. Passengers' respiration and the resulting condensation on the airplane skin are the major sources of moisture inside these aircraft [29].

These are stages that should be developed to get a solution for the moisture related problems, shown on figure 3.7.

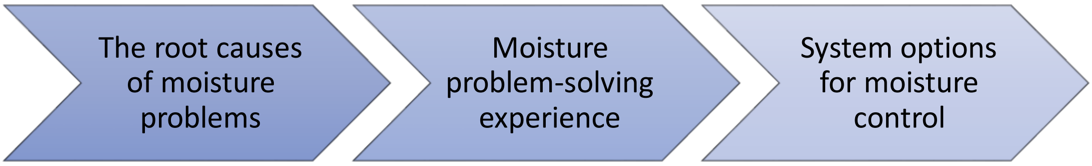

Figure 3.7 – Solution stages for the moisture related issues

First of all, there are many root causes of moisture problems, there are the most common: moisture sources and condensation

Condensation forms during flights when the outside air and the structure are very cold, causing some amount of condensation to form. In addition, since structure temperatures are normally below water's freezing point, most condensation forms as frost. Moist air condenses when it comes into contact with a cold structure. The cabin air cools rapidly through small gaps in the insulation coverage. The buoyancy forces cause a continuous flow of air and moisture to move toward the cold structure.

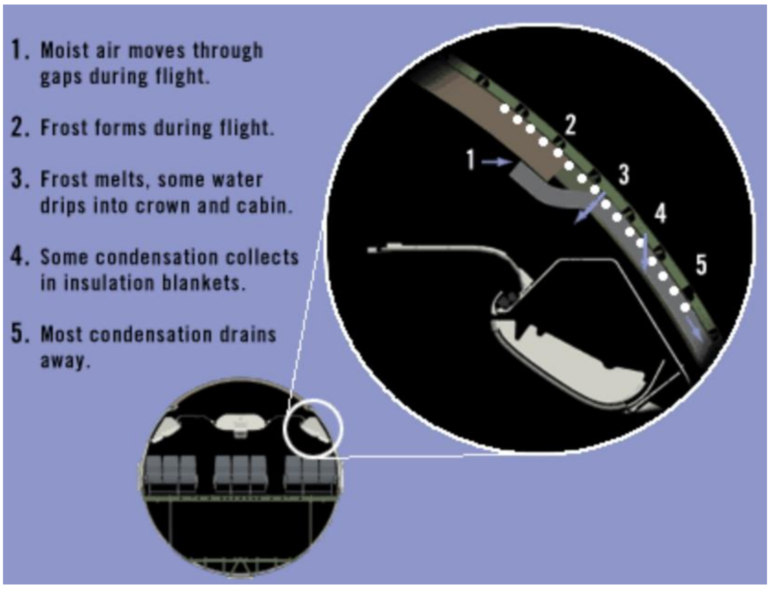

Figure 3.8 – Moisture Cycle

Drainage and dripping

In the event of a temperature rise above freezing on the airplane's skin during descent, frost will melt quickly. A sudden onset of drainage results in dripping into the crown area (attic) of the airplane, and possibly into the passenger cabin, if it's not handled completely.

Condensation and moisture problems differ among models

There is a great deal of variation in the amount of condensation and severity of moisture issues across the models of airplanes.

Moisture problem-solving experience has every single company. The extent of the moisture issue was determined through numerous in-service reviews. For instance, passenger cabin water dripping and extremely wet insulation blankets. In addition, there have been some failures caused by water dripping into electrical equipment.

System options for moisture control should be determined and implemented in order to:

- Minimize condensation;
- Reduce dripping into the passenger compartment and onto equipment;
- Ensure maximum liquid drainage;
- Improve the evaporation of water from wet surfaces and insulation blankets.

Recommendation to reduce impact of moisture on the aircraft design.

Let's examine what moisture problems are encountered in the aggregate for one aircraft. First of all, it is common for blankets to have holes and penetrations and the seals were not successfully sealed during testing. Therefore, the most effective way to reduce condensation is to eliminate holes and gaps around insulation blankets. Moisture can be collected and evaporated easily using nomex felt. Also, a dehumidifier system (ground-based or onboard) removes moisture, but it is not cost-effective. Holes, penetrations, and seams in the insulation blankets will let water in. To drain the water, a drainage path is necessary. Additionally, evaporation is needed to dry wet insulation blankets. Secondly, it is difficult to inspect a structure with spray-on insulation since it is too heavy to meet thermal and acoustic requirements. Thirdly, according to inspections of aging airplanes, corrosion in the crown area is extremely unusual, and corrosion-inhibiting compounds should be incorporated to eliminate corrosion. Furthermore, it is not possible to reduce water retention with fiberglass batting coated with an enhanced hydrophobic coating. And finally, it will become more difficult to deal with moisture problems if you install any system that increases cabin humidity.

It's clear that the problem needs to be tackled with the help of a whole system and not just components targeted at individual stages. Figure 4.1.2 represents the moisture control system in the cabin.

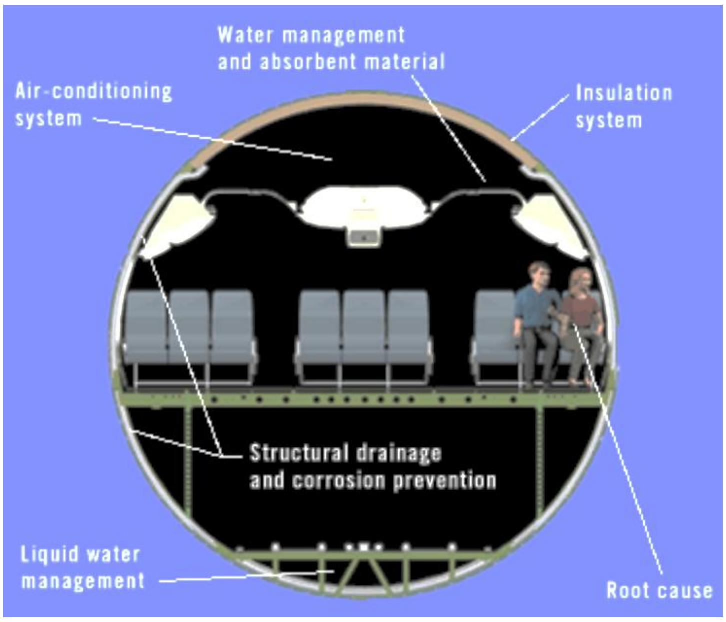

Figure 3.9 – Moisture Control System

The moisture control system includes:

- Insulation blankets; Air movement and condensation can be reduced by overlapping blankets and minimizing gaps between structural supports. It is recommended that penetrations for wire runs, electrical brackets, and other equipment be kept to a minimum. Additionally, all blankets should have drainage holes.
- Airflow systems; Using onboard ventilation systems to ventilate the crown space will reduce moisture problems. Air from the cabin supply will be provided to the crown space through a crown ventilation system, helping to reduce condensation in the cabin and enhancing the drying of wet surfaces and insulation. Furthermore, when an airplane has overhead recirculation fans as part of its air conditioning system, a crown ventilation system should not be installed

- Structural drainage; When designing structural components such as stringers and intercostals, holes and channels for water drainage should be considered
- Bilge trays; Insulation blankets are supported by bilge trays, which are sheets of molded plastic. To prevent insulation blankets from getting wet, bilge trays should be used in the lower lobe of the airplane.
- Moisture-control devices; Ceiling panels, stowage bins, and structural penetrations should be protected with Nomex felt. Evaporation of water collected in the felt will be promoted by active airflow.
- Electrical-equipment protection; It is recommended to protect or remove equipment from wet environments if it is sensitive to them. Moisture should be minimized by using sealed electrical connectors and system failures should be minimized.

The moisture control system was created to deal with:

- Significant increase of electrical failure
- More frequent change/repair of blankets
- Rain in the plane, inconvenience for passengers
- Additional weight

In order to minimize moisture-related problems, operators can take several effective steps (figure 3.10).

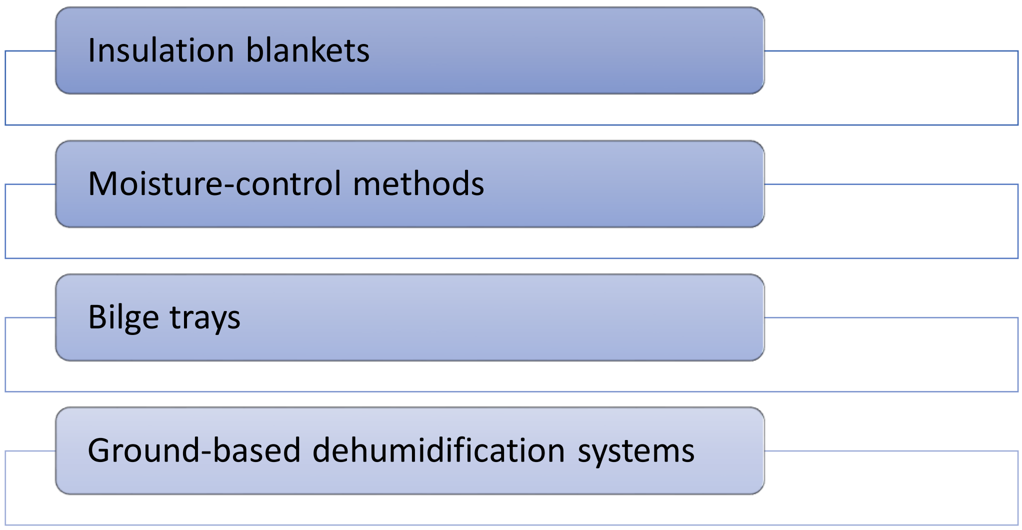

Figure 3.10 – Solutions to minimize the moisture-related problems

Insulation blankets. In order to decrease condensation formation, exposed structures and excessive gaps between insulation blankets should be minimized. Proper installation of blanket joint areas will also reduce the creation of condensation and subsequent drips into the crown area. Drainage holes in the blankets will help keep the cabin dry even if they are overlapped.

As part of maintenance checks, maintenance personnel remove wet insulation blankets and wring them out to expel moisture. As a result, the blankets become drier, but it damages the insulating material, making them less thermal and acoustic efficient.

Moisture-control methods. All operators are recommended to use Nomex felt on ceiling panels and stowage bins. Water will be less likely to drip into the passenger cabin if Nomex felt is applied in these areas.

Most airplane cargo compartments currently use strings and nets as protection, but bilge trays offer better protection.

Ground-based dehumidification systems. An airplane's humidity levels can be maintained at very low levels using ground-based dehumidification systems. They can greatly enhance the drying of wet surfaces and wet insulation. These systems, however, require a considerable amount of time to dry an airplane, and its doors must be closed throughout the process. Consequently, it is unlikely that most operators will use this method every day. The systems, however, may be useful for long-term parking of airplanes.

3.4 Humidification in the aerospace manufacturing facility

3.4.1 Humidity standard for the manufacturing

The aerospace manufacturing facility relies heavily on a proper humidity level. Deficiencies and excesses of humidity can cause severe damages and defects to aerospace components, as well as poor curing environments for sealants, coatings, welding, and composites. Ensuring proper humidification in your aerospace manufacturing facility will improve production output, and product quality and increase aircraft flying time [30].

Figure 3.11 – Use of Humidifier on Manufacture

In order to manufacture products that meet safety standards, your aerospace manufacturing facility should maintain humidity levels between 40% - 60%. Electronic components can fail in the field if equipment is not humidity-controlled. Defects caused by electrostatic discharge can occur if the requirement is not met. Insufficient humidity in a manufacturing environment can also compromise an aircraft's safety because it causes the parts to warp, become brittle, and have compromised finishes. Whenever aerospace parts are compromised, they may not be able to withstand the extreme environments that aerospace vehicles can encounter in the field, which can lead to malfunctions which can threaten the safety of passengers. In the aerospace industry, quality, durability, and long-term integrity of products can seriously affect safety, which makes proper application procedures imperative.

3.4.2 Avionics and electrical component manufacturing humidity control

Avionics is a complex of electronic systems and equipment that are integral to the function specially designed for use on the modern aerospace vehicles. This system includes lots of small, precise electronic workings on board that must be kept in special optimal conditions. Since moisture is dangerous to electricity in sufficient quantities, if something happens with a build-up of moisture within a device, it could pose a potentially dangerous situation. Aviation relies on effective dehumidification to get rid of any worry and keep everything in top condition.

Firstly, Electrostatic Discharge (ESD) should be prevented as it can cause expensive and dangerous electronic failures to avionics and electronics systems when humidity levels are not maintained between 40% and 60% RH. The phenomenon of electrostatic discharge (ESD) occurs when two electrically charged objects are in contact with one another. A visible spark can be generated when objects with different charges come into contact, or when the dielectric between them breaks down.

Secondly, it is necessary to prevent de-soldering and brittle components. It is crucial to correctly maintain humidity levels during wave soldering and surface-mount technology (SMT) processes. Deficiencies in solder joints can result from dry solder paste without sufficient humidity. As a result, aerospace products may lose their shelf life and malfunction due to short circuits or short-term damage. Also, brittle components can be created by insufficient humidity levels in aerospace electronics.

3.4.3 Paint and coating application process humidity control

Paint on aircraft requires reduced static and tight environmental conditions in order to achieve an even coat. Firstly, overspray and inconsistent coating should be avoided. In aerospace applications, electrostatic paint and powder coating offers many advantages, including waste reduction, overspray control, particulate recovery, and solvent reduction. It is necessary to maintain a differential charge between the powder and the affected item in order to electrostatic paint or powder coat. This requires a controlled-humidity environment between 40% and 60 to prevent product waste and increases production costs.

Secondly, surfaces should be prevented from drying quickly. Coating and surface treatments, such as electroplating and dipping, rely heavily on humidity. A low level of humidity can lead to uneven drying at the surface. This can stain and cause problems in later phases of processing, resulting in reduced efficiency in operation.

Conclusion to the part

A variety of aircraft ventilation systems can be distinguished based on three main categories of airflow distribution: mixing, displacement, and personalized. Humidity plays a key role in airborne pathogen transmission. The dry air allows mucosalivary droplets to dehydrate intensely, leading to their transformation into droplet nuclei that can float for a long time, possibly entering other passengers' breathing zones. As a result, personalized-ventilation-based solutions that provide fresh and clean air to this breathing zone deserve consideration. In comparison to traditional ventilation systems, personalized ventilation systems provide better air quality for occupants with higher humidity level.

According to the performed analysis a combination of the PV system and DV system may lead to greater results. A personalized ventilation circuit could also be equipped with a local humidification solution adapted to the needs of each occupant of every seat in the cabin.

The proposed ventilation system doesn’t effect on the avionics and aircraft structure, as the humidity level arises only near the passengers breezing zone, therefore no additional moisture is created in ceiling. Evidently, commercial airplane moisture is a complex issue, and its severity is determined by many factors. It is impossible to eliminate condensation on airplane structures without incurring prohibitive costs. However, cost-effective methods have been developed for managing moisture once it has condensed. Several design improvements and other solutions were developed, taking weight, cost, and installation ease into account.

De-humidification systems reduce appeared moisture problems. In general, there are two types of dehumidification systems: ground-based and ship-based. By identifying the causes of cabin condensation, it possible to initiate maintenance measures that significantly reduce its impact.

Keeping the aerospace manufacturing facility's humidity levels between 40% and 60% will ensure that products adhere to safety standards. It is imperative to maintain adequate humidity control throughout avionics manufacturing in order to ensure the product's quality, reliability, and safety. When humidity is controlled properly, ESD is prevented, electronics fail less frequently, aircraft and flight systems are safer, schedules are followed, and deliveries are made on time. The application of paint sprays and coatings depends on this as well. Products manufactured for the aerospace industry can have serious implications for safety when it comes to quality, durability, and long-term integrity, which is why proper application procedures are crucial.

To sum it up, for aerospace manufacturers, maintaining a humidity level between 40% and 60% has many benefits, including:

- Increased productivity and production output are expected;
- Minimizing waste through lower rework rates;
- Ensure that product quality is maintained and improved;
- Maximize the return on investment (ROI) of facilities and operations;
- Enhance the safety and efficiency of aircraft flights;
- Increase delivery on-time performance;
- Ensure healthy indoor air conditions for employees.

PART 4. LABOR PROTECTION

4.1 Introduction

Labor Protection is a system of legal, economic, social, organizational, technological, sanitary, and hygienic elements that have entered and contributed to the preservation of health and practicality.

Organizational - technical measures and means must ensure such a level of labor organization at the enterprise and such technical solutions for labor protection for the entire technological process that will avoid the danger of production factors on workers, and reduce the harmful effects of production factors on workers to acceptable normative values.

Organizational measures of labor protection are:

- high level of employee qualification, clear and timely instruction and control of occupational safety knowledge;
- correct organization of work;
- working condition of means of collective and individual protection;
- availability of appropriate safety signs, etc.

Technological measures and means of labor protection are:

- use of technically perfect and serviceable equipment, tools and devices;
- means of collective protection (fences, safety blocking devices, alarms, remote control systems, special means of grounding, zeroing, etc.);
- use of advanced means of protection of respiratory organs and other organs, means of protection against falling from a height, etc.

Sanitary-hygienic measures involve the study of the impact of production factors on humans, the establishment of permissible values of these factors at workplaces, the determination of the actual values of specific parameters of production factors, as well as the determination of compliance of conditions at workplaces with the requirements of regulatory documents.

Labor protection solves two tasks at the same time. One of them - engineering and technical - provides for the prevention of dangerous events during the labor process by:

• replacing dangerous materials with less dangerous ones;

• transition to new technologies that reduce the risk of injury and disease;

• design and construction of equipment considering labor safety requirements;

• development of means of individual and collective protection.

A second task is social - it concerns compensation for material, moral, and social damage caused by accidents or occupational diseases, i.e., protecting employees and their rights [31].

The main goal of labor protection in production is to minimize the probability of injury or illness to the worker while ensuring comfort and maximum productivity. In reality, there are usually some hazards associated with production requirements.

The main directions of creating healthy and safe working conditions are:

• safety of production processes;

• safety of production equipment;

• labor process safety;

• raising the level of production culture, industrial aesthetics and production organization;

• implementation of labor safety standards system;

• implementation of a complex of social and health-improving measures;

• industrial sanitation;

• ensuring electrical and fire safety.

In order to ensure a high level of labor protection, it is necessary to create a labor protection system that ensures safe work.

4.2 Harmful and hazardous working factors

The production process at aerospace enterprises involves constant exposure to adverse conditions for workers. Factors in production that are hazardous and dangerous are inextricably linked. Hazardous production factors are those that deteriorate the health or injury of an individual as a result of their long-term or short-term effects.

Factors that, when acting on an employee, reduce his work capacity or lead to different diseases are known as harmful production factors. It is critical to note that the boundary between these two groups of factors is quite arbitrary. A harmful production factor can become a dangerous one under certain circumstances. High humidity, for instance, is associated with unfavorable working conditions, which can result in respiratory diseases. If a person has to work with an electric current in such conditions, then it becomes too dangerous, and not just unsafe.

Dangerous and harmful production factors are divided into the following groups:

• physical;

• chemical;

• biological;

• psychophysiological, which include difficult and stressful working conditions.

It can be noted that there is no clear boundary between harmful and dangerous factors, it is always conditional and can be destroyed at any moment.

Physical factors. In the enterprise, it is simply impossible to avoid the influence of some factors. Among them, a special place is occupied by:

• temperature of surfaces and air;

• high or low humidity;

• radiation;

• electromagnetic fields;

• ultrasonic radiation;

• vibration;

• strong noise;

• lighting, which can be both too intense and insufficient;

• dustiness and gassiness of the air;

• working parts of the equipment and others.

Short-term exposure to each factor does not pose a particular health risk to humans. Employees spend a long time in their environments, and sometimes several at once, so their influence is quite apparent.

Microclimatic conditions in production premises are the most significant sanitary and hygienic factor, which depends on the state of health and working capacity of a person.

The main indicators of the air microclimate of the working area include temperature, relative humidity, and air movement speed. The microclimate parameters and the state of the human body are also affected by the intensity thermal radiation of various heated surfaces, the temperature of which exceeds the temperature in the production room.

Violation of the body's thermal state, overheating, caused by the influence of a complex of unfavorable indicators of the microclimate (temperature, air speed, humidity, thermal radiation) with the limitation or complete exclusion of individual mechanisms and ways of heat transfer, was called heat stress. Humans can also be affected by exposure to low temperatures and work in conditions of a cooling microclimate.

Noise and its impact on a person in an enterprise where there are machines and other equipment on the premises. As a rule, it cannot be done without noise. Frequently, working equipment emits loud sounds that can change their intensity. If a person is forced to regularly experience such exposure, it will have a negative effect on his health. Loud noise causes headaches, increased blood pressure, and reduced hearing, significant load on the human nervous system and has a physiological effect. In such conditions, working capacity is reduced, fatigue appears, attention decreases, and an accident may already occur. In order to reduce the negative impact of noise on the body, the following ways could be use:

• noise suppressors;

• personal protective equipment, such as headphones, etc.;

• produce soundproofing of noisy places with the use of protective covers, booth equipment;

• decoration of premises with sound-absorbing materials.

These measures will help create a more employee-friendly environment.

Vibration is included in the list of harmful production factors. As a result of the constant influence of this factor, not only the nervous system begins to suffer, but also the locomotor system and the analyzer system. Workers forced to work in such conditions often complain of headaches, dizziness, and motion sickness.

If you add the influence of accompanying factors, such as humidity, high temperature, noise, then this only increases the harmful effect of vibration.

The following measures can be offered to protect against it:

• replacement of equipment with a more technological one;

• use of soft coatings on vibrating parts of devices or equipment;

• installation of aggregates on a thorough foundation.

Industrial lighting. Industrial lighting plays a key role in reducing industrial injuries. With poor lighting, the potential danger of wrong actions and accidents increases: up to 5% of injuries can be explained by insufficient lighting, and in 20% of cases, insufficient lighting contributed to their occurrence. Poor lighting can lead to occupational disorders such as myopia and spasm of accommodation. Light starvation may occur in people who are completely or partially deprived of natural light.

Electrical safety. The current passing through a person is the main striking factor in electrocution, when touching open current-carrying parts or current-carrying non-carrying elements of equipment that are under voltage due to damage to the insulation, when touching voltage, when struck by an excess charge of a capacitor.

Chemical and biological factors. Harmful and dangerous production factors of a chemical nature enter the body through the respiratory system, gastrointestinal tract and skin and mucous membranes If the use of protective equipment is effective in hazardous production, workers will be exposed to hazardous substances much less.

Air purity and the impact of dust on humans. Sanitary and hygienic services divide the main harmful production factors into chemicals and industrial dust. A large amount of dust is an actual problem in production. The negative impact of dust is manifested in the fact that it can provoke the development of lung diseases.

Factors of the labor process. Psychophysiological factors include the burden of working conditions and its intensity. The intensity of work refers to the load on the nervous system and sense organs. This includes prolonged mental work, the monotony of the processes being performed, and emotional overload. All of these are harmful production factors, which, practically everyone feels to some degree at their workplace [32].

4.3 Analysis of working conditions and development of protective measures

Microclimate of production premises refers to conditions of the internal environment of these premises that influence the exchange of thermal energy between workers and their surroundings. As a factor of the production environment, the microclimate affects the heat exchange of the human body with this environment. This affects the thermal state of the human body during work.

Microclimatic conditions of industrial premises are characterized by the following indicators:

• temperature;

• relative humidity;

• speed of air movement.

Permissible conditions are a set of microclimate parameters that, with long-term and systematic influence on a person, can cause changes in the thermal state of the body, which quickly pass and normalize and are accompanied by the stress of thermoregulation mechanisms within the limits of physiological adaptation.

The optimal conditions are a set of microclimate parameters that, with long-term and systematic influence on the worker, ensure the preservation of a stable thermal state of the body without activation of thermoregulation mechanisms. They provide a feeling of thermal comfort and create the conditions for increasing labor productivity [33].

When performing work, certain physiological (biological) processes take place in the human body, the intensity of which depends on the total costs of performing the work and which are accompanied by a thermal effect and which support the functioning of the body. Part of this heat is consumed by the body itself, and excess heat must be released into the environment surrounding the body.

The values of microclimate parameters significantly affect a person's well-being and working capacity and, as a result, the level of injury. Prolonged exposure to high air temperature with simultaneously increased humidity leads to an increase in human body temperature to 38–40°C (hyperthermia), as a result of which various physiological disorders occur in the body: changes in metabolism, in the cardiovascular system, changes in internal functions organs (liver, stomach, gall bladder, kidneys), variables in the respiratory system, disorders of the central and peripheral nervous systems.

Significant physiological changes in the body are also carried out during cold exposure, which leads to hypothermia of the body (hypothermia). The most pronounced reactions to low temperatures are muscle and skin vasoconstriction. At the same time, the heart rate decreases, the volume of breathing decreases, and oxygen consumption increases. Cooling of the body temperature causes a violation of reflex reactions, a decrease in tactile and other reactions, and movements become difficult. This can also be the reason for the increase in industrial injuries.

Insufficient air humidity (below 20%) leads to drying of the mucous membranes of the respiratory tract and eyes, as a result of which their protective ability to resist microbes decreases.

The physiological effect of moving air flow is related to changes in the temperature regime of the body, as well as mechanical action (air pressure), which has not yet been studied sufficiently. It was established that the maximum air speed at workplaces should not exceed 2 m/s.

The optimal values of temperature, relative humidity and speed of air movement in the working area of industrial premises are given in table 4.1.

Table 4.1

Season	Category of works	Air temperature, °C	Relative humidity, %	Speed of the air, m/s
Cold period of the year	Light	21–24	60–40	0,1
	Medium	17–21	60–40	0,2
	Hard	16–18	60–40	0,3
Warm period of the year	Light	22–25	60–40	0,1
	Medium	21–23	60–40	0,3
	Hard	18–20	60–40	0,4

4.4 Fire safety rules at the workspace

The goal of fire safety of any premises is to prevent fire at the level determined by current regulations, and in the event of a fire, to limit its spread, timely detection, fire extinguishing, protection of people and property. For workers involved in the development of project documentation, it is critical to follow basic fire safety rules while at their workplace. After all, an irresponsible attitude to such seemingly small things, such as a cigarette butt or an electric heater left unattended, can cause a fire. Often, ignition occurs due to improper storage of flammable substances in the room, flashing of wiring due to overloading of the electric network, and careless handling of fire [34].

Conclusion to the part

This section deals with harmful and dangerous work factors - where a list of work factors that can cause illness, injury and death is provided and the requirements that the worker and the employer must comply with are established.

A detailed analysis of the microclimate of production premises and the working area, namely relative humidity, temperature, and air movement speed, was carried out. Possible damage depending on the influence of certain parameters of the microclimate of the working environment was analyzed. Recommendations on prevention and protective measures for their elimination are given.

Information is provided on fire safety rules and the procedure for workers' actions in the event of a fire.

PART 5. ENVIRONMENTAL MANAGEMENT SYSTEM

5.1 Introduction

The aviation industry originates primarily from the production of structural components, systems and equipment for aircraft. Therefore, it is necessary to consider the aerospace manufacturing facility itself as a matter of environmental protection, as it creates a major part of an ecological issues. Based on the experience of leading aerospace manufacturing facilities in developed countries, it is impossible to operate successfully in a market economy without implementing and developing an Environmental Management System (EMS). A company that undertakes strategic planning without factoring in the solution to environmental problems will likely face numerous problems in the near future. These problems are primarily related to surviving under competitive conditions and the contradiction between private and public interests.

Regulatory and financial support must be provided for the implementation of the main directions for reducing ecological damage caused by aerospace transport. Among the management methods of implementing the principles of sustainable development of transport and reducing the negative impact on the environment, the undisputed leader is the implementation of an environmental management system, which is based on the fulfillment of the requirements of the DSTU ISO 14001:2006 standard [35]. Adherence to the principles of the formation of EMS provides an opportunity to ensure effective and efficient management of the environmental aspects of the enterprise's activities. This is achieved through control and minimization of the negative impact on the environment of all transport activity processes.

5.2 Implementation of the EMS

The environmental management system is a part of the overall management system, which includes the organizational structure, planning, division of responsibilities, practical activities, procedures, processes and resources necessary for the development, implementation, achievement of the goals of the environmental policy, its review and correction.

An ecologically oriented project and work administration system, responsible for their implementation and the results thereof, must meet the following criteria: formation of a unified environment policy and target program; availability of management personnel of the environmental management system with appropriate qualifications and work experience in this area; clear understanding by the employees of the enterprise of their tasks, duties and rights in the process of implementing the target program; development and implementation at the enterprise of uniform methods, processes and creation of means and conditions for the implementation of the target program. In order to fulfill these conditions, motivation, training, informational and technological support of employees, who represent the main force in the process of environmental protection, are necessary. The environmental management system of an aerospace industry is called upon to perform these functions.

In contemporary scientific literature, the concept of environmental management is often used [36, 37]. However, insufficient attention is paid to the problematic aspects of its implementation in domestic aerospace manufacturing facilities. In particular, the use of foreign experience on such topical issues. An effective means of reducing the burden on the environment is to eliminate influencing factors by reducing their aggressiveness towards the environment. The main means of greening the activities of aerospace industry is the implementation of EMS. As a result of the implementation of an ecologically oriented management system, the aerospace enterprise undertakes to unquestionably comply with the requirements of environmental protection legislation, standards of environmental safety and rational use of nature, which is the driving force for gaining competitive advantages both internally, as well as on international markets. The implementation of the EMS allows to reduce the amount of compensation to the environmental protection fund; reduce the amount of waste and improve the system of handling it; to reduce emissions of harmful substances into the atmosphere due to monitoring of aviation transport activities, maintenance and repair of aircraft.

The main factors of aerospace manufacturing facilities impact on the environment are as follows:

- air emissions;

- discharge of wastewater into the city sewer or free flow of rainwater onto the adjacent soil;
- soil pollution;
- groundwater pollution;
- loss of raw materials in case of receipt, storage and delivery of transport;
- consumption of water and electricity;
- impact on the health of employees and residents of the surrounding areas;
- impact on living conditions and standard of living in nearby celibate zones;
- risks of freelance and emergency situations.

A principle is the approach to eliminating pollution. It is common in environmental management to identify activities that affect the environment, which result in payment for the damages caused by those activities. Similarly, in environmental management, the negative impact of the company's actions on the environment is assumed, and it pays for preventative measures. Thus, the possibility of various emergency and unforeseen situations is significantly reduced. Moreover, as already emphasized, modern studies indicate that prevention of atmospheric pollution in the vast majority of cases is much cheaper for enterprises than measures aimed at eliminating the consequences of pollution.

The following are defined as the main goals of environmental management:

- minimization of the negative impact on the environment;
- reduction of waste disposal costs;
- savings in the use of energy and materials;
- increasing the economic efficiency of aerospace enterprises.

Reducing the costs associated with the irrational use of resources and materials is one of the most significant advantages of the implementation of EMS.

Figure 5.1 – International Standards of Environmental Management Logo

The environmental management system can be considered at three levels: international, national and local.

International standards of environmental management, developed by the International Organization for Standardization ISO 14000 series, are aimed at providing companies with elements of an effective ecological management system of the Environmental Management System, which can be combined with other elements of the general management system of enterprises in order to contribute to the achievement of the goals of environmental policy [38].

At the national level, environmental management is regulated by the State Standards and Technical Conditions (DSTU) [39]. In Ukraine, international standards of the ISO 14001 series were adopted as national standards in 1997. In this regard, enterprises must adhere to certain clear standards.

Locally, environmental policy is reduced to environmental management - which outlines the environmental goals and tasks, develops company standards for environmental management, and increases production efficiency while keeping the environment in mind.

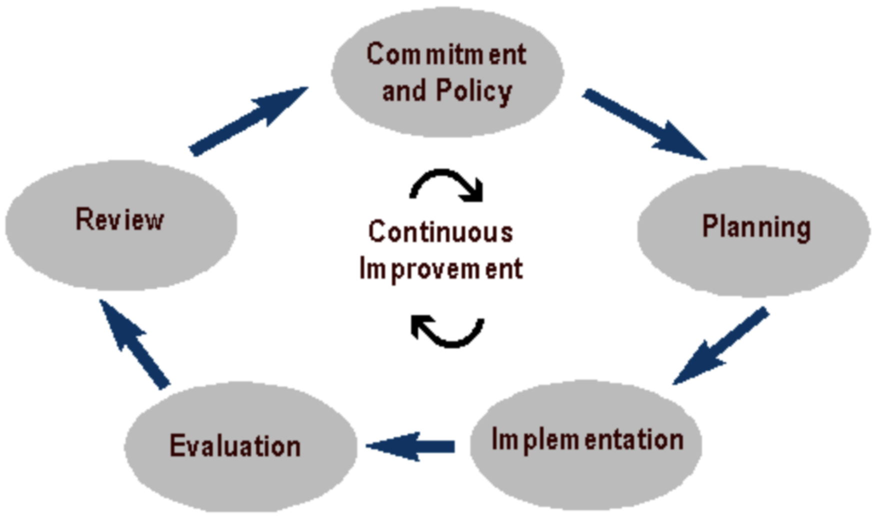

Figure 5.2 – Stages of EMS Process

The five main stages of an EMS, are described below:

Planning involves developing an environmental management program for the enterprise. Defining the goals, actions, responsible persons, terms of implementation of measures, methods, and expected outcomes of the environmental management program is necessary.

In the planning process, the enterprise can focus its primary resources on areas that are most critical to achieving the desired results. The data obtained in the planning process can also be used to develop and improve other elements of the environmental management system. These elements include personnel training, operations management, monitoring and measurement. Planning is an ongoing process that is implemented during the development and implementation of elements of the environmental management system for their support and improvement considering the constantly changing conditions of the external environment, as well as inputs and outputs of the EMS.

Implementation and evaluation involve determining the structure of responsibility, opportunities and resources for achieving the goals and objectives defined by the environment policy. Managing environmental problems effectively requires that the environmental management system be designed and adjusted in such a way that it can effectively interact with and integrate into the existing processes of the general management system. Elements of the management system that benefit from integration are enterprise policy, resource allocation, operations and documentation management, information and support systems, training and development of structural schemes and reporting, incentive systems, monitoring, internal audit processes, information exchange and reporting. At this stage, it is imperative to allocate sufficient resources, both financial and technological, for personnel training.

Inspections (review) are necessary for the effective implementation of the environmental management system at the enterprise, and contribute to timely response to deviations from the planned indicators during implementation. Enterprises must continuously monitor their environmental policies and indicators as well as conduct audits of their environmental management systems to ensure compliance with their standards and norms.

And the last element - analysis from the management side - involves checking the operation of the environmental management system for its effectiveness. As the environment changes constantly, an analysis should be done of the work of the environmental management system as a whole, the goals and objectives of environmental policy, as well as the necessary changes to it. The enterprise must continuously improve its environmental management system. The goals and objectives of environmental management must be tightly connected with the processes of continuous improvement, which must be achieved in all aspects of the enterprise's activities that affect the environment.

5.3 Benefits of EMS for the Aerospace Industry

The primary motivation for aerospace manufacturing facilities to adopt EMS is to meet their internal and external customer requirements. Quality management principles and policies are already strictly adhered to, even without this ISO standard.

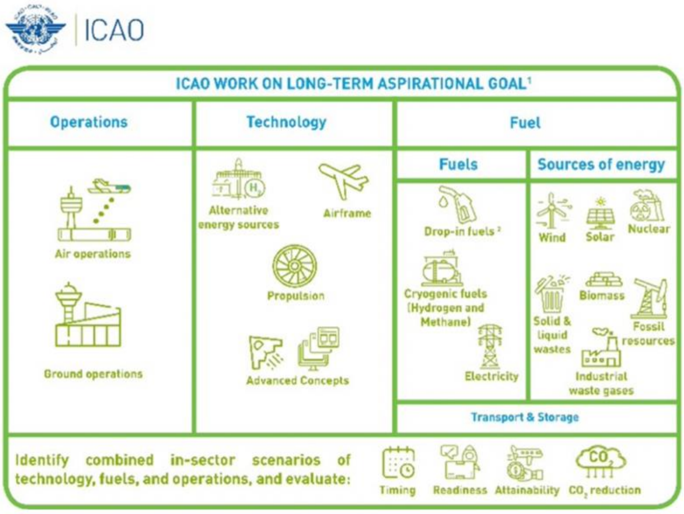

Figure 5.3 – Environmental Protection implemented by ICAO

Those companies who pursue EMS reported a number of internal and external benefits: ability to produce and manage a quality of products that is consistent, ability to charge a higher price, cost prevention or reduction of unforeseen costs, and keeping the organization structured and organized by following the requirements or principles. Whereas external benefits comprise: ease in the participation of projects, customer satisfaction, and attracting new customers. For example, they can charge a higher price. It is because the ISO standard could guarantee their ability to produce a product/service that meets the needs of the customer. It is also possible to prevent warranty claims and other unforeseen costs by producing consistently high-quality products/services. In addition, certification could ease participation in projects that require adoption of the standard as well as increase demand for future customers. It was also a challenge for the organization to implement the project. The aerospace industry is a multitiered industry, so companies in the lower tier face more challenges since they have to meet many different standards [40].

A certified management system will improve business performance for aerospace companies, since major customers require it. However, in order for companies to reap the benefits of adopting the standard, they must fully commit to the management of their quality and environmental systems. Companies need to also track the implementation of the ISO standard over time. They need to investigate whether it conforms to the performance requirements of the organization as part of a continuous improvement strategy [41].

Conclusion to the part

The purpose of EMS is to constantly evaluate performance, improve existing practices, programs, and establish new, higher goals.

Active EMS at aerospace manufacturing facility allows:

- minimize the negative impact of these objects on the environment;
- increase the efficiency of the enterprise in general;
- reduce the risks to the health of engineers and the population of the surrounding areas;
- reduce the risks of unusual and emergency situations during manufacturing.

The EMS does not aim at a one-time enhancement of the level of environmental safety of the object, but at constant progress in increasing the importance of environmental protection in the overall operations of the aerospace enterprise.

For aerospace manufacturing facility to achieve their environmental management goals, it is necessary to use environmentally safe production methods, eliminate negative impacts on the surrounding environment, and introduce the latest technologies to save various types of resources. In order to maintain competitiveness, enterprises need to perform environmental management in order to determine the optimal ratio between resource consumption and results. In order to implement EMS, it is necessary to justify the goals and tasks on which the environmental policy of the enterprise is built. It is in the interest of continuously improving the environmental management system.

GENERAL CONCLUSION

The master degree thesis consists of the following main parts: the first part focused on the importance of humidity in an aircraft. A low humidity problem that all passengers and crew encounter, especially on long distance flights, was discussed and shown.

The second part of master thesis is devoted to make the preliminary design of long-range wide body airplane that will be used as a prototype for the installation of the improved ventilation system in order to meet the optimal standard humidity level.

In the third part of the thesis, it was analyzed the different types of ventilation systems in terms of optimal humidity level on the passengers breezing zone. Compeering results of each system the Personalized Ventilation System in combination with Displacement System was chosen the best for prototype aircraft.

The fourth part was dedicated to the environmental protection. In this part it was discussed the Environmental Management System as a constant progress that should be implemented in order to enhancing environmental protection in aerospace operations.

The fifth part of the study dealt with the labor protection, when key parameters of the engineer's workplace were discussed and calculated, as well as the factors that can affect efficiency.

The presented results of the master thesis show the importance of the effective humidification on aircraft cabin. The optimal and standard humidity level could be achieved with the help of new ventilation system which will positively affect the well-being of passengers and crew, while not causing additional damage to the aircraft structure. The results of the research are not satisfying the goal to maintain the 20% of relative humidity in cabin, anyway the RH is higher than with original mixing ventilation system. Implementation of new air ventilation system with mandatory cabin humidity standard for all aviation will significantly change the spread of respiratory diseases around the world and will set an example for the entire transport structure on the ground.

In the literature, most possible research approaches have been used to investigate airflow patterns and air quality in aircraft cabins. All aircraft airflow and air quality studies cannot be solved with a singular research approach or set of research practices. Experimental and numerical improvements are the focus of further research recommendations. Future experiments should emphasize culture methods and spatially distributed measurements. More advanced wall functions, turbulence models, and Lattice Boltzmann Methods (LBM) can be incorporated into future numerical studies.

REFERENCES

1. Cabin humidifier still subject of controversy [Digital Source] – Access Mode: URL:https://www.ainonline.com/aviation-news/aviation-international-news/2008-05-08/cabin-humidifiers-still-subject-controversy

2. Engebretsen, KA; Johansen, JD; Kezic, S; Linneberg, A; Thyssen, JP "The effect of environmental humidity and temperature on skin barrier function and dermatitis". Journal of the European Academy of Dermatology and Venereology. 30 (2). – 2016. - 223p.

3. Elsersawi, Amin (2012-06-15). Secret of Electricity. Author House. ISBN 9781477216200.

4. Humidifier [Digital Source] – Access Mode: URL: https://www.airconditioning-systems.com/humidifier.html

5. “Anti-Static & Static Elimination Through Humidity Control”. JS Humidifier. – 2009.

6. How does a dehumidifier work [Digital Source] – Access Mode: URL https://www.searspartsdirect.com/diy/article/how-does-a-dehumidifier-work

7. Bella, "Humidistat Guide: What It Is And Why You Need One". The homeyspace.com. - 2021.

8. National Research Council (NRC) National Academy Press; Washington, DC: 2002. The airliner cabin environment and the health of passengers and crew.

9. Air Travel Advice [Digital Source] – Access Mode: URL: https://www.who.int/news-room/q-a-detail/air-travel-advice

10. Tips for better travel [Digital Source] – Access Mode: URL: https://travel.bart.la/page/3/

11. "Dehydration - Symptoms and causes". Mayo Clinic.

12. Department of Health, State Government of Victoria, Australia, https://www.betterhealth.vic.gov.au/health/conditionsandtreatments/immune-system

13. Mucosal immunity and vaccines, Jan Holmgren and Cecil Czerkinsky, Gothenburg University - 2005.

14. Droplet fate in indoor environments, or can we prevent the spread of infection? Lidia Morawska, Queensland University of Technology – 2006.

15. Common cold transmission in commercial aircraft: Industry and passenger implications, the state of our immune system is crucial to defend humans from virus and bacteria and is in direct relation to the humidity of the air we breathe. Martin B. Hocking and Harold D. Foster, Lund University – 2004.

16. Dirtiest places on airplanes [Digital Source] – Access Mode: URL: https://time.com/4877041/dirtiest-places-on-airplanes/

17. Humidity is a consistent climatic factor contributing to SARS-CoV-2 transmission. Michael P. Ward, Shuang Xiao, Zhijie Zhang, The University of Sydney and Fudan University. – 2020.

18. Jayaweera M, Perera H, Gunawardana B, Manatunge J. Transmission of COVID-19 virus by droplets and aerosols: A critical review on the unresolved dichotomy. Environ Res. - 2020.

19. Müller, D.; Schmidt, M.; Müller, B. Application of a displacement ventilation system for air distribution in aircraft cabins. In Proceedings of the 3rd International Workshop on Aircraft System Technologies, Hamburg, Germany. – 2011. - 279–288p.

20. Zhang, T.; Yin, S.; Wang, S. An under-aisle air distribution system facilitating humidification of commercial aircraft cabins. Build. Environ. 2010 907–915p.

21. Cheng, Y.; Niu, J.; Gao, N. Thermal comfort models: A review and numerical investigation. Build. Environ.- 2012. - 13–22.

22. Veselý, M.; Zeiler, W. Personalized conditioning and its impact on thermal comfort and energy performance—A review. Renew. Sustain. Energy Rev. - 2014. - 401–408.

23. Cao, G.; Awbi, H.; Yao, R.; Fan, Y.; Sirén, K.; Kosonen, R.; Zhang, J. A review of the performance of different ventilation and airflow distribution systems in buildings. Build. Environ. - 2014 - 171–186p.

24. Personalized ventilation for commercial aircraft cabins, [Digital Source] – Access Mode: URL: https://doi.org/

25. Alahmer, A.; Mayyas, A.; Mayyas, A.A.; Omar, M.; Shan, D. Vehicular thermal comfort models; a comprehensive review. Appl. Therm. Eng. 2011, 31, 995–1002.

26. Modification of a 747 Aircraft Ventilation System to Reduce Tovacco Smoke Transport - [Digital Source] – Access Mode: URL: http://webserver.dmt.upm.es/~isidoro/tc3/Aircraft%20ECS.pdf

27. Aircraft Environmental control [Digital Source] – Access Mode: URL: http://webserver.dmt.upm.es/~isidoro/tc3/Aircraft%20ECS.pdf

28. Zhang, T.; Wang, S.; Sun Y. Investigation of thermal comfort on innovative personalized ventilation systems for aircraft cabins: A numerical study with computational fluid dynamics. – 2021 – 7-9p.

29. Controlling Nuisance Moisture in Commercial Airplane [Digital Source] – Access Mode: URL: https://www.boeing.com/commercial/aeromagazine/aero_05/textonly/m01txt.html#sidebar

30. 2009 ASHRAE handbook – Fundamentals, 16.14.

31. Fundamentals of labor protection: Textbook. 2nd edition, supplemented and revised. / K.N. Tkachuk, M.O. Halimovskyi, V.V. Tsarist, D.V. Zerkalov, R.V. Sabarno, O. I. Polukarov, V.S. Kozyakov, L.O. Mityuk. - 2006 — 448 p.

32. Classification of dangerous and harmful production factors. [Digital Source] – Access Mode: URL: https://oppb.com.ua/articles/klasyfikaciya-nebezpechnyh-i-shkidlyvyh-vyrobnychyh-faktoriv

33. Hryban V. G. Labor protection: education. Manual, 2nd. / V. G. Hryban, O. V. Negodchenko. — Center of educational literature, 2011. — 280 p.

34. Fire safety at the workplace [Digital Source] – Access Mode: URL: https://ohoronapraci.kiev.ua/article/news/pozezna-bezpeka-na-robocomu-misci

35. Environmental management: study guide. Hryshchuk O.K., Mateychyk V.P. and other; editor Dmitrichenko M.F. – NTU, 2010. – 250p.

36. Dudnikova I.I. Formation and development of environmental management: theoretical and methodological context. Humanitarian Bulletin of Zaporizhzhya State Engineering Academy – 2014. – No. 58. – 259-268p.

37. Kirsanova T.O. Ecological controlling in the enterprise management system. Sumy State University — Sumy, 2004. — 20 p.

38. Kupalova G.I. Formation of an effective system of environmental management and audit. Bulletin of the University of Banking of the National Bank of Ukraine. – 2011. – No1 (11). – 48-53 p.

39. Environmental management systems. Requirements and guidelines for application. DSTU ISO 14001:2006 (ISO 14001:2004, IDT) − State consumer standard of Ukraine, 2006. − 17 p.

40. Tummala, V.M.R. & Tang, C.L. Strategic quality management, Malcolm Baldrige and European Quality Awards and ISO 9000 Certification: Core Concepts and Comparative Analysis. International Journal of Quality & Reliability Management, 13(4), - 1996 - 8-38 p.

41. FAA Fiscal Year 2015: Performance and Accountability Report. Washington, DC: Federal Aviation Administration – FAA 2015.