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INDOOR CLIMATE IN SHIPS

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DESCRIPTION

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Abstract

In the modern world the share of passenger traffic on the ship is not great. Basically passenger ships are used for the entertainment cruises. As regards cargo ships people are responsible for delivering cargo so comfortable indoor conditions should be created for people as well as for cargo.

Life on shipboard has own specific features and specific problems which are not close to problems of life on shore. It's necessary to realize that seafarer spends a lot of time in confined space so requirements for ships are stricter than for buildings. Thesis contains information about indoor air conditions established in Russian and European norms. In addition general information about lighting, use of synthetic materials and specifics of water supply during the voyage is provided. Besides that thesis contains information of specific features of seafarers' life such as an effect of ship vibration and ship motion.

Another important feature of seafarers' life is noise mainly caused by shipboard power plant and different mechanisms. These mechanisms (fans) are included to shipboard ventilation and air conditioning system so noise can spread widely through duct line system. There are several ways to prevent future noise problems and solve existing problems. Main preventive way is to conduct acoustic calculation with calculation of expected noise levels. Thesis contains example of acoustic calculations and comparison of results with Russian and European standards. Solution of existing noise problems are mostly construction solution methods - coatings, insulations, dampers etc.

Subject headings, (keywords)
Ship Indoor Climate, Ship Classification, Noise Problems in Ships, Acoustic Calculation

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CONTENTS

1 INTRODUCTION

People have been traveling around the world on foot, on horses, on boats from the earliest times. There have been invented safety modes of transport as a car, a plane, a ship. This bachelor's thesis is devoted to the last mode of transport.

Different problems of navigation and ship construction from one side and problems of medicine from another side are subjects of maritime medicine. A range of problems of maritime medicine has changed a lot and has become wider while ship construction and navigation have been developing. In last 20 years work conditions of ships have changed a lot: number of ship crew members have reduced noticeably, passenger traffic and duration of voyages have risen. Ship crew works under rising psychological and physical loads. Despite of that requirements considering state of health of seafarers became stricter.

In the modern world the share of passenger traffic on the ship is not great. Basically, passenger ships are used for the entertainment cruises, so it is important that the passengers feel themselves comfortable in the cabins. Situation differs in cargo ships. Although people are responsible for delivering cargo in safe and good conditions which may be quite strict, conditions which are created for people themselves have less meaning. As a consequence, there is more experience in creation conditions in cargo compartments than in cabins.

Cargo carriage by sea is one of the cheapest and the most popular ways to deliver cargo. It has no alternatives in delivery from one place to another which are separated by a sea or an ocean. The share of cargo being delivered by sea shipping is about two-thirds of global turnover /1, p.3/. The process can last long period of time. During these transport operations crew as well as cargo needs comfort for living in ship so good indoor climate should be achieved.

Heating, ventilation and air-conditioning (HVAC) systems on the ship and in the building have little differences from each other because the aim of them is the same – to create adequate indoor conditions. However, they cannot be absolutely similar at least due to different external conditions.

2 AIMS AND METHODS

2.1 Aims

The aims of this work are achieved in several chapters. The first aim of this work is to introduce with indoor climate on ships and parameters of it. This includes also specific description of these parameters from the Russian and international standards, analysis of their differences. Second aim is to give an idea of the ship HVAC systems. More details will be presented with information concerning the ventilation and air-conditioning (AC) systems. Third aim is to describe problem caused by HVAC systems (mainly noise) and to suggest some solutions to solve it.

Although the specialty of the author is mainly heating, ventilation and AC systems related to the buildings, the author wants to describe those systems of ships. Idea was that although there are differences in general between those in the building and in ship they have same initial principles.

2.2 Methods

This work contains theoretical information about the vessels, sometimes occasionally related to practical side (for example, a possible solution to the problems of noise caused by HVAC systems). The work is based on many kinds of literature in Russian and English languages: standards, norms, rules, guidelines, research reports.

Among used methods is acoustic calculation of AC system. In the example there are described expected noise levels at different points of duct lines and information about what has influence on noise level. As the result noise level in cabin is defined and compared with values given in Russian and European standard. Also possible construction methods to solve noise problems are given.

3 INDOOR CLIMATE

3.1 Definition

According to hygiene terminology term “indoor air” includes combination of physical and chemical factors: air temperature, air humidity, air velocity, pressure, gas and ion components, amount of dust components, bacterial composition etc. Physical factors of indoor air (air temperature, air humidity, air velocity) in combination with thermal radiation from enclosures form the term “indoor climate”. Needed amount of air is conducted to the space by ventilation system; indoor air parameters are provided by AC system. This division is quite rude, because air conducted by ventilation system has to have definite parameters, but it shows that purposes which systems are made for are different. So requirements for these systems are different. /2, p.120/

3.2 Creating conditions

This chapter is based on Stenko’s studies about indoor climate in ships /2/. Specificity of indoor climate in shipboard spaces is defined by way of its isolation from outdoor air, often small sizes of shipboard spaces and large amount of people, equipment etc. inside. Another specificity is that ships can make passages from one climate zone to another, for example from Arctic zone to tropics and vice versa. That also has an influence on indoor climate.

Indoor climate is created mainly under the impact of factors which form thermal balance of ships. They are heat outputs from shipboard equipment, lighting, people, heat absorption by cooled enclosures, cool air of AC system, heat absorption by the refrigerating chamber etc.

Heat gains during summer period cause additional air heating: in spaces with normal internal heat gains (cabins, public areas etc.) air temperature can rise for example by 5°C; in spaces with high internal heat gains (engine room, caboose etc.) air temperature can rise for example by 8-10°C. In spaces where is not powerful heat sources (cabins, public areas etc.) temperature of enclosures differs from air temperature by 1-6°C. In rooms with energy sources this difference is more significant. For example, temperature of enclosures of rooms with engines and boilers may reach 50-60°C. It causes intensive heat outputs from these enclosures (about 30-40 cal/(sm^2·min).

Special feature of indoor air in shipboard spaces is its unstable state. Temperature of air and enclosures may vary by 4-5°C during day. Absolute humidity varies less.

Humidity of indoor air is defined mainly by humidity of outdoor air. Of course outdoor air with definite humidity loses some amount of moisture reaching shipboard spaces because temperature of indoor air is usually higher during summer and winter periods (if AC system is absent). But even in spaces without high heat loads relative humidity reaches 70-80% if there is high humidity of air above water surfaces (it may be 80-100%). In special spaces where water is used constantly in large amount (for example, in rooms for fish dressing) relative humidity at any climate conditions may be 90% and higher. Combination of high humidity and high or low temperature can lead to heat imbalance of crew and passengers. For example, there are some problems for people who are in tropics at first time and have low capability of adaptation. On the contrary if outdoor air temperature is -20…-50°C absolute humidity is quite low despite of high relative humidity. Outdoor air with low moisture content loses some moisture moving in heated air ducts or passing heated rooms. So when it reaches rooms its relative humidity may be quite low (9-15%). /2, p.120/

3.3 Influence on human health and comfort

This chapter is based on Stenko's studies about indoor climate in ships /2/. Capacity for work and health of the seafarer depends on the microclimate of ship rooms. Talking about air parameters that have great influence on the thermal state of a person first of all influence of air temperature should be described. At high ambient temperature capacity of human work sharply reduces, the state of health deteriorates: there are weakness, headache, excessive sweating, frequent breathing and pulse. Life and work in conditions of high temperatures are accompanied by the development of asthenic reactions, reduction in the rate of blood flow, violations of water-salt metabolism, vegetative disorders. Long work at such temperatures could lead to the development of thermal shocks. Life and work in the conditions of low temperatures promote the development of hypertensive reactions, increase diuresis, and weaken protective forces of an organism.

Other parameters of the indoor climate such as humidity, indoor air velocity and level of heat exchange can increase the cooling or warming effect of air temperature and change human heat sensation even at a constant air temperature in the room. Because of the specifics of thermoregulation of the human body which are taken into account temperature regime of air in residential and public spaces is limited to definite values (20-25 °C in summer and 19-23°C in winter /2, p.120/). The sensation of thermal condition depends partly on indoor air velocity. At a temperature of 21-23°C air flow with velocity of 0,25 m/s is perceived as pleasant breeze, with velocity of 0,4-0,5 m/s can be endured easily. In areas where there are mechanisms with heat output indoor air velocity is limited to 0,7m/s.

A great influence on a human's health has air humidity. If air temperature is within 18-25°C the most favorable relative humidity is within 40-60%. If humidity is higher it is felt as dampness, and if it is lower - as an unpleasant dryness in the nasopharynx (30%) or burning in the nasopharynx and smarting in eyes (10-15%).

Also air state is described with air composition, amount pollution gases, amount of dust and presence of odors. Clean air has the following volumetric composition (in percent): nitrogen - 78,08; oxygen - 20,95; inert gases - 0,94; carbon dioxide - 0,03. The degree of air pollution with gases is determined by the redundancy of carbon dioxide, hydrocarbons, sulphur dioxide, oxides of nitrogen and carbon in it. In machinery room and boiler plant air pollutants are products of incomplete combustion of fuel, pairs of oils (monoxide and carbon dioxide, hydrocarbons etc.). Headache, dizziness, sleep disturbance, fatigue appear under the influence of carbon monoxide. Gasoline vapors take narcotic and toxic actions. /2, p.121/

Complex effect of all parameters of the indoor climate on the thermal condition of the person has a mathematical statement and can be illustrated with nomogram of the effective temperatures (fig. 1).

Below is example of defying effective temperature with known air temperature, relative humidity and acceptable air velocity by use of nomogram.

<u>Example.</u> Indoor conditions in one room are: air temperature is 24°C, relative humidity is 44%, normal air velocity is 0,2 m/s (30 m/min). Air temperature according to wet thermometer is found with Mollier diagram, it is equal to 16°C. Connecting left and right scale (it can be seen in figure) we cross comfort zone with line. With defined air velocity in the room 30 m/min we find effective temperature 20°C. Point is located in comfort zone.

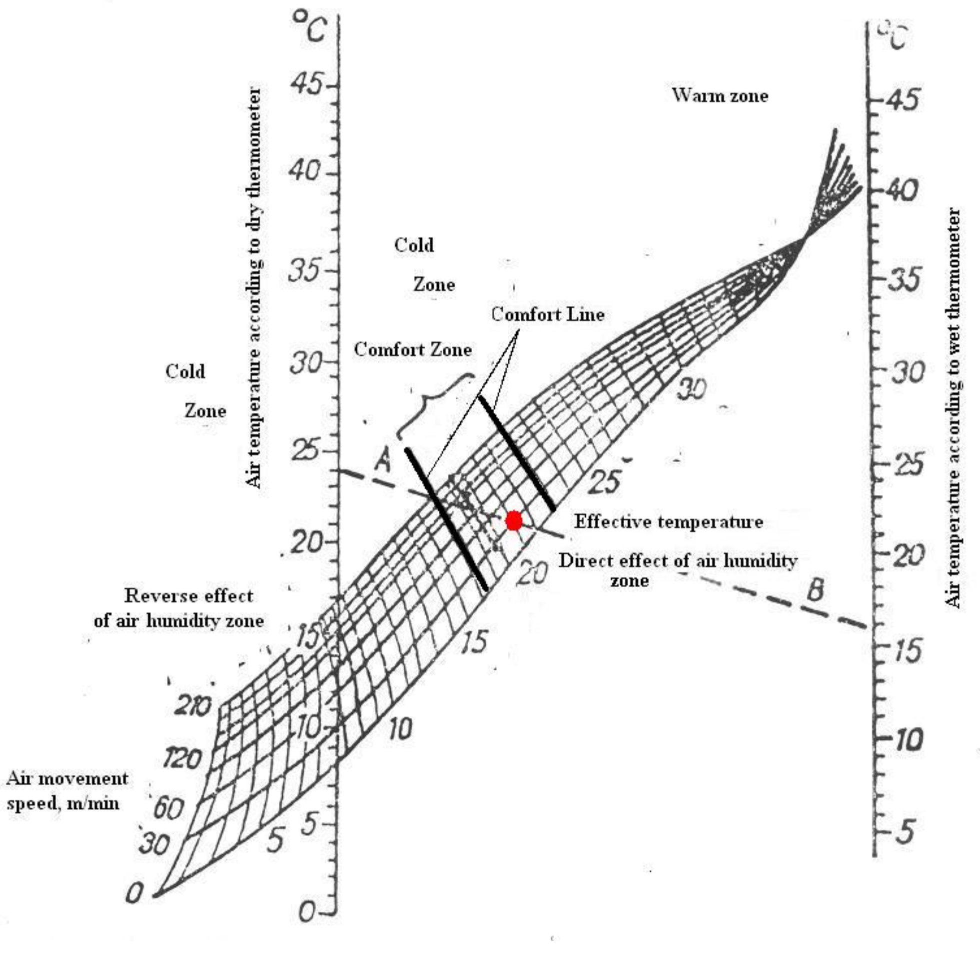


Figure 1. Nomogram of the effective temperature determination

As it is showed by the nomogram only a certain combination of all parameters of the microclimate allows providing the heat balance of the human body, subjectively assessed as thermal comfort. However, the comfortable indoor conditions may not be the same for all crew members, since the thermal condition of a person depends on the work, the speed of adaptation to weather conditions, conditions of the work environment, the individual habits to heat or cold etc. In this regard, during design process of shipboard HVAC systems the possibility of individual adjustment of temperature of air should be provided.

3.4 Standards for accommodation spaces

3.4.1 GOST 24389-89

The description in this chapter is based on the Russian standard GOST 24389-89 “Air conditioning, ventilating and heating systems for shipboard use. Design characteristics of air and design temperature of sea water” /3/.

This standard is about HVAC systems of sea vessels, river vessels, lake boats, vessels of mixed navigation (river-sea) and floating drilling rigs. The standard sets design temperature and relative humidity of outdoor air; design temperature of sea water; design temperature, relative humidity and air velocity of indoor air in spaces for crew accommodation and work, spaces for passengers’ accommodation, spaces related to energy production and other spaces which are served by HVAC systems. These values are used in thermo-technical calculation of shipboard HVAC systems and equipment and in calculation of thermal insulation of spaces.

This standard doesn’t set design temperature and relative humidity of indoor air in spaces designed for cargo transportation in transport vessels and ferries and special spaces in catcher boats designed for processing and storage of production because special indoor climate may be needed.

Design temperature and relative humidity of outdoor air and sea water are given in tables 1 and appendices 2, 3, 4. Design values of indoor climate are given in the table in appendix 5. Design relative humidity in spaces with air conditioning is set within 40-60%. Design air velocity in work area (150 mm from wall surface and 1500 mm height) in spaces with air conditioning is set to 0,15 m/s in residential and public spaces, medical rooms. Value 0,5 m/s is allowed in other spaces.

Difference between mean radiant temperatures of wall surfaces and mean radiant temperature of indoor air in spaces with air conditioning shouldn’t be more than 4ºC in summertime and less than -4° in wintertime. Mean radiant temperatures of wall surfaces are taken from calculation of thermal insulation.

Design values (table 1, appendices 1,2,3) are based on

in summertime

- outdoor air temperature is based on maximum mean temperatures of outdoor air in the hottest month;
- relative humidity of outdoor air is based on relative humidity related to maximum mean temperature of outdoor air in the hottest month;
- sea water temperature is based on monthly average temperatures of sea water in the hottest month;

in wintertime

- outdoor air temperature is based on minimum mean temperatures during the 5 coldest days;
- relative humidity is based on monthly average relative humidity of outdoor air in the coldest month;
- sea water temperature is based on monthly average temperatures of sea water in the coldest month.

Two examples demonstrate how to use tables for finding design values.

<u>Example 1:</u>

We have cabin in a sea vessel with unlimited navigation area. From table 1 we can find

-Abbreviation of unlimited navigation area is “OM”;

-temperature of outdoor air in summertime and wintertime $t_{o,s}$ = 34°C, $t_{o,w}$ = -25°C;

-relative humidity of outdoor air in summertime and wintertime $\varphi_{o,s}$ = 70%, $\varphi_{o,w}$ = 85%;

-temperature of sea water in summertime and wintertime $t_{w,s}$ = 30°C, $t_{w,w}$ = 0°C.

From appendix 5(1) we can find design values of indoor climate depending on navigation area and type of room:

-type of room – cabin – is №1 in the list of rooms;

-temperature of indoor air in cabin with air conditioning in summertime and wintertime $t_{i,air\ cond.,s}$ = 26°C, $t_{i,air\ cond.,w}$ = 22°C;

-temperature of indoor air in cabin with ventilation or heating in summertime and wintertime $t_{i,vent.,s}$ = 39°C (by 5°C higher than $t_{o,s}$), $t_{i,vent.,w}$ = 20 – 21 °C respectively

-air velocity in cabin with ventilation or heating in summertime and wintertime $V_{i,vent.,s}$ up to 0,5m/s, $V_{i,vent.,w}$ up to 0,25 m/s.

This example is for vessel with unlimited navigation area so it can be at any point of world. In table 1 code of navigation area and outdoor air conditions can be found. In appendix 5 indoor air conditions for needed room could be found. Temperature of indoor air only with ventilation or heating in summertime is so high (39°C) because there is heating effect when air passes ventilation system and usually ventilation system has no cooling devices.

<u>Example 2:</u>

We have a restaurant in a lake boat which navigation area is lake Balaton. From appendix 4(1) we can find

-Navigation area is No.6 (position No. 3);

-temperature of outdoor air in summertime and wintertime $t_{o,s}$ = 28°C, $t_{o,w}$ = 4°C;

-relative humidity of outdoor air in summertime and wintertime $\varphi_{o,\,s}$ = 65%, $\varphi_{o,\,w}$ = 85%;

-temperature of sea water in summertime and wintertime $t_{w,s}$ = 24°C, $t_{w,w}$ = 4°C.

Values during winter with no navigation are:

-temperature of outdoor air $t_{o,w}$ = 1°C;

-relative humidity of outdoor air $\varphi_{o,\,w}$ = 80%;

-temperature of sea water $t_{w,w}$ = 1°C.

From appendix 5(1) we can find design values of indoor climate depending on navigation area and type of room:

-type of room – restaurant (common space) – is №2 in the list of rooms;

-temperature of indoor air in restaurant with air conditioning in summertime and wintertime $t_{i,air\ cond.,s}$ = 20°C, $t_{i,air\ cond.,w}$ = 22°C;

-temperature of indoor air in restaurant with ventilation or heating in summertime and wintertime $t_{i,vent.,s}$ = 33°C (by 5°C higher than $t_{o,s}$), $t_{i,vent.,w}$ = 20 – 21 °C

-air velocity in restaurant with ventilation or heating in summertime and wintertime $V_{i,vent.,s}$ up to 0,5m/s, $V_{i,vent.,w}$ up to 0,25 m/s.

This example is for lake boat with limited navigation area on lake Balaton (Russian Federation). In appendix 4 code of navigation area and outdoor air conditions can be found. In appendix 5 indoor air conditions for restaurant could be found.

TABLE 1. Design values for vessels with unlimited navigation area /3/

Abbreviation of unlimited navigation area	Ship type of unlimited navigation area	$t_{o,s}$, ºC	$\varphi_{o,s}$, %	$t_{w,s}$, ºC	$t_{o,w}$, ºC	$\varphi_{o,w}$, %	$t_{w,w}$, ºC
		Summer			Winter		
		Air		Sea water	Air		Sea water
OM	Sea vessels	34	70	30	-25	85	0
OM1	Vessels of mixed navigation	30	65	27	-23	85	0
OM2	River vessels, lake boats	28	55	24	-12	85	1

In table 1 and appendices 2-5 following symbols are used:

$t_{o,s}$ – temperature of outdoor air in summertime, ºC;

$t_{o,w}$ – temperature of outdoor air in wintertime, ºC;

$t_{w,s}$ – temperature of sea water in summertime, ºC;

$t_{w,w}$ – temperature of sea water in wintertime, ºC;

$t_{i,air\ cond.,s}$ – temperature of indoor air in spaces with air conditioning in summertime, ºC;

$t_{i,air\ cond.,w}$ – temperature of indoor air in spaces with air conditioning in wintertime, ºC;

$t_{i,vent.,s}$ – temperature of indoor air in spaces with ventilation or heating in summertime, ºC;

$t_{i,vent.,w}$ – temperature of indoor air in spaces with ventilation or heating in wintertime, ºC;

$\varphi_{o,s}$ – relative humidity of outdoor air in summertime, %;

$\varphi_{o,w}$ – relative humidity of outdoor air in wintertime, %;

$V_{i,vent.,s}$ - air velocity in spaces with ventilation or heating in summertime, m/s;

$V_{i,vent.,w}$ - air velocity in spaces with ventilation or heating in wintertime, m/s.

Note: for unlimited navigation area OM when duration of navigation in the tropics is less than 70% of vessel operation time it is allowed to decrease design temperature of outdoor air ($t_{o,s}$) by 2°C in summertime with simultaneous increase of relative humidity of outdoor air ($\varphi_{o,s}$) by 10%.

3.4.2 ISO 7547-2002

The description in this chapter is based on the international standard ISO 7547 “Ships and marine technology – Air conditioning and ventilation of accommodation spaces – Design conditions and basis of calculation” /4/. With accommodation space the standard ISO 7547 states the “space used as public rooms, cabins, offices, hospitals, cinemas, games and hobby rooms, hairdressing saloons and pantries without cooking appliances” /4, p.1/. This standard defines design conditions, method of heat loss calculation and airflow calculation. In addition to calculation of heat losses the standard defines methods of calculation solar heat gain, heat gains from persons and heat gain from lighting and other sources.

According to the standard there are uniform design values for all types of ship spaces (see table 2). Share of outdoor air supplied to accommodation spaces should not be less than 40% of total supplied air.

TABLE 2. Design conditions /4/

Design value	Summer	Winter
Temperature of indoor air, °C	+27	+22
Humidity of indoor air, %	50	-
Temperature of outdoor air, °C	+35	-20
Humidity of outdoor air, %	70	-

3.4.3 Comparison of standards

When comparing standards the first thing which attracts attention is how detailed and with many factors determination of the indoor conditions is described in Russian standard and how briefly in European standard. Russian standard states that choice of indoor air temperature depends on HVAC systems serving the space. Also values of sea water and outdoor air condition are given for large amount of regions. In European standard indoor air condition differ only for a small number of spaces depending on their designation; outdoor conditions are presented only with outdoor air temperature regardless of any factor. But European standard establishes the order of heat loss calculation and airflow calculation what Russian standard doesn’t contain.

3.5 The specific features of life on the ship

The following chapter is based on Pavlyuchenko’s studies about artistic design of ships /5/.

Working process of transport vessels has intensified in recent years. Speed of vessels has increased with shortening the time of loading / unloading works. Mechanization and automation of production processes were accompanied by reduction in the size of crews. Automation of production processes has significantly simplified physical labor although taut nerves have become more and more often problem. Share of brainwork has increased, what, in turn, requires regular improvement of professional skill of the personnel. Especially the neuropsychic tension of navigator has increased sharply. The human factor has taken a leading position in a number of the factors which influence the accident rate of the fleet. Mistakes of navigator are the direct cause of 55-65% of all accidents. A new problem related to human factor has appeared which has become actual due to the rapid quantitative growth of the transport fleet.

The wellbeing and working capacity of the crew of a ship are affected by a complex of sociological, psychological and physical factors. Constantly being in a closed emotional and psychological sphere of personal communication with a small group of people causes that sailor suffers from lack of the coastal diversity of external stimuli during voyage; he lacks the incoming information (sensor failure); he feels the monotony of life and occupation, lack of regular sources of pleasure and entertainment. All of this contributes to the development of mental strain (stress). Continuous separation of seafarers from the family, from the world of the usual feelings and associations contributes to the emergence and development of a mental condition that is typical for nostalgia - longing for the homeland.

Limited living space on a vessel leads to a lack of physical activity, reduction of 70 to 80% of the normal for human daily dose movements. Low mobility contributes to the development of cardiovascular diseases, especially in the relatively rapid transitions from one climatic zone to another, when the body does not have time to adapt to the rapidly changing conditions of the environment. Such specific for the vessel phenomenon as pitch, vibration and noise also lead to the violation of a number of physiological processes in the body.

Modern vessels are operating year-round; they have to be in different climatic zones of the globe, with the temperature measured on the open deck varying from -20 up to +50 C. The humidity of the air is changed also in a wide range. If to consider that the normal values of air temperature for the person are in the range from +18 to +22 degrees Celsius with relative humidity of 40-60%, the body of seafarers often has the overload.

The complex of all of the factors characterizing conditions of human vital activity during the voyage is called «habitability of the vessel». In other words, the term «habitability» refers to working conditions, life and rest of the crew on board. Factors of habitable zone are for divided convenience into two groups. The first is the receptor factors, i.e. the direct impact of which on the sensitive nerve fibers (receptors) can lead to painful changes of human organism. These include elements of indoor climate, noise, vibration, acceleration of ship motions, the composition of drinking water, etc. More about receptor factors will be said in following chapters. The second group includes design-architectural or technical and aesthetic factors, with the help of which are created the convenience, comfort, working efficiency of the crew: it is determined by the size of the cabins, public and domestic spaces, and the passes; set forth the composition, dimensions and placing of the equipment of spaces; accepted color solution, selected decorative-artistic elements etc.

Let's dwell on some aspects of the problem of the adaptation of the vessel to the life of the crew. The international labor organization adopted the Convention in 1970 /6/, which recommends that all ships shall be provided with the single cabins for the crew, though admits to do some cabins double, and even three - and four-bed cabins in passenger ships. Single cabin provides a temporary isolation of the individual from all the crew, contributes to the psychosomatic regeneration of the seafarer and creates conditions for improvement of professional skill.

Any sleeping room should include four main functional areas: for sleep (cot), for rest and reception of visitors (coffee table, armchairs), for work and study (table, desk, bookshelves, chair or armchair) and for personal hygiene (wash-stand or bathroom). In order to save valuable space sometimes sanitary unit is common for two cabins. Cabins of commanders are designed in the form of cabin blocks, in which the main functional zones are divided with partitions. Another two zones are added on some vessels - a small kitchen for individual preparation of food and children's corner. Special attention should be paid to the design of the room in which the cultural-educational work is conducted.

On a ship with a large crew (for example, research vessels, fishing bases) number of public spaces is substantially increased: the smoking rooms and the music salon, game rooms, spaces amateur talent activities etc. Sports complex of the ship includes a gym, a volleyball court, room for table tennis, outdoor area with sports equipment. Necessary in shipboard conditions equipment is located in the gym: rowing simulators, training ladders, machines, special devices for power exercises. For organization of leisure time of seafarers on ships are created such spaces as a darkroom and workshops for the individual occupants.

The inclusion of elements of nature in marine conditions has a salutary effect on the mental condition and emotional state of seafarers. In the cabins and public areas have been widely applied decorative plants. Modern quarters of the ship are characterized with the simplicity and comfort. The interior blocked with details evokes a feeling of anxiety and quick tiredness. Carpeting, large decorative curtains, comfortable furniture, a moderate range of colors are typical features of the modern ship's interior. Paintings, works of decorative and applied art (ceramics, textile, wood) allow to create a convenient and beautiful interior. /5, p. 59-64./

3.5.1 Noise

Following chapter is based on Pavlyuchenko’s studies about artistic design of ships /5/.

Wide range of oscillation has influence on human in navigation. Oscillations with frequency of up to 16-20 Hz (infrasound) are felt in form of pushes. The range of oscillation of more than 10 - 20 kHz relates to the field of ultrasound. Field of oscillation perceived by the human ear as audible sounds lies between the zones of infra - and ultrasound. Adverse combination of sounds, which interfere with the perception of the useful signal and human speech and has harmful effect on human health, is called noise.

Audible range of sounds (noise) is divided into low-frequency (300 Hz), medium (from 300 to 1000 Hz) and high frequency (more than 1000 Hz). The noise is assessed according to its power (in decibels) and loudness (in the background). The loudness is subjective attitude of the power of sound. Quantitative estimation of the noise is made with special sound measuring equipment (audio-noise meter) graduated in decibels. The level of the noise intensity is defined as the decimal logarithm of ratio between actual sound pressure and pressure of being on audibility threshold at oscillation frequency of 1000 Hz.

In ships noise is transmitted mainly through walls, floors and partitions; at low frequencies transmission occurs because of membrane oscillations of enclosures, at high frequencies transmission has wave character. Of course noise is transmitted through open windows, hatches, different openings, ventilation shafts and channels. Also noise is spread by mechanism of vibration from foundation to ship hull with following noise emission in adjacent and distant spaces.

The degree of the negative impact of noise on health and working capacity of a person depends on a number of factors. Sound power, its duration, range of frequency (pitch), sweatshop labor or not, work intensity, time of day, individual characteristics of the person have significance. Noise adversely affects not only the function of the auditory analyzer, but also on the general condition of the organism: makes worse central nervous system functional condition, reduces attention, decelerates mental and motor reactions, causes fatigue, leads to improper functioning of cardiovascular system.

Harmful effects on the human body can be produced not only by noise, but also by quiet sounds. So infra-sound with the frequency of 6-8 Hz leads to painful sensations because it reaches the internal organs resonance frequency. Long-term influence of ultrasound can cause fatigue, headaches and modify blood pressure. High intensity ultrasound can lead to burns, dyspnea and limb paralysis.

The noise can have so called aerodynamic or mechanical origin. Noise with aerodynamic origin occurs when there are any processes of suction, injection or bleed of air, gas and steam. Noise with mechanical origin is result of a collision of moving parts of machines and vibration caused by the unbalanced mechanisms or imbalance of their rotors.

Nowadays acceptable levels of noise in machine offices, residential, office and public spaces of the vessels shall be established by regulations approved by State Sanitary Inspection of Russian Federation. If the noise levels in any spaces exceed sanitary norms causes of excess noise and measures on its elimination should be established before repeating measurements. The measurements are repeated if frequency components of the noise on the serial vessel are higher than on the lead ship (first vessel in series). Directly before second measurements a complex of additional measures for noise elimination is to be developed.

Measurement of aerodynamic noise levels on the lead vessel including noise levels produced by existing ventilation and AC systems are made on the stage of full readiness of the vessel and are included in the scope of trials of independent programs. Measurements of frequency components in accommodation, public and service spaces as well as in engine compartments and soundproofed central control stations of the power plant usually are included in these programs. /5, p. 71-74./

3.5.2 Standards limiting noise levels

3.5.2.1 SN 2.5.2.047-96

The description in this chapter is based on the Russian standard SN 2.5.2.047-96 “Noise levels on Board Marine Ships. Sanitary norms” /7/.

This standard limits noise levels on workplaces, accommodation, serving and common spaces, zones for rest etc. located on ship board. The information has to be applied to ships which are under design, construction and renovation, and in use, and can't be applied to military vessels and sports vessels which are not used in commercial purposes. This standard is obligatory for use for ship owners and organizations which design, build ships and conduct renovation of ships.

Maximum permissible sound pressure level L, in decibels, in octave band with frequency components 31 Hz, 63 Hz, 125 Hz, 250 Hz, 500 Hz, 1000 Hz, 2000 Hz, 4000 Hz, and 8000 Hz and A-weighted sound pressure level can be found in table 3. Maximum sound pressure levels are set depending on purpose of room, duration of noise influence, conditions of presence of crew on ship board according to ship classification in sanitary norms.

TABLE 3. Maximum sound pressure levels in spaces for common use and accommodation according to SN 2.5.2.047-96 /7/

Name of space	Sound pressure level, dB, in octave band with frequency, Hz									Sound pressure level, LA, dB_A
	31	63	125	250	500	1000	2000	4000	8000	
Spaces for public use										
Saloon, canteen, cabinet in rooms of officers, clubs, library	92	79	70	63	58	55	53	51	49	60
Saloon for passengers, restaurant, buffet, spaces for hobbies and for sports	95	83	74	67	63	60	58	56	54	65
Recreation rooms at open deck	103	92	82	77	73	70	68	66	64	75
Spaces for accommodation (sleeping rooms) and medical purposes										
For ships I and II category	89	76	66	59	53	50	48	46	44	55
For ships III and IV category	92	79	70	63	58	55	53	51	49	60

There are requirements of minimum acoustic insulation between spaces for different purposes in chapter 7 of the standard. It is said that recreation rooms which are for rest of ship crew have to be designed in such way that rest has to be possible even in case loud neighborhood (music, talks, watching movies etc.). So acoustic insulation indexes of isolation materials has to be equal or higher than

-between accommodation spaces - 30 dB;

-between medical spaces and accommodation spaces, between accommodation spaces and saloons, spaces for sports and other noisy rooms (in which sound pressure level can achieve 85 dB) – 45 dB;

-between accommodation spaces and corridors – 30 dB.

Calculations of expected noise levels and average daily noise exposure have to be done on design stage. Accuracy of calculated result is usually checked in lead ship (that ship which is first in series); and results of check are written in Test Protocol. Noise test report has to be done for each ship.

3.5.2.2 Resolution MSC.337(91)

The description in this chapter is based on the resolution MSC.337(91) /8/.This resolution was accepted on the 30th of November 2012 in London by the Maritime Safety Committee (MSC). MSC is included to International Maritime Organization (IMO). The resolution is about ways to conduct measurements of noise levels (chapter 3 of the resolution) and sound pressure levels in different spaces on board (chapter 4 of the resolution). Also it limits noise exposure (mainly for crew – in chapter 5 of the resolution), concerns data about needed sound insulation between spaces in chapter 6 of the resolution and individual protectors in final chapter (chapter 7 of the resolution). It is necessary to describe in details chapter 4 of the resolution.

Maximum allowed sound pressure levels are set in chapter 4 of the resolution. It is especially said that these values are maximum values, not desirable. These limits depend on purpose of space and size of ship in form of gross tonnage (GT). Gross tonnage is a measure which relates to ship's total volume. A-weighted sound pressure levels for different spaces are showed in table 4.

TABLE 4. Maximum sound pressure levels, dB_A, in accommodation spaces and service spaces according to Resolution MSC.337(91) /8/

Space	Ship size	
	1600 - 10000 GT	≥10000 GT
Accommodation spaces		
Cabin and hospital	60	55
Messroom	65	60
Recreation room	65	60
Recreation room at open deck	75	75
Office	65	60
Service spaces		
Galley without food preparing equipment	75	75
Pantry and other service spaces	75	75

3.5.2.3 Comparison of standards

First of all it’s needed to pay attention to the fact that standards repeat each other in many respects. When comparing values of A-weighted sound pressure levels from tables 3 and 4 of the thesis it can be seen that standards state similar values of noise levels for different shipboard spaces. For example, both standards state limiting value of 55 and 60 dB (depending on the category of the vessel in Russian standard and depending on the ship size in European standard). However, Russian standard provides more detailed information on limiting noise levels in the octave band. As regards other chapters of standards both of them provide information about sound insulation of adjacent spaces, order of measurements of noise levels etc.

3.5.3 Other features

Other features that have meaning for seafarers during life on ship are ship vibration, ship motion, lighting, specific materials (synthetic materials), air environment (was described in previous chapters) and water supply. Next paragraphs are to describe briefly all of them and to give an idea about sea life. The description in following five chapters is based on the Pavlyuchenko’s studies about artistic design of ships /5/.

3.5.3.1 Ship vibration

The vibration of hull structures of a vessel is determined by the amplitude, frequency and acceleration fluctuations. Habitability of the vessel deteriorates with the increase of these parameters. Vibration is especially unpleasant when its frequency is close to the natural frequency of vibration of the human body (for example, for the head - 8 Hz, for the body - 4 Hz). The vibration has a negative effect on the cardiovascular system, respiratory apparatus and digestive apparatus. The main sources of overall vibration are wave loading on the vessel's hull (vertical and horizontal bending torsion oscillations); unbalanced movement of parts of the main engine, auxiliary machinery, reduction gear, shafting; periodic perturbing efforts which are transmitted by the propeller on the shell through the water; moments from the irregularity of the flow in the disk screws which are transmitted to the hull of the vessel through the bearings.
/5, p. 69-71./

3.5.3.2 Ship motion

Ship motion causes irritation of the vestibular apparatus of the inner ear, the organ of perception of the head movement and change in the position of the human body in space. This irritation is transmitted to the nucleus of the vagus nerve in the medulla oblongata, thanks to which blood-vascular organs, respiratory apparatus and digestive apparatus are involved in the process through the vegetative nervous system. Ship motions are divided into rolling, pitching and vertical, but in real conditions of navigation crew members feel the motion, in which the acceleration act simultaneously in multiple planes. During ship motions the majority of people (90-95%) has seasickness or nausea. Habitability of the vessel depends on the period and amplitude of the ship motions. The longer the period and the less the amplitude of the ship motions, the less acceleration acting on the person in the conditions of navigation. Ship motions depend on many factors: the nature and strength of the sea wave, the course and speed of the ship, the shape of the hull, the displacement, and the placement of the cargo. For example, the period of ship motions increases with the increase of displacement of the ship; an increase in the mass moment of inertia leads to an increase in the period of the corresponding type of the ship motions. It is necessary to conduct training of the vestibular apparatus of members of crew for the marine diseases' prevention. For this purpose such exercises as rotation on the parallel and horizontal bars, rotations, tilts and rotation of the head and the body are suitable.
/5, p. 68-69./

3.5.3.3 Lighting

The human eye perceives electromagnetic wave with length from 390 up to 760 nm with the intensity of 105 - 106 lx. The more delicate the work and the smaller details that have to be distinguished, the greater should be illumination, or lighting. The visual perception is influenced by the degree of uniformity of illumination of a working surface. Big difference in the light of the adjacent plots causes eye fatigue because there is need of eye to adapt to different light conditions. Ratio between illumination of working area and the full light of the surrounding space should not exceed 10:1. The optimal ratio between adjacent plots is 3:1, 5:1. The reduced illumination has a negative impact on the work of the organs of vision what results in reduced productivity, decrease of its security. When there is a poor light conditions attention decreases, eye pain and headaches appear, the rate of the reaction reduces as well as the mental and motor functions of the body. There are two major sources of light - natural (solar) and artificial. Solar light comes through the portholes, windows and top lights. Rooms deprived of natural light are provided with artificial light. Two systems of artificial lighting are applied on ships: common and combined lighting. In system of combined lighting to common lighting is added local lighting. Local lamps concentrate the light flux on certain surfaces, and common lighting with low power is intended for softening and background lighting. Emergency lights intended to evacuate people from the spaces of the vessel shall provide illumination of the deck and steps of ladders and be not less than definite values, there is to be illumination of wheelhouse, machinery room and boiler plant. /5, p. 74-77./

3.5.3.4 Synthetic materials

Inexhaustible possibilities of use of plastic materials have arisen with expansion of production of plastic materials. They are used in the shipbuilding industry as decorative, vibration damping, thermal and sound insulation synthetic materials. Modern devices from plastic have positive technical, economic and aesthetic sides.

However, they adversely affect the habitability of the ship. Polymeric materials emit into the environment various toxic substances (phenol, formaldehyde, ammonia, dibutyl phthalate etc.). Acting on the central nervous system they cause hyposomnia, lethargy, chafing. Some substances are allergens. A lot of polymeric materials and their products have an unpleasant odor. Polymeric materials can also accumulate on their surface static electricity, which person can feel as unpleasant and even painful. Static electricity has an adverse effect on the central nervous, cardiovascular and endocrine system. Value of static electricity charge depends on the type of material used, the term of its use and the air humidity. With the increase of the relative humidity electrostatic charges are reduced and at a relative humidity of 50-60% are almost not felt. Electricity accumulation of plastic ventilation pipes significantly occurs during the movement of air in them as well as electricity accumulation of synthetic ropes during mooring. So in decoration of the shipboard spaces electricity conductive plastic materials should be used and metal edge of bulkheads with grounded case should be provided. To reduce electricity accumulation of polymeric materials it is recommended to keep the relative humidity of 55-60% in the shipboard spaces. /5, p. 77-78./

3.5.3.5 Water supply

In shipboard conditions fresh water is used for drinking, cooking, washing, dishwashing and washing machines. Share of the city water supply for one vessel is about 150 liters per person per day (50 liters is drinking water and 100 liters is washing water) /5, p.78/. In accordance with the purpose of fresh water on board the vessel will be equipped with two independent water supply source for drinking and washing water. Drinking water is supposed to meet specific requirements in order to avoid gastric diseases. It is stored in independent tanks, separate from the sides and deck, located away from heat and pollution sources as well as from fuel and oil tanks. Whole system of fresh water is made of harmless anticorrosive materials or with protection against corrosion. Fresh drinking water is put into free tank in order to avoid mixing with old untouched water.

In hot climate conditions even chlorinated water is stored not more than two-three weeks, after it acquires unpleasant taste and smell. For water supply number of vessels have desalination plants processing sea water during voyage. The use of desalinated water for drinking purposes is allowed only after aeration and mineralization are completed. In the case of necessary storage of drinking water during more than 10 days water is disinfected before use, i.e. with destruction of pathogenic microbes (chlorination), boiling or with other method. Recently is developed special equipment for conditioning of long-term stored water in which water passes disinfection, filtration and deodorization.

Washing water is allowed to store in tanks built in hull. They are provided with protection from pollution and damage under the influence of heat. In order to avoid freezing in the wintertime the tank of washing water are equipped with heating coils.
/5, p. 78-79./

4 TECHNICAL SYSTEMS PROVIDING GOOD INDOOR CLIMATE IN SHIPS

To create a comfortable microclimate most of modern vessels are equipped with AC systems in residential, public, office and medical spaces. AC system ensures extract of excess moisture and heat loads in summer; and extract of excess moisture load and heat supply to compensate losses of heat in winter. The air that is provided by artificial means is cleaned from dust and gases. Air is supplied into the upper zone of the spaces.

Separate ventilation systems are designed for machinery rooms and shipboard boiler plants, medical rooms, smoking rooms, battery rooms, refrigerator, accommodation and other spaces in which should be definite indoor air conditions or release of harmful gases and specific smells is possible.

The following two chapters contain information about ventilation and AC systems built for accommodation spaces. The description is based on Mundinger’s book about shipboard ventilation and AC systems /9/.

4.1 Ventilation system

As in buildings there are two types of ventilation system – natural and mechanical. Nowadays use of natural ventilation is limited. Spaces with natural ventilation usually are utility rooms of small volume and they have exit to open deck. The process runs because of wind power and density difference (outdoor and indoor air have different density). Ducts directly lead to open deck.

For ventilation of accommodation spaces and cabins the most common supply and exhaust ventilation systems are mechanical: with supply system fresh air is delivered directly to accommodation spaces and to keep balance air is exhausted from WCs etc. (see fig. 2). /9, p. 37-38./. Nowadays there is another way of ventilation - the cabins might have only supply diffusers and for extract there are grilles in the cabin doors.

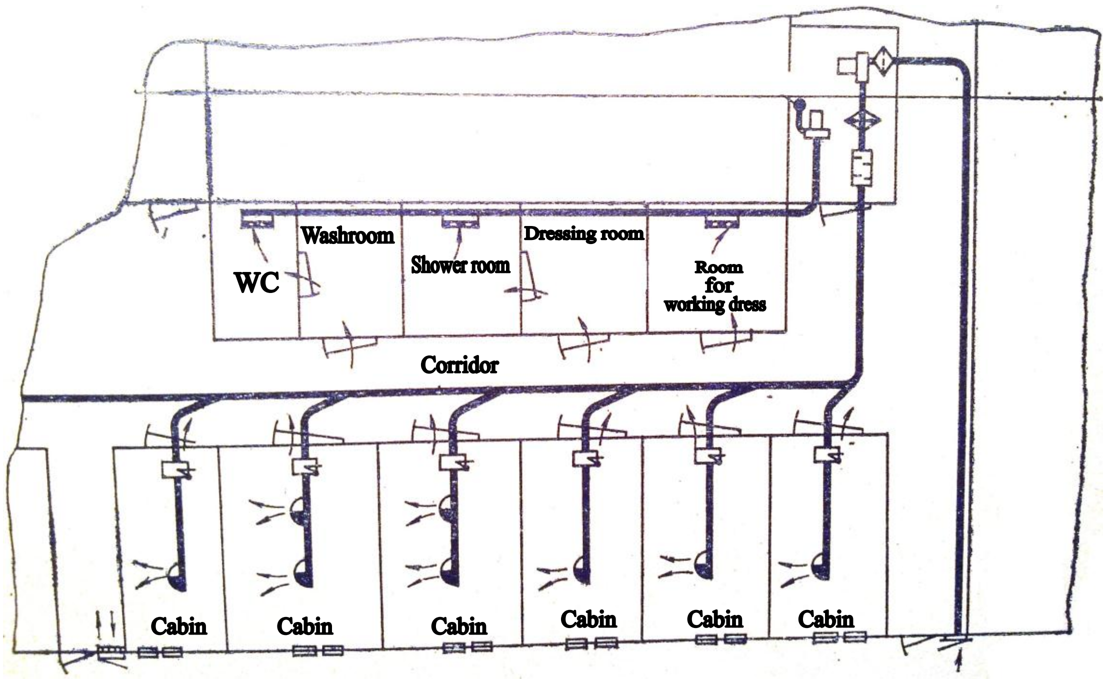


Fig. 2. Ventilation system of accommodation and sanitary rooms /9, p.39/

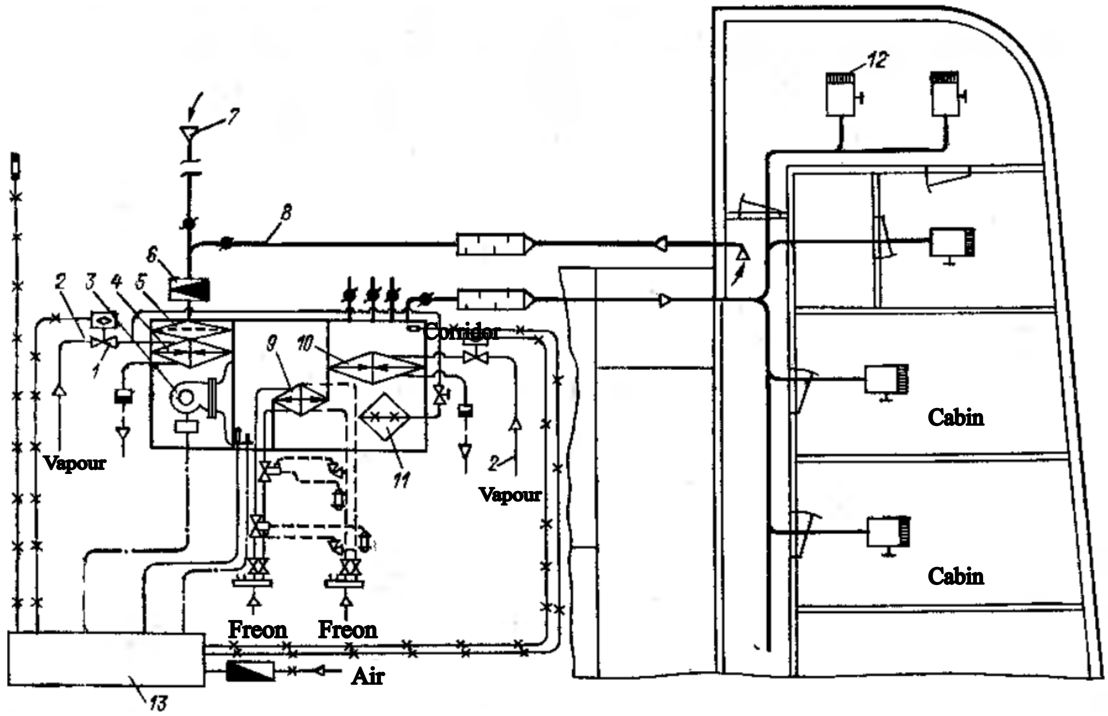
4.2 Air conditioning system

AC-systems are classified according to period of use, cooling agent use (use of freon vaporization directly or with intermediary cooling agent), amount of channels (one or two), air velocity in ducts, air pressure, with or without return air etc.

This paragraph contains information about another important classification feature. It is type of heating agent in the circuit between engine room and HVAC and other systems. It is an old tradition to use water vapour as heating agent. But in last several years new type of heating agent appeared - mineral oils. They have significant advantages and are often used in tankers and similar vessels where there is need in large amount of heat energy for cargo. Their main advantage in comparison with steam is that they transfer significant amount of heat energy over great distances in a short period of time. Vapour at the temperature of +300 °C will have a pressure of 90 bar and higher (to prevent condensation). It leads to significant capital and operational costs at high risk. On the other hand physical properties of mineral oils allow to deliver thermal energy to consumers at low working pressure and without considerable expenses for the equipment and its operation.

On the shipboard several types of AC-systems have wide application. They will be described briefly below.

<u>Type I.</u> One channel system with full air treatment in central AHU (see fig. 3 /9,p.79/). This type usually includes return air. Its amount is restricted in standards.



1 – automatic valve; 2 – vapour delivery duct; 3 – electric fan; 4, 10 – 1st and 2nd air heaters; 5 – filter; 6 – pressure regulator; 7 – fresh air intaking device; 8 – air return duct; 9 – cooler; 11 – vapour humidifier; 12 – terminal unit; 13 – controller and alarm system.

Fig. 3. One channel AC-system: type I /9, p.79/

Treating process starts with air cleaning in filter (5) and air heating in 1st heater (4). After the 1st heater air temperature is from +15°C till +17°C (heating regime). Then in air cooler (9) air is cooled till +11…+15°C (cooling regime). 2nd heater (10) and humidifier (11) prepare on final stage (heating regime). Air temperature after 2nd heater depends on external air temperature. Treated air passes duct system and through terminal unit (12) enters spaces. Additional vapour heater is installed for group of spaces if there is group of rooms with different thermal conditions. By varying the supply air flow rate the regulation of air temperature in each room is possible.

Vapour heater has form of rectangular case where is placed finned coil pipe. Vapour is delivered from turbines of shipboard engines. It is fed to vapour heater, condenses there, and it is discharged back to turbines. Heated air passes outside of finned coil pipe.

Main advantages of such system (type I) are low cost (comparing to other types), easy routing, low weight and insignificant area of duct system. Significant disadvantage is low possibility of individual change of parameters in rooms, especially in wintertime and transition period (period between summertime and wintertime).

Type II. One channel AC-system with air treatment in AHU and additional heaters built in terminal units (see fig. 4 /9, p.81/). In this system return air usually is used. Central AHU doesn't include 2nd heater so automation system has changes comparing to automation system of central AHU in system type I.

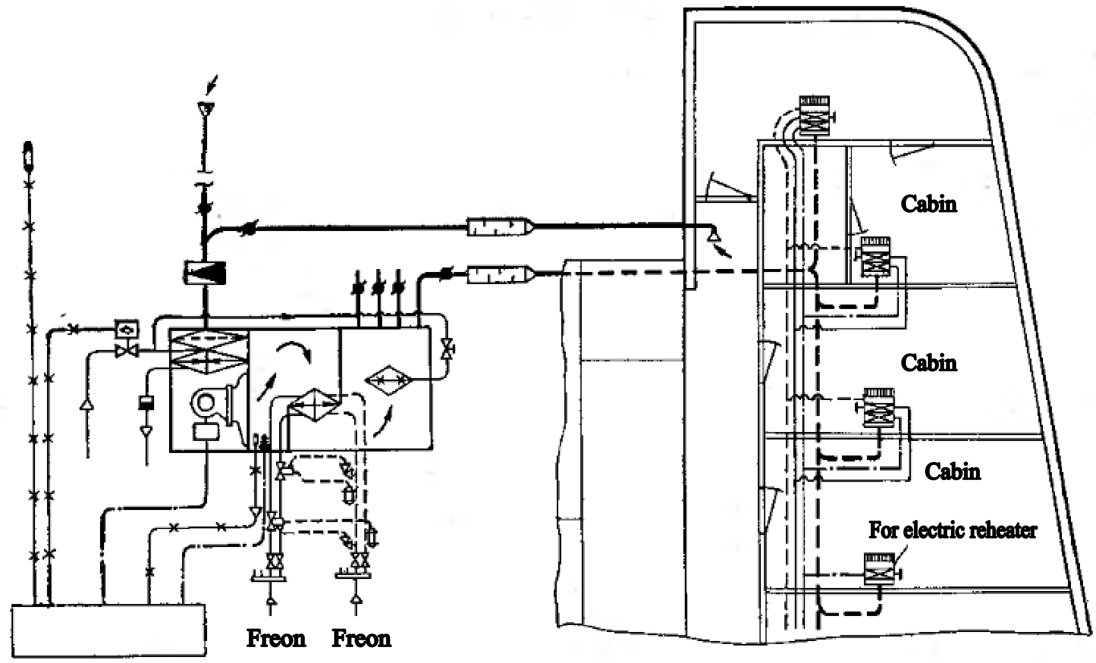


Fig. 4. One channel AC-system: type II and III /9, p.81/

Treated air is heated till +20…+30°C in 1st heater (heating regime). Next heating is in heaters built in terminal units. In cooling regime air is cooled till +11…+15°C and with this temperature is delivered to room. Individual change of air parameters in cooling regime is possible by changing air flow and in heating regime by changing settings of second heaters.

Advantage of this type is individual change of air parameters by changing settings of second heaters. Disadvantages are more complicated routing of water pipelines and possible leakages in second heaters, more complicated routing of electric net (for electric heaters), increase of heat power of the system in heating regime, permanent control of electric system (for electric heaters), higher cost of system.

Type III. One channel AC-system without use of return air with air treatment in AHU and water heaters and coolers built in terminal units (see figure above**)**. Outdoor air is treated in central AHU and after that it is supplied to heaters and coolers in spaces. Treated in AHU air is mixed with indoor air treated in heaters and coolers and then mix is delivered through terminal unit to room.

Outdoor air is heated in central AHU till +15…+25°C in heating regime and till +12…+17°C in cooling regime. Indoor air which is taken from space is heated till +30…+45°C in heating regime and till +14…+18°C in cooling regime.

Advantages of this type is 1,5-2 times lower air capacity of AHU comparing to other types, cooling power need is lower by 20-25%, individual parameters are possible in each room, lower weight and area of duct system. Indoor air parameters are changed by changing settings of heater or cooler in space. Main disadvantages are increase of noise level in rooms due to taking indoor air in heater or cooler (by fan or ejector); in room have to be drainage pipe for condensate discharge from cooler; possible leakages and complication of their detection (water pipes are usually hidden); the highest cost from all system types.

Type IV. Two channel system with full air treatment in central AHU (see fig. 5 /9,p.84/). This type differs from type I with additional chamber for air extracting after 1st heater. So from AHU two channels with air of different parameters run. Channel after 1st heater is called 1st stage channel and second one – 2nd stage channel.

Treatment of air is conducted in such way (heating regime):
- by 1st stage channel air is delivered to terminal units with temperature $(15+\Delta t_{vent})$°C where +15° is temperature after 1st heater and Δt_{vent} is heating in fan (depending on fan; usually 3…5°C);

- by 2[nd] stage channel air is delivered to terminal units with temperature $t_{IIstage}=f(t_{outd.air}+\Delta t_{pipes})$ where $t_{outd.air}$ is temperature of outdoor air and Δt_{pipes} is air cooling while passing pipes.

In cooling regime:

- by 1[st] stage channel air is delivered to terminal units with temperature $(t_{mix}+\Delta t_{vent})$°C where t_{mix} is temperature of mix of outdoor air and return air;
- by 2[nd] stage channel air after cooler is delivered to terminal units with temperature $t_{IIstage}=[(11\ldots15)+\Delta t_{pipes}]$°C. Here Δt_{pipes} is air heating while passing pipes.

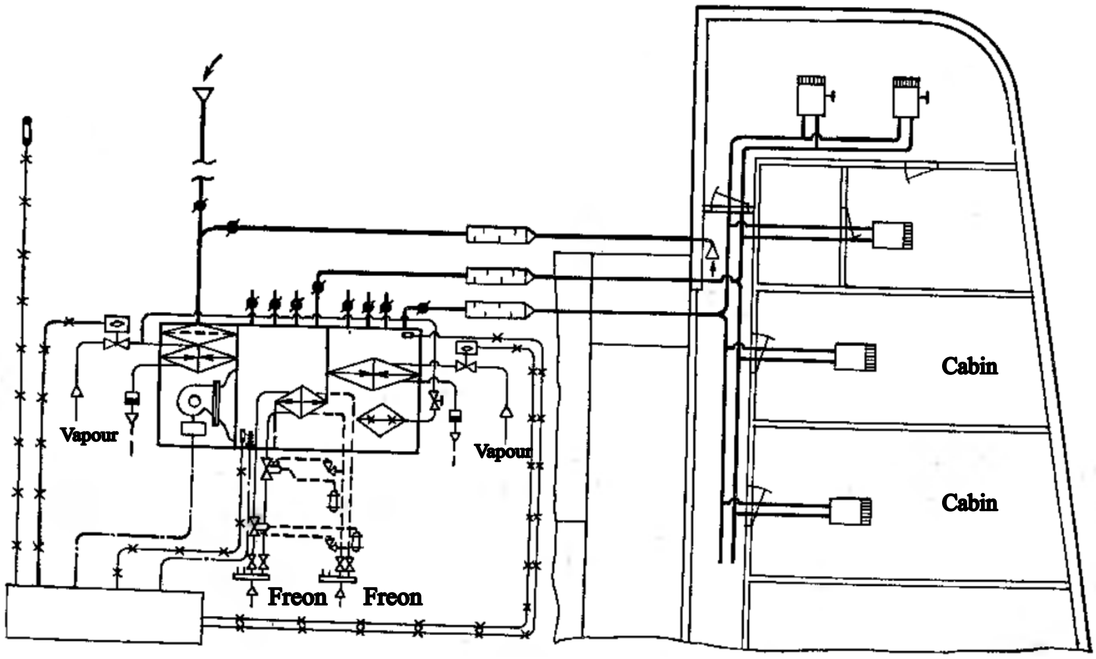


Fig. 5. Two channel AC-system: type IV /9, p.84/

Advantages of this type are wide range of possible air parameters in each space (by mixing air with different parameters in devices placed in cabins it is possible to set individual air parameters in a wide range in each space), good air distribution, and low noise level in spaces. Due to use of only air to achieve individual regulation system is quite reliable and easy. Main disadvantages are obvious – large weight and volume of duct system, additional duct (1[st] stage channel), higher cost as compared to type I. /9, p. 78-86./

5 NOISE CAUSED BY SHIPBOARD HVAC-SYSTEMS

5.1 Sources of noise in ships

There are two types of noise – air noise and structural noise. Acoustic oscillations transmitted through air create air noise, and fluctuations that are transmitted in enough long solids create structural noise. Rigid connection of noise sources with a hull of ship and the high sound conductivity of metal structures contributes to spread of the structural noise in spaces in addition to air noise.

There are two main sources of noise in ships - shipboard power plant and ventilation and AC systems. Besides these ones support mechanisms, shaft lines, electric radio-navigation equipment, other shipboard systems, wave and ice forces acting on ship's hull, sound signals, loud talks, marine broadcast etc. can be sources of noise. Increase of available energy power of vessels is accompanied by increase of intensity of working processes in the energy installation, systems transporting air, water and steam. As a result levels of air noise in engine room in a number of cases reach 120 dB, and in accommodation and service spaces 80 dB /5, p.72/. More details about main noise sources are below.

One of the main sources of noise is shipboard power plant. The noise level of power plants depends on the type, developed capacity, rotation speed of main and auxiliary mechanisms. The highest noise levels are produced by high speed engines of internal combustion, engines with free-piston gas generator, and the gear reductions intended to reduce rotation speed of main engine - steam or gas turbines. The noise created by the main or auxiliary engines and mechanisms can have so called aerodynamic or mechanical origin (for details see chapter 3.5.1 of the thesis).

Also ventilation and AC systems can be a source of noise. The noise level of these systems depends on the characteristics of the fans (centrifugal or axial), type of dampers, air terminal units and engineering and geometric characteristics of duct elements.

Air movement in ducts can be also regarded as noise source. This process is accompanied by the vortex formation in the boundary layer as well as fluctuations of velocity and pressure in a turbulent flow. Limited rigidity of ventilation channels in conditions of turbulent flow of air flow leads to acoustic excitation of the walls of the channels, and they become a source of additional noise in the spaces. The noise level depends on the airflow, on the shape of the duct and the thickness of its walls, on vibrodamping coatings. Experimental research shows that air velocity (if it is not more than 25 m/s) affect noise level around ducts to a lesser extent /9, p.366/.

5.2 Solution methods to prevent noise problems

The complex of measures of needed protection from noise is developed by designers of the vessel. It is mostly determined by the type of vessel and its displacement. Need of protective measures depends on designation of the spaces and mechanical "saturation" (large amount of mechanisms, devices, and systems that can be sources of aerodynamic or structural noise). Usually protective measures are developed for machinery room, control station of power plants, accommodation and public spaces, and spaces for navigation system.

In the development of methods of noise level reduction first of all noise sources, their interaction and ways of sound energy distribution should be identified. After that problems of noise reduction in the sources, energy transfer to the hull and transformation of other forms of energy into acoustic energy are solved. For example, reduction of air noise in the source can be achieved by improving the technology of manufacturing and assembling of ship mechanisms.

5.2.1 Acoustic calculation

Example of acoustic calculation was taken from Mundinger's book "Shipboard ventilation and air conditioning systems" /9, p.373-388/. In this work only results of calculation were taken, for more details see chapter 56 of the book.

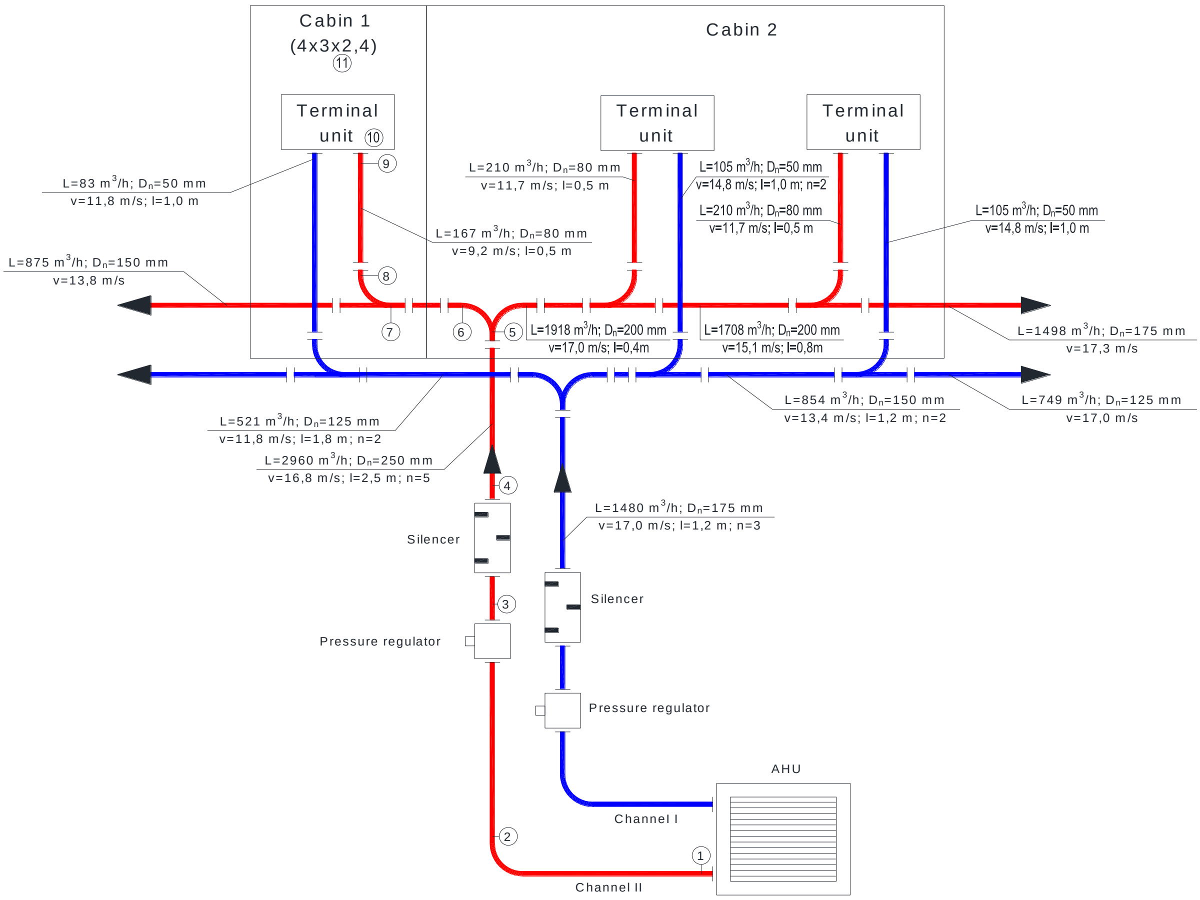
Following information needs when performing acoustic calculation:

- noise levels created by noise sources of the system (usually they are published by manufacturer in list of characteristics of equipment);

- noise levels created by air passing duct lines (experimental information or reference data);
- noise reduction on way from noise sources to point where expected noise levels are defined.

Design scheme is shown in fig. 6. There is two channel AC system, and acoustic calculations are made for channel II as most loaded for 100% air volume flow.

According to fig.6 there are 3 main noise sources: AHU (mainly because of fan), pressure regulator, and air terminal unit. Noise levels created by them are given in table 5. In the fig. 6 those points are shown where expected noise levels are calculated. They are marked with numbers in circles. Values for frequency components at those points are given in table 6.



L - air volume flow, m3/h; D_n - duct diameter, mm; v - air velocity, m/s; l - length of section, m; P - number of noise source

Fig. 6. Scheme for noise level calculation /9, p. 386/

TABLE 5. Noise levels created by noise sources

Noise source	Noise levels in octave band with frequency components, Hz							
	63	125	250	500	1000	2000	4000	8000
AHU	80	70	59	53	48	66	46	46
Pressure regulator (taking into account velocity 16,8 m/s)	116	115,5	112,5	109,5	105	102	101	101
Air terminal unit	54	56	53	45	35	-	-	-

TABLE 6. Expected noise levels at points

Point	Notes	Noise levels in octave band with frequency components, Hz							
		63	125	250	500	1000	2000	4000	8000
1	Noise levels created by AHU, dB	80,0	70,0	59,0	53,0	48,0	66,0	46,0	46,0
2	Noise reduction in 2 benches, dB	79,9	69,8	58,7	52,6	47,5	65,4	45,3	45,2
3	Noise levels created by pressure regulator, dB	116,0	115,5	112,5	109,5	105,0	102,0	101,0	101,0
4	Noise reduction in silencer, dB	115,0	111,5	96,5	87,5	75,0	77,0	83,0	89,0
5	Noise reduction in duct of 2,5m length, dB	113,8	110,3	95,5	86,8	74,5	76,5	82,5	88,5
6	Noise reduction in T-branch	113,7	110,1	95,2	86,4	74,0	75,9	81,8	87,7
7	Noise reduction in duct of 1,5m length, dB	112,9	109,3	94,6	85,9	73,7	75,6	81,5	87,4
8	Noise reduction in T-branch, dB	112,8	109,1	94,3	85,5	73,2	75	80,8	86,6
9	Noise reduction in duct of 0,5m length, dB	112,6	108,9	94,1	85,4	73,1	74,9	80,7	86,5
10	Noise reduction in terminal unit, dB	111,6	106,9	88,1	73,4	53,1	51,9	61,7	74,5
10'	Noise reduction from terminal unit to point in space (1,5 m from terminal unit)	51,6	52,9	40,1	30,9	14,1	16,4	27,7	39,5
10"	Noise levels from air terminal unit in point of space (1,5 m from terminal unit)	54	56	53	45	35	-	-	-
11	**Noise level**	**63,5**	**62,0**	**61,5**	**48,0**	**37,0**	**25,5**	**26,0**	**35,5**

Noise levels created by AHU and pressure regulator differ by more than 10 dB in all frequency components. So we can expect noise levels created by AHU till pressure regulator (points 1, 2 in the fig. 6) and assume that AHU has no significant influence on noise levels after pressure regulator (points 2-10 in the fig. 6). So at some distance from pressure regulator they work as one noise source.

Noise reduction happens in silencer, straight duct lines, benches and T-branches (points 2, 4-9 in the fig. 6). Noise reduction in terminal unit (point 10 in the fig. 6) happens because of special construction of terminal device which allows air to pass more smoothly (without creating turbulence). Reduction of noise created by pressure regulator (position 10’ in table 6) happens because of sound energy reflection on the way from terminal unit to point in space at 1m distance from terminal unit. Considering point 11 that is at 1,5m distance from terminal unit (see fig. 6) there are two noise sources - terminal unit itself and pressure regulator with taking account noise reduction. Calculating expected noise levels from two sources common noise levels are expectedly higher than noise levels from one of them but it’s not the algebraic sum. In addition distance from noise source and so called acoustic constant of the space should be taken into account when noise is spread in space. Acoustic constant depends on mean coefficient of sound absorption of enclosures and their area.

5.2.2 Construction solution methods

When designing and creating mechanisms such as pumps, fans, engines etc. great attention is paid to improvement of their noise performance with applying vibration damping devices and coatings, internal vibration damping insulation, silencers, screens and acoustic insulation casings. For noise control in ship insulating and sound-absorbing structures are used. First (sound insulating structures) are designed to reduce the penetration of air noise, second (sound-absorbing structures) – to reduce structural noise.

Speaking in details about coating and insulation to reduce the noise spread outside the machinery space ceilings, bulkheads and upholstery are insulated with sound-absorption porous or fibrous materials (mineral fiber, mats made from glass fiber etc.). Reduction of noise in residential and office spaces is reached as a result of applying the deck constructions of a «floating» type and air diffusers type «perforated ceilings» with simultaneous installation of diesel engines and all of pipelines on the elastic shock-absorbers. Bulkheads in residential, office and public spaces have acoustic insulation (for example, the mineral fiber). The deck of the spaces is covered with mastic which is glued with linoleum or soft carpet. To ensure good acoustic insulation of residential spaces it is important not to locate them close to the main engines.

Utility or other rooms in which individuals are occasionally can be between sleeping rooms and machinery spaces. In case of a ship with ice navigation all accommodation spaces should located in superstructures, because noise level is much lower in the spaces in superstructure than in hull compartments during passage in the ice. (A superstructure is an upward extension of an existing structure above the main deck.)

As regards ventilation and AC systems rectangular ducts with less rigidity than round ducts of same thickness generate higher levels of overall noise level. From this point of view the reduction of forced vibration of the duct walls by increasing their thickness can contribute to a reduction in overall noise level. In design process of ventilation and AC systems during performing acoustic calculations and arrangement of the protection from noise the following steps should be considered /9, p. 373-374/:

- in case of increasing air flow rate with maintaining air velocity at constant level (so duct size is increased) overall noise level generally increases;
- overall noise level is higher in rectangular ducts than in round ducts if hydraulic diameters are equal. The difference of noise levels around rectangular and round ducts may reach for example 20-25 dB. This fact should be taken into account if the noise level in spaces is critical. In some cases preference is given to round ducts even though it is advisable to to use rectangular ducts;
- increase of wall thickness of ducts of different cross-section contributes to a reduction of noise around them. In some cases increasing wall thickness by 1-3 mm can lead to reduction of noise level around duct by 2-5 dB;
- in case of rectangular duct if there is vibrodamping coating noise reduction (especially at low frequencies) can be quite significant.

There are several effective measures to reduce noise produced by the ventilation and AC systems of residential, public, medical and utility rooms. One of them is installation of electric fan and air conditioners in independent and soundproofing partitions. Next measure is to install fans, pumps, compressors on dampers or elastic strips. Another measure is to limit amount of transit ducts in spaces with needed low noise level: accommodation cabins, public spaces etc. Significantly effective measure is to install silencers to discharge and suction ducts of fans and air conditioners. In the presence of dampers which usually create a significant increase in noise level silencers are recommended to be located next to damper closer to protected spaces.

6 DISCUSSION

Results of acoustic calculations of example in chapter 5.2.1 of the thesis will be compared with values from standards in chapters 3.5.2.1 and 3.5.2.2 of the thesis.

At first we will compare values for frequency components which are given in Russian standard SN 2.5.2.047-96 (see chapter 3.5.2.1 of the thesis). For clarity it is shown in table 7.

TABLE 7. Comparison of results and standard SN 2.5.2.047-96

	63 Hz	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	8000 Hz
Expected noise level in cabin, L, dB	63,5	62,0	61,5	48,0	37,0	25,5	26,0	35,5
Noise levels according to SN 2.5.2.047-96 for ships I and II category, dB	76	66	59	53	48	46	44	55

As we can see from table 7 noise level at frequency 250 Hz exceeds required value by 2,5 dB. So there is risqué that in cabin will be noise problem, and measures to prevent noise should be done. In addition to it if values of noise levels at neighboring frequencies in octave band differ by more than 10 dB (for 250 Hz and 500 Hz Δ = 13,5 dB, for 500 Hz and 1000 Hz Δ = 11 dB etc.) human ear will especially perceive noise at these frequencies (as it perceives squeak).

For comparing with A-weighted sound pressure level given in standards we need to calculate the A-weighted sound pressure level of the exampe. According to table 2.4 /10, p.45/ we add certain coefficient δ to calculated values L (formula 1): for 63 Hz δ = -26, for 125 Hz δ = -16, for 250 Hz δ = -9, for 500 Hz δ = -3, for 1000 Hz δ = 0, for 2000 Hz δ = +1, for 4000 Hz δ = +1, for 8000 Hz δ = -1.

$$L_i = L - \delta \qquad (1)$$

where L is calculated value of octave band with frequencies 63, …, 8000 Hz.

Then A-weighted sound pressure level is calculated according to formula 2.

$$L_A = 10 \cdot \lg \sum 10^{0,1 L_i} \tag{2}$$

Result L_A is equal to 54,4 dB_A. As we can see in tables 3 and 4 of the thesis A-weighted sound pressure level given by standards is equal to 55 dB.

As it is written above A-weighted sound pressure level for the example meets required values of standards. But one value in octave band at frequency 250 Hz exceed required value of Russian standard SN 2.5.2.047-96 (table 3 of the thesis) by 2,5 dB. It means that construction solution methods should be used. Possible solution methods are: another terminal unit with lower noise levels, another silencer with better sound absorption or sound-proof coating for ducts.

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APPENDIX 1.

Classification table of civil ships /11, p. 26-27/

Civil ships																								
Purpose				Navigation area				Power source		Main engine	Position in water					Type of propulsion					Hull material	Vessel construction	Amount of propeller shaft	Other
Transport ship	Fishing vessel	Auxiliary ship	Vessel for mechanical services	Sea vessel	Estuary trade vessel	River vessel and lake boat	Vessel with mixed navigation area	Self-propelled	Non-self-propelled	1.Internal combustion engine; 2.Piston steam engine; 3.Steam turbine; 4.Gas turbine; 5.Electric motor; 6.Nuclear plant; 7.Oars	Surface vessel	Underwater vessel (submarine)	Airboat	Hydrofoil boat	Hovercraft	Screw propeller	Paddle wheel	Special propulsion	Oars	Sails	1. Steel; 2. Light alloys; 3. Plastic; 4.Wood; 5.Ferro-concrete; 6.Composite materials	1.Hull amount; 2.Amount and position of superstructures; 3.Deck amount; 4.Position of freeboard deck; 5.Position of engine room	1; 2; 3; 4	Ice conditions etc.

APPENDIX 2(1).

Classification table depending on ship purpose /10, p. 29-55/

Transport ship	Cargo ship	Dry cargo ship	General cargo ship	
			Special dry cargo ship	Refrigerator
				Container ship
				Lighter aboard ship
				Vessel with horizontal way of cargo handling
				Bulker
				Timber ship (incl. chip carrier)
		Tank vessel	Oil tanker	
			Refrigerated gas tanker	
		Combined		
	Passenger	Scheduled service		
		Tourist		
		Mass transit		
		Local traffic		
	Cargo-and-passenger			
	Special	Ferry		
		Barge-towing vessel		
		Push-convoy		
		Pusher, tugs-pusher, non-self-propelled barge or push-convoy		
Fishing vessel	Catching vessel			
	Catching-processing vessel			
	Fish processing vessel			
	Tending vessel			
Auxiliary ship	Tending vessel	Ice-breaker		
		Tugboat		
		Rescue boat		
		Fire-fighting vessel		
		Ship lifting vessel etc.		
	Service vessel	Research vessel		
		Hospital ship		
		Floatel		
		Exhibition-vessel		
		Training ship etc.		

APPENDIX 2(2).

Vessel for mechanical services	Vessel for mechanical service of ships, port facilities, waterways etc.	Dredger
		Dumb lighter
		Oil spill boat
		Floating crane
		Crane ship
		Floating dock
		Repair vessel etc.
	Vessel for construction, floating, reclamation works	Vessel for lying cable
		Vessel for oil&gas production
		Vessel for sand and gravel extraction
		Drill ship
		Pipelaying vessel
		Floating power plant etc.

APPENDIX 3.

Design values for sea vessels with limited navigation area

<table>
<tr><th rowspan="3">Navigation area</th><th rowspan="3">Local navigation area</th><th>$t_{o,s}$, ºC</th><th>$\varphi_{o,s}$, %</th><th>$t_{w,s}$, ºC</th><th>$t_{o,w}$, ºC</th><th>$\varphi_{o,w}$, %</th><th>$t_{w,w}$, ºC</th></tr>
<tr><th colspan="3">Summer</th><th colspan="3">Winter</th></tr>
<tr><th colspan="2">Air</th><th>Sea water</th><th colspan="2">Air</th><th>Sea water</th></tr>
<tr><td rowspan="4">1</td><td>1. Seas and Pacific, Indian, and Atlantic Oceans from 30°N to 30°S</td><td>35</td><td>80</td><td>34</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>2. Carribean Sea and Gulf of Mexico</td><td>38</td><td>85</td><td>34</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>3. Persian Gulf and Gulf of Oman</td><td>45</td><td>40</td><td>33</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>4. Red Sea and Gulf of Aden, area of the Pacific Ocean from 10°N to 40°N and from 35°W to 120°W</td><td>40</td><td>50</td><td>32</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td rowspan="5">2</td><td>5. Mediterranean Sea</td><td>30</td><td>65</td><td>26</td><td>-3</td><td>70</td><td>10</td></tr>
<tr><td>6. Caspian Sea</td><td></td><td>60</td><td>27</td><td>-20</td><td rowspan="14">85</td><td rowspan="2">1</td></tr>
<tr><td>7. Yellow Sea</td><td rowspan="2">29</td><td>80</td><td>26</td><td>-13</td></tr>
<tr><td>8. Black Sea</td><td rowspan="2">60</td><td>27</td><td>-15</td><td>5</td></tr>
<tr><td>9. Azov Sea</td><td>27</td><td>25</td><td>-21</td><td>1</td></tr>
<tr><td rowspan="6">3</td><td>10. Northern part of the Sea of Japan</td><td>25</td><td>75</td><td>20</td><td rowspan="3">-23</td><td rowspan="7">0</td></tr>
<tr><td>11. Baltic Sea (whole)</td><td>22</td><td>60</td><td>16</td></tr>
<tr><td>11a. Northern part of the Baltic Sea</td><td>20</td><td>70</td><td>15</td></tr>
<tr><td>11b. Southern part of the Baltic Sea</td><td>22</td><td>60</td><td rowspan="2">16</td><td>-15</td></tr>
<tr><td>12. North Sea, northern part of Atlantic Ocean (more northern than 50°N)</td><td>21</td><td>65</td><td>-11</td></tr>
<tr><td>13. Southern part of the Bering Sea, southern part of the Sea of Okhotsk</td><td>20</td><td>80</td><td>11</td><td>-20</td></tr>
<tr><td rowspan="6">4</td><td>14. White Sea</td><td>18</td><td>60</td><td>12</td><td>-32</td></tr>
<tr><td>15. Norwegian Sea, southern part of the Greenland Sea</td><td rowspan="3">15</td><td rowspan="2">70</td><td>11</td><td>-14</td></tr>
<tr><td>16. Barents Sea</td><td>7</td><td>-30</td></tr>
<tr><td>17. Northern part of the Sea of Okhotsk</td><td>75</td><td>11</td><td rowspan="3">-40</td><td rowspan="3">-2</td></tr>
<tr><td>18. Northern Sea Route: Kara Sea, Laptev Sea, East Siberian Sea, Chukchi Sea, northern part of the Bering Sea</td><td>12</td><td>80</td><td>8</td></tr>
<tr><td>19. Northern part of the Greenland Sea</td><td>7</td><td>90</td><td>5</td></tr>
</table>

APPENDIX 4 (1).

Design values for river vessels and lake boats with limited navigation area

Navigation area	Local navigation area	$t_{o,s}$, °C	$\varphi_{o,s}$, %	$t_{w,s}$, °C	$t_{o,w}$, °C	$\varphi_{o,w}$, %	$t_{w,w}$, °C	$t_{o,w}$, °C	$\varphi_{o,w}$, %	$t_{w,w}$, °C
		Navigation period						No navigation		
		Summer			Winter			Winter		
		Air		Sea water	Air		Sea water	Air		Sea water
5	1. Drainage basins of rivers Jana, Indigirka, Kolyma	19	70	15	-6	75	1	-50	85	0
	2. Rivers Northern Dvina, Pechora, Vychegda, Usa, Sukhona, Sheksna, Vologda, Svir, Volkhov, Neva, Pregolya; Lakes Ladoga, Onega, Ilmen, Beloye; Canals White Sea-Baltic Sea, Northern Dvina etc.	21	70	19	-8	85	1	-35		0
6	3. Lake Balaton	28	65	24	4		4	1	80	1
	4. Drainage basins of rivers Yenisei, Lena and lake Baikal (rivers Yenisei, Selenga, Angara, Zima, Lena, Vitim, Aldan, Vilyuy); Lake Baikal	24	70	19	-12	75	1	-55	85	0
	5. Drainage basins of rivers Ob and Irtysh (rivers Ob, Tom, Irtysh, Tobol, Tura)	25	70	21	-10	80	-1	-42	85	0
	6. Drainage basin of the Amur River				-5	75		-37		
	7. Rivers Volga, Oka, Moskva, Kama, Don, Kuban, Dnieper; Canals Moscow, Volga-Don; Reservoirs Rybinsk, Tsimlyansk, Volgograg	28	50	24	-7	85	2	-30	85	0

APPENDIX 4 (2).

Navigation area	Local navigation area	$t_{o,s}$, °C	$\varphi_{o,s}$, %	$t_{w,s}$, °C	$t_{o,w}$, °C	$\varphi_{o,w}$, %	$t_{w,w}$, °C	$t_{o,w}$, °C	$\varphi_{o,w}$, %	$t_{w,w}$, °C
		Navigation period						No navigation		
		Summer			Winter			Winter		
		Air		Sea water	Air		Sea water	Air		Sea water
6	8. Rivers Elbe, the Havel (GDR)	28	50	18	-5	85	0	-15	90	0
	9. Rivers Elbe, Vltava, Danube (Czechoslovak Socialist Republic, People's Republic of Hungary)		65	16		80	1		85	
	10. Oder	30	45	20	-10	90		-17	90	
	11. Issyk Kul		65		-3	70	2	-8	70	1
	12. Danube (Soviet Union, Communist Romania, PRB)		60	27	5	80	4	-20	85	0
	13. Way Visla-Oder (rivers Visla, Warta, Noteć, Bydgoszcz Canal)	32	45	24	-8	90	1	-18	90	0
7	14. Drainage basins of rivers Amu Darya, Syr Darya	36	45	24	-2	75	2	-15	80	

APPENDIX 5 (1).

Design values for different types of ship rooms

Type of room	Design value	Design value for navigation area								
		1	2	3	4	OM	OM1 OM2	5	6	7
1. Dwelling rooms (cabins)	$t_{i,air\ cond.,w}$, °C	-	22							
	$t_{i,air\ cond.,s}$, °C	26	25	20		26	25	20	21	25
	$t_{i,vent.,w}$, °C	-	20 - 21							
	$V_{i,vent.,w}$, m/s	-	Up to 0,25							
	$t_{i,vent.,s}$, °C	-		5°C more than $t_{o,s}$						-
	$V_{i,vent.,s}$, m/s	Up to 0,5								
2. Common spaces for passengers and crew: restaurant, canteen, passengers' lounge, bar, cafe, smoking room, saloon, cinema hall, post room, library, gym hall etc. (sport cabins)	$t_{i,air\ cond.,w}$, °C	-	22							
	$t_{i,air\ cond.,s}$, °C	26	25	20		26	25	20	21	25
	$t_{i,vent.,w}$, °C	-	20 - 21							
	$V_{i,vent.,w}$, m/s	-	Up to 0,25							
	$t_{i,vent.,s}$, °C	-		5°C more than $t_{o,s}$						-
	$V_{i,vent.,s}$, m/s	Up to 0,5								
indoor swimming pool	$t_{i,vent.,w}$, °C	-	25							
	$V_{i,vent.,w}$, m/s	-								
	$t_{i,vent.,s}$, °C	-								
	$V_{i,vent.,s}$, m/s	Up to 0,5								
3. Room giving access into another: indoor promenade deck, lobby, foyer, corridor, tambour	$t_{i,vent.,w}$, °C	-	18				16			
	$V_{i,vent.,w}$, m/s	-								
	$t_{i,vent.,s}$, °C	-								
	$V_{i,vent.,s}$, m/s	Up to 0,5					-			
4. Laundry room, ironing room etc.	$t_{i,vent.,w}$, °C	-	16							
	$V_{i,vent.,w}$, m/s	-	Up to 0,5							
	$t_{i,vent.,s}$, °C	-		8°C more than $t_{o,s}$						-
	$V_{i,vent.,s}$, m/s	Up to 0,5								
drying room	$t_{i,vent.,w}$, °C	45								
	$V_{i,vent.,w}$, m/s	-								
	$t_{i,vent.,s}$, °C	-								
	$V_{i,vent.,s}$, m/s	-								

APPENDIX 5 (2).

Type of room	Design value	Design value for navigation area 1	2	3	4	OM	OM1 OM2	5	6	7
5. Rooms of household services: custom atelier (clothing and shoe repair), hair salon, photo studio etc.	$t_{i,vent.,w}$, °C	-	20 - 21							
	$V_{i,vent.,w}$, m/s	-	Up to 0,25							
	$t_{i,vent.,s}$, °C	-		5°C more than $t_{o,s}$						
	$V_{i,vent.,s}$, m/s	Up to 0,5								
6. Hygiene rooms: shower, bathroom, bath, changing room	$t_{i,vent.,w}$, °C	-	25							
	$V_{i,vent.,w}$, m/s	-								
	$t_{i,vent.,s}$, °C	-								
	$V_{i,vent.,s}$, m/s	-								
wash room; individual bathroom unit including the toilet (with bath or shower)	$t_{i,vent.,w}$, °C	-	20							
	$V_{i,vent.,w}$, m/s	-								
	$t_{i,vent.,s}$, °C	-								
	$V_{i,vent.,s}$, m/s	-								
WC	$t_{i,vent.,w}$, °C	-	16							
	$V_{i,vent.,w}$, m/s	-								
	$t_{i,vent.,s}$, °C	-								
7. Medical, penitentiary and day-care establishments: sickbay, isolation ward, outpatients' department, doctor's consulting room (without undressing), pharmacy	$t_{i,air\ cond.,w}$, °C	-	22							
	$t_{i,air\ cond.,s}$, °C	26	25	20		26	25	20	21	25
	$t_{i,vent.,w}$, °C	-	21							
	$V_{i,vent.,w}$, m/s	-	Up to 0,25							
	$t_{i,vent.,s}$, °C	-		5°C more than $t_{o,s}$						-
	$V_{i,vent.,s}$, m/s	Up to 0,5								
8. Food preparation spaces: caboose, dishwashing room, rooms for samovars and immersion heaters (with heat emission in work place)	$t_{i,vent.,w}$, °C	-	16							
	$V_{i,vent.,w}$, m/s	-	Up to 0,5							
	$t_{i,vent.,s}$, °C	-		8°C more than $t_{o,s}$						-
	$V_{i,vent.,s}$, m/s	Up to 0,7								
9. Preparation room: room for butchery, fish and vegetable preparation, bread slicing (without heat emission in work place)	$t_{i,air\ cond.,w}$, °C	-	22							
	$t_{i,air\ cond.,s}$, °C	26	25	20		26	25	20	21	25
	$t_{i,vent.,w}$, °C	-	16							
	$V_{i,vent.,w}$, m/s	-	Up to 0,25							
	$t_{i,vent.,s}$, °C	-		5°C more than $t_{o,s}$						-
	$V_{i,vent.,s}$, m/s	Up to 0,5								

APPENDIX 5 (3).

Type of room	Design value	Design value for navigation area								
		1	2	3	4	OM	OM1 OM2	5	6	7
10. Administration and administration utility room, laboratory, office etc.	$t_{i,air\ cond.,w}$, °C	-	22							
	$t_{i,air\ cond.,s}$, °C	26	25	20		26	25	20	21	25
	$t_{i,vent.,w}$, °C	-	20							
	$V_{i,vent.,w}$, m/s	-	Up to 0,25							
	$t_{i,vent.,s}$, °C	-		5°C more than $t_{o,s}$						-
	$V_{i,vent.,s}$, m/s	Up to 0,5								
11. Room for staff only: wheelhouse, captain's room	$t_{i,air\ cond.,w}$, °C	-	16 - 20							
	$t_{i,air\ cond.,s}$, °C	26	25	20		26	25	20	21	25
	$t_{i,vent.,w}$, °C	-	16 - 20							
	$V_{i,vent.,w}$, m/s	-	Up to 0,25							
	$t_{i,vent.,s}$, °C	-		8°C more than $t_{o,s}$			5°C more than $t_{o,s}$			-
	$V_{i,vent.,s}$, m/s	Up to 0,3					Up to 0,5			
radio cabin, room with television equipment, separate chart house	$t_{i,air\ cond.,w}$, °C	-	20							
	$t_{i,air\ cond.,s}$, °C	26	25	20		26	25	20	21	25
	$t_{i,vent.,w}$, °C	-	20							
	$V_{i,vent.,w}$, m/s	-	Up to 0,25							
	$t_{i,vent.,s}$, °C	-		8°C more than $t_{o,s}$						-
	$V_{i,vent.,s}$, m/s	Up to 0,3					Up to 0,5			