Considerations on the Calculation of Ventilation Systems for Special Ships

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Abstract: *In the normal operation of ships, as a result of heat discharges from different machinery and people, the increase in humidity as well as due to the various releases of gases from the on-board systems or from the goods being carried, the air in the rooms is degraded, with the need for replacement and processing. Artificial microclimate systems have the function of thermally and humidly processing the air so that in the interior of the naval compartments the proper state parameters are maintained: comfort conditions in living spaces, storage conditions, the operation of machines and aggregates.*

Keywords: *Ventilation system, citadel system, HVAC, air treatment unit, air filter unit*

1. Introduction

HVAC installations include: ventilation installations, heating installations, cooling systems, conditioning plants (complex processing).
Ventilation systems have the function of delivering air without wetting, eliminating heat, NOx and humidity.
Ventilation and conditioning systems provide [1]:

- for surface vessels: complex air humidity processing so that its status parameters are automatically maintained at comfort levels;
- for seagoing and submarine compartments: in addition to the parameters it performs for surface vessels [2], it also provides a chemical composition for filling the oxygen consumed and retaining carbon dioxide released on board.

Fig. 1. Special ship – military ship

2. Microclimate condition for special ships compartments

2.1. Microclimate condition for crew rooms

Air conditions in the ship's compartments depend on temperature, humidity and movement. The effect of air on the crew in the compartments is dictated by their metabolism, health, acclimatization, effort and their clothing [3,4].
The temperature graph is based on the results. For example at a temperature of 26 [°C], a value of humidity of 50 [%] and air speed of $1\left[\frac{m}{s}\right]$, the effective temperature should be 21.2 [°C].
The minimum amount of fresh air / outside air supplied must not be less than 8 liters / second / person. At the same time, it must be at least 40% of the total amount of air introduced into a given space.

2.2. Microclimate condition for ship compartments in CBRN area

At the collective protection system (CPS), the inlet air is filtered by means of CBRN (chemical, biological, radiological, nuclear) filters. This system has a higher pressure than atmospheric pressure all the time.
Ventilation of the special ship citadel is intended to operate in a contaminated atmosphere and the overpressure must not fall below 0.5 [mbar] than the outside atmosphere in any of the spaces.

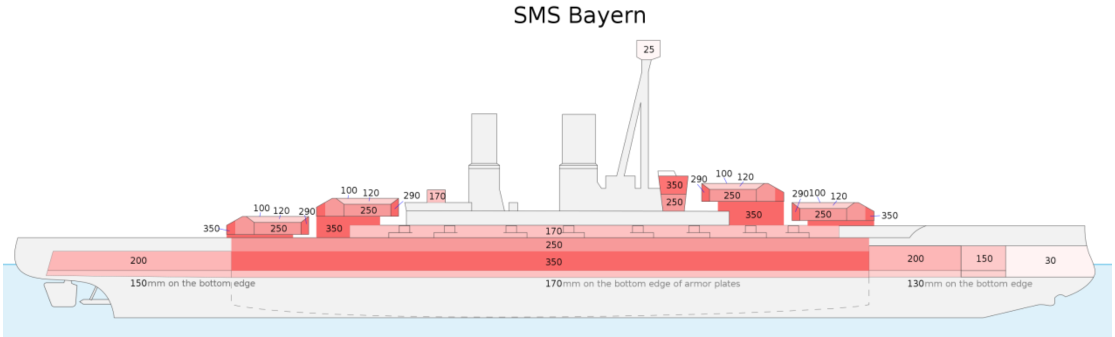

Fig. 2. Citadel system protection for a military ship

Outdoor air filtration units must meet the following conditions [5]:
- aspiration of the outdoor unit must be placed in zone 2;
- the filters must be capable of separating poisonous substances from the breathable air,
- the installation must be equipped with a safety filter after the main filter;
- filtered air must be monitored between the main filter and the safety filter. In case we have substances that pass filters, the warning alert must be activated automatically.

The following overpressure values must be followed in relation to the outside atmosphere as follows:
- living rooms, service and working spaces: 4 [mbar];
- machinery rooms: 3 [mbar];
- machinery modules: 2 [mbar] [6];

$$\dot{V}_{aerfilt} = \dot{V}_{aerresp} \cdot n \cdot \frac{a}{b2-b1} \left[\frac{m^3}{\Box}\right] \quad (1)$$

- $\dot{V}_{aerfilt}$ – filtered air quantity;
- $\dot{V}_{aerresp}$ – amount of breathing air has values:
- a person who is resting: 0.50 $\left[\frac{m^3}{\Box}\right]$;
- a person working light: 0.75 $\left[\frac{m^3}{\Box}\right]$;
- a person working hard: 1.25 $\left[\frac{m^3}{\Box}\right]$;
- *n* – number of the person onboard [6, 7];
- *a* – CO_2 quantity from breathing air (4 % of volume);
- b_1 – CO_2 quantity from outside atmosphere (0.03 % of volume);
- b_2 – CO_2 quantity from onboard air volume:
- 0.15 % in service and resting spaces[8];
- 0.25 % in dining spaces;
- 0.50 % in workshops.

3. NATO specifications rules for special ships

3.1. Special performance requirements

The ventilation system must have special performance requirements for:
- machinery spaces;
- compartments with technical equipment;

- living spaces;
- space of complementary crew on board;
- medical compartments and facilities;
- galleys;
- storage rooms for hazardous materials;
- hangars for aviation;
- warehouses including refrigeration areas.

3.3. Risk situations for the ventilation system:

- the ambient conditions provided by the ventilation system are those conditions in which the operation of the machinery will not be significantly degraded or lead to failure;
- unfavorable environmental conditions can endanger personnel;
- the CO_2 level will have to be taken into account. All spaces requiring regular staff visits must be adequately ventilated;
- consideration must be given to the extraction of fire and smoke gases (eg CO_2 and equivalents) in an area that will not harm personnel;
- water inlet through the ventilation holes. Ventilation holes or appropriate locking devices shall be provided to ensure the ship's integrity;
- propagation of fire. The number and location of the stops depend on the type of ship. In all cases, ventilation must be done outside the ventilation space.

4. Special HVAC systems

In simple terms, there are three types of subsystems of the artificial microclimate system onboard ship (intake fans, extraction fans and recirculation fans). The compartments of the vessel are either ventilated or air-conditioned. In ventilated compartments, there is an air intake system and an extraction system that returns air to the atmosphere. In the air-conditioned compartments, the air is recirculated, an amount of air in the compartment is evacuated to the atmosphere, and a quantity is replaced by fresh air. Generally, air is introduced into the ship through fans installed in compartments fitted with heaters and coolers.
In both, normal and contaminated atmospheres, all air conditioners are designed to work with AFUs (air filtration units) all the time. From air filtration units, the air is introduced into the ship and then recirculated through the air treatment unit (ATU) throughout the ship.

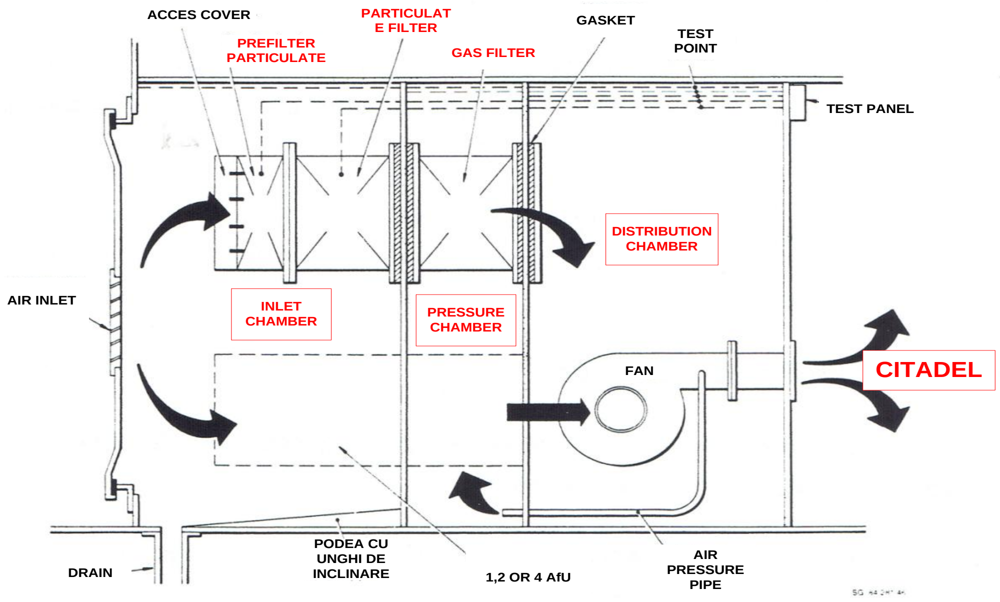

Fig. 3. System operation Air Filter Unit

For special ships, the artificial microclimate system is complex, vital and large size, impacting each compartment of the ship. The artificial microclimate system is divided into zones and is integrated with the chilled water system of the ship.

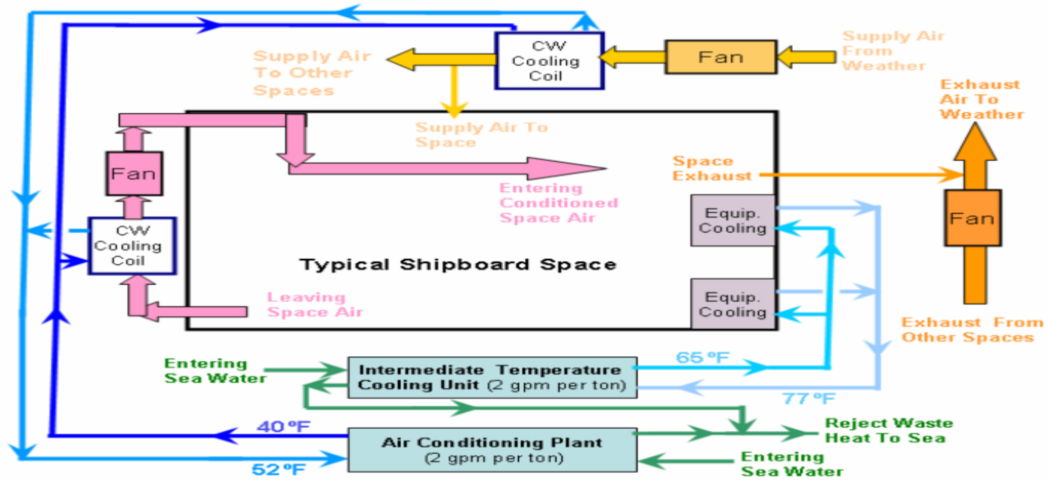

Fig. 4. HVAC operation

5. Machinery spaces ventilation

5.1. Machinery spaces configuration

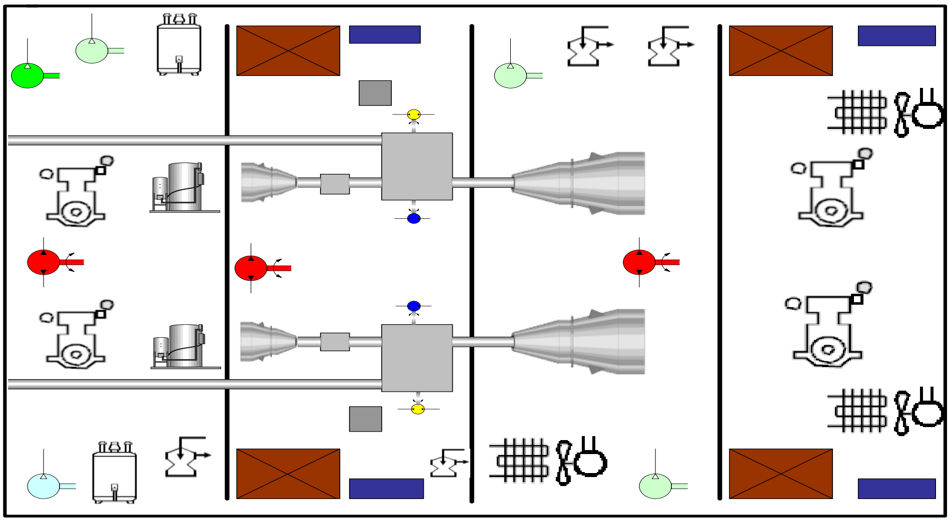

Fig. 5. Machinery spaces configuration with gas turbines for special ships

Each of the engine compartments (Forward Diesel Generator Space, Aft Diesel Generator Space, Forward Gas Turbine Space, Aft Gas Turbine Space) are ventilated with 2 supply fans and 2 exhaust fans. When the special ship is watertight against the contaminated atmosphere, the air in the engine compartments is recirculated by means of chilled water coolers for air-induction fans. The extraction capacity is greater than the air intake capacity in the machine compartments in order to ensure smoke and gas extraction in the compartments and to cool off the gas discharge routes (inlet capacity: 11530 $\left[\frac{m^3}{\square}\right]$, exhaust capacity: 13250 $\left[\frac{m^3}{\square}\right]$).
Coolers of machinery spaces should be insulated and drained as needed. The system must be ventilated during coolers recharging.
The machinery spaces ventilation must be reduced sufficiently in order to maintain the ambient temperature above 2 [ºC].
In the CBRN atmosphere, the machinery spaces will be contaminated with gas and the area will

become a contaminated one. Before starting the intake fans, the intake galleries must be drained by the water that has accumulated during spraying of the ship with the sprinkler.
Machine room exhausts are also used to cool out gas routes for engines and turbines.
The turbine modules are ventilated by a separate natural ventilation system that uses the depression in the turbine suction galleries to maintain a cooling air flow for the mode when the turbines are in operation [9, 10].
All fans mounted in machinery spaces are of the axial type with constant flow and vertical position. The upper end of the fan is provided with a screen to protect foreign objects that may enter.
The rainwater infiltration shutters are fitted to all the openings in the deck for ventilation. At the top of the vessel, the ventilation openings are provided with hinged caps, except for openings for ventilation of turbine modules.
In a contaminated atmosphere, the air of the machinery is evacuated by means of air valves that open when the internal pressure is more than half the atmospheric pressure.

5.2. Air flow calculation for cruising gas turbines compartment

We will consider a machine compartment for a special ship equipped with two Rolls Royce Tyne RM1C turbines.
The characteristics of the reference engine are as follows:
- effective power: 2 x 4500 = 9000 [kW];
- specific fuel consumption: 0.260 $\left[\frac{Kg}{kWh}\right]$;

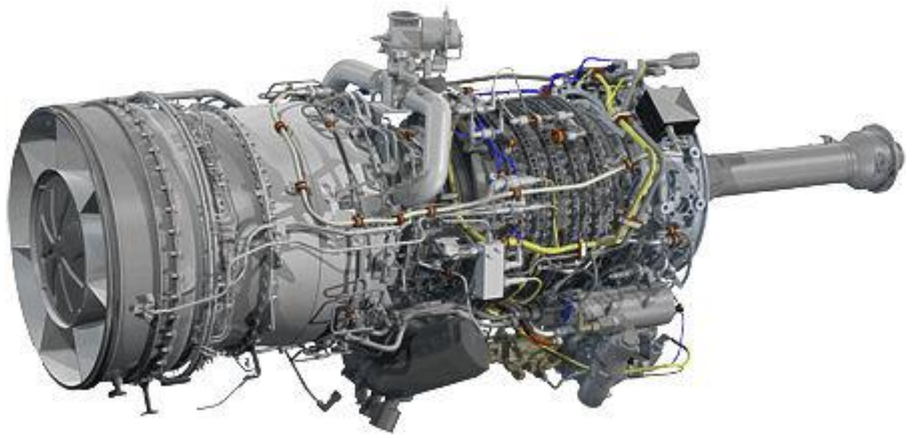

Fig. 6. Rolls Royce Tyne RM1C gas turbine [11]

Specific air flow for gas exchange:

$$d_{asg} = m_{tsg} \cdot \alpha_{sg} \cdot C_e \left[\frac{Kgair}{kWh}\right] \quad (2)$$

where:
- m_{tsg} = 14.2 $\left[\frac{Kgair}{Kgcomb}\right]$ - theoretical air mass needed for burn of one fuel kilogram;
- α_{sg} = 1.8 - excess air coefficient for gas exchange;
- C_e = 0.260 $\left[\frac{Kgcomb}{kWh}\right]$ - specific fuel consumption;

$$d_{asg} = 14.2 \cdot 1.8 \cdot 0.260 = 6.64 \left[\frac{Kgair}{kWh}\right] \quad (3)$$

Specific air flow needed for ventilation:

$$d_{av} = 2 \cdot d_{asg} = 13.29 \left[\frac{Kgair}{kWh}\right] \quad (4)$$

Mass Air Flow for Ventilation:

$$\dot{D}_{av} = 2 \cdot d_{asg} \cdot P_e = 119620.8 \left[\frac{Kgair}{\square}\right] \quad (5)$$

Volumetric Air Flow for Ventilation:

$$\dot{V}_{av} = 2 \cdot \frac{d_{asg}}{\rho_a} \cdot P_e = 108845.1 \left[\frac{m^3_{air}}{\square}\right] \quad (6)$$

6. Ventilation flow simulation in machinery spaces

Ansys offers a complete range of simulation solutions [12,13,14], engineering kits offer almost any field of simulation engineering, and a pre-rendering machine is required.

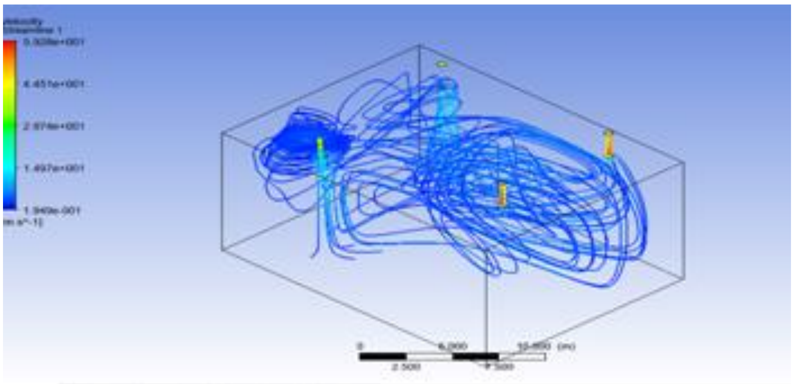

Fig. 7. Air velocity – Ansys CFX – 25 points [4]

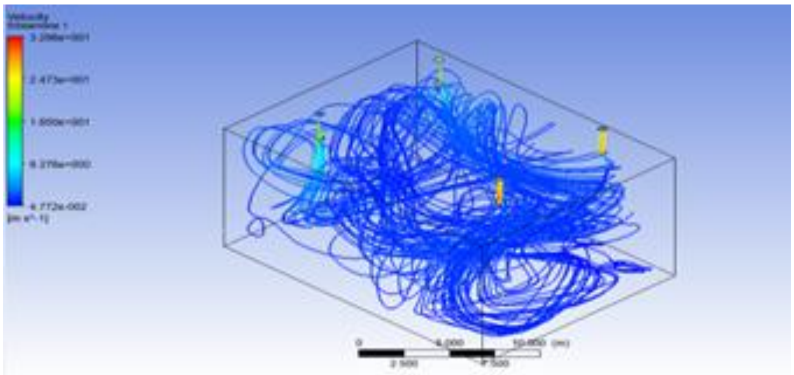

Fig. 8. Air velocity – Ansys CFX – 40 points [4]

7. Conclusions

For special ships, the artificial microclimate system is complex, vital and of large size, impacting each compartment of the ship. The artificial microclimate system is divided into zones and is integrated with the chilled water system of the ship.

The NATO functional objectives for the ventilation system are as follows:

- ambient conditions must be controlled in accordance with the requirements of on-board aggregates;
- ambient conditions must be controlled in accordance with the requirements of on-board personnel;
- ventilation must be provided in hazardous areas.

In order to eliminate thermal flows in the compartments of the ship, it is necessary to calculate the following sizes:

- calculation of the air flow introduced into air-conditioned compartments;
- calculation of the air flow extracted from the crew compartments;

- the calculation of the airflow required to evacuate the heat flow from the engine compartments

To optimize the energy utilization required for air entrainment fans must consider the weight of warm drive machine works, to be specific the quantity of motors to run all the while, the quantity of steam boilers burners in operation at the same time.
Ambient conditions require adjusting the air flow which ventilates the engine room and supplies the necessary air for engines, and engine room air temperature control.

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