Modeling and optimization of HVAC system for special ships

O. N. Volintiru 1, I. C. Scurtu 2, T. M. Stefănescu 1
1Romanian Navy
2Naval Academy, Constanta, Romania
octavianmarcs@yahoo.com

Abstract. For chilled water marine systems, calculation and operating parameters are specified in the standards. In the preliminary and design phase, other norms should be considered to increase crew comfort on board, optimize operating conditions for engines, auxiliary systems and other subassemblies. The efficiency of air conditioning and ventilation operation depends on the processes taking place in the compartments as well as the external weather conditions.

1. Introduction
The need for ventilation of special ship compartments comes from the following conditions imposed:
- Reduction of ship's waste energy.
- Ambient conditions provided by the ventilation and air conditioning 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 ship crew.
- The CO₂ level will have to be taken into account. All spaces requiring regular crew visits should be properly ventilated or air treated. No combustion products or noxious gases are permitted through the ventilation system, means engine exhaust or coolant gas. Particular attention will be paid to the inlet and outlet locations of the ventilation galleries. The location of outlet galleries from dangerous compartments such as battery or tanks must be properly positioned to avoid danger to personnel.
- Consideration must be given to the extraction of gases and smoke (eg CO₂ and equivalents) in an area that will not harm personnel.[1]

2. HVAC (heat, ventilation and air conditioning) system for special ships
For a 5000 tonne frigate, the chilled water system operates with 4 chilled water aggregates working and the number 5 is in standby mode. The system comprises 5 sections, each with a flow rate that can be provided by a single ACP (Air Conditioning Plant). This type of ship is equipped with 5 ACP with a capacity of 300 [kWh] or 1000000 [BTU].

The chilled water system has a centrifugal compressor that compresses the refrigerant gas and discharges it into an oil separator. The gas passes through the top of the oil separator to a condenser where it is cooled by sea water. The gas condenses and the refrigerant liquid flows into a second cooler. The liquid then passes through a thermostatic control valve and then into a liquid or evaporator cooler where the heat is transferred from the chilled water to the liquid refrigerant. Because the refrigerant absorbs heat, it reverts back to gas and is returned to the suction side of the compressor.

The seawater pump takes the sea and evacuates through a condenser and a thermostatic valve. This valve regulates the seawater flow to overboard, recirculating water on the suction side of the pump to
maintain a temperature of 28 ... 32 °C. The chilled water pump discharge water through the chiller in which it is cooled before it passes into the chilled water supply ring.

![Thermal distribution for a frigate ship](image1.png)

**Figure 1.** Thermal distribution for a frigate ship

The oil and cooling gas are discharged from the compressor and separated into an oil separator. The oil is collected at the bottom of the separator and is pumped through the compressor through a cooler, a filter and an oil distributor.[2]

![Chilled water system for a special ship](image2.png)

**Figure 2.** Chilled water system for a special ship [7]
3. Calculation of the cooling energy flow for the ship compartments
The calculation will refer to the operations compartment (operation room). The compartment includes in-service electronic equipment and crew.

![Figure 3. Operation room compartment for special ship [9]](image)

Because the nominal room temperatures are different, the calculation is done separately for each room and then summed in order to choose the microclimate aggregates. The calculation is made for the most unfavorable working conditions: the highest outside air temperature and maximum thermal load. With the values obtained are dimensioned the compressors, the heat transfer surfaces, the pipes and so on.

\[ \dot{Q} = \dot{Q}_1 + \dot{Q}_2 + \dot{Q}_3 + \dot{Q}_4 + \dot{Q}_5 + \dot{Q}_6 \text{ [kW]} \]  

- \( \dot{Q}_1 \) – is the energy flow by heat exchange through the external wall
- \( \dot{Q}_2 \) – is the energy flow consumption for cooling the compartment electronics
- \( \dot{Q}_3 \) - is the energy flow consumption for cooling and drying the air that ventilates the compartment
- \( \dot{Q}_4 \) - is the energy flow caused by the opening of doors
- \( \dot{Q}_5 \) – is the energy flow caused by the heat produced by personnel
- \( \dot{Q}_6 \) - is the energy flow caused by room lighting. [3]

3.1. Calculation of energy flow for heat exchange
External environment temperature:

\[ t_{me} = 25 \text{ [°C]} \]
The temperature in the compartment required to be produced:

\[ t_{mi} = 20 \text{ [°C]} \]

\[ \Delta T_{comp} = 25 - 20 = 5 \text{[°C]} \]

**Table 1. Compartments total heat transfer coefficient [5]**

| No. | Surfaces                                                                 | Total heat transfer coefficient [kW m\(^2\)K] |
|-----|-------------------------------------------------------------------------|---------------------------------------------|
| 1.  | Deck not exposed to solar radiation, ship's side edges, external bulkheads | 0.9                                         |
| 2.  | Bridges and bulkheads near machinery spaces, freight space and air-conditioned spaces | 0.8                                         |
| 3.  | Bridges and bulkheads near the hotplate or hotplate in the same compartment | 0.7                                         |
| 4.  | Open air bridges, bridges exposed to solar radiation, bridges near warm tanks | 0.6                                         |
| 5.  | One glass window                                                       | 6.5                                         |
| 6.  | Double glass windows                                                   | 3.5                                         |
| 7.  | Walls beside the windows, without noise insulation                      | 2.5                                         |
| 8.  | Walls beside the windows, with noise insulation                         | 0.9                                         |

The heat transfer coefficient for wall insulation:

\[ K_{comp} = 0.6 \left[ \frac{kW}{m^2\cdot K} \right] - \text{external walls exposed to solar radiation.} \]

Compartment surface taking into account: ceiling, floor and walls.
Compartment dimensions are: \( L \times l \times h = 9 \times 15 \times 3 \text{ [m]} \).
Compartment surface:

\[ A_{comp} = 54 \text{ [m}^2] \]

\[ Q_1 = c_{comp} \cdot A_{comp} \cdot \Delta T_{comp} = 0.9 \cdot 54 \cdot 5 \text{ [kW]} \]  

\[ Q_1 = 162 \text{ [kW]} \]  

3.2. Calculation of energy flow for electronic devices cooling

The hot air mass flow from electronic devices:

\[ D_{heat} = 0.5 \left[ \frac{m^3}{s} \right] = 1800 \left[ \frac{m^3}{h} \right] \]

Hot air density:

\[ \rho = 1.11 \left[ \frac{Kg}{m^3} \right] \]
Air enthalpy:

\[
i_{\text{aerteh } 45^\circ C} = 50.8 \frac{\text{KCal}}{\text{Kg}} \]
\[
i_{\text{aerteh } 30^\circ C} = 23.8 \frac{\text{KCal}}{\text{Kg}}
\]

\[
\dot{Q}_2 = \rho \cdot D_{\text{hot}} \cdot (i_{\text{aerteh } 45^\circ C} - i_{\text{aerteh } 30^\circ C}) \left[ \frac{\text{KCal}}{\text{h}} \right]
\]

(3)

\[
\dot{Q}_2 = 54000 \left[ \frac{\text{KCal}}{\text{h}} \right] = 62.8 \text{ [kW]}
\]

3.3. Calculation of the energy flow for cooling and drying the air that ventilates the compartment

Air exchange rate:

\[
a = 15 \text{ [exchanges/hour]}
\]

External air density:

\[
\rho = 1.15 \left[ \frac{\text{Kg}}{\text{m}^3} \right]
\]

Compartment volume:

\[
V_{\text{comp}} = 405 \text{ [m}^3\text{]}
\]

Air enthalpy:

\[
i_{\text{aercomp } 35^\circ C} = 30.8 \left[ \frac{\text{KCal}}{\text{Kg}} \right]
\]
\[
i_{\text{aercomp } 17^\circ C} = 11.4 \left[ \frac{\text{KCal}}{\text{Kg}} \right]
\]

\[
\dot{Q}_3 = a \cdot \rho \cdot V_{\text{comp}} \cdot \frac{(i_{\text{comp } 35^\circ C} - i_{\text{comp } 17^\circ C})}{24} \left[ \frac{\text{KCal}}{\text{h}} \right]
\]

(4)

\[
\dot{Q}_3 = 5647.21 \left[ \frac{\text{KCal}}{\text{h}} \right] = 6.56 \text{ [kW]}
\]

3.4. Calculation of energy flow by opening doors

\[
\dot{Q}_4 = (0.1 ... 0.4) \cdot \dot{Q}_1 \text{ [kW]}
\]

(5)

\[
\dot{Q}_4 = 0.1 \cdot \dot{Q}_1 \text{ [kW]}
\]

(6)

\[
\dot{Q}_4 = 16.2 \text{ [kW]}
\]
3.5. Calculation of energy flow released by the crew in the compartment

An adult man making a slight effort will release at room temperature of 20 [°C] an energy flow of:

\[ Q_{om} = 117 \text{[W]} \]

In the compartment, there are permanently 12 people forming the ship’s cart:

\[ Q_5 = 12 \cdot 117 = 1.4 \text{[kW]} \]  

(7)

3.6. Calculation of energy flow from electric lighting

The compartment is equipped with a total of 30 floodlights with a power of 8 [W] each.

\[ Q_{il} = 0.8 \cdot S \cdot P \text{[W]} \]  

(8)

where:

- S – coefficient of simultaneity representing the ratio between the power of the lamps working and the total installed power. Value will be 1.
- P = 30 \cdot 8 = 240 [W] – total installed power.

\[ Q_6 = 0.8 \cdot 1 \cdot 240 = 0.192 \text{[kW]} \]  

(9)

3.7. Calculation of total energy flow and cooling power

\[ Q = Q_1 + Q_2 + Q_3 + Q_4 + Q_5 + Q_6 \text{[kW]} \]  

(10)

\[ Q = 249.15 \text{[kW]} \]

4. Modeling the energy flow for cooling

_ansys offers a complete range of simulation solutions, engineering kits offer almost any field of simulation engineering, and a pre-rendering machine is required. The results obtained from the modeling can be helpful to optimize energy systems._

Figure 4. Operation room compartment temperature contour for starboard side
The results of the simulation in the Ansys program were:

- temperature contour for port side of compartment: from 299.99 to 310.00 [K];
- temperature contour for starboard side of compartment: from 299.99 to 315.00 [K];
- air velocity inlet compartment: from 0 to 2.2 \( \text{m/s} \).

5. Conclusions
In order to eliminate the thermal flows from the compartments of the ship, it is necessary to calculate the following:

- calculation of the airflow needs to be introduced in the compartments
- calculation of the airflow needs to be extracted from the compartments
- calculation of the airflow required to be air conditioning treated.

Ansys software has displayed a series of information resulting from physical data and related calculations identified with the geometry of the compartment. Environmental conditions require adjusting the flow of air that ventilates the compartment.[4]

References
[1] Volintiru O N, Studiul principalilor parametrii funcționali ai sistemelor care asigura ventilarea și microclimatul la bordul navelor speciale, Academia Tehnică Militară, București, Iunie 2018;
[2] Volintiru O N, Pruiu A, Scurtu C I, Ventilation systems for special ships, Workshop-ul național Cercetare și Expertiză Înginerească la Constanța. Buletinul Agir, 2017. ISSN-L 1224-7928, BDI: Index Copernicus International, Academic Keys, getCITED, ISSN Online: 2247-3548-
http://www.buletinulagir.agir.ro/articol.php?id=2903;
[3] Volintiru O N, Pruiu A, Scurtu C I, Considerations on the Calculation of Ventilation Systems for Special Ships, Hidraulica, Issue 4 pages 49, 2017, ISSN 1453 – 7303-
http://hidraulica.fluidas.ro/2017/nr4/18-24.pdf;
[4] Volintiru O N, Stefanescu T M, Dragomir E, Pruiu A, Contributions to the study of functional parameters in exploitation of the heat, ventilation and air conditioning system for special ships, Sea Conf 2018;
[5] ISO 7547, Ships and marine technology - Air-conditioning and ventilation of accommodation spaces, pag.6;
[6] ISO 8861, Engine room ventilation in diesel-engine ships, January 2001;
[7] Standard 02 – 102 (NES 102), Requirements for air conditioning and ventilation, part 1 - (ftp://ftp.iks-jena.de/mitarb/lutz/standards/dstan/02/102/01000200.pdf), UK, September 2000;
[8] https://www.fasant.com/en/products/ir
[9] http://www.computinghistory.org.uk/pages/16755/History-of-the-Cook-Building-at-MoD-Southwick-Park-(Formerly-HMS-Dryad).