



Marine Air Conditioning: How is it Different?

By Cdr. (Retd.) Atul Kumar Rohatgi
Ex-Indian Navy

A warship cutting through waves in the high seas

Introduction

Marine air conditioning is a specialized domain in air conditioning where the basics of HVAC have to mix with the basics of Naval Architectural and the principles of water tight integrity of ships. The essential features of HVAC, of course, remain the same, but they have to be applied taking into account the peculiar operational environment.

Very often, the author has been asked to describe the difference between marine air conditioning and land based air conditioning. In this article, the specific differences between a marine HVAC system and a typical land-based system have been enumerated and explained. The skills needed for a successful marine HVAC professional are a fine mix of knowledge of HVAC basics

as well as Naval Architecture and ship building practices.

The concepts of citadel and NBC filters introduced in this article are specific to naval vessels. However, the other concepts like water tight integrity are equally applicable to merchant ships.

Why do Ships Need HVAC?

Today, HVAC is one of the basic requirements for a ship. There are a number of high technology electronic and electrical equipment on board that need cooling. Without adequate cooling, their performance may deteriorate or they may not be able to work at all or, in the worst case scenario, they could burn down. This could have a devastating effect on the ship's performance and national security.

HVAC is also needed for human safety on board. During its operation, a ship may have to pass through an NBC (Nuclear, Biological or Chemical) contaminated zone. Without adequate protection, human beings operating the ship may not be able survive such an

About the Author

Commander (Retired) Atul Rohatgi is an alumnus of IIT-BHU (B. Tech.), IIT Delhi (PG) and FMS-Delhi (MBA) with about 28 years of experience. He has worked in various positions in the Indian Navy, as Head of Engineering at Noske-Kaeser GmbH (a Hamburg based marine HVAC firm) and as Senior Project Manager in Johnson Controls. He has designed HVAC systems for a number of warships. He has conducted multiple HVAC training workshops for budding engineers and designers in Naval Shipwright School, Visakhapatnam and Mazagaon Docks, Mumbai in addition to day long workshops for ISHRAE.



Figure 1: Ships during a naval exercise

environment. The HVAC system provides cover for the ship's crew.

HVAC is also required for maintaining the morale of the crew. Long stays on a ship, away from land and family, cause immense psychological pressure on the crew's mind. It is important that they are provided a pleasant atmosphere to work in, so that their efficiency and effectiveness can be enhanced.

In addition, on-board HVAC systems provide the smoke management system to take care of the eventuality of a fire.

How is Marine HVAC Different?

Complexity

One of the primary attributes of marine HVAC is the complexity of the system with regard to what it is expected to do. A land based infrastructure would be dedicated to a specific purpose and the HVAC system would be suitable for meeting that particular requirement; for example, a theatre, an office complex, a shopping mall, a hospital, an electronic data back office, a biological laboratory, a store house or a large kitchen. However, on board a ship, the HVAC system will need to fulfill all these different requirements within the small confines of the ship.

The HVAC system of a ship is a complex affair as it does not just involve heat load calculations and provision of equipment. HVAC on board a warship has to provide a pressurized clean and safe atmosphere for people to work in. It also has to take care of smoke management in case of a fire. It takes care of various compartments with different kinds of gases inside, some of which could even be explosive and poisonous. The HVAC design also needs to have adequate features to take care of water tight integrity of the ship and be provided with anti-sabotage features.

Size

While land based HVAC equipment are normally large, each handling several thousand cfm of air, a marine HVAC equipment would be smaller – the maximum air handling capacity being about 10,000 m³/hr, as locating the supply and return ducts above that capacity would not be possible in the limited space on board. The compartments are also smaller in size, each demanding relatively less cooling air quantity.

On the other hand, the capacity of chiller plants on board a ship is normally quite high. A corvette of approximately 2000 ton

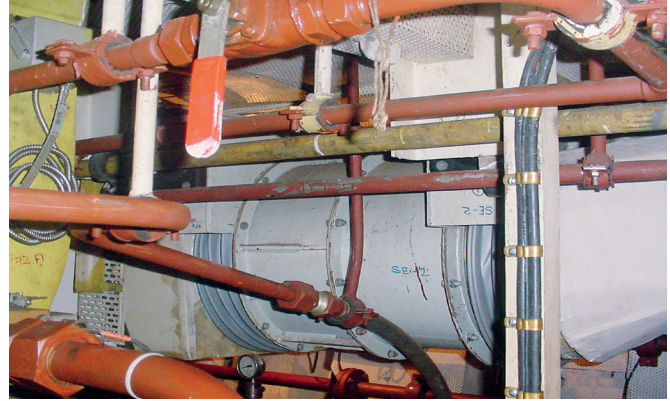


Figure 2: Equipment complexity and space constraints

displacement would have a cooling requirement of close to 1,200 kW, a 3,000 ton frigate would need 2,000 kW, a 5,000 ton destroyer would need 3,500 kW while a 45,000 ton aircraft carrier would need about 12,000 kW.

The high tonnage of chiller plants on board could be attributed to two reasons – the excessively hot and moist environment in which the ships have to operate, and the very high amount of equipment heat load due to the presence of a multitude of electronic and electrical equipment for communication, navigation, fire safety and damage control and weaponry.

Air Velocity

The deck to deck height on a ship is limited to around 3 meters. The clear height requirement for people to stand and walk is about 2.2 meters. Above this, there are frames and girders supporting the deck, insulation, various system pipes, electrical cables and false ceiling.

Due to the limited deck height and the requirement to maintain adequate head clearance, the duct height on board a ship is normally limited to 250 to 300 mm. The space constraint further reduces the width of the duct as several other system pipes and electrical cables compete limited space. The result is that the air velocity used for duct design on ships is far higher than that used on land jobs. The air velocity on a ship could be as high as 12.5 m/s as against 4 to 5 m/s for land-based applications. This results in higher total pressure head requirements for the fans and air handling units.

Higher Pressure in Citadel and Compartments

On board a typical warship, an overpressure of 200 to 500 Pa is maintained to ensure safety against NBC contamination. This brings in the need for specialized air filtration units (AFUs) and air bleed valves (ABVs) to control the flow of air out of the air conditioned system. Filtered fresh air is continuously supplied through the AFUs to the citadel. This helps in raising the air pressure inside. ABVs are specialized valves that normally operate based on a spring supported diaphragm mounted on the citadel boundary that release excess air causing the overpressure into the atmosphere. On land-based applications, such equipment is used only in nuclear plants or in highly sophisticated biological laboratories.

A citadel is the protected space on board a ship where sailors could continue to live and operate the ship and its navigational and fire control systems from. In a war scenario, the open atmosphere could possibly be contaminated and may not be fit for human beings to survive. The citadel space, that is kept pressurized with the help of fresh air filtered of NBC contaminants, would be safe for people, whereas the open space may not be. Pressurization of the citadel ensures that even in the eventuality of a small damage like a hole or unsealed boundary, the leakage will be from inside to outside and not in reverse direction, and the internal space in the citadel would remain safe for human occupation and work. The citadel space on such a vessel is a protected area with special entry and exit routes that are purged continuously with the help of used excess filtered clean air present in the citadel.

Use of AFUs

AFUs are used to filter out the NBC contaminated air. Use of such equipment protects those on board and allows them to complete the mission they are assigned to. These filtration units are primarily HEPA filters along with activated charcoal that absorb the contaminants. They have a very high pressure drop across them and, therefore, have to be used with very high pressure fans. The arrangement could have a fan either before the filter or after the filter.

The entry to and exit from the citadel is through specially designed air locks and cleansing stations. Please see *Figure 4*.

In open condition, the cleansing station is used as a normal bath space, while the two air locks are used for entry and exit. People can directly use the three doors on the two air locks to come in and go out.

However, in closed down conditions, the central door between the air locks is always kept closed. To go out, an individual has to come to the first air lock, remove his clothes and wear the NBC protection suit. He then walks through the cleansing station to the second air lock, closing the gas tight door behind him each time, and then goes out from the last air lock. While coming in, he comes to the first air lock and closes the outer door, removes his contaminated suit and leaves it there. He comes to the cleansing stations to wash himself completely. After the wash he can come



Figure 3: Air tight damper

to the inner air lock where he can wear fresh clothes and then enter the citadel. This whole space is continuously purged with the help of excess used filtered air from the citadel. This helps in maintaining the cleanliness of these spaces. The point to note is that while going out each time one crosses a door, one enters a relatively more contaminated space; while coming in, one gradually moves to a cleaner space.

Chiller Plant

The chilled water plant includes a sea water cooled condenser made up of Cu-Ni material. A land-based plant is either air cooled or fresh water cooled and is made up of GI or MS pipes. There is no need to have any cooling tower on board a ship as there is an infinitely large heat sink available in the form of sea water. The condenser cooling water is taken from the sea through pipes and is discharged after use back into the sea. However, as this sea water is saline and highly corrosive in nature, one has to take care in the selection of the material of construction of the condenser. This necessitates the use of specialized material like Cu-Ni (with very little Fe content), which is expensive but makes sense when one considers the savings in life time costs and reliability.

Redundancy Criterion for Chillers

The ships are divided into zones. Each zone is normally required to have all chillers of the same capacity and at least one standby chiller. Depending on the total number of equally sized chiller plants, redundancy in cooling capacity could therefore be 100% or 67% or 33% or less.

Another school of thought prescribes division of ships in three different zones, each having provision of 60% of the total chilling capacity. This way, there is a total of 180% of chilling capacity available, and any breakdown of chilling plants may be taken care of by interlinking chilled water pipes of the adjacent zones.

District Cooling Concepts

District cooling is the concept in which it is preferred to have cooling plants located centrally rather than having a number of small sized chiller plants. It leads to reduction in initial investment and running cost. While, for buildings, we have started talking about the use of this concept, it is already in place on board ships. Sea water cooled centralized chillers produce chilled water, which is then made to run through a system extending to all the

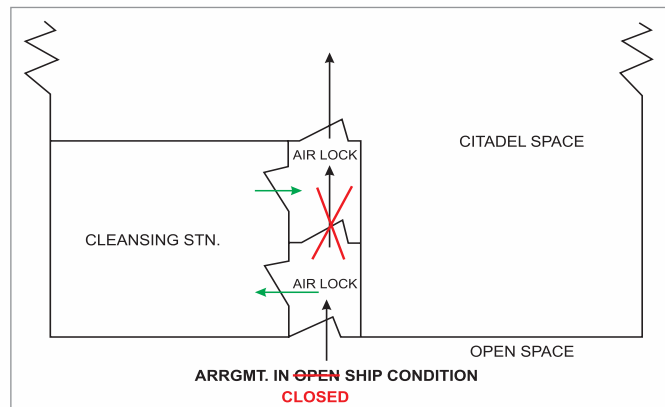


Figure 4: Way into and out from a citadel

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Figure 5: NBC filtration unit and AFU fan

consumers – Air Treatment Units (ATUs) and Fan Coil Units (FCUs). The chiller plants are placed way down the ship, in two or three different water tight spaces, so that they remain available even in certain stages of damage conditions. An intricate system of chilled water supply and return pipes ensures that chilled water is made available at each and every consumer point (and is brought back through return lines) in the required quantity and at the desired temperature and pressure.

The distribution system can be explained with the help of Figure 6. The green lines denote the supply and the red lines show the return of chilled water. The heat exchangers (HEs) in between are the various ATUs in the system. The chilled water lines could be either in a tree and branch arrangement, or in a ring and branch arrangement.

Ambient Moisture and Salt Content

Marine HVAC has to deal with very high moisture and salt content in the air. This leads to a very high rate of condensation, latent load, corrosion and fouling of the cooling coils and ducts. The typical design condition for fresh air enthalpy is approximately 100 kJ/kg of dry air. This causes very high fresh air high heat load on the chiller plants.

In old ships, the effect of very high moisture content in ambient air is observed very often in the form of severe condensation on chilled water pipes and supply air ducts, wherever there is an insulation failure. There are times when compartments housing the ATUs get flooded with condensate due to the clogging of

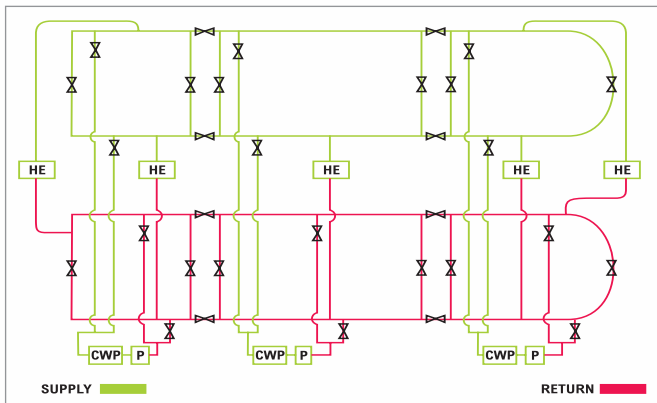


Figure 6: Ring main concept for chilled water piping



Figure 7: An illuminated ship in harbour

drains. Condensate rain is also seen in many places where the designer is forced to have high air velocity over the cooling coils.

Space Constraint

We have earlier discussed the space constraint for ducts on board a ship. Even for equipment, the space available is limited. Therefore, all equipment are extremely compact in design; the duct work and pipe work have much sharper bends and yet the air velocity used through ducts on board ships is much higher than that used in land-based buildings.

Figure 8 of an ATU for a submarine shows how complicated the equipment could become for meeting the space requirements. There has to be a lot of dialogue and sharing of data between the ship builder and the HVAC supplier to find optimal solutions that could work.

Heat Load Calculation

Unlike buildings, ships do not remain in fixed geographical locations. The sun rays might fall on the ship from left or right (port or starboard); they could be directly overhead or extremely slanting. The outside temperature could be 35°C at one place and -10°C at another place and time.

Across the width of the ship, if there is more than one compartment (which is normal), both the port and starboard compartment would need sufficient cooling air to cater to the condition when they could be facing the sun directly. The design of a marine system would need to take care of these varying outside conditions.



Figure 8: Tailor made ATU for constrained space

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Due to the above reasons, the heat load calculation procedure for ships takes into account both the temperature extremes and is not direction specific. Both heating and cooling systems may need to be provided for them.

Ships that are reported to be very cold during commissioning trials sometimes bring back stories of very high temperature and sultry conditions when deployed in extreme tropical waters in peak summer conditions.

Reliability

Ships are normally expected to have a life in excess of 30 years. During this period, they are continuously engaged in their mission and, therefore, repairs are difficult. Of course, there are refits at regular intervals; the requirement is that the number of breakdowns should be minimal. The selection of material for specific components, therefore, is much more stringent. Chilled water pipes and expansion tanks are made from Cu-Ni; valves are made from bronze; condenser pipes, being in contact with salt water, are made from Cu-Ni, and so on.

Once again, a building does not become completely unusable due to a small problem in HVAC. Repairs can be carried out relatively easily. However, a ship cannot be sent to the high seas with a known problem, as repairs will normally not be feasible there. The reliability criteria for a ship, therefore, have to be very high.

Compartments with Poisonous or Explosive Gases

There are a number of compartments on board a ship that are likely to have poisonous and explosive gases inside, and the HVAC equipment must be suited for the purpose. Compartments like aircraft hangar, AVCAT (aviation fuel) pump room, battery charging room, paint store, petroleum oil store, ghee/ edible oil store, wheat flour store, various magazine compartments and sewage treatment plant compartment could have explosive or poisonous gases. The HVAC system is required to ventilate these compartments in a safe manner so that the compartment temperatures as well as air quality may remain conducive for work. One needs to select spark resistant and explosion proof fans whenever there is a possibility of such gases coming in contact with the sparks in the fans or motors. One also needs to be careful in grouping of compartments with fans and AHUs, so that the poisonous or explosive gases do not travel through the ducts to other compartments.

The galley, machinery compartment and Sewage Treatment Plant (STP) compartment are some other dangerous areas that

are prone to fire and one needs to take special precautions while designing the HVAC system for them.

A design error here could become the cause of a future accident involving lives on board. Several cases have been reported worldwide of accidents and even deaths due to lack of or improper ventilation in certain compartments. There have been fatal gaseous accumulations in sewage treatment plant rooms, explosions in paint stores and terrible spread of carbon dioxide due to leakage from storage cylinders kept on board.

One has to be careful about the nature of the gases that might be emanating from within the compartments, depending on their use. Hydrogen that emanates from the battery charging room is explosive and is lighter than air. It has to be extracted from the top. On the other hand, fuel gases that get accumulated in the aircraft hangars, fuel pump rooms, engine rooms and Diesel Alternator (DA) compartment etc. are also combustible but are heavier than air and must be extracted from the bottom of the compartment. The operation theatre on board also must have the gas extract hoods down below as the medical gases used for anesthesia are heavier than air.

For the compartments that are likely to have dangerous gases, much higher air change rate is provided for as compared to other compartments with no such threat.

Humidification

In marine conditions, evaporative cooling is not required, nor can it be used, due to high moisture content in ambient air. However, in cold climates, humidification would be required as the humidity content in fresh air would be very low. This requires provision of vaporizers or steam generators, and steam injection facility in fresh air or treated air.

Cold air would normally not have the capability to carry this moisture unless heated to a high enough temperature. Therefore, the cold and dry fresh air is first heated with the help of pre-heaters prior to mixing with injected water vapour. The water vapour must be injected slowly and over sufficient length of the duct, or else it will separate out immediately in the form of condensate. This is done with specially designed water vapor injectors. Such humidification systems are needed in ships that could get deployed in cold climatic conditions.

A typical land-based unit in a tropical country would rarely be fitted with a humidification device.

Heating

At different periods during their lifetime, ships could be operating in different places. The same ship that needs cooling

Table 1: Hazardous gases in various compartments

Paint store	AVCAT pump room	CO ₂ compartment	AC & R compartment	Battery charging room	Operation theatre
Petroleum gases	Petroleum, explosive	CO ₂ does not support life, and is poisonous at higher concentrations	Refrigerant does not support life	Hydrogen, explosive	
Heavier than air	Heavier than air	Heavier than air	Heavier than air	Lighter than air	Heavier than air
Exhaust from bottom	Exhaust from bottom	Exhaust from bottom	Exhaust from bottom	Exhaust from top	Exhaust from bottom
Exhaust from bottom	Exhaust from bottom	Exhaust from bottom	Exhaust from bottom	Exhaust from top	Exhaust from bottom

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in tropical waters could need heating, if deployed close to the Antarctic or Arctic regions. One might need to fit heaters in the ducts, ATUs or the compartments. The comfort level increases with decentralization of the heaters, i.e., there is least temperature control when we have heaters fitted in the ATUs, and maximum comfort when the heaters are in the compartments. However, as we move the heaters from the ATUs to the compartments, the total number of the heaters increases drastically while their individual sizes decrease. The increase in the number of heaters makes the controls more complex, and one has to strike a compromise between comfort and ease of operation and maintenance.

Once again, heating systems are not normally present in most land-based HVAC systems.

Dampers for Water Tight Integrity

In case of damage to a ship, there is a possibility that water could cross the bulkhead (vertical) and deck (horizontal) partitions that are supposed to provide water tight integrity on board through the air ducts. This could cause serious threat to the survivability of the ship. Therefore, in all such areas (and there are many of them), where ducts cross the bulkheads and decks below a well-defined waterline, water tight valves are fitted on the ducts. These valves could be hand-operated or remotely-operated. The required portions of these ducts are with water tight construction. The closing devices on these dampers are normally provided in the direction of escape.

The water tight dampers are possibly the major differentiators between land based and marine HVAC systems.

Shock Testing of Equipment

Ships experience various degrees of movements, shock and vibration on account of wave interaction and storms, and sometimes due to ammunition hit. The equipment and the system will have to face these situations regularly in use. The equipment used on board, therefore, has to pass shock tests to prove their structural stability. In these tests, the equipment is mounted on a test bed and is dropped, or made to experience shock and its response is studied. These tests are normally conducted by defence or aeronautical laboratories.

Tilt Test

Ships experience various movements due to wave action at sea. Depending on the specification, the equipment is required to be tested for its satisfactory operation in tilted condition. This is so as a ship could, in certain conditions of loading and in case of damage, get tilted longitudinally (trim) or transversely (list) or both at the same time. It is required that the HVAC equipment keeps on working even in tilted condition.

To ensure that the equipment keeps on functioning irrespective of the condition the ship is operating in, it has to pass the tilt test. For this test, the equipment is mounted on a test bed and the whole bed is tilted to various degrees as required, and the equipment is run.

Land based equipment will never be required to operate in anything but the designed tilt condition, but all marine HVAC equipment will invariably need to be capable of operating in various degrees of tilted conditions.

Tenure of Ship Building Projects

The air conditioning project tenure of a ship depends on ship-building tenure, and is normally long term. The period depends on the kind of ship being built, and whether the design has been completed already or is running parallel to the ship building project. In many cases, the design and the ship building process proceed together so that latest technological changes could be incorporated into the design. However, this leads to an unduly long ship-building schedule.

The HVAC designer is brought in the early stages of ship design, and the construction continues through the ship-building process. Normally, the HVAC system has to get completed much before the commissioning of the ship, as various electronic equipment for communication, navigation and other functions are brought in only after cooling and dehumidification have been made possible by the HVAC system.

The total tenure of marine HVAC projects is, therefore, much higher compared to land-based projects.

Conclusion

The above is a brief introduction to the inherent differences between the HVAC system for a land-based application and a marine vessel. The basics of air conditioning remain unchanged. The difference primarily lies in the understanding of the environment around the ships and inclusion of the Naval Architectural features for the ship's stability and operability. ❖