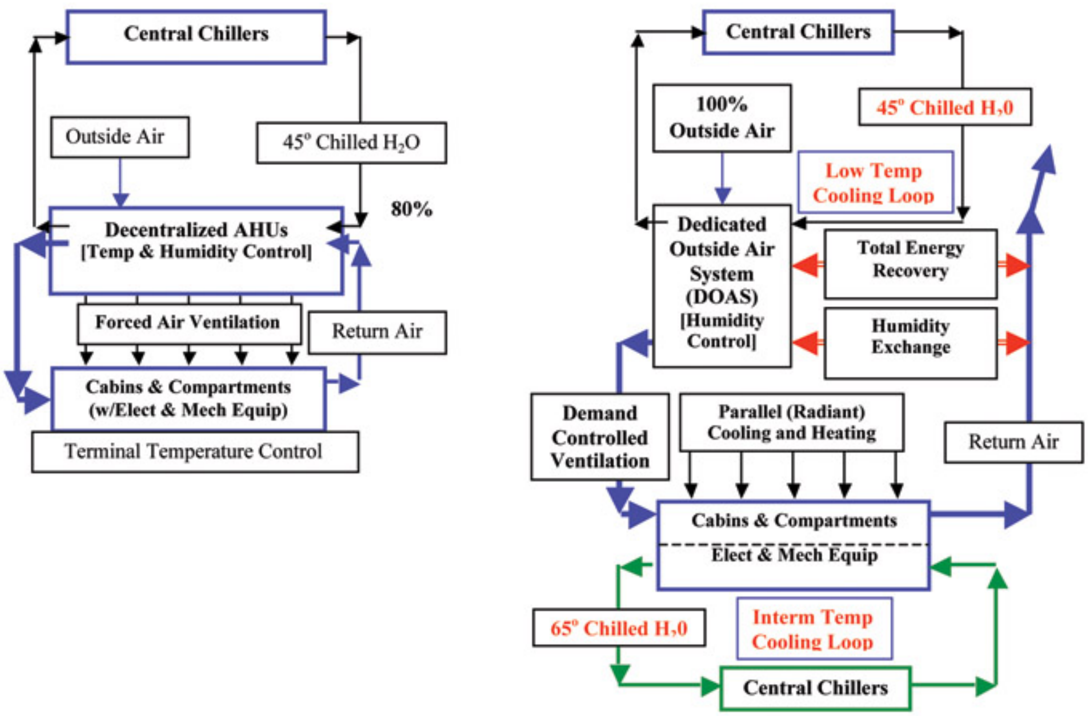
High Efficiency HVAC for Marine Vessels

Description of technology

Since the energy for the entire ship's electrical load is produced from diesel generator sets, each electrical load has a direct impact on overall fuel economy and emissions. Key areas for fuel efficiency improvement for 100 m class passenger vessel were identified through completion of a study to quantify the annual fuel consumption associated with each of the major electrical loads. Second to the propulsion load is HVAC. The HVAC load can account for 15% of annual fuel consumption.

HVAC marine architecture is typically very conventional and is usually put together based on designs for similar, previous ship builds. However, there are significant opportunities for efficiency upgrades using approaches that are a major departure from conventional practice. This report summarizes a number of commercially available HVAC technologies for efficiency enhancements and are summarized in the following figure:



<u>**High Efficiency HVAC Features**</u>

- Dedicated intermediate temperature cooling of electronic and mechanical equipment
- Demand-controlled ventilation of cabins and compartments, perhaps based on CO2 sensing
- Smaller central chillers and air handling equipment with increased efficiency of HVAC
- Comfort, efficiency, and volume saving advantages of radiant heating and cooling
- No recirculation of return air; energy and humidity exchange with compartment air
- Additional energy recovery opportunities not shown in the figure:
- Waste heat from gensets for production of chilled and fresh water
- Waste heat from chiller condensers for domestic hot water heating

Four key elements to reduce HVAC energy consumption while maintaining a comparable level of flexibility and function are discussed below. The proposed technology is used on land-based systems, but much less on ships. It appears that the technology, however, is quite appropriate for ship applications.

1. Intermediate temperature cooling loop for electronics and equipment – a significant portion of the HVAC chilled water load will be dedicated for space conditioning to accomplish electronic and mechanical equipment cooling. This cooling is typically accomplished by drawing compartment air at 70-80° F through hot equipment and exhausting the heated air back into the conditioned space for subsequent recirculation through the air handling ductwork. Cooling of equipment using the primary HVAC system in this way is clearly inefficient. A portion of the added burden is caused by the additional fan power required to move significantly more hot air through compartments in which these equipment loads are located.

Fortunately, there is an alternative thermal management strategy that is more energy efficient. A dedicated intermediate temperature cooling loop could be installed for direct cooling of equipment loads. The intermediate sink fluid would be circulated through installed equipment using either a conventional cold plate design or a cooling coil and closed system recirculation fan within the equipment cabinet. By de-coupling equipment cooling from the comfort conditioning load, the following benefits are possible:

- Reduced energy consumption by optimizing the intermediate cooling loop specifically for installed equipment
- Increased efficiency of equipment cooling through point-source conduction and convection waste heat removal
- Lowered power consumption in the primary cooling loop which is unburdened from cooling electronics and installed mechanical equipment
- Reduced recirculation-fan power requirements in the primary loop
- Elimination of some of the “hotel load” recirculation ductwork
- Enhanced efficiency for cooling equipment, thus extending its service life

An initial assessment of the benefits of an intermediate temperature cooling water loop aboard a 100 m class vessel was completed. The relative energy savings from chiller operation are about 13%.

2. Demand controlled ventilation – The conventional HVAC systems are designed to supply ventilation (outside) air based on assumed, rather than actual, occupancy. This often results in over-ventilation, thus wasting both energy and placing an additional burden on the primary HVAC system. A demand controlled ventilation (DCV) system is specifically tailored to monitor conditions in every conditioned zone and then deliver required ventilation when and where it is needed. Using DCV, excessive over-ventilation is avoided while providing the required volume (cfm/person) of outside air specified by applicable codes and standards.

In direct digital control systems, the required controls are easily implemented because all of the necessary real-time information can be already available. CO2 occupancy sensing is particularly attractive and is increasingly being used to modulate outside air ventilation based on real-time occupancy.
Energy savings in a given application depend on actual occupancy level patterns, as well as type of conditioned space and the ambient climate. A well-designed DCV ventilation system capable of meeting exact occupancy needs could be expected to save on-the-order-of 25% of HVAC operating costs.

3. Dedicated outdoor air system with energy recovery – Traditional HVAC systems employ air handling units that simultaneously meet both outside air ventilation and space conditioning requirements by providing supply air to a conditioned space that is a mixture of outside air and re-circulated air. These systems mix large quantities of re-circulated air, often over 80%, with outside air in the air handling unit. These systems often suffer from deficiencies in air quality, humidity control, and energy efficiency.

Dedicated outside air systems (DOAS) are designed to treat the outside air before it enters the conditioned space by recovering the proper conditioned air properties (thermal and humidity) from the outgoing exhaust air, thereby improving overall HVAC efficiency. Such systems separately pre-condition both the temperature and humidity of incoming outside air, while providing sufficient fresh air to maintain the proper air quality. With a DOAS system, the primary HVAC system no longer re-circulates air. Ship compartment air is directly exhausted through the DOAS system, which then preferentially exchanges the thermal and humidity constituents back into the incoming outside air. Due to the thermal and humidity recovery, the HVAC system can be downsized, which is then used to satisfy the remaining heating or cooling requirements in the conditioned space.

The DOAS system can remove contaminants from outside air, so is suitable for sensitive environments such as data centers and laboratories. By conditioning only outside air, the buildup of mold and the introduction of bacteria, microbes, etc. is minimized. This achieves energy savings while improving air quality.

The DOAS approach saves energy by reducing the cooling load in the summer and heating load in the winter on the primary HVAC system. Consequently, it can significantly reduce the required size of the chiller plant for the system. For land-based systems, this reduction has been more than 40% in some cases.

4. Radiant heating and cooling – In a 2002 Department of Energy study, radiant ceiling cooling was identified as the top-rated energy saving technology. In this approach, either chilled or heated water is used directly at the conditioned space in lieu of forced air. The cooling and heating grid typically consist of capillary tubes imbedded in or mounted inside architectural ceiling panels. There are also a considerable number of electrically heated, radiant ceiling panels on the market today. Integration of chilled water cooling panels and electrical heating is possible.

Between 75 and 90% of the energy from a radiant panel is propagated by thermal radiation, not by forced convection of air. Therefore, the energy is transferred more uniformly to or from all bodies “seen” by the panel that are at an absolute temperature different from the panel itself.

The radiant system exchanges heat with water, a much better heating and cooling transport agent than air (1000 times better on a volume basis). Water also requires significantly less energy for circulation (pumping) than forced air (blowing). In addition, unlike traditional duct work and cabin air handling units, the ceiling plenum and distribution network require only a very small space. The radiant panel and capillary tubes are virtually silent. The system is inherently low maintenance as there are very few electro-mechanical devices and moving parts. Finally, a radiant system essentially eliminates the contamination associated with re-circulated air, improving indoor air quality and reducing airborne transmitted contaminants.

The energy cost savings from heating with water, as opposed to heating with air, can be as much as 25%. Researchers at the National Association of Home Builders Research Center in the US found that heating a home with ceiling-mounted radiant panels produced energy savings of 33% compared to a heat pump and 52% compared to baseboard heaters.

In addition, due to the high heat capacity and density of water, thermal energy can be transported by water in pipes with little pump power, saving approximately 70 to 80% of fan power normally used to service a forced air system. These combined factors can reduce peak-power of the HVAC system by 30 to 45%.

Individually, each of these approaches has the potential to substantially improve HVAC efficiency. When multiple technologies are applied in series or parallel, the compounding effect on system-level HVAC performance and control is potentially profound.