Green air-conditioning

By Martijn Wuis, Maarten Wuister

Bart Janssen

Contents

01. Explanation of relevant terms, expressions and abbreviations

HVAC: Heating Ventilation Air-conditioning Cooling

CFC: C**hloroFluoroCarbon (Cooling agent)**

HCFC: HydroChloroFluroCarbon (Cooling agent)

1. Introduction:

As part of our second year school project we are commissioned to write a scientific report about our subject “Cruise ship Air-conditioning”. Our main research subject is the energy efficiency of the Heating, Ventilation and air conditioning systems onboard these ships. It is an interesting subject because of the high energy consumption of these systems and the amount of savings that can be gotten from making these systems more efficient. The purpose of this report is to inform the reader about the different systems currently used and the advantages and disadvantages of these systems, and how to choose which system would be best to install in cruise ships. To achieve this we will answer and explain the following questions:

- How does air-conditioning work on cruise ships?
- What types of systems are available for air-conditioning?
    - What are the differences between the air-conditioning systems?
    - What differences are there regarding environmental impact?
    - What differences are there regarding efficiency?
    - What differences are there regarding the purchasing costs?
    - How dependable are the systems?
    - How suitable are the systems for use on cruise ships?
- In what direction are improvements on air-conditioning systems currently sought by air-conditioning suppliers?
- How is/can waste energy from the main-engines (be) used for air-conditioning systems?

Furthermore we will briefly look into where the latest improvements to HVAC systems are currently made, as well as how the waste energy from the engines could be used to power the HVAC systems. Or other better solutions that have not yet been used on cruise ships.

To achieve these goals we will first discuss the different types of HVAC Systems. Then we will give a detailed view of cruise ship systems regarding the stated aspects. After that we make a comparison between the systems. Hereafter we will give a short look at the future improvements, with suggestions for discussion and further investigation. We will close with the conclusions drawn based on our findings.

For this report the information will be sought in proper books and internet sites. Also will the imtech company be contacted to receive current detailed information on HVAC-systems. The HAL will be contacted for quantifications that explain the relevance of good working HVAC systems on cruise ships.

2. Different types of Marine HVAC systems

The types of HVAC systems are divided in high and low pressure, the number of pipes and if they are centralised or decentralised units. Before going into an outline on what each of these characteristics entail we will quickly explain the general working principles

2.1 General working principles

The evaporator extracts heat from surroundings by means of evaporation. The Condenser gives off heat, created by the condensation of a liquid, to its surroundings. This system can be used on small or large scale. This is shown in figure 1. in a ship you can have a freshwater cooling system that works with a number of evaporators working in parallel and a condenser which is cooled by seawater. This cool freshwater can then be sent to an condenser in a Water chiller which uses a cooling HCFC to cool water that can then be sent to the air handling units which will use it to cool the air send to the cabins. This is an example of the most complicated system. Of course there are easier ways which involve dropping any of those systems but this will create a loss of efficiency. A concise version of this is put below to show the different steps that are possible and to show the steps that can be cut.

Seawater cools the central water cooling system, which cools the Water chiller, which cools the air handling unit coolant, which cools the cabin air.

Depending on if you use a system that uses circulated water send to the air handling units for the cooling process provided by a central cooling plant or individual units per air handling unit. The air handling unit uses one of these systems to cool the air that is in turn used to cool the specified area. This can result in many expensive but more efficient cooling systems before the cooling effect from sea water is eventually transferred to the air used for cooling. Or by simply using air as a coolant which is less efficient but requires a less elaborate system because it can be done in the air handling unit itself. Figure 2 shows an air handling unit and how it supplies cool air to the cabins and how it removes the old air.

Figure 2.1.1

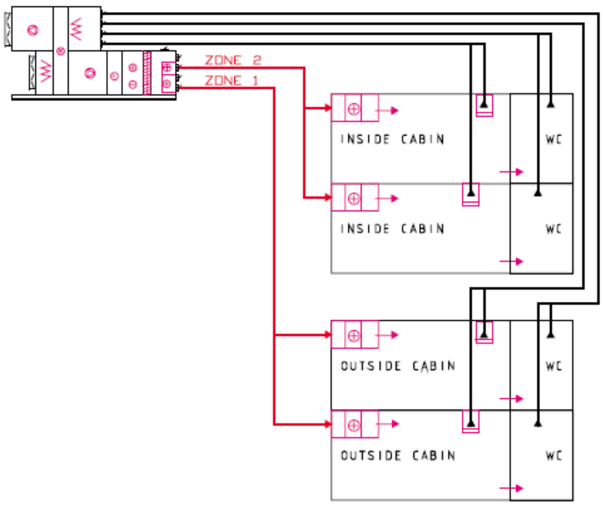
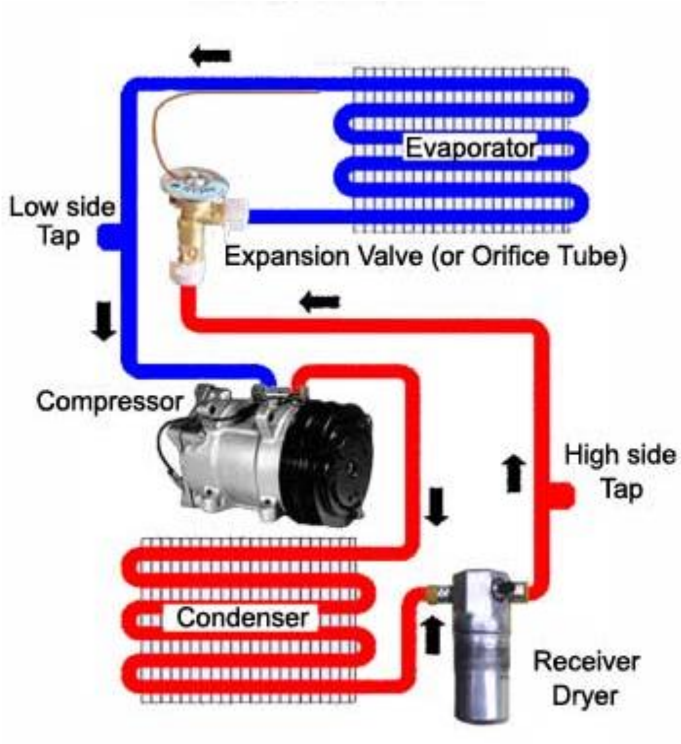


Figure 2.1.2



The main principle of any HVAC-unit, such as shown in figure 2.1.2, starts with the evaporator. When the liquid it is still liquid, but because of the temperature and the space after the evaporator the liquid will become a gas, to do this it will extract heat from the space around the evaporator. As a gas it will enter the compressor which will bring the gas under high pressure. In the condenser the high temperature will be reduced and the gas will turn to a liquid. The expansion valve regulates the amount of liquid that goes into the evaporator. This way the liquid will turn from 100% liquid in the expansion valve to 100% gas immediately after the evaporator.

2.2 High Pressure System vs. Low Pressure system

The main principle behind the high pressure system is that the air is compressed so that more mass of air can be transported used less space. The air is delivered at a rate of 8 to 18 m/s. It is well fit for smaller compartments.

The main principal of the low pressure system is to bring great volumes of air into the compartments. It will use much space but the desired conditions in the room can be achieved quickly since the amount of air that is brought into the room is relatively big compared to the air that already is in the area.

The advantages of the High Pressure system compared to the Low Pressure system:

The high pressure system uses less space in its construction which makes the installation easier and cheaper. It is also easier to control the air of the rooms differently, this way separate rooms can have different climates provided by the same installation.

The advantages of the Low Pressure system compared to the High Pressure system:

The low pressure system can handle far bigger areas than the high pressure system. It produces less inconvenience by noise. Also the high pressure system consumes more energy through the fan which has to compress the air.

2.3 Number of Pipes

This refers to the supply and return of chilled and/or heated water to the air-handling unit. Up to 4 pipes can be used to do this. The 2 pipe solution uses 1 pipe for the supply of hot or cold water and 1 pipe for the return of this water. This is cheap to implement and is fairly simple to build. It does however have the disadvantage of not being able to supply hot and cold water at the same time so it isn't very flexible in its heating or cooling capabilities. The 3 pipe system uses 1 pipe for the supply of hot water, 1 pipe for the supply of cool water and 1 return pipe. The advantage of this is that it is more flexible than the 2 pipe system. It does however need more equipment and you can't reuse the return flow easily because it is a mixture of the supplied air and the original air. Then there is the most expensive 4 pipe option where there is a separate pipe for the supply and return for both the hot and cold water. This is fairly expensive to purchase and maintain. It offers the highest amount of flexibility because both hot and cold water are separately available at the air-handling unit.

Table 2.3

	Costs (+ = cheap / - = expensive)	**Flexibility (+ = flexible / - = not flexible)**
2-pipes	++	-
3-pipes	+	+
4-pipes	-	++

2.4 Centralised units

A centralised unit has all the mechanical equipment in one plant. The plant is connected to the areas with ducts and pipes. Both the strength and weakness of the system is that all the technical intensive equipment is kept together on bigger scale. The advantage of this is that the fragile parts of the system are kept together far away from, for instance, public areas. Another advantage is that all the noise is kept away from these public areas as well. Disadvantages come with the size of the system, in the duct- and piping this will bring little trouble, but the machinery is complicated and large scaled wherefore a well educated operator is necessary.

2.5 Decentralised units

Every area has its own independent, smaller unit to handle the air. This keeps the units far less complex and thus easy to work with. The individual areas can be differently handled to the requests that fit the room or the users of the room. When one unit has a malfunction only the room it is installed in is affected. Disadvantages are that the heating and cooling capacity of the units are very limited. It takes very advanced systems to fit the change in climate the unit will experience during a voyage, making these units the more expensive versions in their branch. The systems are more fragile and since they are operating in the area it self they will also be noisier.

2.6 Cruise ship HVAC

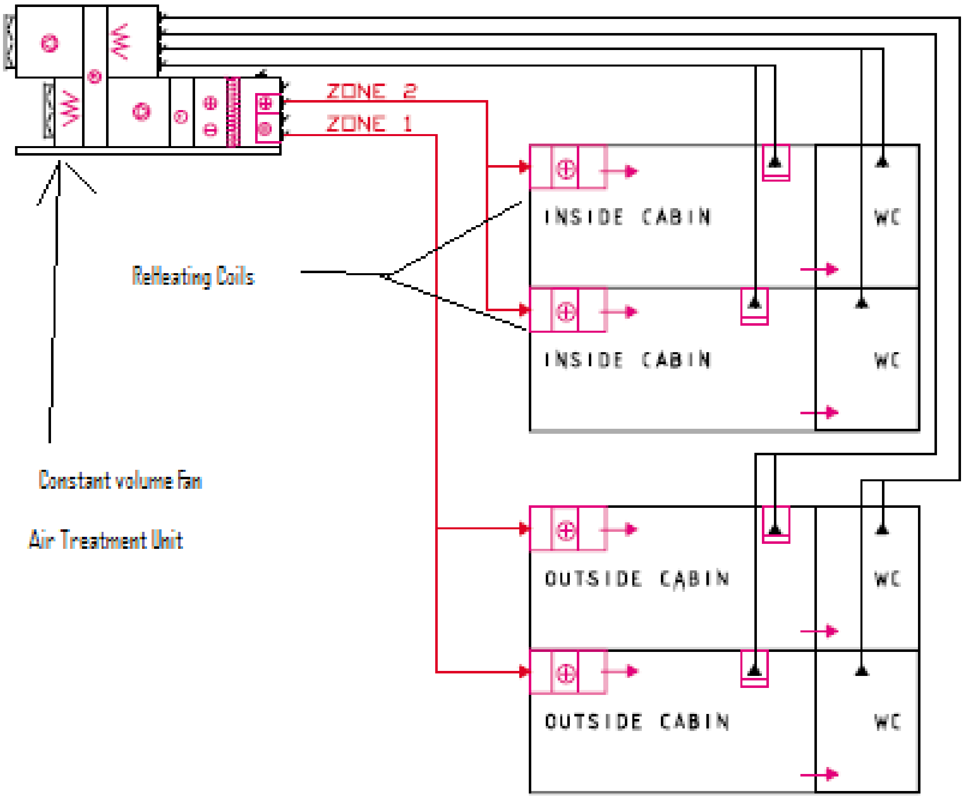
On cruise ships the Cabin areas are usually serviced by a High pressure Decentralized system that is either completely self-sufficient or one that makes use of water circulation, because of the easily replaceable parts and some other advantages (the cabins can control their air individually, this way one can adjust the climate in his cabin to his own desire without affecting, or being affected by the other cabins). In the large areas a low pressure system is used for the reason that it transports a big volume of air. We will focus mainly on the cabin systems seeing as this is one of the bigger parts in energy consumption of the complete air conditioning system.

3. The HVAC Systems

3.1 Constant airflow with Reheating (CAV + Reheating)

This system delivers a constant volume of air and works by regulating the temperature of the supplied air by reheating it from the base supply level to one that is wanted in the specific area using reheating coils.

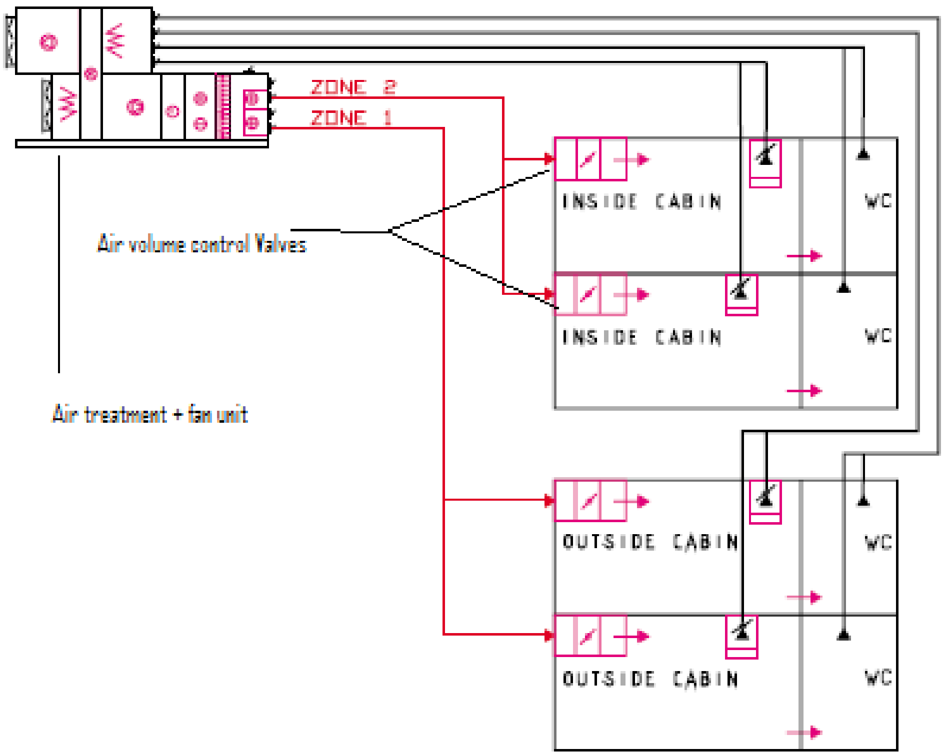
This is the simplest of the systems and it works well without a complicated automation system. Reheating, Heating of the air sent to the cabins at a cabin level so called because first you cool the air to a certain temperature at the air handling unit and then you reheat it at the cabin, is separately arranged at the air handling unit for the different cabin zones and it is based on the outside temperature and a regulating curve. The cabin device always provides a constant air flow that is additionally reheated in the device when needed. Electric reheating is regulated either with on/off principle or analogue. Reheating provides the required cabin-specific temperature rise. It's a simple system but it is very inefficient it is also not very flexible in the temperature ranges it can provide. It makes up for this with its cost and due to its simplicity it has few parts that can break resulting in a better reliability and a small size because it does not need any cool water piping.



3.2 Variable Airflow (VAV)

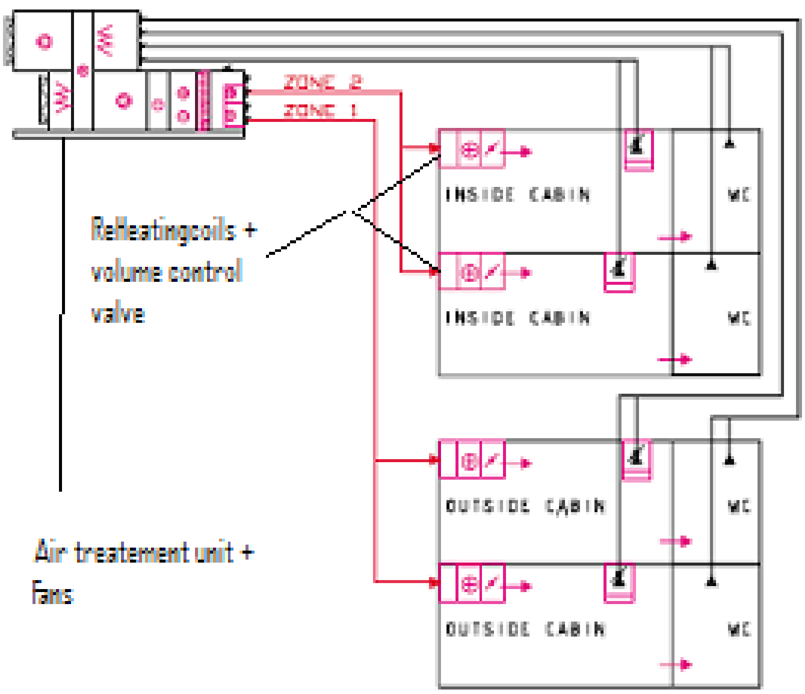
This system uses air of a constant temperature and adjusts the volume of air that is supplied to cope with the area's needs in cooling. The more cooling needed the higher the volume of air that needs to be admitted to attain the required cooling effect.

This system is based on the regulation of air flow and it works well without a complicated automation system. Temperature regulation is zone specific in the air handling unit, which does not allow major heat load variations between the different cabins in the zone. The air flow in the cabin unit is regulated manually or using cabin automation. This system is equally suitable for warm operational areas. A simple system but it is not very user friendly because you can only set the temperature for an entire zone. It is however more efficient then the CAV. It is a relatively cheap system with few parts and because it's a decentralised system it requires less space and is quite reliable.



3.3 Variable Airflow with reheating (VAV + Reheating)

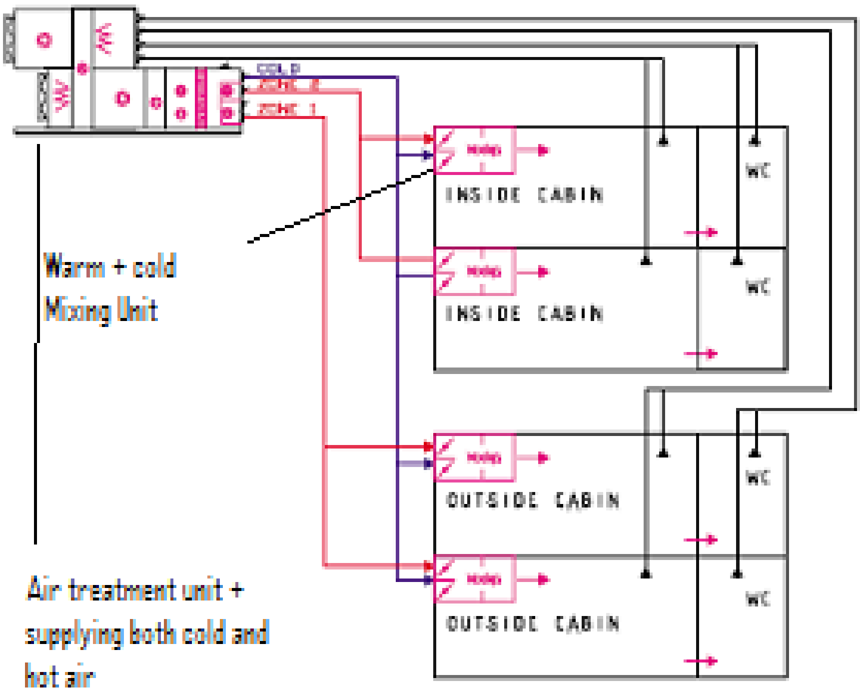
This is an improved version of the air flow regulated cabin system. It is based on air flow regulating and electric reheating. The extra heating makes this system very competitive for ships in colder operational areas. The electric heating coil is usually integrated in the cabin unit. Regulation can be manual or use a cabin thermostat. This system is much like the normal VAV but it raises the comfort level by adding a heating unit in the cabin. This will take a slight toll on the efficiency but this could be a price worth paying. Because of the extra heating and cabin control unit it is slightly more expensive than the normal VAV.



3.4 Twin Duct

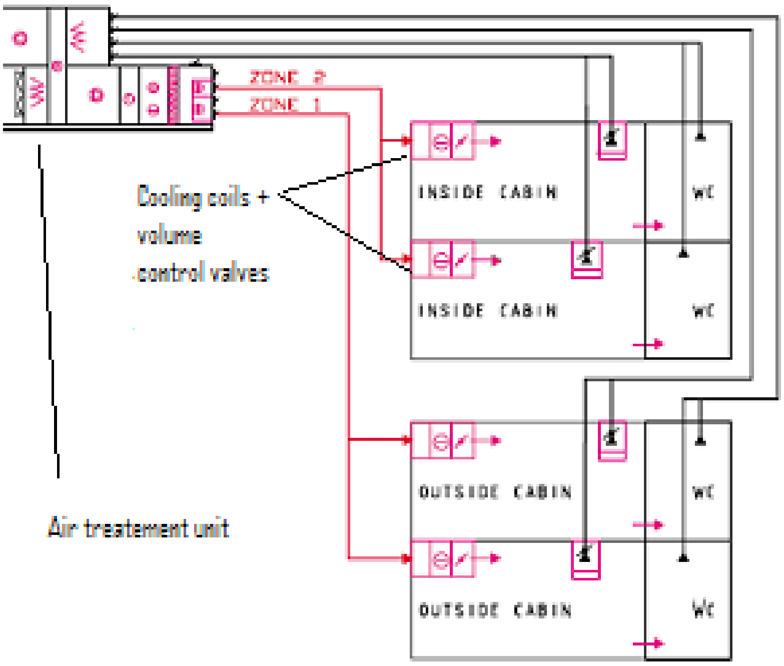
This system works by mixing hot and cold air. It’s rather inefficient because it needs to be on constantly to keep a comfortable temperature. However this type of system lends itself to the using of cooling water from the engine and then to mix it with the cold air.

This is a traditionally used system. Supply air is led into cabins through 2 ducts. One of them is a cold air duct and the other is provided with a heating coil located in the air handling unit. Cabin specific regulation is carried out by adjusting the mixing ratio of cold and warm air. The system requires the space for twin ducting and also increases the ship’s weight. It is not a very efficient system but it does offer a high level of comfort to the passengers. Because of the extra ducting and control systems that need to be installed it is moderately expensive. It has an good reliability because of relatively simple control systems.



3.5 Airflow regulated with water circulation (Smart Air)

The system is based on air flow regulation and cooling with water circulation. The accurate regulating system provides good cabin temperature control. The system is excellent for ships in warm operational areas. The cooling coil is integrated in the cabin unit. The temperature regulation is usually done with the aid of sensors, cabin regulators and automation systems. The system does not require insulated supply air ducts because cooling is arranged in the cabin. The system however requires water circulation piping. It is an expensive system but it does have a very high efficiency because of the water cooling which reduced the energy required for cooling the air by a fair amount. But it is not capable of heating which can be a problem. It has a fairly large size overall because of the extra piping that is required but because the air ducts don't need to be insulated some space is saved. Because of the extra system cooling requires it has a larger chance of parts malfunctioning.

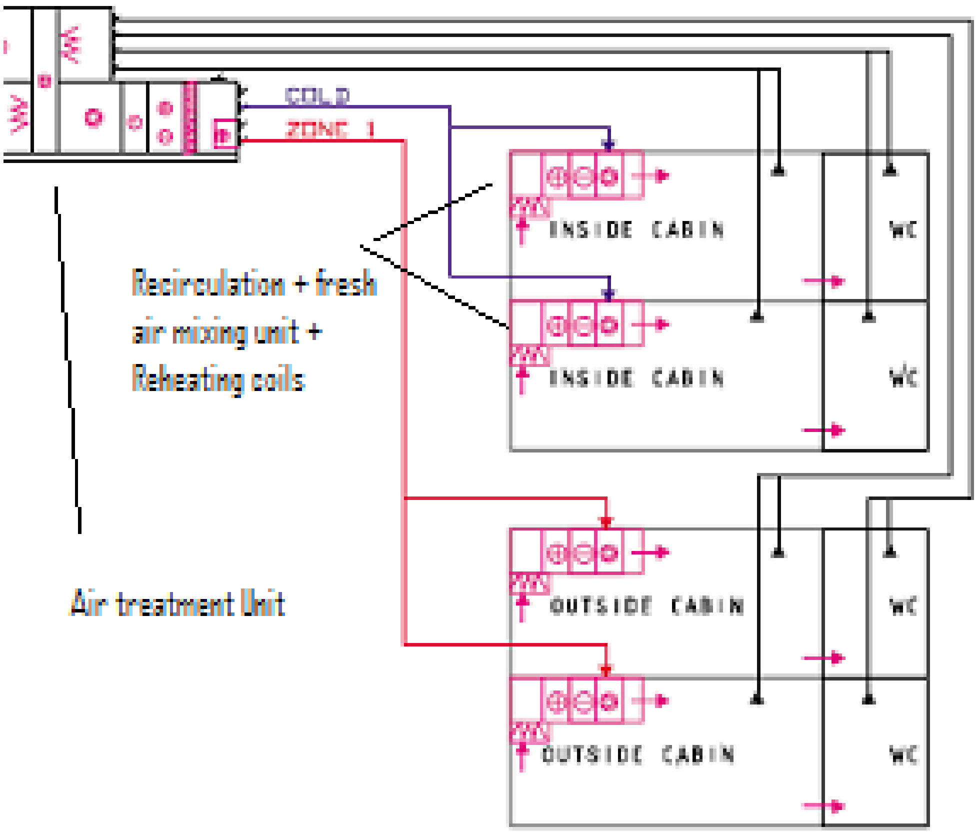


3.6 Air recirculation with reheating and water circulation (CFAF)

This system works my mixing old and fresh air and then reheating it to the required temperature in the cabin with a reheating coil. It uses water cooling for use with the cold air duct. This system could also use warm exhaust water to create a mixing system.

Fan coil includes a fan, reheating, cooling and a filter. The fan recirculates air through the cabin unit so that a specified amount of fresh air is constantly mixed into the recirculated air.

The minimum amount of fresh air is determined by the number of occupants of a cabin. The conditions in the cabin can be regulated with the heating/cooling coil. Exhaust air is usually extracted through the toilet. With its accurate regulating system, this system provides very precise temperature control, and it is excellent for ships with warm as well as cold operational areas. One of the benefits of this system is the small amount of fresh air needed, which means a reduced number of air handling units. The cabin system needs a separate cooling water piping and insulated supply air ducts. The fan located in the cabin will slightly raise the noise level but this can be offset by proper duct insulation. The use of recirculated air requires good filtering to maintain proper air quality. This is the most expensive system but it also offers the best efficiency. Because of all the ducting and piping required it also a very sizable system which is slightly offset by the reduction of the amount of air handling units required. It offers maximum comfort in every climate. Yet it is still prone to failing parts because of all the control systems that are required and the amount of parts that can break down.



4. Comparison Table

The systems mentioned in chapter 3 are here compared to one another upon the following aspects:

Environment: How environmentally friendly is the system?

Efficiency: How energy efficient is the system at cooling?

Purchasing cost: The costs of installing the system

Reliability: How much maintenance is required?

Size: How much space does the system require?

Comfort: How much user comfort does it offer?

System	Environment	Efficiency	Purchasing Cost	Reliability	Size	Comfort
CAV + Reheating	--	--	++	++	+	-
VAV	-	0	+	+	++	--
VAV + Reheating	-	-	0	+	+	+
Twin Duct	+	-	-	+	-	++
VAV + WC	++	+	--	0	--	+
CFAF + WC	+	++	--	-	-	++

(-- = Catastrophic , - = Bad , 0 = mediocre, + = Good, ++ = Excellent)

5.Future of HVAC

5.1 The environment

The biggest change here compared to the last years is the change of cooling liquid that is used to cool the water because of the Montreal protocol. For the Montreal protocol see chapter 5.3. But of course any progress made in efficiency directly effects the environmental impact because of less fuel consumption resulting in less exhaust gases.

5.2 Efficiency

The biggest progress being made nowadays is using intelligent electronic control devices that minimize the cooling and heating of rooms that are not being used and maximize the efficiency of the entire HVAC system. This can result in up to 30% less power consumption. The HVAC systems are mostly updated to provide better and more reliable cooling and heating and no great leaps in efficiency are expected.

5.2.1 High Efficiency Air Conditioning

Air conditioners are rated on their efficiency using a measurement known as the *Seasonal Energy Efficiency Ratio* (SEER). This measurement is the cooling output divided by the energy consumption with climate and certain other variables factored in. The higher the SEER number, the more efficient the unit, is the general rule. Older units might have a SEER as low as 7 or 8. For a long time, The Department of Energy mandated a SEER of 10 as the minimum for all newly installed units. This figure has recently been raised to 13, and is a topic for debate currently. Some units are capable of SEER ratings as high as 17 or 18.

For a example see **appendix 1**

Window units use EER (Energy Efficient Ratio) rather than SEER, but the principle is basically the same. The principle of “bigger is not necessarily better” applies to window units also. Humidity plays such an important role in comfort, and is often more important than just mere temperature. Smaller units tend to remove more moisture because they have longer runs. When a unit first starts it actually blows a bit of moisture out of the unit. Once the cycle is running smoothly, the condensation of moisture on the cooling cools begins. SEER is related to the Energy Efficiency Ratio (EER), which is the ratio of *output* cooling in Watts/Hr and the *input* power in watts W at a given operating point and also to the coefficient of performance (COP) commonly used in thermodynamics. Performance ratios can be a unitless output over input ratio, never to exceed one, and it is also proper to state what kind of energy is in the numerator and denominator. The COP of a heat pump is determined by dividing the power output of the heat pump by the electrical power needed to run the heat pump, with both powers measured using the same units, e.g. watts. The higher the COP, the more efficient the heat pump. For example resistive heat has a COP = 1. The EER is the efficiency rating for the equipment at a particular pair of external and internal temperatures.

<u>1 BTU = (British Thermal Units)= 0.0002929 kW</u>

<u>1 Watt = 3,4121 BTU</u>

<u>1kW = 3414 BTU</u>

5.2.2 Theoretical maximum

The SEER and EER of an air conditioner are limited by the laws of thermodynamics The refrigeration process with the maximum possible efficiency is the Carnot cycle. The COP of an air conditioner using the Carnot cycle is:

$$COP_{Carnot} = \frac{T_C}{T_H - T_C}$$

where TC is the indoor temperature and TH is the outdoor temperature. Both temperatures must be measured using a thermodynamic temperature scale such as Kelvin.

$$COP_{\text{cooling}} = \frac{\Delta Q_{\text{cool}}}{\Delta A} \leq \frac{T_{\text{cool}}}{T_{\text{hot}} - T_{\text{cool}}}$$

where

ΔQcool is the amount of heat extracted from a cold reservoir at temperature Tcool,

ΔQhot is the amount of heat delivered to a hot reservoir at temperature Thot,

ΔA is the compressor's dissipated work.

All temperatures are absolute temperatures usually measured in kelvins (K).

For an indoor temperature of 299.81 K (26.7 ˚C) and an outdoor temperature of 308.15 K, (34.9 ˚C) the above equation gives an COP of 36.0, or an EER of 123. This is about 10 times as efficient as a typical home air conditioner available today.

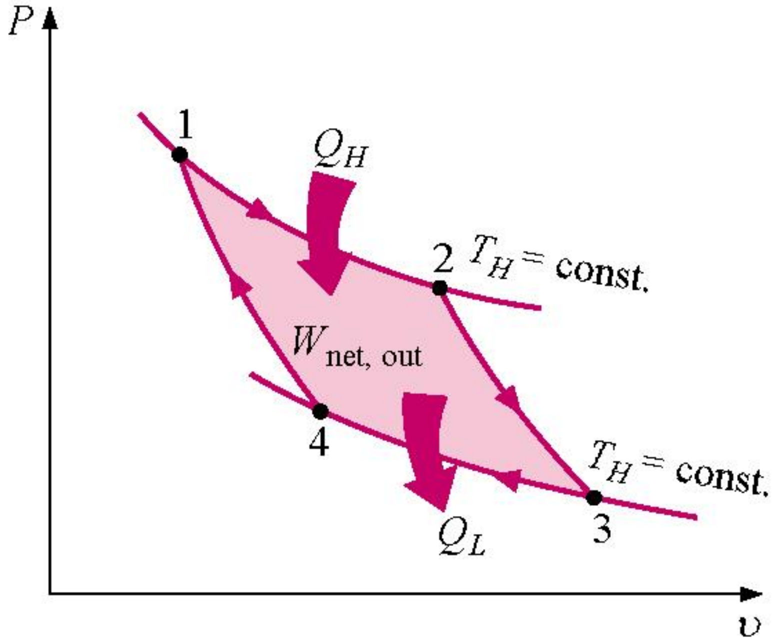
The maximum EER decreases as the difference between the inside and outside air temperature increases, and vice versa. In desert climates, where the temperature may be as high as 50˚C, the maximum COP drops to 13.5, or an EER of 46 (assuming an outdoor temperature of as 50˚C and an indoor temperature of 26.7˚C).

The maximum SEER can be calculated by averaging the maximum EER over the range of expected temperatures for the season.

The carnot-cycle is a theoretic thermo dynamical cycle whereby all the heat is supplied by the hottest temperature, and is drained off by the lowest temperature.

Carnot says that the efficiency of the machine is not dependent on the type of fluid, rather it depends on the maximum and minimum temperatures between which the heat engine cycle operates.

The high temperature reservoir from where the heat is absorbed at high temperature is called as source and low temperature reservoir, usually atmosphere, where the heat is rejected is called as sink. Thus the efficiency of Carnot cycle depends on the temperatures of the source and sink, measured in Kelvin i.e. the absolute temperature.



5.2.3 Solar Air Conditioning

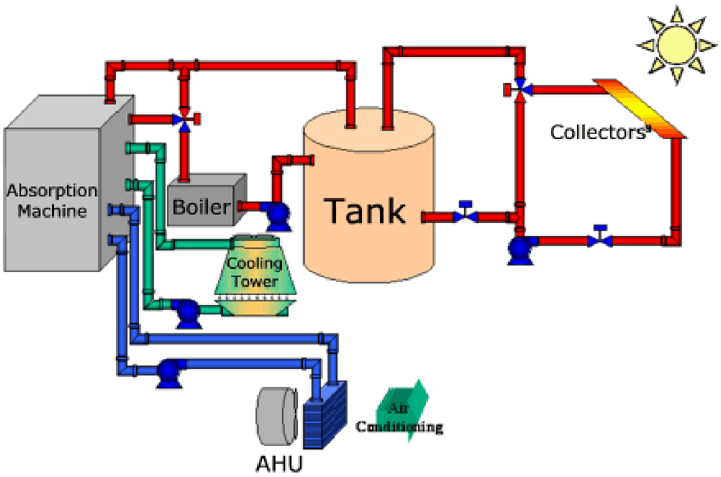
Environmental concerns are a very important factor in a number of areas and air conditioning is one of them. The wide spread use of air conditioning has created ever increasing electrical energy demands, and the power generating capacity is struggling to keep up with this demand. During demand peaks created by hot spells, there have been power outages and brown-outs in the past. One of the ideas that has been developed to cope with this problem is the use of the sun as a power source. This seems a logical concept since the sun creates the problem by creating heat. Wouldn't it be great if the sun could also provide the solution.

The method used is based on the thermo-chemical process known as sorption. Sorption takes two forms. When a liquid or gas is attached to a porous, solid material it is called adsorption. When the liquid or gas is taken in by liquid or a solid, it is called absorption. The European technology involves the use of a sorbant, usually silica gel. The silica gel is heated by the sun and is dehumidified. When water vapor or steam is added to the dehumidified gel, adsorption takes place and heat is released.

Basically, when heated ambient air is drawn through the system in what is called a heat reclamation rotor, the heat is drawn out of the air, cooling it. The cooled air is recycled back into the ship. The major drawback to this system is the large size of the units, and of the area that must be exposed to the sun.

Solar energy for home use is an emerging technology also. However, the idea here is to use the energy to power existing air conditioning units rather than replacing them with new technology. Photovoltaic cells mounted on the roof converts solar energy into AC power that can be used to power the air conditioner. In most cases, the amount of power is not sufficient to run the unit, but can supplement the regular electrical supply. The major advantage here is that when the electrical demand is the highest, which would be during the peak daylight hours, the sun will be bearing down most directly on the PV cells.

There is a surge in power consumption during start up of an air conditioner unit. Solar photovoltaic cells can be used to keep the unit running at a very low speed during times it would normally be shut down. This can further reduce the regular electrical use by eliminating many of the starts and stops of the cycle. Solar energy is an emerging technology in a world that is seeking alternative sources of power. Hopefully, in the future, the sun, which creates the heat and humidity that we seek to eliminate with air conditioning, will provide the solution to our continued comfort.



5.3 The Montreal Protocol

The Montreal Protocol on Substances That Deplete the Ozone Layer (a protocol to the Vienna Convention for the Protection of the Ozone Layer) is an international treaty designed to protect the ozone layer by phasing out the production of a number of substances believed to be responsible for ozone depletion. The treaty was opened for signature on September 16, 1987, and entered into force on January 1, 1989, followed by a first meeting in Helsinki, May 1989. Since then, it has undergone seven revisions, in 1990 (London), 1991 (Nairobi), 1992 (Copenhagen), 1993 (Bangkok), 1995 (Vienna), 1997 (Montreal), and 1999 (Beijing). It is believed that if the international agreement is adhered to, the ozone layer is expected to recover by 2050. Due to its widespread adoption and implementation it has been hailed as an example of exceptional international co-operation with Kofi Annan quoted as saying that "perhaps the single most successful international agreement to date has been the Montreal Protocol".

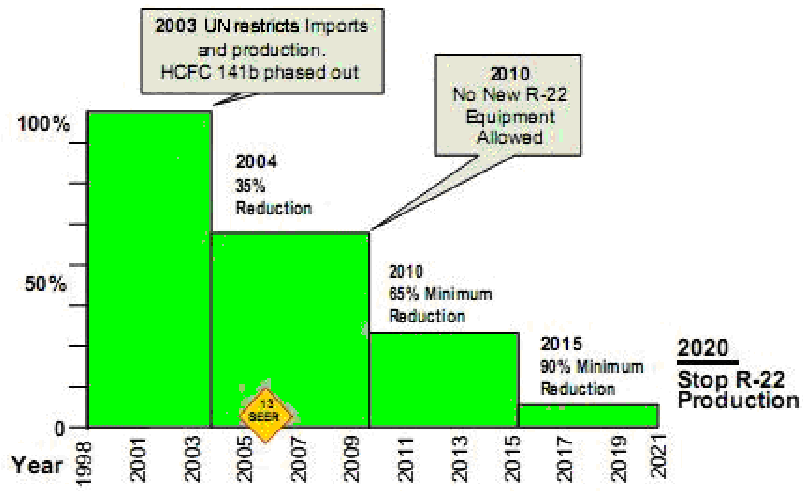
As per EPA (Environmental Protection Agency), the timeline is as follows:

January 1, 2010: By this date there would be complete ban on the production and import of R22 and R142b. However, there is exception for the on-going servicing needs of the existing plants and equipment.

January 1, 2015: By this date there would be ban on the sale and use of R22. There is exception for certain cases, including the serving needs of the existing refrigeration and air conditioning equipment.

January 1, 2020: By this date there would complete ban on the production and import of R22 refrigerant. The gas would not be available even for servicing of the existing plants.

R-22 Supply Phase Out:



This chart overviews the phase out of HCFC rights between 1998 and 2020.

5.4 Cooling Liquids

Freon is a chlorofluorocarbon, which is an organic compound that contains carbon, chlorine, and fluorine. Freon was developed as a safer alternative for ammonium(NH_3), Chloromethane (CH_3Cl), and Sulfur dioxide (SO_2), that was used in cooling systems before Freon was discovered. Freon is extremely safe, inflammable and not poison.

Connecting environmental impact the Freon's are classified in this groups:

CFC's : Chlorofluorocarbons, without H-atoms. These substances have a big impact on the ozone layer, and are illegal to sell.

HFC's : hydrochlorofluorocarbons, without chloride, but with hydrogen atoms. An example of this is 134a.

HCFC's: Hydrochlorofluorocarbons, they are also bad for the ozon layer, but less than CFC's. An example of this is Freon 22

The most common cooling liquids are R134a; R407C; R410a on new vessels.

5.4.1 Refrigerant R410A

R-410A, sold under the trademarked names Puron, Genetron R410A, and AZ-20, is a near-azeotropic mixture of difluoromethane (CH_2F_2, called R-32) and pentafluoroethane (C_2HF_5, called R-125), which is used as a refrigerant in HVAC air conditioning applications.

Unlike many haloalkane refrigerants it does not contribute to ozone depletion, and is therefore becoming more widely used as ozone-depleting refrigerants like R-22 are phased out. However, it has a high global warming potential of 1725 (1725 times the effect of carbon dioxide) similar to that of R-22. R-410A is also the preferred refrigerant for use in residential and commercial air conditioners in Japan and Europe, replacing R-22.

R-410A is incompatible with R-22 refrigerant. R-410A is used at much higher operating pressures than R-22 and other newer refrigerants.

New equipment that uses R-410A will require service personnel to acquire different tools and equipment, safety standards and fundamentals when installing, replacing older split A/C systems, and repairing systems in the field.

HVAC service persons need to understand the safe handling, proper charging, operating characteristics, proper applications, and general use of R-410A refrigerant.

R-410A should only be used in equipment specifically designed and constructed for higher pressure refrigerants. R-410A operates at considerably higher pressures and requires the use of special tanks, gauges and recovery equipment.

R-410A requires training of installation and service personnel in the proper and safe handling of R-410A.

R-410A needs service personnel to understand why all refrigerant flow controls, valves and driers have changed and must be properly applied with newly designed and built compressors.

Many equipment manufacturers are well aware of the concerns and safety issues of working with R-410A and other HFC refrigerants and are requiring installation and service professionals who purchase their R-410A systems to be R-410A Certified.

In order to prepare air conditioning professionals for the challenges presented by R410A, some of the major organizations in the HVACR created the AC&R Safety Coalition.

5.4.2 Physical properties R410A

Property	Value
Formula	50% CH2F2/50% CHF2CF3
Molecular Weight (Da)	72.6
Melting point (°C)	-155
Boiling point (°C)	-48.5
Liquid density (30°C), kg/m3	1040
Vapour density (30°C), air=1.0	3.0
Vapor pressure at 21.1°C (MPa)	1.383
Critical temperature (°C)	72.8
Critical pressure, MPa	4.86
Gas heat capacity @ 1 atm, 30°C (kJ/(kg·°C))	8.8
Liquid heat capacity @ 1 atm, 30°C, (kJ/(kg·°C))	1.8

For other refrigerants see **appendix 2**.

6. Recommendations/Conclusion

We will start by shortly summarising the information we have found concerning our research questions this will be followed by a general conclusion.

How does air-conditioning work on cruise ships?

Generally on Cruise ships Air conditioning will be provided by Decentralised Systems, Delivering Air conditioning to a group of cabins or areas.

What types of systems are available for air-conditioning?

Constant airflow with Reheating

A cheap system with little flexibility in provided temperature range. This system is fairly reliable but does not provide a lot of comfort to passengers.

Variable Airflow

A cheap system, this provides a modicum of control over the temperature . It's fairly reliable and provides better Air conditioning then the constant airflow system. This is not suitable for cold climates

Variable Airflow with reheating

A reasonably costly system. It provides good conditioning but is not very efficient in achieving this. it can serve each individuals passengers climate while not being overly expensive in installation costs.

Airflow regulated with water circulation

An expensive system. A high efficiency is achieved by using water circulation. It has high installation costs but good temperature control.

Air recirculation with reheating and water circulation

The most efficient and best system in our analysis. It delivers the best efficiency and air conditioning but this comes at a cost. Due to the amount of working parts more maintenance can be required

Twin Duct

A costly system that requires room for the installation. It provides good passenger comfort but isn't very efficient.

What are the differences between the air-conditioning systems?

The differences are shown in the table in chapter 4, The differences are mainly in the efficiency of the system and installation cost and the temperature range they can operate.

What differences are there regarding environmental impact?

If all the systems use the latest Freon substitutes, there is little environmental impact from those. How ever the more efficient a system is the less power needs to be generated to power the system and so the fuel consumption of a ship can be reduced. Which results in less exhaust emissions which reduces the environmental impact.

What differences are there regarding efficiency?

There are fairly big differences in efficiency that can be gotten through using centralized cooling system. A good automatic control system to regulate the entire air conditioning system can also reduce energy consumption by up to 25%.

What differences are there regarding the purchasing costs?

There are big diffrences mainly because some systems are fairly easy to install and require few complicated components while there also systems that require elaborate piping and electronics to be installed to get the most out of the system

How dependable are the systems?

Overall the systems are quite dependable in that most can operate on their own . Still the more elaborate systems can cause trouble because there are more parts that can malfunction and cause a problem.

How suitable are the systems for use on cruise ships?

The systems that are available work relatively well although some are only suitable for use in warm locations. The systems are made so that they are resistant to the high salinity in the air and the changes in climates that a normal system does not have to cope with.

In what direction are improvements on air-conditioning systems currently sought by air-conditioning suppliers?

Most improvements are currently being made in the field of automatic control of the climate system to reduce unnecessary air conditioning and supplying exactly the right amount of cooling that is required.

How is/can waste energy from the main-engines (be) used for air-conditioning systems?

When sailing in cold climates the waste energy from the engines could be used to heat the air to a correct temperature without using an electric reheating coil this could increase efficiency at the cost of installing lots of insulated piping.

General Conclusion

There are several main factors that need to be looked at when choosing an Air conditioning System. These are the climate of the places the ship is expected to sail, the size of your vessel, the amount of comfort required by the users of the system and the projected lifespan of the ship. Generally it can be said that the air conditioning options with the highest purchasing costs are environmentally friendlier because of their higher efficiency. But overall the initial costs will be won back quite quickly because of the reduced fuel consumption. Further research could focus more on the HVAC control systems, or an in depth look at the future of Cooling liquids.

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Hulpwerktuigen 1 en 2, W. Smit

Appendix 1

SEER

The SEER rating is the Btu of cooling output during a typical cooling-season divided by the total electric energy input in watt-hours during the same period.

For example, consider a 5000 BTU/h air-conditioning unit, with a SEER of 10, operating for a total of 1000 hours during an annual cooling season (e.g., 8 hours per day for 125 days).

The annual total cooling output would be:

5000 BTU/h * 8 h/day * 125 days = 5,000,000 BTU

With a SEER of 10, the annual electrical energy usage would be about:

5,000,000 BTU / 10 BTU/W·h = 500,000 W·h

The average power usage may also be calculated more simply by:

Average power = (BTU/h) / (SEER, BTU/W·h) = 5000 / 10 = 500 W

If your electricity cost is 20¢/kW·h, then your operating cost is:

0.5 kW * 20¢/kW·h = 10¢/h

1 BTU = (British Thermal Units)= 0.0002929 kW

1 Watt = 3,4121 BTU

1kW = 3414 BTU

EER

EER (Btu/(W*hr)) is converted to COP (Btu/Btu by dividing by 3.413 Btu/(Hr*W).

The SEER is calculated at a part loaded standardized ARI test. (Defined on/off cycle) This more closely represents the performance from equipment cycling, instead of the steady state conditions under which the EER is measured.

Typical EER for residential central cooling units = 0.875 X SEER
SEER is always a higher value than EER for the same equipment.

A SEER of 13 is approximately equivalent to a COP of 3.43, which means that 3.43 units of heat energy are removed from indoors per unit of work energy used to run the heat pump.

Properly maintaining the system will also result in increased efficiency. Routine changing of filters is one of the most important maintenance requirements. The wide spread use of air conditioning has created a large strain on electrical power demand especially during heat waves. Power generation is struggling to keep up with demand and brown-outs have become frequent during periods of high demand. Air conditioning efficiency takes place on an individual level, but the air conditioning industry is working to improve efficiency with improved models and the development of new technology as well.

Appendix 2

Other refrigerants:

R-401A is a HCFC zeotropic blend of R-32, R-152a, and R-124. It is designed as a replacement for R-12.

R-404A is a HCFC "nearly azeotropic" blend of 52 wt.% R-143a, 44 wt.% R-125, and 4 wt.% R-134a. It is designed as a replacement of R-22 and R-502 CFC. Its boiling point at normal pressure is -46.5 °C, its liquid density is 0.485 g/cm3.

R-406A is a zeotropic blend of 55 wt.% R-22, 4 wt.% R-600a, and 41 wt.% R-142b.

R-407A is a HCFC zeotropic blend of 20 wt.% R-32, 40 wt.% R-125, and 40 wt.% R-134a.

R-407C is a zeotropic hydrofluorocarbon blend of R-32, R-125, and R-134a. The R-32 serves to provide the heat capacity, R-125 decreases flammability, R-134a reduces pressure.

R-408A is a zeotropic HCFC blend of R-22, R-125, and R-143a. It is a substitute for R-502. Its boiling point is -44.4 °C.

R-409A is a zeotropic HCFC blend of R-22, R-124, and R-142b. Its boiling point is -35.3 °C. Its critical temperatiure is 109.4 °C.

R-410A is a near-azeotropic blend of R-32 and R-125. The US Environmental Protection Agency recognizes it as an acceptable substitute for R-22 in household and light commercial air conditioning systems. It appears to have gained widespread market acceptance under several trade names.

R-500 is an azeotropic blend of 73.8 wt.% R-12 and 26.2 wt.% of R-152a.

R-502 is an azeotropic blend of R-22 and R-115.

Year	Chemical	Quantity
1994	141b	0% (other than foam)

1996	All HCFCs	CAP = HCFCs + 2.8% CFCs in 1989
2003	141b	0%
2004	All HCFCs	65% of CAP
2010	All HCFCs 142b 22 142b, 22	35% of CAP 0% of new products 0% of new products Freeze at 2009 levels
2015	All HCFCs All HCFCs	10% of CAP Freeze at 2014 level
2020	All HCFCs 22 142b 123 124	0.5% of CAP 0% 0% 0% of new products 0% of new products
2030	All HCFCs	0% of CAP