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Air Conditioning
A Refrigeration Problem

by

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INTRODUCTION

As the climate changes and the demand for some form of air conditioning or comfort cooling increases, we are forced with the dilemma of trying to maintain a building within a comfortable range of conditions, whilst endeavouring to minimise any impact on the environment.

It is more than likely that in commercial buildings some form of mechanical cooling or refrigeration is required. Where this is necessary the Building Services Engineer should look towards the Refrigeration Engineer for assistance and guidance in selecting the most appropriate refrigeration system for a particular application.

This paper gives an overview of air conditioning, the approach to its design, discusses the problems of refrigeration and suggests how a better understanding will improve both air conditioning design and their respective refrigeration systems.

Air Conditioning

Air conditioning implies the total automatic control of the internal environment primarily for the comfort of humans.

The term is also misused in that it is often adopted to describe a simple ventilation system or comfort cooling i.e. just the control of temperature.

As summertime temperatures increase and it would appear that businesses are using more and more power to be effective, we find that to control the internal environment requires some form of mechanical cooling or refrigeration.

For thermal well being the body must lose heat at the same rate as the heat being produced. The body temperature is around 37°C db with the lungs a 37°C (wb). Changes in these conditions will affect thermal comfort.

The air conditioning designer has a range of products and systems to choose from and must have a wider understanding of all the issues when selecting the type of refrigeration system suitable for a particular application.

For the purpose of this paper we will only consider changing the air temperature and reducing the moisture content by the use of refrigeration.

Air Conditioning Design Approach

Ideally the air conditioning designer should endeavour to avoid the use of mechanical cooling if at all possible, but should it be necessary then the amount of energy required by the refrigeration system should be minimised.

The target for the air conditioning designer is to achieve his optimum internal design condition or as near as possible to it, without using any energy in the cooling process.

In reality this is highly unlikely and therefore the energy used in the cooling process needs to be minimised by effective and efficient design of the refrigeration system.

As a point of interest the air conditioning designer should in all cases carefully review internal and external design conditions in an effort to minimise the cooling load.

Low external winter conditions mean more heating is required and high external summer conditions mean more cooling is required.

The following techniques should be applied in minimizing the cooling load.

1. *Building Layout*
The orientation of a building should be such that shading is easy to achieve and use made of winter solar gains.

2. *Space Planning*
Rooms with high heat gains or where overheating would be a problem, should be sited on the north side of the building.

3. *Solar Shading*
External - a simple overhang can be very effective in blanking summer sun.
Internal - Blinds can contribute but are less effective than external shading.
Solar Glass - Reflective glass is better at rejecting solar gain.

4. *Thermal Mass*
Heavyweight structures tend to absorb heat resulting in lower peak temperatures in summer.

Night time ventilation will need consideration but It should be remembered that Heavyweight Structures will not readily release heat once absorbed.

5. *Natural Ventilation*
Ventilation will be required to maintain an indoor air quality.

The ability to increase the number of air changes by wind driven ventilation and openable windows can be an effective way of controlling overheating.

Although in some cases opening windows can in fact make matters worse by creating excessive draughts, dirt and noise, particularly in urban areas.

6. *Reduce Internal Gains*
Specify energy efficient equipment, lighting etc., switching off when not required.

7. *Latent Cooling*
Latent cooling loads i.e a change in humidity or moisture content, should be avoided if possible.

If it is not possible to eliminate the latent load then the control band for relative humidity/ moisture content should be made as wide as possible and the air conditioning control system set up to make use of the whole band.

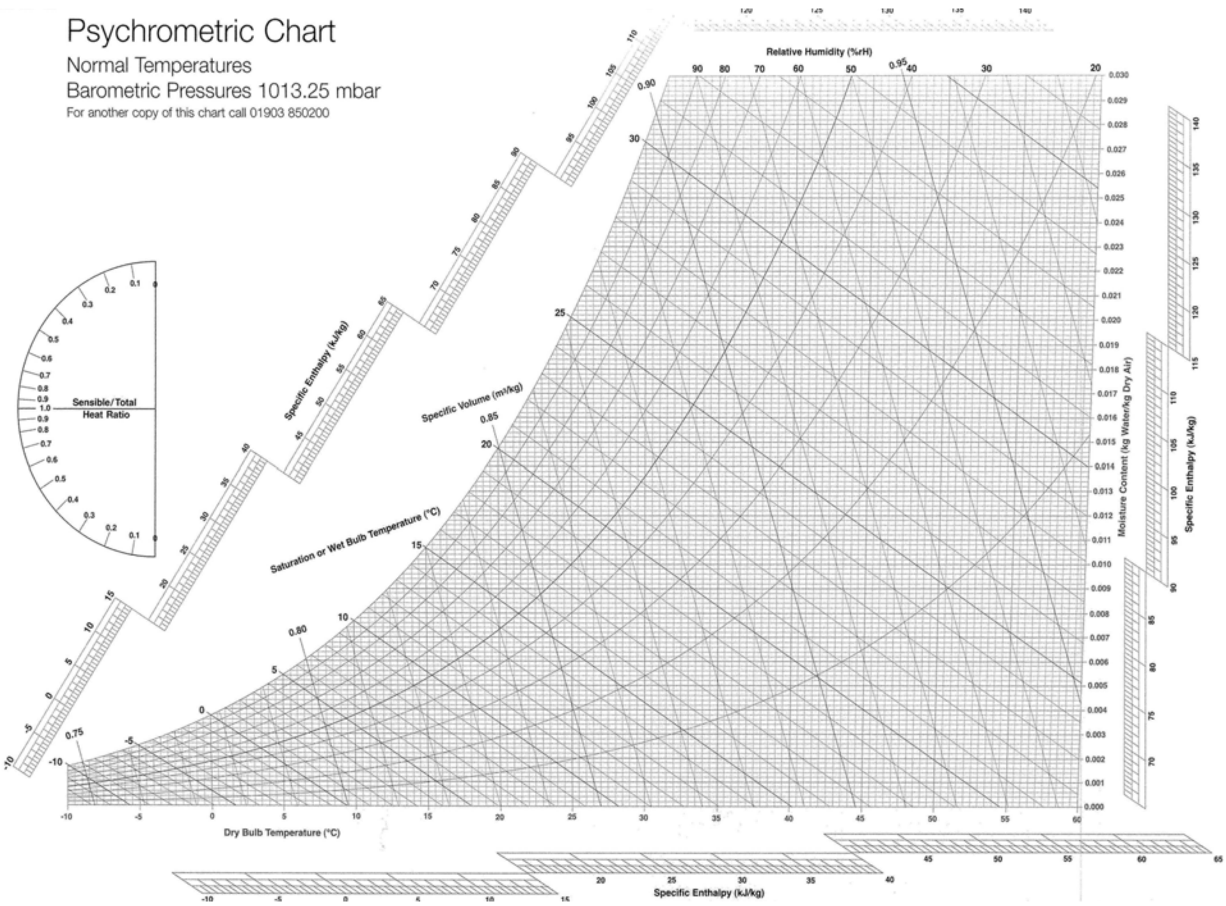

Fig. 1. Psychrometric Chart

8. *Calculation*

It is essential, particularly in view of the Building Regulations (Part L), that calculations are undertaken with care and are accurate. Figures used in heat gain calculations should not be rounded up nor should a % be added to the final loads. Inaccuracies in calculations can add to power consumption and thereby reduce efficiency. As a brief example we can look at an air cooled condenser.

In an air conditioning application a 1 degree increase in condensing temperature can increase the power input to the compressor by around 3%.

It is easy to appreciate that if under design conditions we wish to reject heat at 30°C, there is a substantial increase in power if we then simply say the refrigeration plant must be capable of rejecting heat at 35°C.

If after all the efforts of avoiding refrigeration have been exhausted and mechanical cooling is required then we must be sure that we install the most effective and efficient system.

Energy used in Cooling

The Psychrometric chart is the Air Conditioning Engineer's Mollier diagram (See Fig 1). The difference being that in refrigeration the chart plots pressure against enthalpy and in air conditioning the chart plots dry bulb temperature against moisture content for a constant barometric pressure.

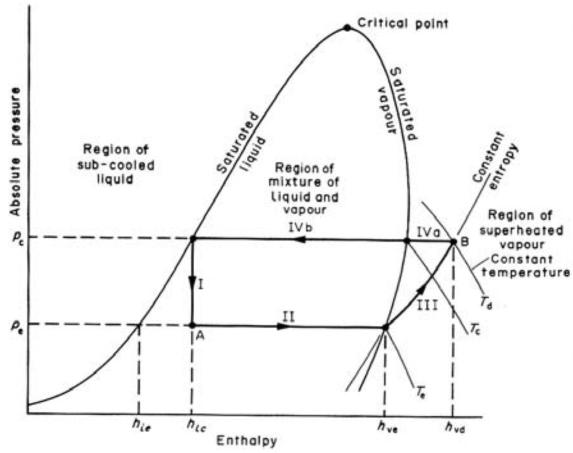

Fig. 2. Refrigeration P-H Diagram

By plotting the condition of the air before and after the evaporator means that the amount of energy required from the refrigeration system can be calculated:

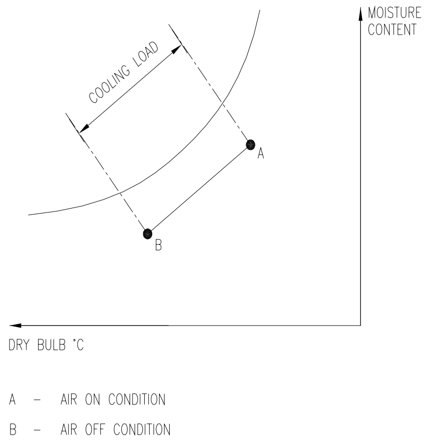

Fig 3. Cooling Load

Air on condition 30°C dry bulb/22°C wet bulb
Air off condition 22°C dry bulb/50% r h

Cooling load = Air Mass Flow x Change in enthalpy
$= M_{air} \times (h_a - h_b)$

This cooling load consists of two components – sensible and latent. As a typical example we could have the following:
For a Mass Flow of 1 kg/s

Cooling load	=	h_a - h_b
	=	64 – 43
	=	21 kW

of which 13 kW represents the sensible load and 8 kW represents the latent load

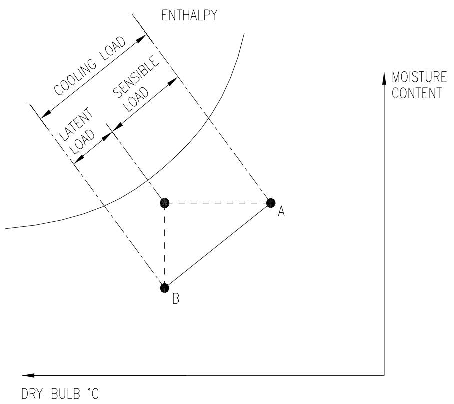

Fig 4. Sensible and Latent Cooling Loads

In the example shown the latent load represents nearly 40% of the total cooling load.

If we ignored the latent load the room condition would be:-

22°C dry bulb / 75% rh

Whilst in this example the ambient condition is outside the comfort zone (it's muggy), the point being made is that latent cooling loads are a significant proportion of the total cooling load.

Considerable refrigeration energy can be saved by widening the acceptable levels for controlling relative humidity, or simply accepting that at some times of the year the relative humidity and temperature for that matter, may be just beyond the design limitations for a short period of time.

THE REFRIGERATION PROBLEM

If refrigeration is necessary then it is essential that this system is designed efficiently and maintained correctly throughout its life.

This is the area where the air conditioning/ building services designer can work along with the refrigeration engineer to ensure the optimum system is selected.

Refrigeration

Refrigeration is the cooling of a body by transferring part of its heat away from it.

The cooling of something hot can simply be done by blowing ambient air across it.

Where a temperature below ambient air is required, or chilled water needs to be produced, then a refrigeration machine or chiller is required to take in heat at the low temperature and reject it at a higher temperature using external energy, normally electricity, to drive the process and a fluid (refrigerant) to transfer the heat.

Refrigeration System Selection

The selection and final details of the refrigeration system is not generally carried out by the air conditioning designer. It is more likely to be carried out by the manufacturer.

The information passed to the manufacturer usually consists of the air or water condition required on and off the evaporator and quantity of heat rejected, or ambient conditions at which the heat needs to be rejected, from the condenser.

The manufacturer will then usually dictate the details of component parts including the type of refrigerant to be used within the system.

The effectiveness of the selected refrigeration system may not be known, but by working together the following questions could be easily answered:-

Can we design a better system to minimise energy usage by splitting the cooling loads and making use of some form of "Free Cooling" system?

Are the component parts of the refrigeration system selected for maximum efficiency?

What is the best control philosophy to follow?

Are there any particular operating or maintenance regimes that need to be followed?

Selecting a Refrigerant

There are over a hundred categorised refrigerants, so how should we go about selecting one and what are the desired properties.

We are already aware that the commonest gases previously used in air conditioning, applications namely CFCs and HCFs, are no longer an option and we must turn to HFCs, Hydrocarbons or Natural Refrigerants. Again this is an area where the Building Services Engineer needs guidance from the Refrigeration Engineer.

In selecting a refrigerant there are a number of key issues that require consideration:-

- Zero Ozone Depletion
- Zero or Low Global Warming Potential
- Low Toxicity
- Non-flammable
- Chemically Stable
- Compatible with materials and oils
- Suitable Pressure/Temperature Relationship
  i) High Pressurisation
     Stronger components
  ii) High Pressure ratios
     mean lower energy efficiency
- High Latent Heat
  i) This determines the mass flow of the refrigerant
- High Critical Temperature
  i) This is the temperature above which the refrigerant behaves as a gas
  ii) Latent heat of vaporisation decreases as the critical temperature is approached.
  iii) The critical temperature should be way above the condensing temperature.
- Low vapour specific heat ratio
  i) This ratio determines the temperature rise during compression.
  ii) The lower the rise the better.
- Low Cost
- Availability

There is no refrigerant that matches all of the requirements, which means we have a range to choose from.

Primarily in air conditioning we choose from one of the following:-

1. *HFCs*
   R134a
   R407c (blend)
   R410a (blend)

2. *Hydrocarbons*
   R290 - Propane
   R600a - Isobutane

3. *Natural*
   R717 Ammonia
   R718 Water
   R744 Carbon Dioxide
   Air

It is normally the equipment manufacturers that selects the refrigerant but air conditioning engineers should have at least some basic understanding of the properties of the refrigerants used.

The two commonest HFC gases used in air conditioning are R134a and R410A.

R410A has higher operating pressures, requiring a high standard of component selection and assembly, but it also has a relatively high refrigeration capacity leading to a reduction in size of compressor pipework etc.

R134a tends to be selected for larger machines as its operating pressure is relatively low, but so is its refrigerating capacity – leading to it requiring larger equipment.

The Government's Policy on HFCs

The Government recognises that the successful phase out of ozone depleting substances under the Montreal Protocol, is being achieved by a range of technologies and accepts that HFCs are necessary to replace the ozone depleting substances.

In view of these the Government's position on HFCs is as follows:-

1. HFCs should only be used where other safe, technically feasible, cost effective and more environmentally acceptable alternatives do not exist.

2. HFCs are not sustainable in the long term – the Government believes that continued technological developments will mean the HFCs may eventually be able to be replaced in the applications where they are used.

3. HFC emission reduction strategies should not undermine commitments to phase out ozone depleting substances under the Montreal Protocol.

4. HFC emissions will not be allowed to rise unchecked.

Theoretically we should only consider those refrigerants that have zero ozone depletion and zero global warming potential and not use an HFC.

The Institute of Refrigeration's position is as follows:-

Energy efficiency of refrigeration systems is governed by the laws of physics and by practicality. Practicality embraces cost, cycle, legislative requirements, refrigerant choice and maintenance. Efficiency is primarily dependent on good design, selection of appropriate system, good maintenance and not on choice of refrigerant. At today's (2005) level of knowledge and expertise, practicality often leads to a choice of HFCs for good efficiency to be realistically achieved and maintained. In some applications, ammonia or hydrocarbons would be the preferred choice, but these refrigerants are not suitable for all applications. Good efficiency is vital to minimise emissions of greenhouse gases.

The key message in all of this is refrigerant choice matters, but many other design issues matter much more.

It is more important to choose a well designed highly efficient system rather than an inefficient system running on a natural refrigerant.

Coefficient of Performance

Refrigeration machines always appear to be good value for money in that they produce more in cooling than the amount of power introduced.

The ratio of heat absorbed in the evaporator for a single unit of power is known as the Coefficient of Performance or Measure of Efficiency

The higher the CoP the more efficient the machine:

$$\text{CoP} = \frac{\text{Refrigeration effect}}{\text{Work Input}}$$

$$\text{CoP} = \frac{h_1 - h_4}{h_2 - h_1}$$

The refrigerating effect = $h_1 - h_4 \cong$ Mass flow Ch. W x Cp x Δt

The power input to the compressor $h_2 - h_1$ can be measured or obtained from $M_{ref} \times (h_2 - h_1)$

To improve the CoP i.e. the efficiency of the machine, for the same refrigerating effect it is necessary to minimise the work input.

The Work Input is the difference in heat or power going into the compressor and heat or power leaving the compressor. This is related to the difference in temperature between the evaporator and condenser.

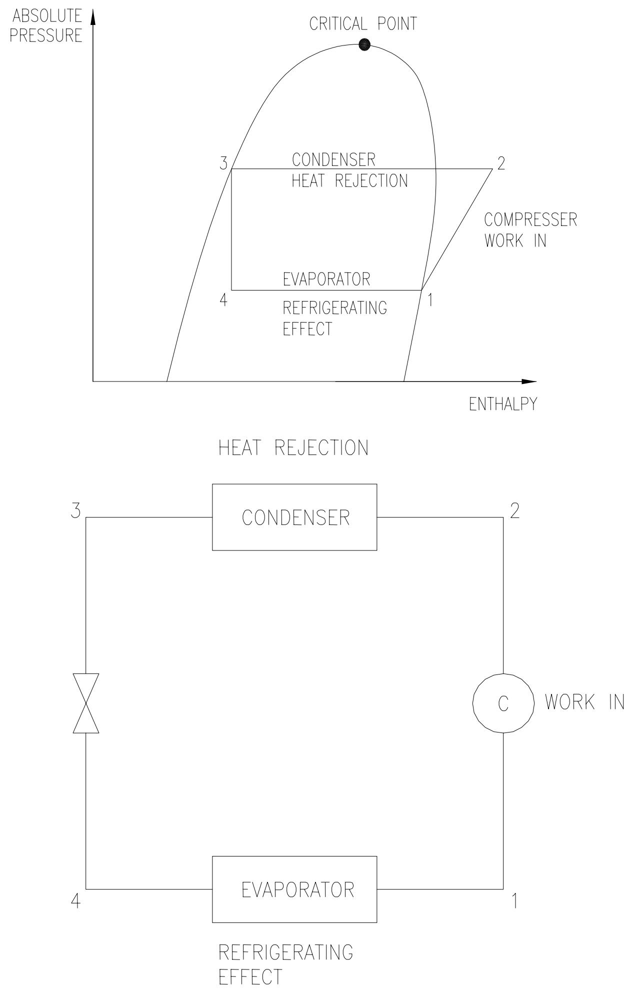

Fig 5. Coefficient of Performance

The temperature within the evaporator needs to be as high as possible, i.e. in the case of chilled water the chilled water outlet temperature should be as high as possible and the temperature of the heat being rejected at the condenser needs to be as low as possible.

All of the above points need to be considered along with the selection of component parts of the refrigeration system if we are to achieve the most effective and efficient air conditioning and refrigeration system designs.

SUMMARY

In order to achieve the best in design and the Environmental constraints imposed by the Government, it is essential that these two professionals along with their respective Institutions CIBSE and IOR work together to find a satisfactory solution to the air conditioning refrigeration problem.

BASIC REFRIGERATION TERMS

The air conditioning engineer may not necessarily understand some of the intricacies and words used in the language of Refrigeration. Similarly the refrigeration engineer may not be fluent in the language of air conditioning. The following brief list of refrigeration terms have been broken down into the lowest common denominator which may help in any translation.

Thermodynamics

1st Law

When a closed system is taken through a cycle the net work delivered to the surroundings or done on the system is proportional to the net heat taken from the surroundings or delivered to the surroundings.
or
Energy cannot be created nor destroyed, although you can move it around.
or
You can't win

2nd Law

It is impossible to construct a system which will operate in a cycle, extract heat from a reservoir and do an equivalent amount of work on the surroundings.
or
Heat can only go from hot to cold unaided.
or
You can't break even.

Coefficient of Performance

The Coefficient of Performance is stated as the ratio of the heat absorbed in the refrigerated space (evaporator) for each unit of heat energy supplied to the compressor.

$$\text{CoP} = \frac{\text{Refrigeration Effect}}{\text{Heat of Compression}}$$

or
The efficiency of the machine is the amount of cooling we can get out of every kW we put into the compressor.

Cooling Out kW : Power in kW
The higher the better

or
Amount of cooling out for every kW of power into the compressor

The Evaporator

The evaporator is a heat transfer device that allows heat to be conducted from the space or liquid being cooled to the refrigerant flowing through the evaporator
or
The device that creates the cold and turns liquid into gas (The Kettle)

The Condenser

A heat transfer device used to conduct heat from the hot refrigerant vapours leaving the compressor to the ambient surroundings.

The device that rejects the heat, that we collected in the bit that makes it cold.

The Compressor

An electromechanical device that is used to develop and maintain the flow of the working fluid through the refrigeration system
or
The pump or heart of the system.

The Expansion Valve

A modulating valve used to vary the flow of refrigerant into the evaporator based on the current thermal load
Or
Automatic Control Valve

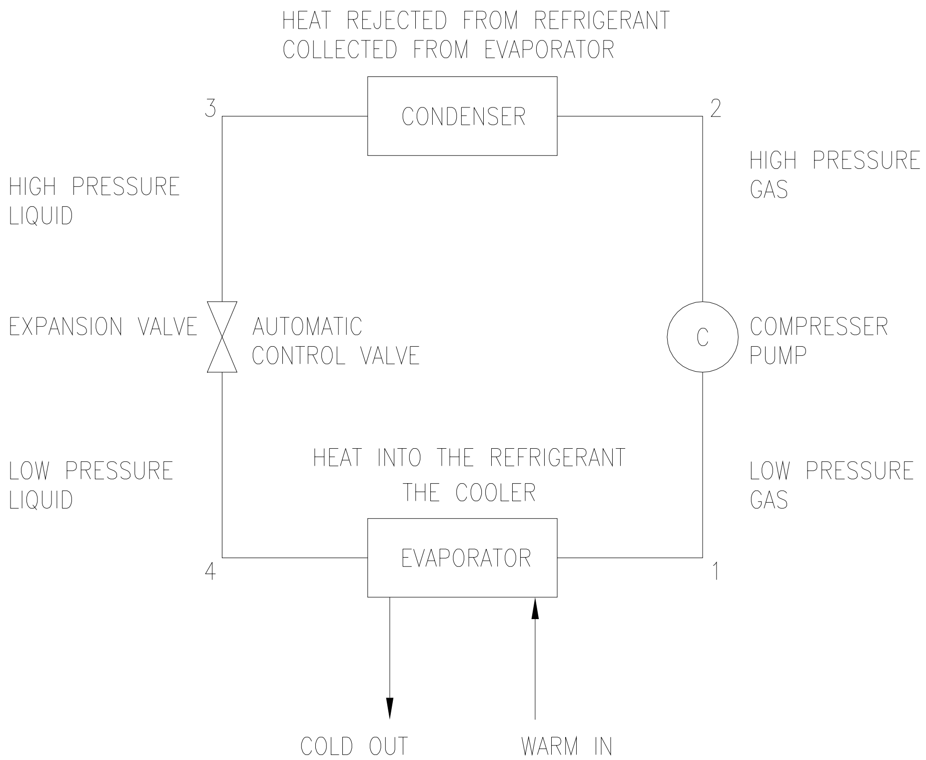

Fig 6. The Refrigeration System

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A TIMELINE OF AIR CONDITIONING AND REFRIGERATION EVENTS

BC
1000 The Chinese cut and stored ice
500 Egyptians and Indians made ice on cold nights by setting water out in earthenware pots
AD
1700 In England, servants collected ice in the winter and put it into icehouses for use in the summer.
1720 Dr. William Cullen, a Scotsman, studied the evaporation of liquids in a vacuum.
1755 Scientific recognition that expanding gases and evaporating liquids absorb heat.
1803 Thomas Moor of Maryland received a patent on refrigeration.
1805 Oliver Evans of Pennsylvania, compressed either machine, the machine is never built.
1820 Michael Faraday, liquefied ammonia to cause cooling.
1824 Attempt to ventilate a hospital in India with cool air from tunnels.
1834 Jacob Perkins, ether vapour compression cycle, Ice Making Machine.
1844 James Harrison of Australia invents compressed ether machine.
1844 Charles Piazzi Smyth built machine for comfort cooling.
1848 Dr. David Boswell Reid proposed cooling Parliament air with well water and ice.
1850 Edmond Carre of France, invents an absorption process machine.
1852 William Thomson & James Prescott cooling increases in proportion to the pressure Difference
1855 Dr. John Gorrie builds compression refrigeration system based on Faraday's experiments.
1856 James Harrison commissioned by a brewery to build a machine that cooled beer.
1859 Ferdinand Carre of France, developed the first ammonia/water refrigeration machine.
1865 Cold storage warehouse in New York.
1869 Cold storage plant installed by Charles Tellier in France.
1873 Carl von Linde first practical and portable compressor refrigeration machine was built in Munich.
1874 Raoul Pictet of Switzerland, a compressor system using sulphur dioxide instead of ammonia.
1875 Cold storage & freezing complex designed by Thomas Mort began operation in Australia.
1876 Carl von Linde, early models he used methyl ether, but changed to an ammonia cycle.
1879 There are 35 commercial oil plants in America.
1882 Thanks to Thomas Edison the first electric power plant opens in New York making it possible for the first time to have an inexpensive source of energy for residential and commercial buildings.
1888 Industrial air cooling system installed in New York building.
1889 Central station refrigeration is used in large cities to preserve foods and documents.
1894 Linde developed a new method (Linde technique) for the liquefaction of large quantities of air.
1894 Linde AG installs refrigerator at the Guinness brewery in Dublin, Ireland.
1895 Carl von Linde produced large amounts of liquid air using the Thomson-Joule effect.
1897 Institute of Heating and Ventilating Engineers founded. Now – The Chartered Institution of Building Services Engineers.
1899 Institute of Refrigeration founded as the Cold Storage and Ice Association.
1902 Willis Carrier builds the first air conditioner to combat humidity inside a printing company. Controlling the humidity in printing companies and textile mills was the start of managing the inside environments.
1902 Year round air conditioning system installed at New York Stock Exch.
1902 Air dehumidifying system designed by Willis Carrier.
1904 Public debut of air conditioning at St. Louis World's Fair.
1906 Willis Carrier patents his invention calling it an "Apparatus for Treating Air".
1906 Stuart W Cramer coins the term "Air Conditioning".
1911 Willis Carrier disclosed his basic Rational Psychometric Formulae to the American Society of Mechanical Engineers. This still stands today as the basis in all fundamental calculations.
1911 General Electric company unveiled a refrigerator invented by a French monk. Abbe Audiffren.
1913 The first exposition devoted exclusively to refrigeration is held in Chicago.
1915 Alfred Mellowes starts Guardian Frigerato to build first self-container refrigerator for home.
1917 The first documented theatre to use refrigeration is the New Empire Theatre in Montegomery, Alabama. In that same year, the Central Park Theater in Chicago is built to incorporate the new technology: air conditioning.
1920 There were some 200 different refrigerator models on the market.
1922 Baltzar von Platen and Carl Munters introduce absorption process refrigerator.
1923 AB Arctic begins production of refrigerators based on Platen-Munter's invention.
1928 The Chamber of the House of Representatives becomes air conditioned.

1929 The Senate becomes air conditioned.
1930 First built-in refrigerator is launched by Electrolux.
1930 The White House, the Executive Office Building, the Department of Commerce are air conditioned.
1931 Dupont produced commercial quantities of R-12, trademarked as Freon.
1931 The first air-cooled refrigerator introduced by Electrolux.
1936 Albert Henne synthesizes refrigerant R-2134a.
1937 More than 2 million Americans owned refrigerators.
1939 Refrigerator with one section for frozen food and a second for chilled food, introduced by G.E.
1942 Pepco becomes the nation's first summer peaking utility.
1946 After World War II, the demand for room air conditioners begins to increase. Thirty thousand room air conditioners are produced that year.
1947 GE two-door refrigerator-freezer combination.
1947 Air conditioning becomes a bargaining issue when textile workers in North Carolina strike because of stressful heat and humidity in the workplace.
1950 A major study shows that families living in air conditioned homes sleep longer in summer, enjoy their food more and have more leisure time.
1953 Room air conditioner sales exceed one million units with demand still exceeding supply.
1953 The Air Conditioning and Refrigeration Institute is formed from two associations: the Refrigeration Equipment Manufacturers Association and the Air Conditioning and Refrigerating Machinery Association.
1955 80% of American homes now have refrigerators.
1955 Mass marketing of frozen dinners begins: ads promoted "TV dinners".
1957 The first rotary compressor was introduced, permitting units to be smaller, quieter, weigh less and more efficient than the reciprocating type.
1969 Neil Armstrong and Buzz Aldrin walk on the moon in space suits with life support and cooling systems.
1973 Prof. James Lovelock reported finding trace amounts of refrigerant gas in the atmosphere.
1974 Sherwood Roland & Mario Molina predicted that CFCs would damage the ozone layer.
1977 New technology allows heat pumps to operate at lower outdoor temperatures while heating on the reversed refrigeration cycle.
1985 The "Ozone Hole" over the Antartic discovered.
1987 The united Nations Montreal Protocol for protection of the earth's ozone layer is signed. The Protocol establishes international co-operation on the phase out of stratospheric ozone depleting substances, including the chlorofluorocarbon (CFC) refrigerants used in some refrigeration and air conditioning equipment.
1990 ARI, in conjunction with the U.S. Department of Energy, initiates the Materials Compatibility Lubricants Research (MCLR) program, which helps manufacturers to accelerate away from CFC refrigerants.
1990 Roland and Molina's prediction was proved correct.
1992 The R22 Alternative Refrigeration Evaluation Program (AREP) begins a four year program to investigate alternatives to R502 and HCFC 22.
1995 Chloroflourocarbon (CFC) production in the United States ends December 31.
1997 North American Technician Excellence (NATE) formed to promote excellence in technicians who install and service air conditioning and refrigeration equipment. The NATE certified logo means the best!
1998 Research for the 21st Century, a multi-year, million dollar research program for air conditioning and refrigeration equipment, begins. The objective is to decrease building energy usage while improving indoor air quality.
1998 Shipments of unitary air conditioners and heat pumps set a record of more than 6.2 million units.
1998 After receiving five annual awards from the U.S. Environmental Protection Agency for contributions to environmental protection, ARI was awarded a Best of the Best award for continued environmental concern.
2005 A domestic refrigerator is present in 99.5% of American homes.