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# Report on the Compression Chillers

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## Introduction

There are many benefits involved when considering compression chillers as one of the key components of preferred systems' cooling devices. Compression chillers also called centrifugal chillers or mechanical chillers have very few moving parts. Therefore, they usually offer high reliability and low maintenance requirements (more about the processes and machine types in the theory section). Vapor compression chillers that use electricity are the most commonly used chiller types in the world today with higher COP (Coefficient Of Performance, (more abbreviations are in the chapter of general solution assessment)) and higher value (2-5 or more [1]) than absorption chillers (0,6-0,8 or slightly more). It is important to understand that chillers are actually a part of a chilled water system. Thus the efficiency and control of cooling towers and pumps have a significant role in determining the overall efficiency.

In a typical commercial application a central chilled water plant, consisting of one or several chillers, produces chilled water. A chiller is often run at less than optimal operating efficiencies during its useful life. Optimizing a chiller requires a thorough understanding of the operating parameters that affect the efficiency of a chilled water system. In addition what steps are the most suitable to improve chiller operation.

One very interesting application is a hybrid electric-steam chiller plant. It has its advantages. The ability to use electricity or steam gives the flexibility to manage the energy costs better. In the United States there has been at least one target for this kind of approach. The project manager for this venture has had positive experience about the matter. His analysis projected a life-cycle operating-costs advantage with the hybrid plant (vs. an all-electric plant), because of some considerable annual savings (5%). Not even thermal energy storage usage was needed according to calculations.

Heat driven absorption cooling is an environmentally friendly way to produce cooling as it reduces the use of electrically driven compression chillers in the energy system. Trigeneration systems (combined production of power, heating and cooling) have a potential to further increase the electrical yield and reduce the $CO_2$ emissions. Using absorption chillers reduces the need of electricity for cooling. The results show the importance studying the energy system as a whole and not only the separate component.

## Theory

The refrigeration cycle of a simple mechanical compression system is shown below. The mechanical compression cycle has four basic components through which the refrigerant passes: (1) the evaporator, (2) the compressor, (3) the condenser, and (4) the expansion valve. The evaporator operates at a low pressure (and low temperature) and the condenser operates at high pressure (and temperature).

The cycle begins in the evaporator where the liquid refrigerant flows over the evaporator tube bundle and evaporates, absorbing heat from the chilled water circulating through the tube bundle. The refrigerant vapour, which is somewhat cooler than the chilled water temperature, is drawn out of the evaporator by the compressor. The compressor "pumps" the refrigerant vapour to the condenser by raising the refrigerant pressure (and thus the temperature). The refrigerant condenses on the cooling water coils of the condenser giving up its heat to the cooling water. The high-pressure liquid refrigerant from the condenser then passes through the expansion device that reduces the refrigerant pressure (and temperature) to that of the evaporator. The refrigerant flows over the chilled water coils absorbing more heat and completing the cycle.

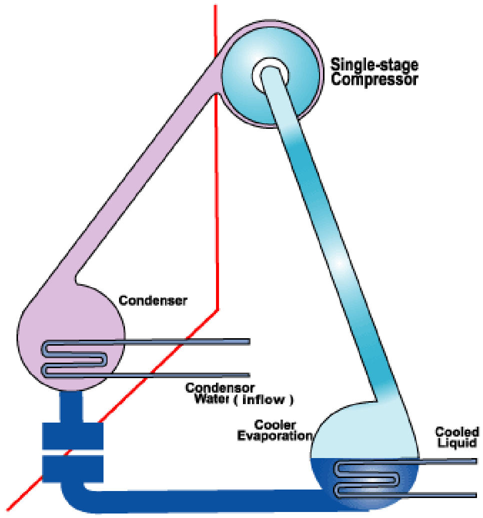


**Figure 1 Centrifugal single-stage compressor** [2]

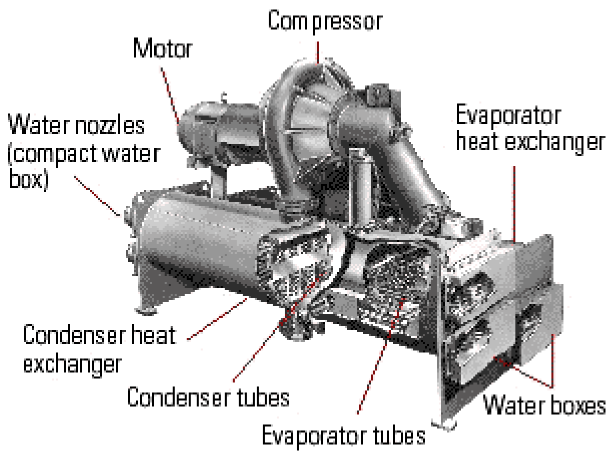


**Figure 2 Centrifugal chiller cutaway** [3]

Mechanical compression chillers are generally classified by compressor type: centrifugal, reciprocating and screw.

**Centrifugal** – This type of compressor raises the refrigerant pressure by imparting momentum to the refrigerant with a spinning impeller, then stopping the flow in a diffuser section around the impeller tip. They are noted for high capacity with compact design. Typical capacities range from 100 to 10,000 tons.

**Reciprocating** – This is a positive displacement machine that maintains fairly constant volumetric flow over a wide range of pressure ratios. They are almost exclusively driven by fixed speed electric motors.

**Screw** – The screw or helical compressor is a positive displacement machine that has a nearly constant flow performance characteristic. The machine essentially consists of two matting helically grooved rotors, a male (lobes) and a female (gullies) in a stationary housing. As the helical rotors rotate the gas is compressed by direct volume reduction between the two rotors.

## General solution assessment

Maximizing the efficiency of the chiller alone does not ensure the efficient operation of the system. To optimize the cost-effectiveness it is recommended to analyze the entire chilled water system as well as exercising care in specifying the efficiency of the chiller itself.

Centrifugal chillers are available in sizes ranging from 70 to 2,500 tons factory-assembled and up to 9,000 tons field-assembled. They use HCFC-123, HFC-134a, or HCFC-22 refrigerants. Chillers that use HCFC-123 currently have the highest efficiencies. Although full-load efficiency is often cited in the sales literature [3] and in the energy codes, it is usually not the most important metric of efficiency in practice. Because most chillers rarely operate under full-load conditions (1%), it is usually more important to consider chiller efficiency at "off design" conditions when the chiller delivers only a fraction of its full cooling capacity.

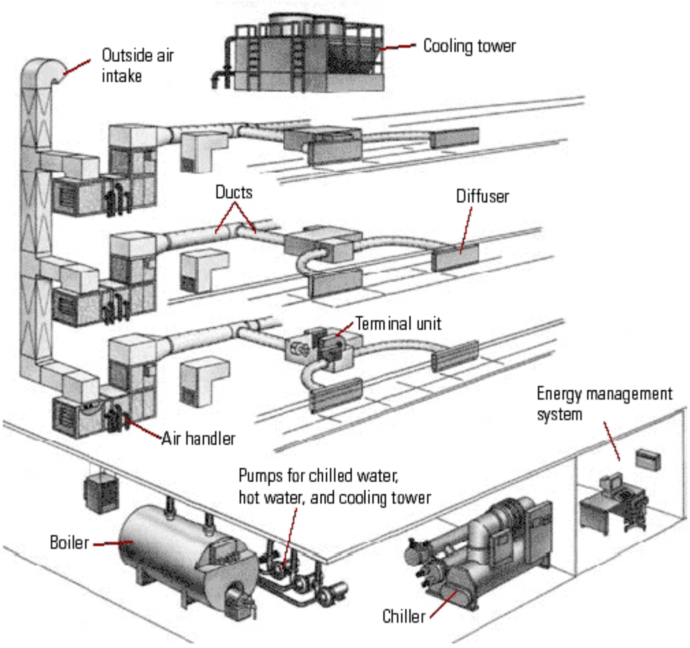


**Figure 3 Components of a typical chilled water system** [3]

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|---|
| **Chiller Terminology** |
| **Tons:** One ton of cooling is the amount of heat absorbed by one ton of ice melting in one day, which is equivalent to 12,000 Btu/h or 3.516 thermal kW. |
| **kW/ton rating:** Commonly referred to as efficiency, but actually power input to compressor motor divided by tons of cooling produced, or kilowatts per ton (kW/ton). Lower kW/ton indicates higher efficiency. |
| **Coefficient of performance (COP):** Chiller efficiency measured in Btu output (cooling) divided by Btu input (electric power). Multiplying the COP by 3.412 yields the energy-efficiency ratio. |
| **Energy-efficiency ratio (EER):** Performance of smaller chillers and rooftop units is frequently measured in EER rather than kW/ton. EER is calculated by dividing a chiller's cooling capacity (in Btu/h) by its power input (in watts) at full-load conditions. The higher the EER, the more efficient the unit. |
| **ARI conditions:** Standard reference conditions at which chiller performance is measured, as defined by the Air-Conditioning and Refrigeration Institute (ARI): 6.6°C for water leaving the chiller and, for water entering the condenser, 29.5°C at 100 percent load and 15.6°C at zero percent load. |
| **Integrated part-load value (IPLV):** This metric attempts to capture a more representative "average" chiller efficiency over a representative operating range. It is the efficiency of the chiller, measured in kW/ton, averaged over four operating points, according to a standard formula. |

**Table 1 Chiller Terminology** [3]

The amount of cooling towers depends of the sizes of our chilling devices. Normally a standard 1000 ton (3,5MW) chiller installation requires one cooling tower [4]. Modern cooling devices can exploit also lower ECWT (entering-condenser-water temperature). This asset can be taken account when deciding whether to buy thermal storages or cooling storages (cooling towers). There are also some other prospects to be taken to account when evaluating the need of thermal storages. An article on HVAC (heating, ventilation and air conditioning) engineering magazine [5] revealed that in a basketball arena type of installation (USA: near Maryland's University) it was not a very good solution to install thermal storage. The costs would have been too high and the scenery would have been spoiled.

The general solution assessment to chilling (and heating) installations implied that it might be a good idea to consider separate pipes to consumers rather than have distributed absorption chillers for every costumer. I have made this evaluation solely on the experience of a Finnish company "Helsingin Energia". It supplies heating, cooling and electrical support to ordinary and industrial costumers in the area of Helsinki. It has a good reputation in keeping its energy supply level high, no breakouts, and it has relatively cheap electricity. So I trust their assessment to use separate chilling and hot watering pipes to meet the need of their consumers. One has to remember though that in Finland it is useful to go with this kind of approach but in other colder (northern Russia) or hotter countries (Egypt) it is worthwhile considering a different kind of approach. Also the amount of users in the area affects the general solution application.

It is not a straightforward task to choose which chiller installation to buy. It is good to assess chillers at a variety of efficiency levels to determine the best purchase. Annual costs of chillers are high, so modest improvements can yield substantial energy savings. Lower savings might be anticipated if one uses the chiller less than normally. Other important subjects in buying the chiller are for example comparing chillers under the conditions they are most likely to experience and using computer simulations (e.g. DOE-2) to model building cool loads throughout the year. If you are thinking of getting multiple chiller installation it is recommended to select unequally sized machines. Having the option of switching between plants with different capacities will result in a more efficient operation than if one or two same-sized chillers were operating at a lighter load. Though in this case I understand that the other is for the base load and the other is for

the emergencies. One should also consider buying a chiller with a variable frequency drive (VFD) to maximize the part load efficiency and the energy savings.

## Characteristic features of the selected compression chiller

The best alternative to a steam-driven absorption chiller is an electrical compression chiller. Our group has selected a company that provides chilling equipments. This company, YORK, is one of the largest in the world in this specific industry. My task was to choose a proper compression chiller from YORK's selection. One chiller type rose above the others. This chiller is called "YORK® MaxE™ Electric-drive Centrifugal Chiller" [6] and it is in the capacity range of 250 to 6000 TR.

YORK® MaxE™ electric-drive centrifugal chillers provide the best route to a real-world energy performance because 99% of the time chillers in the world operate at "off design" conditions. It is therefore a major factor in the energy consumption. The ARI chiller certifigare program endorses the validity of off-design analysis to compare chiller energy consumption. A selected chiller with a variable-speed drive can reduce the energy –usage rations to new lows: 0.40, 0.30 and even 0.20 kW/TR at off-design conditions and annual savings of 30 %. MaxE centrifugal chillers are equipped with an "OptiSpeed drive" (YORK's VFD) that continually optimizes the chiller operation. Optispeed drive has also the ability of an adaptive capacity control, a good connectivity to multiple-chiller plants and the effect of reducing the motor heat alongside with the electric-current harmonic distortion. This drive also causes lower noise levels, up to 10 decibels.

Unlike the competitive chillers that require ECWT from the cooling tower to be held artificially high, YORK's MaxE centrifugal chillers can utilize a lower ECWT. MaxE chillers feature the OptiView control centre, which uses microprocessor capabilities to save your energy. It has a resolution of 0.05 centigrade and as a result one can eliminate the energy wasted by drifting a degree or more from the set point. A plain-language-display Control Centre with a full-colour and code-free enables the efficient usage of MaxE centrifugal chillers. Detailed logs can be read directly from the screen or printed form the printer without interfacing through a BAS (building automation system) system. It is also possible to connect this chiller with BAS, which gives more possibilities.

YORK® MaxE™ electric-drive centrifugal chiller option gives you the flexibility to meet virtually any application need you may encounter. The HFC-134a refrigerant used in this type of chillers is an environmentally responsible solution. It has a zero ozone-depletion and no phase-out schedule. An open-drive design allows quick and economical changeovers to alternative refrigerants in the future. Certain jobs require a chiller to operate beyond the limits found in typical air-conditioning applications. YORK meets this challenge with a compound-compressor design that handles brine chilling, heat pump applications, and other unusually demanding applications.

## Comparative study of the compression versus absorption chillers

An absorption chiller uses heat as the driving energy, as compared to vapor compression chillers (the most used type in the world) that use electricity. A potential disadvantage with the absorption chillers is the low COP compared to compression chillers' COP. Another setback for an absorption chiller is the need for external cooling (discussed also in the general assessment chapter[1]) to cool the absorber and the condenser. Compression chillers do not need that much cooling. Despite of these setbacks an absorption chiller is a device worth considering. It

might come more economical because it uses steam instead of electricity. It is also more environmentally friendly due to usage of water as the refrigerant and the waste heat usage that lowers the $CO_2$ emissions. Previous studies show [IEA, 1999; Rydstrand, 2004] that the use of waste heat in the absorption chillers could save considerable amounts of the primary energy being a so-called thermodynamic shortcut. Maidment (et al) [1999] investigated CHP including absorption cooling for supermarket applications. In this study, approximately 20 % of the primary energy savings were obtained and the $CO_2$ emissions were lower.

It is important to remember that there are risks of losing revenue if the production of heating and cooling is not optimized together. From an economic perspective, the optimal choice for cooling technologies is a combination of absorption cooling and compression cooling. In general, the absorption chillers are used for base load during periods when there is a surplus capacity. Other studies show that it is not economical to move the shutdown period from summer to spring. This is so because we want more waste heat for the absorption chillers during summer. Also an optimal scheme for shutdown is possible to find using absorption chillers.

The level of the electricity price can influence the amount of the absorption cooling. A high electricity price will then favor the use of the absorption chillers compared to the compression chillers. The results indicate how the energy system affects the choice of cooling applications and vice versa, which shows the importance of studying the dynamics of the overall energy system instead of studying the components by themselves. An integrated district heating and a cooling system gives possibilities to reduce the $CO_2$ emissions. Also the possibility of using an absorption machine has been investigated for multipurpose. For example an absorption chiller could be used as a pump in the winter and chiller in the summer.

## Conclusion

Depending on the local energy costs and the rate structures, a combination of electric and non-electric chillers can provide the lowest life-cycle cost. Of course, none of the chiller plants are identical, or are their energy costs, so determining the optimum chiller combination and the best operation strategy involves complex calculations [7]. Fortunately cost analysis software programs can analyze multiple variables quickly and help narrow equipment selections. These programs can perform a sensitivity analysis to show the effect of the fluctuating energy costs and help determine, for example, the crossover points to switch from an electric chiller to steam chillers.

The different aspects of the absorption chillers and the compression chillers are relatively plain. Broadly speaking the absorption chillers generally are more cost-effective at capacities less than 1000 tons (3500 kW), while the (steam-turbine) centrifugal chillers are generally more cost-effective at capacities 1000 tons (3500 kW). The use of steam involves more piping connections in addition to the usual chilled and condenser water piping. Microcomputer control centers have become standard features on both chiller types, permitting sophisticated control capabilities.

One has to consider also the off-design performance. Variable speed drive can enhance the efficiency in off-design conditions. This combined with a low ECWT usage enables the compression chillers become more effective. If electrical compression cooling is compared with an absorption cooling driven by heat-focuses CHP's, compression cooling is more favorable (if COP>5). From the perspective of the $CO_2$ emissions, the compression cooling is shown more favorable only in certain conditions (grid is BAT (Best available technology), COP>1.5), otherwise

the absorption cooling. If the electrical compression cooling is compared to the absorption cooling driven by electricity-focused CHP's, then the electrical compression is more favorable (COP>6.1). If the COP is less then absorption is more favorable. This is true also from the perspective of the energy efficiency as well as $CO_2$ emissions. This statement applies regardless of which reference scenario is chosen for electricity grid.

The main idea is that you can install the highest-efficiency chiller available in your building, but if it is a part of an inefficient system, you will not capture all the benefits of the chiller. You need to optimize the entire chiller system to reap the best savings.

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