Meeting Industries Increasing Sustainability Demands by Utilising Water as a Refrigerant
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Abstract

An energy efficient water chiller (R718) has been developed in Germany by Efficient Energy using unique and innovative technology. A paper detailing the technology was delivered to the Institute back in 2015 when the chiller was in the final stages of development and a lot has happened since then.

Over the last 5 years the technology has moved through the development stage and has now built a solid customer portfolio with scaled production and growing demand. The drivers in the market have changed somewhat since 2015 and we now see a real intent across various sectors to reduce energy costs and importantly also reduce carbon emissions. The result of this sustainable focus has created a chiller using water as the refrigerant which can provide real benefits to the user. This paper is intended to provide a 2021 update showing how R718 is now a practical proven method of delivering higher flow temperature cooling.

1. Introduction

The main components of the water refrigerant chiller have not changed since the presentation to the institute in 2015.

The first IOR paper in 2015:
Development – 2006 to 2015

Market launch of the eChiller35 and eChiller45 in 2015

The technology now:
eChiller120 model

Like any other chiller a system using water as its refrigerant works on the principles of evaporation, compression, and condensation.

(eChiller is a R718 Water Chiller and is used within this report as a representative example of the technology).

In terms of differentiation, the important change from conventional plant is that the refrigerant being used here is water and the R718 Chiller functions with a very low operating pressure within the refrigeration system.

From a legislation perspective, Refrigeration Equipment Safety Standard EN378 Certification is not required due to the low operating pressure of the chiller and because there is no risk of F Gas refrigerant leaks (no F GAS required) no leak detection equipment or F Gas monitoring procedure is necessary.

In comparison to other natural refrigerant choices Water R718 arguably has the highest level of availability and sustainability with a high level of attraction to the user for a number of reasons. Importantly a R718 based system, as noted above, has no PED certification requirement, no risk of flammability or any of the standard considerations where DSEAR assessments are concerned.

With regard to the attraction of Natural Refrigerants, industry is more than aware of the F Gas phase out and the increasing focus that this is placing on the selection and use of Low GWP and Natural refrigerants. Hence in this context R718 provides a refreshing opportunity and is able to deliver the most sustainable cooling system with a completely benign refrigerant.

Whilst R718 as a refrigerant is an attractive proposition due to its environment credentials, the main question is how efficient is the chiller. This paper looks to examine the technology and identify the application drivers that could encourage wider application including:

Why consider R718?

- Environmentally benign
- Natural refrigerant
- No PED certification
- No DSEAR considerations
- High performing and efficient
- SEER 16

What are the application considerations?

- Operating range
- Minimum 15°C leaving water temperature

Where can a R718 Chiller be used?

- High chilled water temperature systems
- IT and data cooling
- Comfort cooling i.e. Chilled Beams
- Production/manufacturing cooling

The main point to consider is the viability of the technology and to consider where the opportunities lie with regard to the R718 Chiller and its current point on the development scale. Considering that over 120 x R718 Chillers are now in operation, and have been successfully applied for over five years, the technology can be accepted as being proven and validated in terms of both reliability and efficiency.

Environmental and sustainable benefits provide an obvious and important reason to consider a R718/Water Refrigerant Chiller but in addition the energy and carbon savings that can be achieved in comparison to standard refrigerants are also highly relevant.

This paper will examine efficiency data within applications covering IT/data cooling and manufacturing applications in order to fully understand the complete range of benefits available.

It is important to consider how industry will be able to apply this technology when at present water is associated with air to air evaporative cooling and not within the context of a water chiller.

The market sectors where a R718 chiller would be used provide a genuine opportunity to apply highly efficient cooling systems that deliver the most sustainable refrigerant choice. But it is also clear that the application of this technology is key to user adoption.

2. Main Section

R718 Chillers are available in capacities of 45kW and 120kW and are able to operate in single unit or parallel configuration to deliver completely scalable installations.

The illustration below shows a typical R718 Chiller application with a roof mounted adiabatic cooler and Chillers located within each floor of a building as per Figure 1.

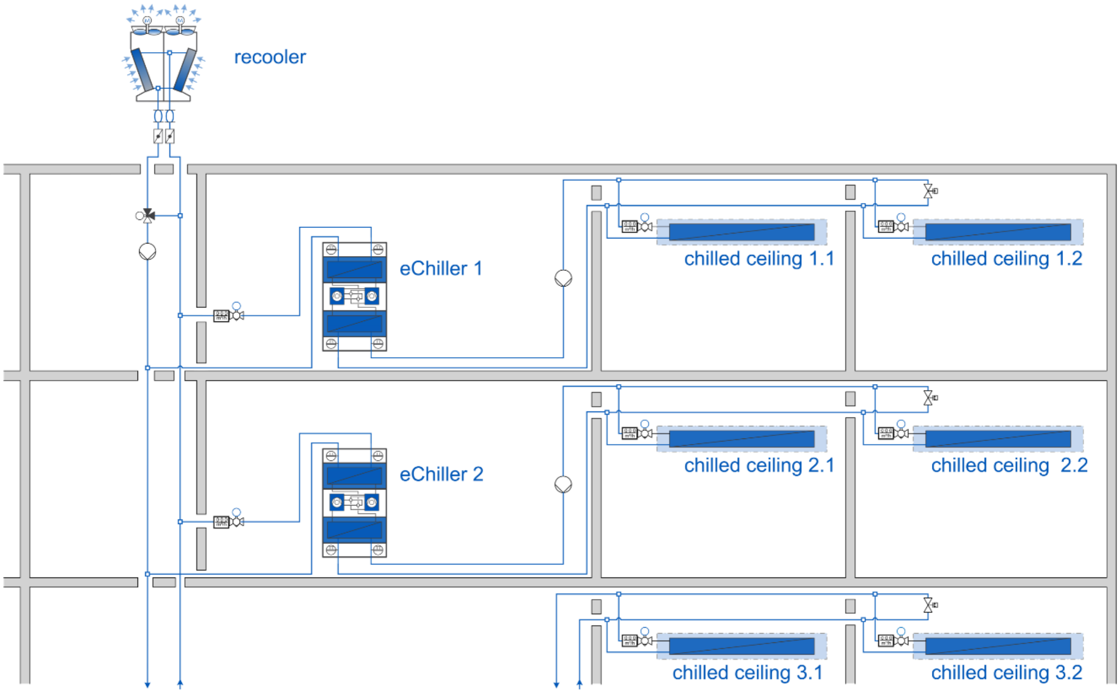

Figure 1. Central Adiabatic Cooler supplying 2 x internally located R718 Chiller units (eChiller)

The method of operation is very simple, the system is a two part combination of R718 Chiller and Adiabatic Cooler. This enables flexible plant location and very low noise levels to be achieved both internally and also externally as illustrated within Figure 1.

When using R718 in a chiller, the safety systems detailed in EN378 do not apply for the pressure system, ventilation, and gas detection systems.

A typical twin R718 Chiller installation with n + 1 configuration is illustrated within Figure 2.

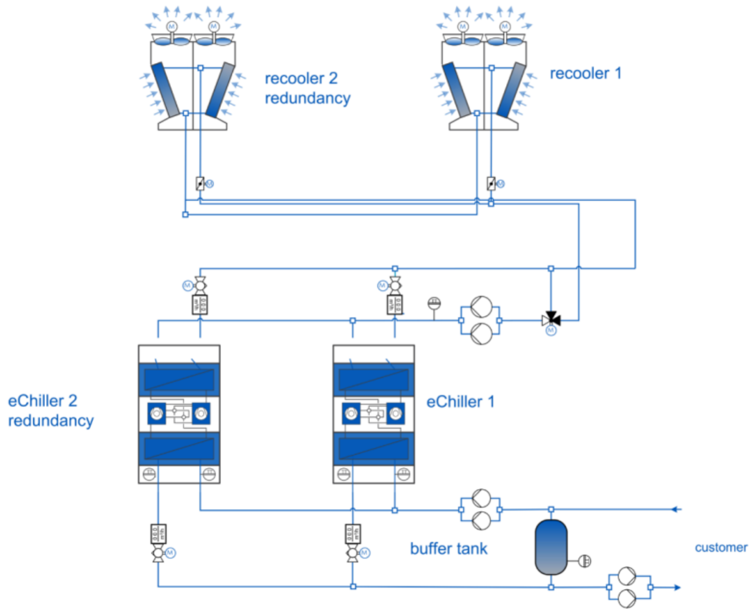

Figure 2. Typical n+1 R718 Chiller configuration

In general, compression refrigeration systems using water as a refrigerant essentially consist of the same components as conventional compression refrigeration systems: an evaporator, condenser, compressor, and expansion element. The heat source and sink are the two interfaces for heat transfer in the compression refrigeration system.

Water enters the evaporator, where around 1% of the water evaporates, drawing energy from the remaining water and cooling it down. The pressure inside the evaporator is around 18mbar (0.26psi). In the compressor, the pressure is then increased to 136mbar (1.97psi) and the temperature rises from 16°C to 52°C. The next stage being that the water vapour is cooled down, condensed, and fed back into the evaporator through the expansion device to complete the refrigeration cycle. The Chiller is connected to a matched means of heat rejection to deliver a water-cooled system. The heat rejection circuit can be a dry cooler or adiabatic cooler. Alternatively the R718 Chiller can operate using a centralised condenser loop installed within a potential application such as a cooling tower circuit or similar.

The dry/adiabatic cooler or condenser circuit, also enables the eChiller to operate in 100% free cooling and free cooling mix mode.

The free cooling function is integrated in the unit, no extra installations are necessary. The benefits of free cooling take place at a much earlier point than as would be the case with standard free cooling HFC F Gas chillers as noted below.

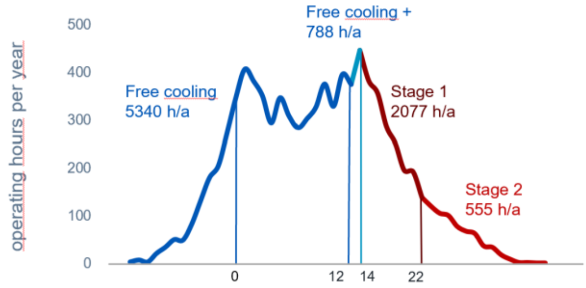

Figure 3. R718 Chiller operating mode profile

Actual efficiency is obviously subject to the cooling load profile of each individual project, however this mix of mechanical and free cooling results in the eChiller system delivering a very high combined annual efficiency SEER level in excess of 16 (in representative Southern UK ambients).

In the 0°C – 100°C temperature range, which is theoretically suitable for water, the vapour pressures are below normal atmospheric pressure.
This requires operation in a rough vacuum of between approx. 10 and 1,000 mbar. In terms of the heat-source and heat-sink design, a distinction is possible between two different concepts: concepts with internal (Figure 4) and external (Figure 5) heat exchangers.

Both configurations are intrinsically identical and consist of a refrigeration module and the required heat exchangers. The refrigeration module contains the evaporator, compressor, condenser, and control system.

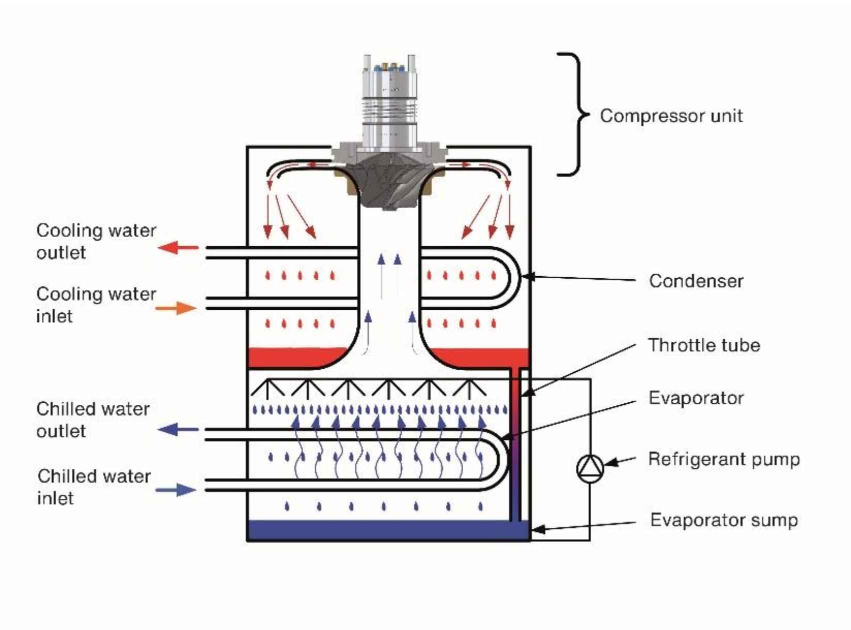

Figure 4. Internal Heat Exchanger system

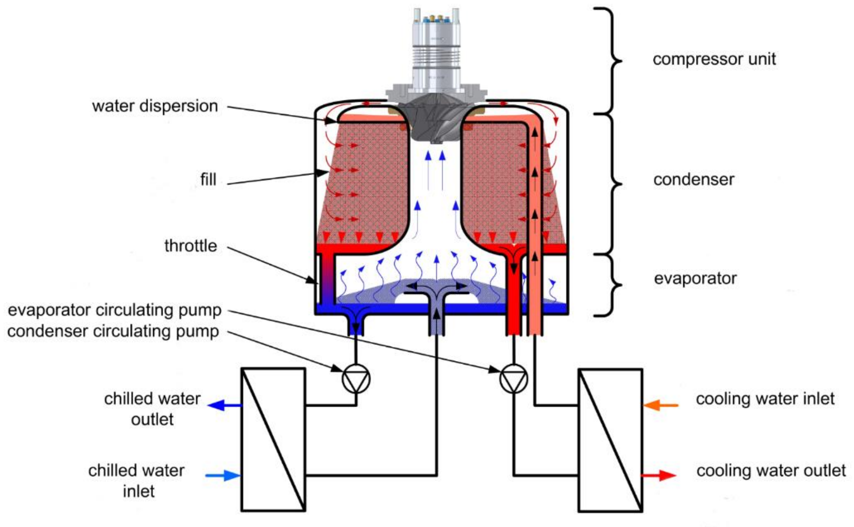

Figure 5. External Heat Exchanger system

A closer look at the external heat-exchanger concept (Figure 5) shows that the heat transfer between the refrigerant and the chilled/cooling water takes place outside the refrigeration module in the two plate heat exchangers in the liquid phase.

The actual evaporation, i.e. the phase change, occurs in the evaporator area of the refrigeration module. After compression, the vapourised refrigerant is fed into the condenser area. Here, the vapour flows together with liquid refrigerant through a packed bed. In the process, the gaseous refrigerant condenses entirely at the interface with the liquid refrigerant. The circuit is closed via the self-regulating throttle element. A circulation pump is required for the circulation of the liquid refrigerant in both the evaporator and condenser circuits.

The concept using the internal heat exchangers (1.4.) differs in the location of the heat exchangers. The heat transfer between the refrigerant and the chilled/cooling water occurs within the refrigeration module. The chilled/cooling water flows through the inside of the ribbed tube heat exchangers integrated into the refrigeration module. Evaporation and condensation take place on the outer surface of the respective heat exchangers. This means that the two circulation pumps between the heat transfer point and the evaporator or condenser are no longer needed. Only a single refrigerant pump is required for evaporation within the R718 Chiller.

When considering performance we must examine installations that can provide reliable comparative data which enables the application benefits of the R718 Chiller to be understood.

With this in mind, a R718 Chiller installation for datacentre cooling is considered at the German Aerospace Centre (DLR) in Southern Germany (Figure 7). The performance of this R718 Chiller is shown below (Figure 6) and identifies a circa 50% energy saving in comparison to a R290 Chiller with free cooling functionality. Hence, this is a like for like comparison where both Chillers are operating in a similar configuration.

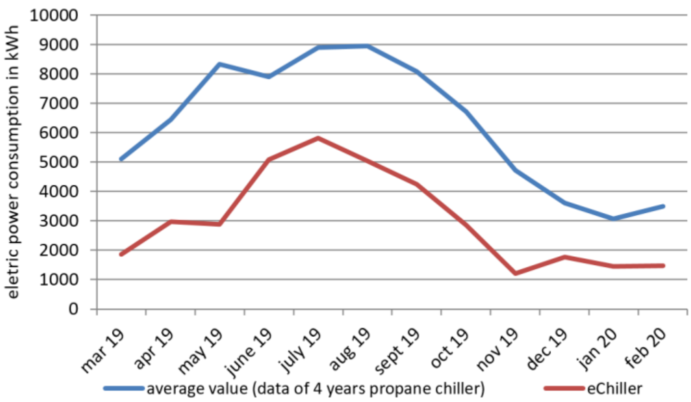

Figure 6. Comparison of performance R718 (eChiller) vs R290

Figure 7. The installed R718 Chiller at the German Aerospace Centre

When the performance of an R718 Chiller is considered standard Ecodesign methods cannot be used due to the leaving temperature of an R718 Chiller being at a level of 16°C rather than lower temperatures used within the standard.

However if the Ecodesign operating profile is used the Annual efficiency is produced as shown within Figure 7.

Q. 30kW	External ambient	40°C	30°C	20°C	17°C	13°C	7°C
CHW 16°C	Operating mode	double-stage	double-stage	single-stage	single-stage	FC plus	FC
Operating hours		28	308	951	1611	774	5087
R718 power input kW		10,5	7,37	3,89	3,09	1,16	0,35
Adiabatic Cooler power input in kW		0,42	0,42	0,42	0,42	0,42	0,1
CHW pump power input in kW		0,2	0,2	0,2	0,2	0,2	0,2
CW pump power input in kW		0,4	0,4	0,4	0,4	0,4	0,4
Power input total in kW		11,52	8,39	4,91	4,11	2,18	1,37
System Efficiency		2,6	3,58	6,11	7,3	13,76	21,9
Annual EER	16.07						

Figure 7. Annual EER figures are based on the Ecodesign standard operating profile

The illustration shown above is based on a R718 Chiller operating within a 30kW cooling application at a 16°C flow temperature (CHW) with adiabatic cooler (CW).

FC = Free Cooling
FC Plus = Free Cooling + partial mechanical cooling via first stage
Single Stage = First stage operation
Double stage = First + second stage operation

3. Conclusions

In conclusion it is apparent from the application of higher output temperature R718 Chillers, that are operating within various applications across a number of industry sectors, indicates that this technology is practical from both specification and operational perspectives.

As industry starts down the path of encouraging higher operating temperature cooling systems that less standard opportunities arise to create applications for refrigerants that sit outside the normal scope of application.

This is particularly the case with R718, however as a sustainable and environmental choice water is at the front of the refrigerant pack for the clear and obvious reasons noted within this paper.

As noted, the Annual Efficiency of an R718 Chiller is identified as being circa 16 within the application examples and testing scenarios carried out in producing this report.

Additionally the Free Cooling energy saving benefits of this unit in comparison to more conventional refrigerants is noted in Figure 3 showing that the Technology is particularly suited to UK climatic conditions where Free Cooling savings provided via a suitably specified R718 Chiller would be significant.

The caveat must be stated around the application specific nature of the higher flow temperatures necessary when applying an R718 Chiller, but this should definitely not stop this technology from taking its place as a practical and efficient refrigerant choice.

Considering the success to date of R718 Chillers in the field would certainly indicate that there is market acceptance of the technology.

This illustrates that applications which are able to drive chilled water temperatures to more efficient higher levels can benefit from using this technology and hence utilise what is arguably the most sustainable refrigerant choice.

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Submitted by Pure Thermal Ltd as the UK partner for Efficient Energy GmbH.

Efficient Energy is a developer and manufacturer of R718 based cooling systems with a manufacturing facility located in Southern Germany.
Pure Thermal is a specialist UK provider of Natural Refrigerant Chillers and Heat Pumps.