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# THE PART-LOAD EFFICIENCY BENEFIT OF OIL-FREE, HIGH-SPEED, DIRECT-DRIVE CENTRIFUGAL COMPRESSORS

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## ABSTRACT

This paper will present a seasonal energy efficiency analysis of a water-cooled chiller with multiple oil-free, high-speed direct-drive centrifugal compressors and compare the results against the seasonal energy efficiency that can be expected from water-cooled chillers with screw and scroll compressors.

It will be shown that the fixed built-in compression ratio of screw compressors limits the compressor efficiency at the lower-lift off-design conditions where chillers operate most of the time while the variable speed direct drive centrifugal compressor maintains its peak efficiency at off-design conditions.

Following the Air-Conditioning, Heating and Refrigeration Institute (AHRI) Standard 550-590 for performance rating of water-chilling packages it will be shown that high-speed direct-drive centrifugal chillers have the capability to reduce the annual energy consumption of water-cooled chillers by more than 30% compared to typical chillers with screw compressors as a result of better compressor efficiency at off-design conditions.

## 1. INTRODUCTION

Heating, ventilation, and air-conditioning (HVAC) systems are one of the highest energy consumption systems in most building configurations. The AHRI Standard 550-590 defines that water-chilling packages operate only one percent (1%) of time at full load design conditions and 99%, at part load or off-design conditions. The performance of cooling chillers, especially at part load conditions, has a significant impact on the operating performance of the HVAC system.

The energy performance and carbon dioxide emission analysis at multiple capacity points and various annual operating hours shows that typical water-cooled oil-free, high-speed, direct-drive centrifugal chillers can provide annual savings of more than 30% when compared to typical water-cooled screw or scroll chiller.

## 2. DESCRIPTION

Three typical water-cooled chillers used in HVAC systems were considered in this analysis. The first chiller configuration is a chiller with single and dual oil-free, high-speed, direct-drive compressors with individual variable speed drive. The second and third configurations are, respectively, typical water-cooled chiller with screw and scroll compressors which are commonly available in the industry. The number of screw or scroll compressors will vary from one to six depending on the chiller capacity.

Figure 1 shows that the absence of oil in the system will result in a simple piping arrangement due to elimination of components associated with oil management such as oil separator, oil pumps, oil heaters, and oil coolers. Also, as a consequence of oil elimination, better heat transfer in the evaporator or condenser vessels will improve resulting in smaller approach temperatures. The pressure ratio that the compressor has to deliver reduces as a result of the smaller approach temperatures thus improving overall system efficiency.

The next figures show the schematic of each chiller configuration.

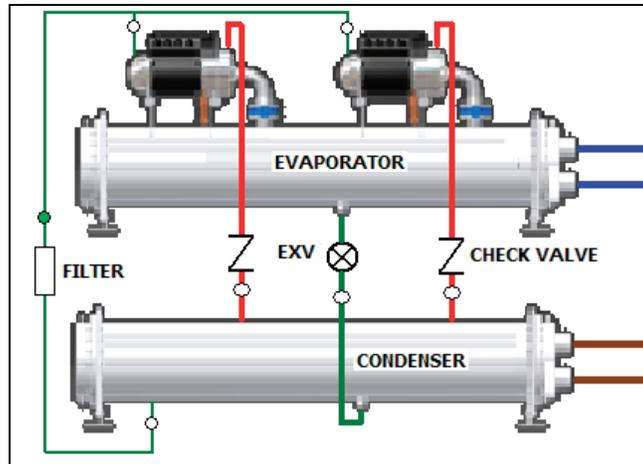


Figure 1 – Typical water-cooled oil-free, high-speed, direct-drive centrifugal chiller

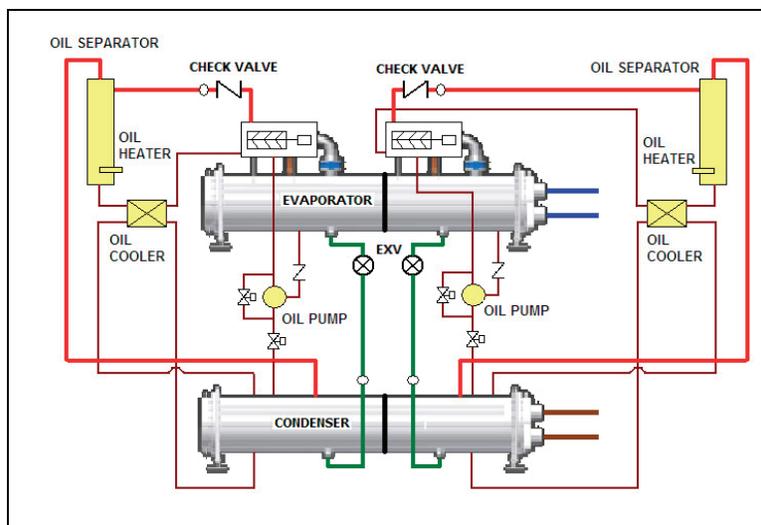


Figure 2 – Typical water-cooled screw chiller

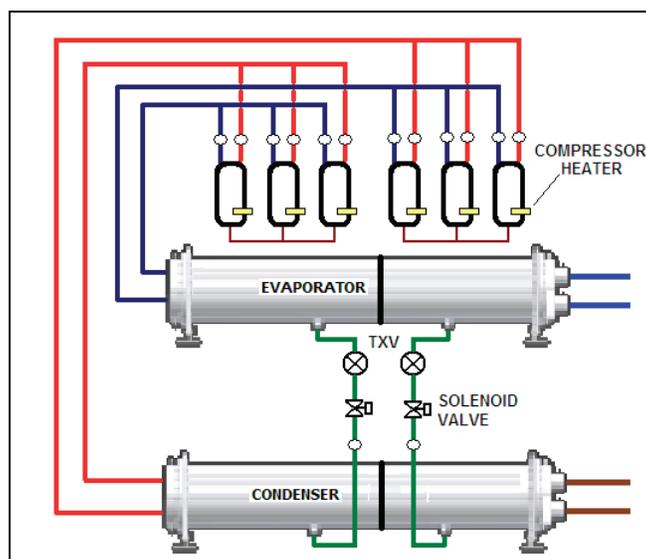


Figure 3 – Typical water-cooled scroll chiller

### 3. DATA ANALYSIS

#### 3.1. Part Load Performance Analysis

The seasonal energy efficiency performance rating of water-chilling packages, which is calculated based on the integrated part load value (IPLV), is defined by AHRI Standard 550-590.

Table 1 – AHRI Standard 550-590 rating points

Percent Load	Seasonal Factor
100%	1%
75%	42%
50%	45%
25%	12%

The IPLV of oil-free, high-speed, direct-drive centrifugal chillers was calculated for five capacity points based on the seasonal factor defined above and considering 2.0 [°F] (1.1 [°C]) temperature approach on the evaporator and condenser. The IPLV of a typical water-cooled screw and scroll chiller packages is publically available at the chiller manufacturer's website. The next figure shows the seasonal performance rating for each different compressor technology as a function of chiller capacity.

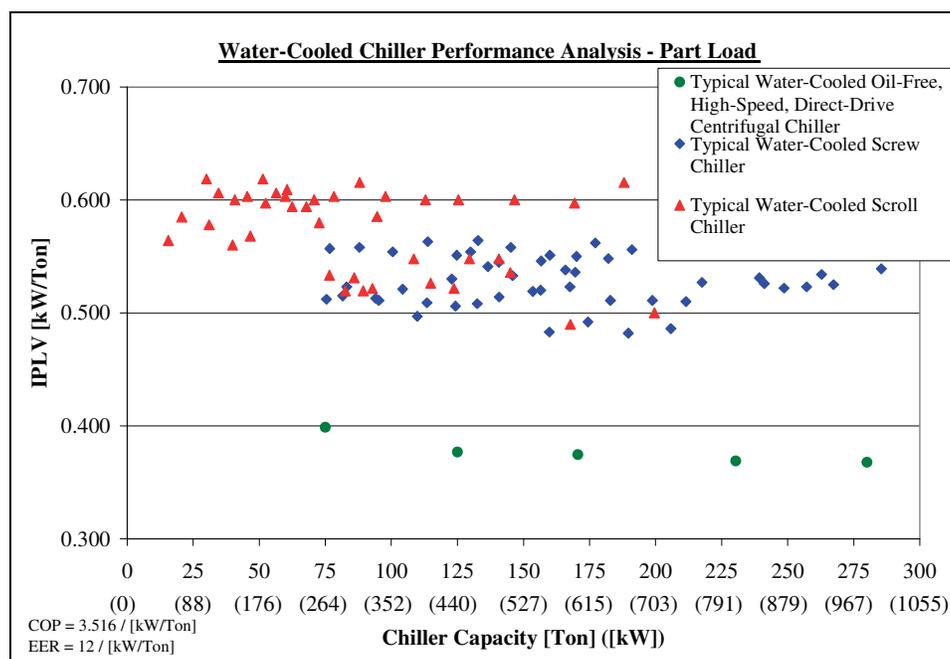


Figure 4 – Typical water-cooled chiller part load performance

The part load performance is significantly higher for a typical water-cooled oil-free, high-speed, direct-drive centrifugal than for typical water-cooled screw or scroll chillers that are currently available in the market.

Table 2 – Capacity ranges and number of samples

Chiller Capacity Point		Minimum Capacity		Maximum Capacity		Number of samples	
[Ton]	[kW]	[Ton]	[kW]	[Ton]	[kW]	Screw	Scroll
75	264	62.5	220	87.5	308	4	7
125	440	112.5	396	137.5	483	9	5
175	615	162.5	571	187.5	659	8	2
225	791	212.5	747	237.5	835	1	-
275	967	262.5	923	287.5	1,011	3	-

In order to compare the performance of each water-cooled chiller technology, the capacity range was defined as the main criteria to determine the average, minimum and maximum part load performance for five pre-defined capacity points. The capacity ranges for each comparison point including the number of samples used are shown in table 2.

### 3.2. Energy Performance Analysis

The energy performance or energy consumption of each system is function of the chiller capacity, part load performance, and the number of operating hours per year, and it can be expressed by the following equation:

$$\text{Annual Energy Consumption} = \text{Chiller Capacity} * \text{IPLV} * \text{Annual Operating Hours} * \text{Full Load Factor} \quad (1)$$

Where: annual energy consumption is expressed in [kWh], chiller capacity is expressed in [Ton], IPLV is expressed in [kW/Ton], operating hours is expressed in [h], and the full load factor based on AHRI Standard 550-590 rating points.

The full load factor used is equal to 0.58, which is the result of the sum of the multiplication of the load percent by the corresponding seasonal factor for each AHRI Standard 550-590 rating point shown on table 1 ( $100\% * 1\% + 75\% * 42\% + 50\% * 45\% + 25\% * 12\% = 58\%$  or 0.58).

The estimated annual energy consumption for each system was calculated by using the equation (1) based on 3,000 annual operating hours, and the results are plotted on figure 5.

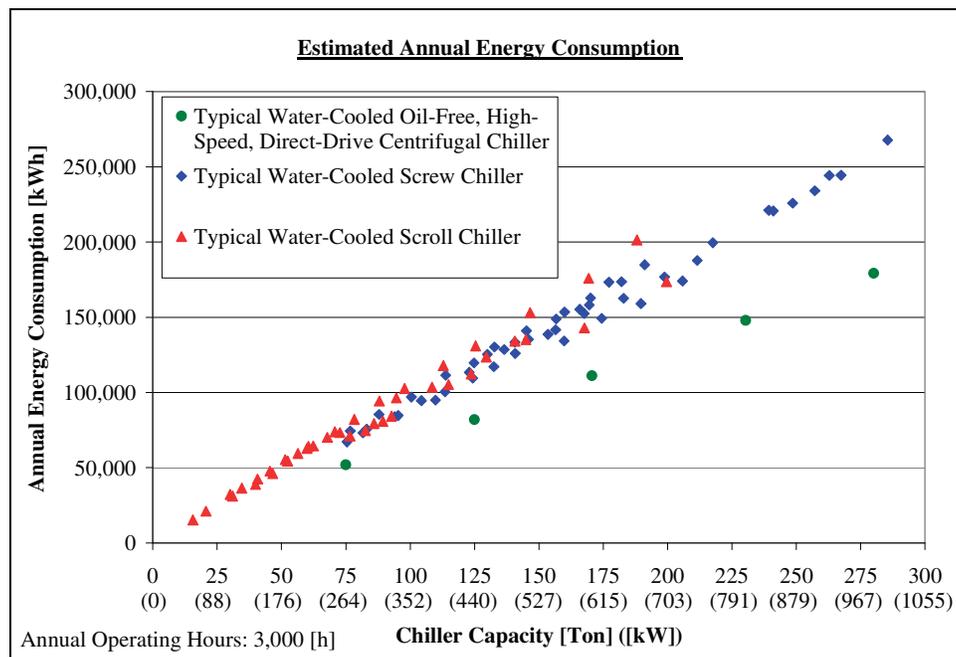


Figure 5 – Estimated annual energy consumption

The estimated annual energy savings of a typical water-cooled oil-free, high-speed, direct-drive centrifugal chiller when compared to a typical water-cooled screw chiller can vary from 22% to 33%, with average of approximately 30%, depending on the chiller capacity as shown on figure 6.

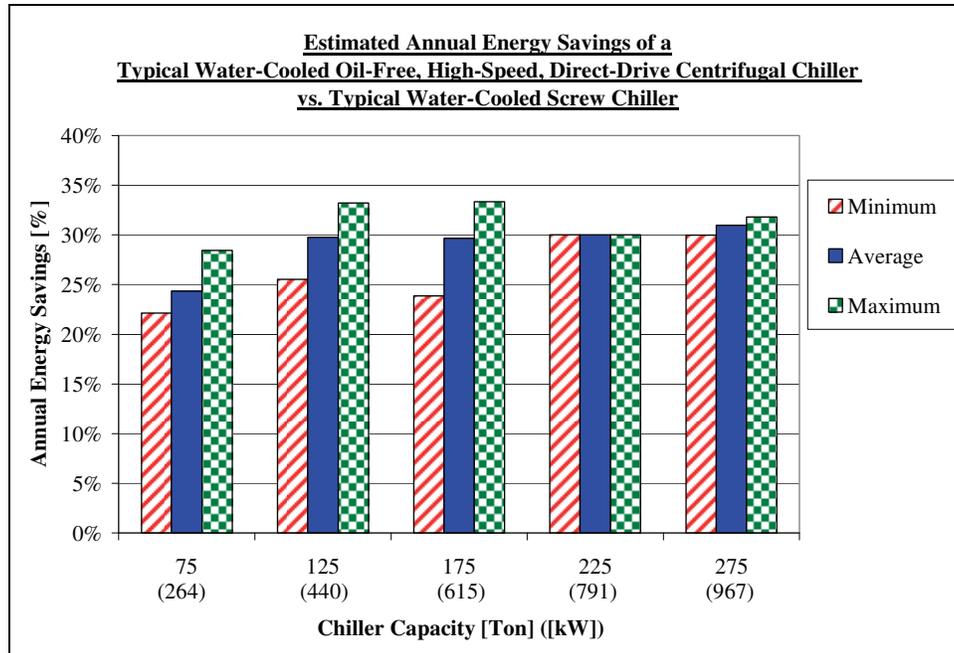


Figure 6 – Estimated annual energy savings when compared to typical water-cooled screw chiller

When compared to typical water-cooled scroll chillers, as shown on figure 7, the estimated annual energy savings of a typical water-cooled oil-free, high-speed, direct-drive centrifugal chiller can vary from 23% to 37% depending on the chiller capacity.

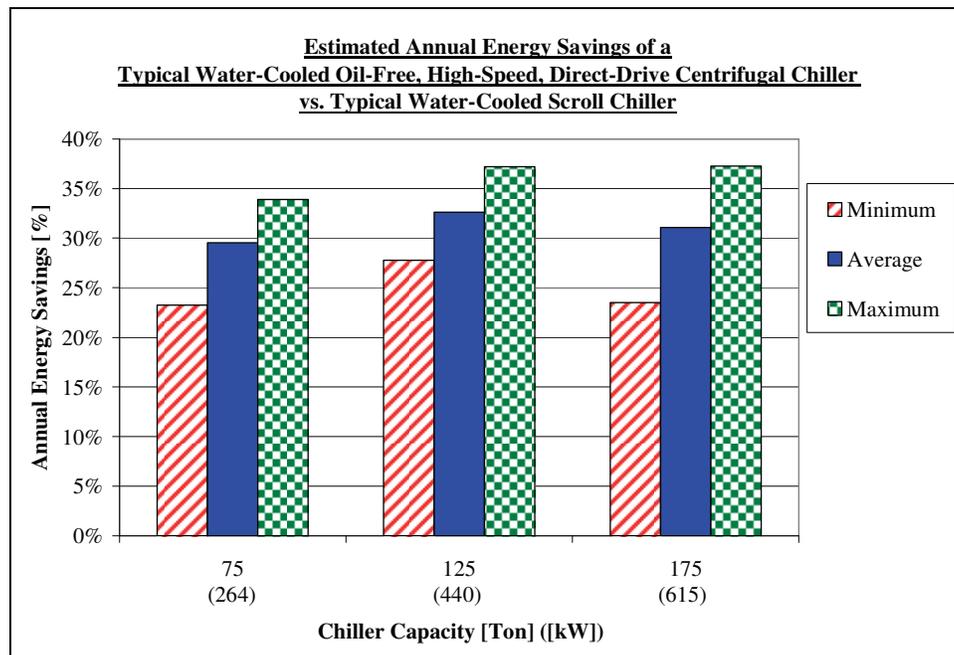


Figure 7 – Estimated annual energy savings when compared to typical water-cooled scroll chiller

The figures 8 and 9 show, respectively, the estimated average annual energy savings in kilo-watt-hour [kWh] and United States dollars [USD] of a typical water-cooled oil-free, high-speed, direct-drive centrifugal chiller versus a typical water-cooled screw and scroll chillers at three different annual operating hours (3,000 [h], 5,000 [h], and 8,000 [h]). The energy rate considered on figure 9 was USD 0.10 per kWh.

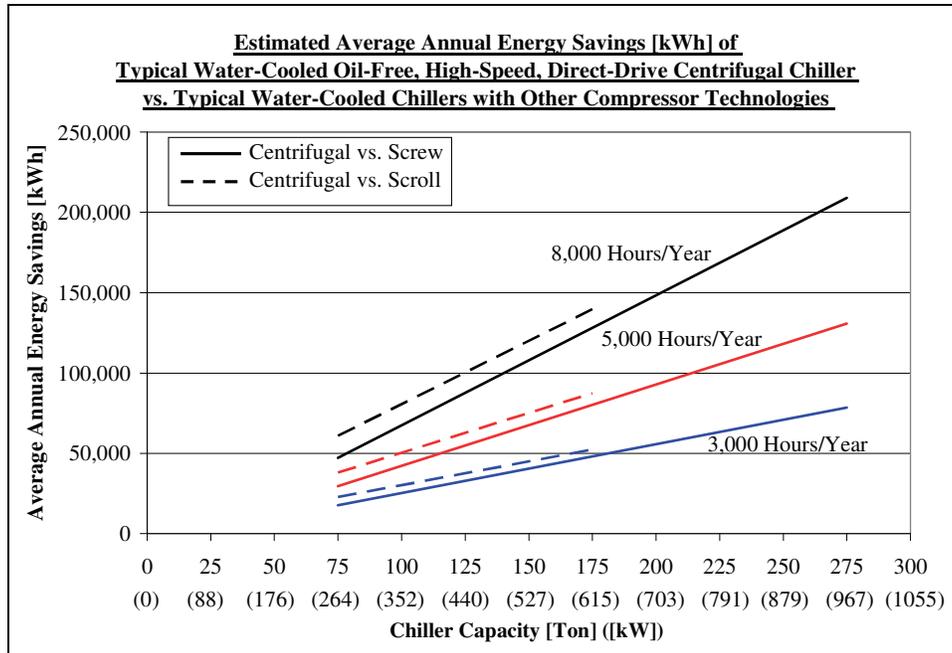


Figure 8 – Estimated average annual energy savings [kWh]

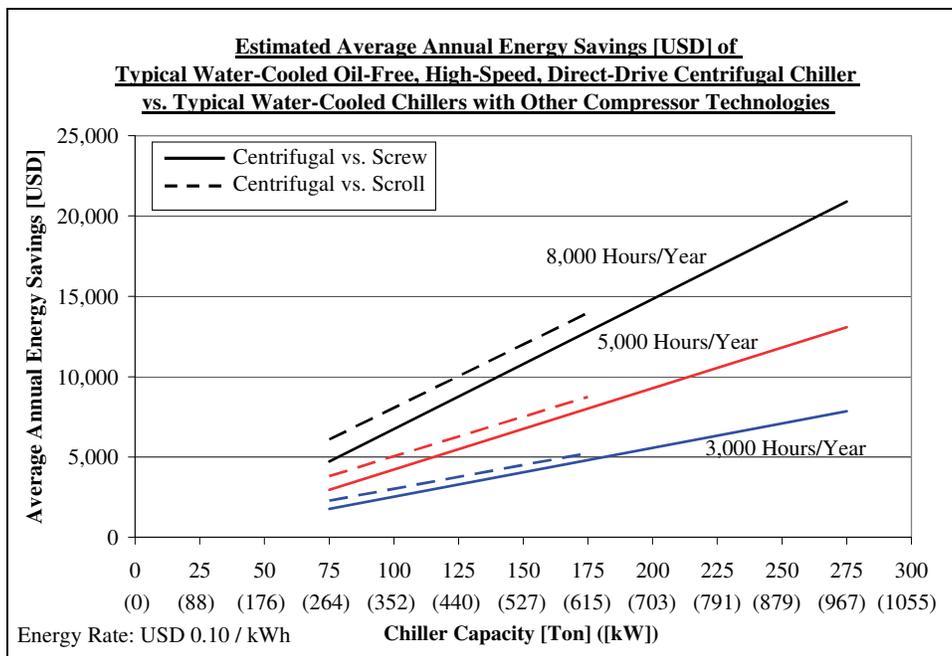


Figure 9 – Estimated average annual energy savings [USD]

The annual operating hours have a significant impact on the energy performance of water-chilling packages. At 275 [Ton] (967 [kW]) chiller capacity, a typical water-cooled oil-free, high-speed, direct-drive centrifugal chiller can provide an estimated average annual energy savings, when compared to a typical water-cooled screw chiller, of approximately 79,000 [kWh], 131,500 [kWh], and 210,500 [kWh] based on annual operating hours of 3,000 [h], 5,000 [h], and 8,000 [h], respectively.

The equivalent energy savings in United States dollars are approximately USD 7,900, USD 13,150, and USD 21,500 based on annual operating hours of 3,000 [h], 5,000 [h], and 8,000 [h], respectively.

### 3.3. Carbon Dioxide (CO<sub>2</sub>) Emission Analysis

The estimated annual carbon dioxide (CO<sub>2</sub>) emission was calculated based on the annual energy consumption of each system multiplied by the CO<sub>2</sub> emission factor.

$$\text{Annual CO}_2 \text{ Emission} = \text{Annual Energy Consumption} * \text{CO}_2 \text{ Emission Factor} \quad (2)$$

Where: annual CO<sub>2</sub> emission is expressed in [metric Ton of CO<sub>2</sub>], annual energy consumption is expressed in [kWh], and the CO<sub>2</sub> emission factor is equal to 0.000718 [metric Ton of CO<sub>2</sub> / kWh] (U.S. EPA, 2010).

The estimated average annual CO<sub>2</sub> emission savings of a typical water-cooled oil-free, high-speed, direct-drive centrifugal chiller versus a typical water-cooled screw and scroll chillers is shown on the next figure and it is based on three different annual operating hours (3,000 [h], 5,000 [h], and 8,000 [h]).

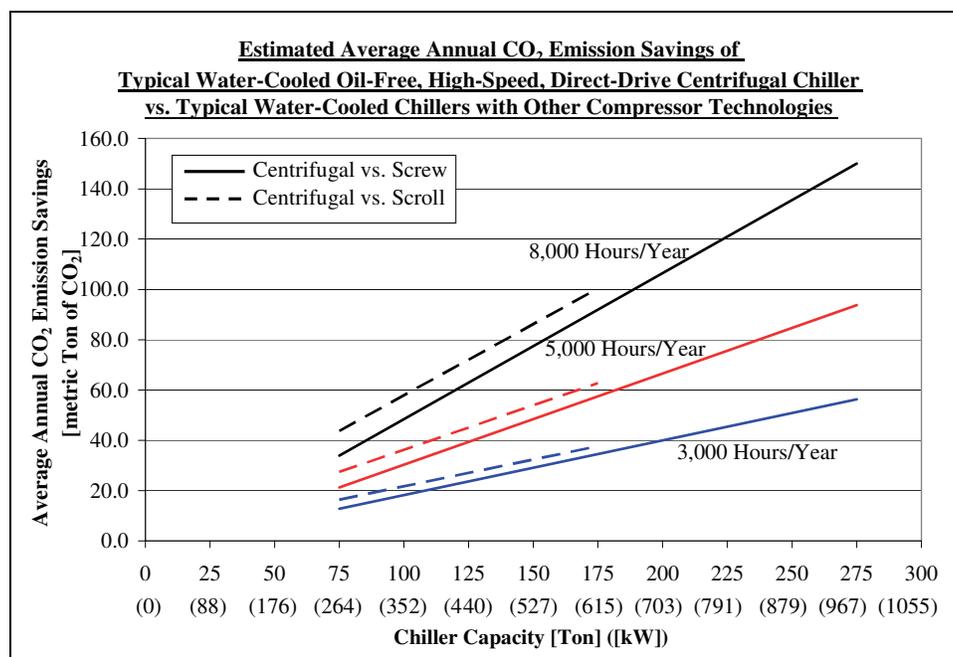


Figure 10 – Estimated average annual CO<sub>2</sub> emission savings [metric Ton of CO<sub>2</sub>]

The effect of annual operating hours is also seen on the estimated annual CO<sub>2</sub> emission savings. A typical 275 [Ton] (967 [kW]) water-cooled oil-free, high-speed, direct-drive centrifugal chiller that operates at rates of 3,000, 5,000, and 8,000 hours per year can provide an estimated average annual CO<sub>2</sub> emission reduction of 56.7, 94.5, and 151.1 [metric Ton of CO<sub>2</sub>], respectively, when compared to a typical water-cooled screw chiller.

## 4. CONCLUSION

Typical water-cooled oil-free, high-speed, direct-drive centrifugal chillers have simpler design configuration when compared to typical water-cooled screw chillers due to the elimination of the many components required for the oil management system.

The analysis shows that typical water-cooled oil-free, high-speed, direct-drive centrifugal chiller can achieve energy savings and, consequently, CO<sub>2</sub> emission savings of more than 30% when compared to typical water-cooled screw and scroll chillers depending on the chiller capacity.

Also, the annual operating hours of the water-chilling packages have a significant impact on the annual energy and CO<sub>2</sub> emission savings when applying typical water-cooled oil-free, high-speed, direct-drive centrifugal chillers as shown on figures 8, 9, and 10.

## 5. REFERENCES

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