Energy Efficiency Potential of Nanofluids

Conservation Applied Research and Development (CARD) FINAL Report

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Dakota County Air Cooled Chiller

System Description

The Dakota County Annex is an addition to the Dakota County Administration facility and functions as a municipal office building. A separate chilled water plant provides mechanical cooling to a variable volume air handler dedicated to the addition. The air handling unit mixes outdoor air with return air from the conditioned spaces in the building to a mixed air state. This mixed air undergoes both sensible and latent cooling as it passes across the cooling coil. The air handling unit distributes the conditioned supply air to the building spaces.

The chilled water plant consists of an air-cooled chiller with a rotary screw compressor. Redundant constant speed pumps deliver chilled water to the air handler. The air handler contains a three-way valve to control chilled water input to the cooling coil. The working heat transfer fluid in the system is a mixture of 30% ethylene glycol and 70% water.

Table 1 shows the specifications of the primary system components.

Table 1. Air Cooled Chiller Equipment Specifications

Equipment	Type	Qty	Size	Units
Chiller	Screw	1	100	Ton
Chilled Water Pumps	Centrifugal	2	7.5	HP
Air Handler - Supply Fan	Centrifugal	1	50	HP
Air Handler - Return Fan	Centrifugal	1	15	HP

Figure 1 shows a diagram of the air-cooled system.

Figure 1. Air-Cooled Chilled Water System

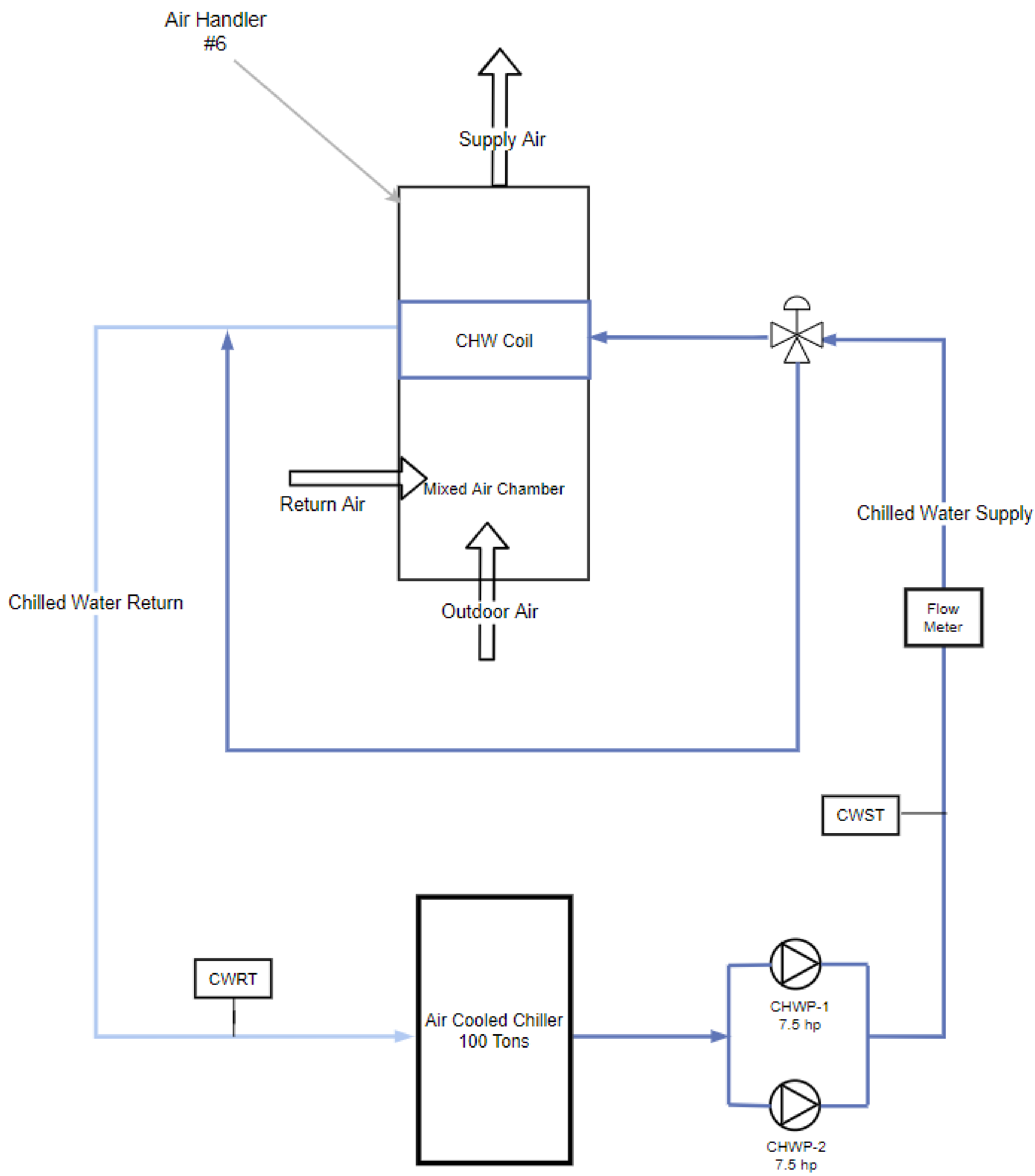


Figure 2. Air Cooled Chiller

Data Collection

The air handler is the only end-use served by the chilled water loop. Therefore, the load on the air handler chilled water coil was utilized to determine the load on the chiller. Table 2 lists the data points collected from the facility's digital automation system.

Table 2. Air Cooled Chiller Data Points

BAS Data Point	Units	Collection Interval (Min)
Outdoor Air Dry Bulb Temperature	Deg F	5
Outdoor Air Wet Bulb Temperature	Deg F	60
Outdoor Air Humidity	%	60
Air Handler Outdoor Air Volume	CFM	5
Chiller Power	kW	3

BAS Data Point	Units	Collection Interval (Min)
Chiller Evaporator Flow Rate	Gallons per Minute	3
Chilled Water Supply Temperature	Deg F	3
Chilled Water Return Temperature	Deg F	3
Air Handler Return Air Humidity	%	5
Air Handler Return Air Volume	CFM	5
Air Handler Mixed Air Temperature	Deg F	5
Air Handler Supply Air Temperature	Deg F	5
Air Handler Supply Volume	Cubic Feet Per Minute	5
Air Handler Supply Fan Speed	Percent	5
Cooling Valve Position	Percent Open	5

The chiller system utilized a glycol/water mixture as the heat transfer medium in the baseline condition. The mixture contained approximately 30% glycol, providing freeze protection at 7°F outdoor air temperature. The baseline monitoring period occurred from August 12, 2020 to October 30, 2020.

Data was collected from the building automation system in five-minute increments to capture system performance. To process the large amounts of data into identifiable trends, relevant data points were averaged based on outdoor air temperature bins of three degrees Fahrenheit.

The baseline data collection period captured over 3,300 data points encompassing roughly 275 hours of chiller operation. Since the test period began in mid-August, the baseline monitoring period did not contain operating data where outdoor air temperatures exceeded 87°F.

The fluid in the chiller system was replaced on April 13, 2021 with a mixture of 45% HYDROMX and 55% city water. The total loop volume of the chiller system was found to be 720 gallons. The air-cooled chiller system was monitored from May 3, 2021 to October 14, 2021.

The nanofluid data collection period captured over 12,600 data points over the entire cooling season, equating to roughly 1,050 hours of chiller operation.

Nanofluid kWh	39.094
Annual kWh Savings	-6,927
Percent Savings	-22%
Annual Carbon Savings (lbs)	-3,380
Simple Payback (Years)	N/A

Since the loading of the chiller system was abnormally low due to COVID-19 impacts, the savings were also calculated using the equivalent full load hours (EFLH) methodology for chillers presented in the Minnesota Technical Reference Manual, version 2.2. **Error! Reference source not found.** shows these results.

The chiller's integrated part-load values (IPLVs) using water and the nanofluid were estimated using the average kW/ton across the monitoring periods. This average efficiency was determined by dividing the kWh consumed by the total ton-hours of cooling produced by the chiller.

The building served by the system is a low-rise structure in Zone 3; therefore, the calculation used 446 EFLH. This methodology shows that a typical cooling season would likely have four times the cooling load observed during the late summer of 2021, as the chiller only ran 107 EFLH during this monitoring

System 2 – Dakota County Air-Cooled Chiller

The operation of the Dakota County air cooled chiller is summarized by outdoor air temperature bins to present the data in an easy-to-consume format. The tables contain the number of data points per bin, average outdoor air dry bulb temperature, average chiller tons delivered, average power consumption of the chiller, chiller kW/ton, average air handler supply air volume, average outdoor air volume, average air handler supply temperature, mixed air temperature, and zone temperature.

Baseline Results

Table 3 displays the calculated kW/ton of the chiller system in the baseline condition, as well as other select system attributes broken down by outdoor air (dry bulb) temperature bin.

Table 3. Baseline Results (Glycol-Water)

Temp Range	Observations	Avg OAT (°F)	Avg Tons	Avg Chiller kW	Avg kW/ton	Avg Supply CFM	Avg OA CFM	Avg SAT	Avg MAT	Avg Zone Temp (°F)
87-84	104	85.4	14.3	19.9	1.38	10,947	2,005	62.2	75.8	73.6
84-81	209	81.9	11.0	15.9	1.45	9,393	1,873	63.4	75.0	73.5
81-78	625	79.4	9.2	13.4	1.46	8,650	1,830	64.0	74.6	73.4
78-75	354	76.6	9.2	12.9	1.41	9,102	2,611	63.9	74.4	73.3
75-72	433	73.3	9.1	12.3	1.35	9,146	3,273	63.9	74.3	73.3
72-69	612	70.5	7.9	10.6	1.35	8,862	5,632	64.2	73.5	73.2
69-66	604	67.4	8.2	10.4	1.27	8,867	8,024	63.5	72.6	73.4
66-63	386	64.6	6.2	9.1	1.47	8,208	8,005	64.0	71.4	73.3
63-60	188	61.8	6.2	8.2	1.33	8,528	5,998	64.1	71.4	73.1
60-57	115	58.6	11.1	14.4	1.30	9,413	2,381	62.1	74.7	74.0

Nanofluid Results

Table 4 displays the calculated kW/ton of the chiller system in the nanofluid condition as well as other select system attributes broken down by outdoor air (dry bulb) temperature bin.

Table 4. Nanofluid Results

Temp Range	Observations	Avg OAT (°F)	Avg Tons	Avg Chiller kW	Avg kW/ton	Avg Supply CFM	Avg OA CFM	Avg SAT	Avg MAT	Avg Zone Temp (°F)
99-96	93	96.6	12.2	16.7	1.37	9,357	1,702	61.9	74.7	73.3
96-93	342	94.3	10.8	14.9	1.39	8,884	1,589	62.1	74.6	73.3
93-90	450	91.3	11.7	16.0	1.37	9,444	1,702	61.9	74.6	73.3
90-87	564	88.5	10.9	15.0	1.38	9,135	1,649	62.1	74.5	73.3
87-84	1022	85.3	11.2	15.2	1.36	9,123	1,632	62.1	74.6	73.2

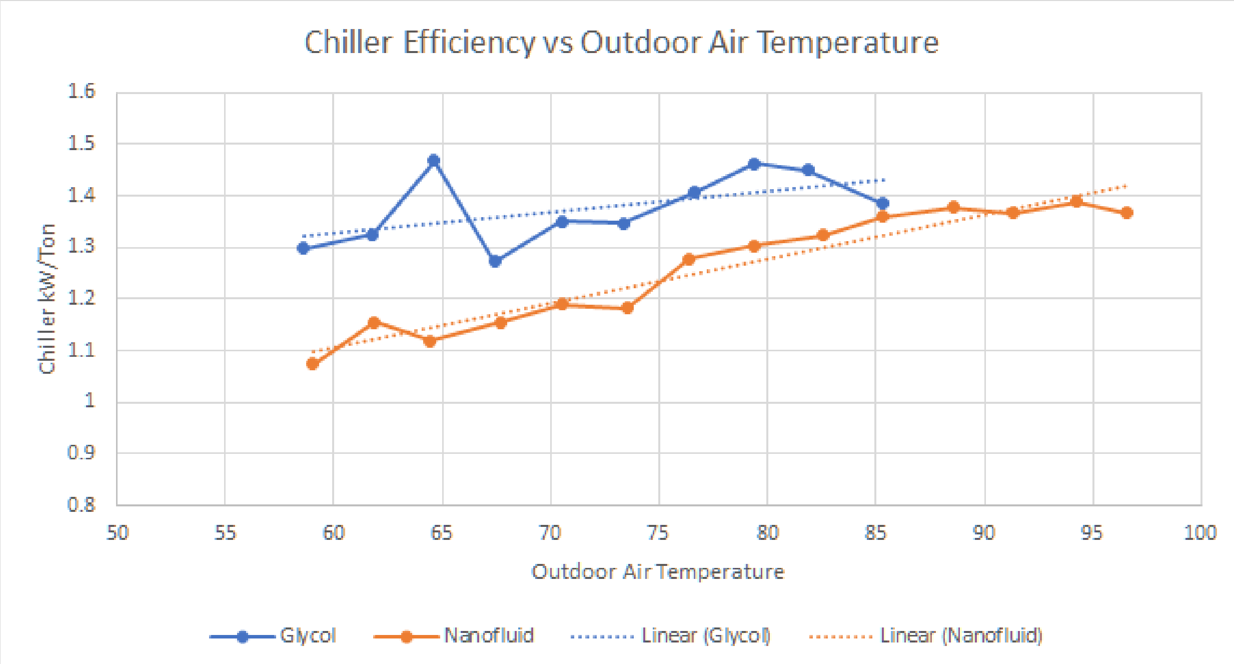
Temp Range	Observations	Avg OAT (°F)	Avg Tons	Avg Chiller kW	Avg kW/ton	Avg Supply CFM	Avg OA CFM	Avg SAT	Avg MAT	Avg Zone Temp (°F)
84-81	1238	82.6	10.3	13.6	1.32	8,380	1,866	62.4	74.5	73.3
81-78	1357	79.4	10.1	13.1	1.30	8,460	2,284	62.3	74.4	73.3
78-75	1680	76.4	10.5	13.5	1.28	8,998	2,170	62.0	74.2	73.2
75-72	1759	73.5	11.1	13.1	1.18	9,352	2,627	62.1	74.0	73.1
72-69	1973	70.5	10.1	12.0	1.19	8,942	3,237	62.5	73.7	73.2
69-66	1182	67.7	10.5	12.1	1.16	9,331	4,807	61.1	72.5	72.8
66-63	952	64.4	10.3	11.6	1.12	8,302	2,944	60.3	72.8	72.5
63-60	666	61.9	11.0	12.6	1.15	9,264	3,051	59.8	72.9	72.2
60-57	228	59.0	7.6	8.2	1.07	6,097	2,300	57.5	72.1	71.8

The metered operating efficiency of the chiller improved by an average of 0.16 kW/ton. The efficiency gains in each temperature bin vary.

Annual Savings Estimates

The nanofluid installation resulted in energy savings or a more efficient (lower) kW/ton. While linear trends show more considerable efficiency gains at lower outdoor air temperatures and loadings, the efficiency increased at all temperature ranges after the nanofluid installation. A graphical comparison of the chiller efficiency across a range of outdoor air temperatures is shown in Figure 3.

Figure 3. Chiller Efficiency vs Outdoor Air Temperature



We created an efficiency regression curve plotting the efficiency impacts of the nanofluid installation against the outdoor air temperature in order to determine the efficiency gain of the system across the range of operating conditions. (This curve is shown later in the discussion section.) The baseline energy consumption of the system was normalized to the operating conditions observed during the nanofluid operation by applying the chiller efficiency gain regression curve to the metered data observed in summer 2021 for the nanofluid monitoring period. This approach yielded a savings of approximately 9% across the summer or 1,278 kWh, as shown in Table 5.

Table 5. Air-Cooled Chiller Savings in 2021

Data Point	Result
Nanofluid kWh	13,682
Glycol kWh	14,960
kWh Savings	1,278
Percent Savings	9%
Annual Carbon Savings (lbs)	624
Simple Payback (Years)	189

Since the loading of the chiller system was abnormally low due to COVID-19 impacts, the savings were also calculated using the equivalent full load hours (EFLH) methodology for chillers presented in the Minnesota Technical Reference Manual, version 2.2.

Table 6. TRM Water-Cooled Chiller Savings

Parameter	Value
Nanofluid IPLV	1.22 kW/ton
Glycol IPLV	1.33 kW/ton
Equivalent Full Load Hours (EFLH)	446 hours
Chiller Capacity	100 Tons
Minnesota TRM Equivalent Annual Savings	5,077 kWh
Annual Carbon Savings	2,478 lbs
Simple Payback	47.5 years

The chiller system's integrated part-load value (IPLV) using glycol and the nanofluid were estimated using the average kW/ton across the operating seasons, determined by dividing the average kWh consumed by the total ton-hours of cooling produced. The facility is a low-rise office building in zone 3; therefore, the calculation used 446 EFLH. As shown in Table 6, the TRM methodology shows that a typical cooling season would likely have four times the cooling load observed during the summer of 2021, as the chiller only ran 112 EFLH.