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Integrated Chiller System Reduce Building Operation and Maintenance Costs in Cold Climates

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Abstract

Although water-cooled chillers are more energy efficient than air-cooled chillers, a majority of chilled water systems use air-cooled chillers. In cold weather climates, air-cooled chillers are capable of functioning in low ambient temperatures with few operational concerns, where as water-cooled chiller systems must be equipped to prevent cooling tower freezing. The integrated chiller system attempts to take advantage of each chiller's strengths and eliminate any cold weather operational concerns. An integrated chiller system includes a cooling tower and air-cooled condenser. During the summer, both the cooling tower and air condenser can be operated. In cold weather, the cooling tower is drained and the air condenser is used to dissipate the heat of the cooling system. The integrated chiller system eliminates the water storage tank and frequent charging and discharging of the cooling tower system. It reduces the size of the mechanical room and simplifies the operation of the system. The integrated chiller system is most suitable in climates where the mechanical cooling is required on a short-term basis during cold weather periods. This paper presents the system configuration, system design, optimal control, and energy impact. An example is used to demonstrate the design concepts of the integrated chiller systems.

Introduction

Electric driven water-cooled chiller systems consume 0.7 kilowatts per ton of cooling produced, while electric driven air-cooled chiller systems require 1.2 kilowatts. The water-cooled chiller system offers a sizable energy advantage, yet approximately 60% of chiller systems use an air-cooled chiller. Differences between the systems' initial cost and operational concerns explain the variance in these statistics. A majority of HVAC systems are constrained by a budget set forth by the building's owner. The lower initial cost of the air-cooled chiller system becomes an attractive quality in these situations and weighs heavily on the final chiller decision. System designers are also often willing to sacrifice the extra energy consumption in order to simplify the system operation. Air-cooled chiller systems can provide cooling under almost any ambient conditions without any operational problems, while water-cooled chiller systems become difficult to operate and control in cold weather due to cooling tower freezing.

HVAC systems are required to operate under a wide range of conditions and climates. Varying seasonal climate conditions can have a significant effect on the operation and maintenance of a water-cooled chiller system. This is often the case for buildings located in climates characterized by extreme seasonal temperatures with periodic warm periods during traditional non-cooling seasons. For example, Omaha, Nebraska's typical winter is extremely cold with an ASHRAE winter design temperature of -7˚F, but it is not uncommon to have outside temperatures in excess of 70˚F during the same time span. The unpredictable variance of outside weather conditions can cause winter cooling loads within a building; therefore, the cooling tower must be available year-round. Several additional design considerations for cooling tower operation exist for continual tower availability in these types of climates.

When a cooling tower is idle during periods of cold weather, the basin water must be protected from freezing to prevent pipes from bursting and to keep the tower available. If the cooling tower were required to operate under freezing conditions, ice formation may occur on tower components. The possibility of ice formation requires additional maintenance and regular visual inspection to prevent excessive ice formation, which can cause capacity control issues, temporary shutdown periods to deice, or damage to cooling tower components to the extent of replacement. Currently, there are several methods (discussed below) to prevent tower contents from freezing and enable tower operation under all ambient conditions.

Choosing the optimal cooling tower design/operation strategy is a major concern for building operators who rely solely on water-cooled chiller systems to provide yearly building cooling. The following paper discusses the current cooling tower system designs, proposes a new design solution, and presents a case study comparing the new design's performance to a common industry design practice.

Existing Freeze Protection Methods

Currently, a wide range of control strategies are used to prevent capacity control issues and physical damage experienced by cooling towers when ambient conditions cause their contents to freeze.

The simplest control strategy consists of draining the cooling tower system during potential freeze periods and refilling it as dictated by building cooling requirements. This is an acceptable strategy for buildings with a minimum number of draining/refilling cycles throughout the year; however, it does not provide the necessary flexibility in cooling capacity for buildings requiring cooling during potential freeze periods and/or climates requiring frequent drain/fill cycles without consuming excessive amounts of water, water treatment materials, preventive maintenance, and money.

A slightly more complex control strategy utilizes a remotely located water storage tank and pump within an interior heated space that stores the cooling tower system's water and pumps it back into the system. The basic control theory is similar to that mentioned above, except that the tower water is stored rather than discharged to a sewer system. The addition of an auxiliary storage tank conserves significant amounts of water and water treatment materials during frequent drain/refill cycles, allows simple system cleaning and removal of solids within the water, and reduces algae build-up and corrosion. However, the extra equipment requires interior space, adds to the initial and annual maintenance costs of the system, and may require some special structural reinforcement. This can be very difficult for some existing buildings where the mechanical spaces are limited.

Another freeze protection control strategy provides supplemental heat to the basin water. Heat is supplied via electric resistance, hot water coils, steam coils, or hot water injection. The heat source's capacity is designed to maintain a minimum tower water temperature, typically 40˚F, as ambient conditions become conducive to freezing. This strategy requires the purchase of additional equipment. It also results in the consumption of excessive amounts of energy during extensive cold weather periods to simply prevent the water from freezing, which does not help condition the building.

A final control strategy, applicable in only a small number of cases, is to provide a basin pump to circulate cooling tower water during idle periods. By circulating the water, it becomes more difficult to freeze. However, this is not effective in extremely cold conditions and has limited applicability in real world situations.

Although the above control strategies successfully prevent cooling tower water freezing, other superior engineering solutions may exist. Current design methods require special equipment, special seasonal maintenance, and/or additional energy to maintain operations throughout the year. The following paragraphs propose a new design method that attempts to alleviate cold weather cooling tower operational issues for typical office buildings located in climates similar to Omaha, Nebraska.

Integrated Chiller System

The proposed integrated chiller system attempts to eliminate the cooling tower operation for the cold weather season while providing cooling capacity for winter loads. Figure 1 presents the schematic diagram of the system.

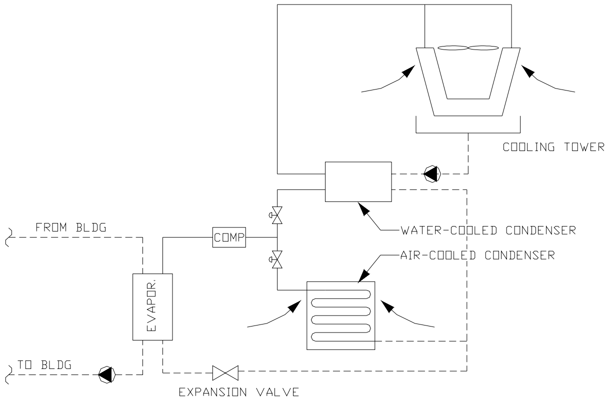

Figure1: Schematic Diagram of the Integrated Chiller System

The integrated chiller system is the same as a typical water-cooled chiller system, except that a parallel air-cooled condenser is added. During the winter season the cooling tower water is drained and the refrigerant flow to the water-cooled condenser is shut off and directed to the air-cooled condenser. Both condensers are used during the summer season. When the air-cooled condenser is sized properly, the integrated chiller provides necessary winter season cooling without activating the water-cooled condenser. Consequently, no water storage tank is necessary, thus significantly reducing maintenance costs.

During summer operations, the water-cooled condenser can directly control the expansion valve. The air-cooled condenser is controlled to match the exit conditions of the water-cooled condenser. During winter, the air-cooled condenser can directly control the expansion valve.

The air-cooled condenser must have enough capacity to provide sufficient chilled water to satisfy the peak cooling demands of the building when the water-cooled condenser is unavailable. The cooling tower will be unavailable for certain periods of each year when outside conditions become conducive to tower freezing, typically when temperatures are consistently below 40˚F (determined from local weather data). The duration and timing of this period will vary widely based on building location and respective weather patterns and is a key indicator as to the applicability of the integrated system. The condenser should be selected using the design ambient air temperature during the period when the cooling tower is unavailable. In most cases, the lowest ambient air temperature selection information provided by manufacturers will be used, as most do not allow for interpolated capacities below these values.

The water-cooled condenser can be determined from the annual cooling load profile of the building. The load profile provides vital information including the building's peak load and the number of hours at each cooling load. The air-cooled condenser will be used simultaneously with the water-cooled condenser during peak cooling loads throughout the year. Since the air-cooled condenser is selected based on the lower ambient air temperatures, its reduced capacity must be determined under the higher ambient temperatures.

Case Study

The feasibility and economy of the integrated chiller design is investigated using a case study. The case study building is a 6-story office building located in Omaha, Nebraska. The existing water-cooled chiller is over 30 years old and needs to be replaced. The existing chiller is located on the penthouse level, which is too small to install a water tank. If a water tank is used, building structure reinforcement is required. Obviously, eliminating the need for the water tank can result in significant project cost savings. This case study focuses on the integrated chiller system design and the annual energy performance.

The proposed integrated chiller system was not commercially available at the time this paper was written. To implement the concept of the integrated chiller system, an air-cooled chiller was connected to a water-cooled chiller in parallel. Figure 2 presents the system diagram of the integrated chiller system design used in the case study. During the winter season, only the air-cooled chiller was used. During the summer season, both chillers could be used. This innovative design avoids the installation of a water tank in the penthouse. It also significantly reduces the maintenance cost of the chiller system.

Through a detailed site measurement and computer analysis, the following key technical parameters were identified:

Summer design cooling capacity is 150 tons when 20% outside air is used.

Winter building cooling load is 40% of the summer building cooling load excluding the ventilation load when outside air temperature is 75°F.

In a typical year in Omaha, Nebraska, the water-cooled chiller can be safely operated continuously from April 1 to October 30. From November 1 to March 30, mechanical cooling is required for about 40 hours per year based on Omaha monthly bin data. The maximum mechanical cooling load is 81.7 tons when the outside air temperature is 72°F. The next maximum cooling load is 37.4 tons when the outside air temperature is 68°F. Therefore, the air-cooled chiller is designed to provide 37.4 tons of cooling. Due to the limit of the chiller size, the air cooled chiller is selected to have 30 nominal tons, which is capable to provide 40 ton cooling when the outside air temperature is 75°F. Because both air- and water-cooled chillers are used at the same time, the water-cooled chiller is sized as 120 tons.

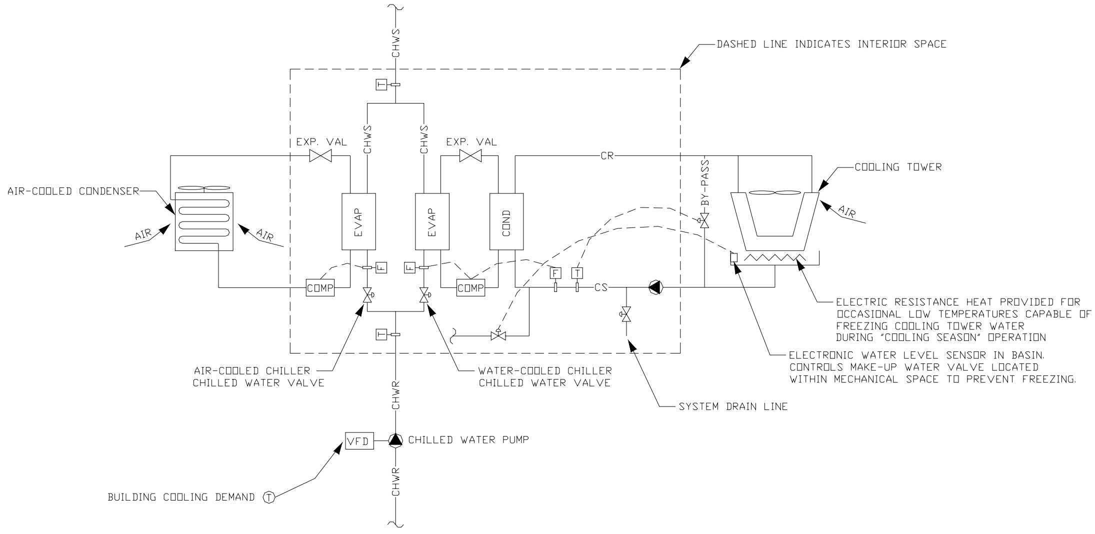

Figure 2: Systematic Diagram of the Integrated Chiller System Implementation in the Case Study

In order to perform energy analysis in the following case study, the building's annual hourly load profile was generated using simulations based on Omaha's weather bin data. Monthly bin data was used to further break down the load profile to determine the number of winter hours the building will require cooling. These values were necessary to calculate the energy consumption of the air-cooled chiller because low loads will occur in both winter and summer but will require separate chiller operations.

Table 1 provides a numerical break down of the case study building's annual load profile. At outside air temperatures at or below the 57˚F bin, the building does not require any mechanical cooling and therefore benefits from the full economizer mode. The summer hour/winter hour breakdown of annual hours was determined from visual inspection of monthly bin data for Omaha's average weather conditions. The water-cooled chiller will operate 3,526 hours in a typical year. The air-cooled chiller will operate 40 hours when the water-cooled chiller is unavailable from November 1 to March 30.

Table 1: Cooling Load Profile Data

O.A. Temp	Total Hours	Summer Hours	Winter Hours	Load (MMBtu)	Load (tons)
97	19	19	0	1.758	146.5
92	130	130	0	1.574	131.2
87	314	314	0	1.358	113.2
82	415	415	0	1.14	95.0
77	616	616	0	0.968	80.7
72	678	677	1	0.98	81.7
67	786	768	18	0.449	37.4
62	608	587	21	0.265	22.1
< 57	5194	1610	3584	0	0.0

The annual energy consumption of the integrated chiller system was compared to a typical water cooled system that uses a single 150 ton water-cooled chiller, a 185 ton cooling tower, a single chilled water loop, a chilled water pump, and a 455 gpm condenser water pump.

An annual energy consumption calculation/simulation was performed for both the base and the innovative chiller system operations. Tables 2 and 3 show the breakdown of energy consumption for the water-cooled chiller and condenser water pump, respectively, based on outside air temperatures.

The base system operates 3,566 hours per year. The electricity energy consumption of the chiller system excluding chilled water pump is 187,680 kilowatt-hours. At an electricity consumption charge of $0.08 per kilowatt-hour, this equals an annual utility bill of $15,014.

Tables 4, 5, 6, and 7 present the detailed energy simulation of the integrated system. The water-cooled chiller operates for 3,526 hours, the air-cooled chiller operates for 149 hours during the summer and 39 hours during the winter, and the condenser water pump operates for 3,526 hours out of the year. They combine to consume 182,159 kilowatt-hours annually. At an electricity consumption charge of $0.08 per kilowatt-hour, this equals an annual utility bill of $14,573.

Table 2: 150 Ton Water-Cooled Chiller Performance

O.A. Temp	Load	% Load	kW	%kW	kW/ton	Hrs of Operation	kWh
102	150.0	100.0	121	100	0.8067	0	0
97	146.5	97.7	117.4	97	0.8012	19	2,230
92	131.2	87.4	94.4	78	0.7195	130	12,269
87	113.2	75.4	75.0	62	0.6629	314	23,556
82	95.0	63.3	59.3	49	0.6241	415	24,605
77	80.7	53.8	49.6	41	0.6150	616	30,560
72	81.7	54.4	50.8	42	0.6223	678	34,456
67	37.4	24.9	29.0	24	0.7761	786	22,825
62	22.1	14.7	29.0	24	1.3150	608	17,656
< 57	0.0	0.0	N/A	N/A	N/A	5194	0
				Annual Consumption =			168,159

Table 3: Condenser Water Pump Performance (Constant Flow)

O.A. Temp	Load	GPM	Head Loss	kW	Hr	kWh
102	150.0	445.0	65.3	5.47	0	0
97	146.5	445.0	65.3	5.47	19	104
92	131.2	445.0	65.3	5.47	130	712
87	113.2	445.0	65.3	5.47	314	1,719
82	95.0	445.0	65.3	5.47	415	2,272
77	80.7	445.0	65.3	5.47	616	3,372
72	81.7	445.0	65.3	5.47	678	3,711
67	37.4	445.0	65.3	5.47	786	4,303
62	22.1	445.0	65.3	5.47	608	3,328
< 57	0.0	0.0	0	0.00	5194	0
			Annual Consumption =			19,521

Table 4: Water Cooled Chiller Performance (120 tons)

O.A. Temp	Load	% Load	kW	%kW	kW/ton	Hrs	kWh
102	120.0	100.0	94.7	100.0	0.7895	0	0
97	120.0	100.0	94.7	100.0	0.7895	19	1,800
92	120.0	100.0	94.7	100.0	0.7895	130	12,316
87	113.2	94.3	86.5	91.3	0.7643	314	27,160
82	95.0	79.2	67.1	70.8	0.7059	415	27,829
77	80.7	67.2	52.3	55.2	0.6486	616	32,232
72	81.7	68.1	53.0	55.9	0.6486	677	35,863
67	37.4	31.2	23.5	24.8	0.6283	768	18,054
62	22.1	18.4	13.9	14.6	0.6283	587	8,144
< 57	0.0	0.0	N/A	N/A	N/A	1610	0
					Total Electricity =		163,398

Table 5: Condenser Water Pump Performance (Constant Flow)

O.A. Temp	Load	GPM	Head Loss	kW	Hr	kWh
102	120.0	355	65.3	4.37	0	0
97	120.0	355	65.3	4.37	19	83
92	120.0	355	65.3	4.37	130	568
87	113.2	355	65.3	4.37	314	1371
82	95.0	355	65.3	4.37	415	1812
77	80.7	355	65.3	4.37	616	2690
72	81.7	355	65.3	4.37	678	2961
67	37.4	355	65.3	4.37	786	3432
62	22.1	355	65.3	4.37	608	2655
< 57	0.0	0.0	0	0.00	5194	0
				Total Energy =		15,573

Table 6: Air Cooled Chiller Summer Performance

O.A. Temp	Load	% Load	kW	% kW	kW/ton	Hrs	kWh
97	26.5	75.07	28.8	75	1.09	19	548
92	11.2	31.63	12.1	32	1.09	130	1,579
					Total Energy =		2,127

Table 7: Air Cooled Chiller Winter Performance

O.A. Temp	Load	% Load	kW	% kW	kW/ton	Hrs	kWh
67	37.4	101	34.8	100	0.930	18	626
62	22.1	60	20.7	60	0.938	21	435
< 57	0.0	0	0.0	0	0	0	0
					Total Energy =		1,061

The integrated chiller system consumes 5,520 kWh less than the base model, which produces an annual utility savings of $442. Figure 3 provides a graphical representation of the annual energy consumption comparison. This energy savings is very conservative since additional energy consumed by the base model, i.e. additional energy to prevent cooling tower freezing, was ignored.

The integrated chiller system design also reduces the project cost by eliminating the need for approximately 100 square feet of mechanical room space. The cost of the additional mechanical room space is higher than the cost of the additional air-cooled chiller.

The benefits of the integrated water-cooled/air-cooled chiller system include improved building comfort, reduced O&M cost, reduced initial system cost, and times, reduced energy costs.

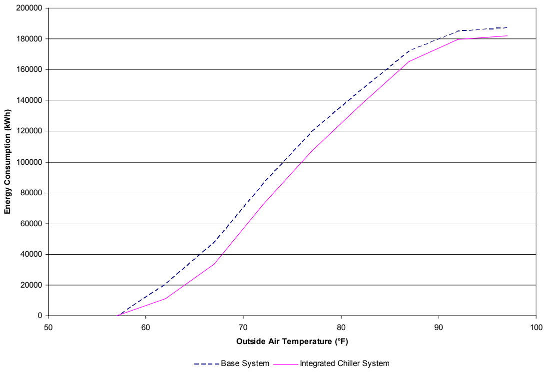

Figure 3: Annual Energy Consumption Comparison

Conclusions

A new chiller system was proposed to eliminate the cold weather operational concerns with cooling towers that are typically used with water-cooled chillers for higher efficiency. The new system uses a combination of water-cooled and air-cooled chillers to provide building cooling throughout the year, while allowing the tower to remain drained and idle during the cold weather months. This system was used in a case study and compared to the current system in the building. On an annual basis, the integrated system consumed less energy, approximately 5,520 kWh, than the current system. Perhaps the biggest advantage of this system, however, is its abolishment of cold weather cooling tower operational concerns. The integrated system is only logically used under optimum conditions and may not provide the best engineering solution in all instances. However, based on the information provided above, the integrated system appears to result in better system performance for buildings similar to the America Securities building located in Omaha, Nebraska.

Acknowledgement

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