operating in series or parallel with one another to meet a cooling load of a building having one or more chillers. Where multiple cooling towers are used, the cooling towers may configured to switch between different modes of operation, such as dry, wet, and adiabatic modes. Some cooling systems may include ice thermal storage systems or chilled water storage systems to charge or store cooling capacity when the cooling demand and/or energy rates are low and utilize the stored cooling capacity when the cooling demand and/or energy rates are high.

[0005] One issue with some of these prior cooling systems is that they operate their cooling towers according to fixed rules or programming so that when certain conditions are present, the cooling tower operates in a certain mode and/or the fan of the cooling tower is operated at a certain speed. Since these cooling systems operate according to fixed rules, they often are not operating efficiently and consume more energy and/or more water than is necessary.

[0006] Some cooling systems are known that utilize artificial intelligence to control the operation of the cooling system. However, these prior systems often overlook how components of the cooling system interact to affect the overall operation of the cooling system. Additionally, some of these cooling systems are configured to optimize energy consumption, but do not account for the consumption of water and chemicals that are used by the cooling tower of the system. Since these systems do not account for all inputs utilized by the cooling system, these systems may not be able to accurately optimize the cost of operating the cooling system.

SUMMARY OF INVENTION

[0006a] According to a first aspect of the present invention, there is provided a heat exchanger system comprising:

a cooling system comprising:

a heat generating apparatus configured to transfer heat to a process fluid;

a heat rejection apparatus configured to remove heat from the process fluid;

a sensor configured to detect a variable of the cooling system at a first time;

processor circuitry operably coupled to the sensor and configured to provide the variable and a plurality of potential operating parameters for operating the cooling system at

a second time to a machine learning model representative of the cooling system to estimate at least one of energy consumption, water usage, and chemical usage of the cooling system for each of the potential operating parameters;

the processor circuitry configured to determine, based at least in part on the estimated at least one of energy consumption, water usage, and chemical consumption for the potential operating parameters, an optimal operating parameter of the cooling system to satisfy a target optimization criterion; and

the processor circuitry configured to cause the cooling system to utilize the optimal operating parameter as the cooling system operates at the second time.

[0006b] There is disclosed a heat rejection apparatus for a cooling system, the heat rejection apparatus comprising:

a cooling tower comprising an evaporative heat exchanger operable to cool process fluid;

a sensor configured to detect a variable of the cooling tower;

a controller operably coupled to the cooling tower and the sensor, the controller configured to implement an optimal operating parameter for the cooling tower to satisfy a target optimization criterion;

the optimal operating parameter being determined at least in part by providing the variable and a plurality of potential operating parameters of the cooling tower to a machine learning model representative of the cooling tower to estimate power consumption and water usage for the potential operating parameters.

[0006c] According to a second aspect of the present invention, there is provided a method for operating a cooling system, the method comprising:

at a processor associated with a cooling system:

receiving a variable of the cooling system detected by a sensor of the cooling system at a first time;

providing the variable and a plurality of potential operating parameters for operating the cooling system at a second time to the machine learning model representative of

the cooling system to estimate at least one of energy consumption, water usage, and chemical usage of the cooling system for each of the potential operating parameters;

determining, based at least in part on the estimated at least one of energy consumption, water usage, and chemical usage for the potential operating parameters, an optimal operating parameter of the cooling system to satisfy a target optimization criterion; and

effecting utilization of the optimal operating parameter by the cooling system as the cooling system operates at the second time.

BRIEF DESCRIPTION OF THE DRAWINGS

[0007] FIG. 1A is a schematic view of a cooling system including a cooling subsystem having a cooling tower, pump, and a chiller, FIG. 1A further showing a cooling subsystem controller in communication with a master controller and a server computer;

[0008] FIG. 1B is a schematic view of an alternative cooling tower including an indirect heat exchanger having a series of serpentine tube runs;

[0009] FIG. 2 is a flow diagram of a method that includes determining one or more optimal set points of the cooling subsystem of FIG. 1 and an operating mode of the cooling

CLAIMS

What is claimed is:

1. A heat exchanger system comprising:

a cooling system comprising:

a heat generating apparatus configured to transfer heat to a process fluid;

a heat rejection apparatus configured to remove heat from the process fluid;

a sensor configured to detect a variable of the cooling system at a first time;

processor circuitry operably coupled to the sensor and configured to provide the variable and a plurality of potential operating parameters for operating the cooling system at a second time to a machine learning model representative of the cooling system to estimate at least one of energy consumption, water usage, and chemical usage of the cooling system for each of the potential operating parameters;

the processor circuitry configured to determine, based at least in part on the estimated at least one of energy consumption, water usage, and chemical consumption for the potential operating parameters, an optimal operating parameter of the cooling system to satisfy a target optimization criterion; and

the processor circuitry configured to cause the cooling system to utilize the optimal operating parameter as the cooling system operates at the second time.

2. The heat exchanger system of claim 1 wherein the target optimization criterion is minimizing energy consumption, minimizing water usage, minimizing chemical consumption, or minimizing cost.

3. The heat exchanger system of claim 1 wherein the heat rejection apparatus includes at least one cooling tower.

4. The heat exchanger system of claim 1 wherein the optimal operating parameter includes at least one of an operating mode of the heat rejection apparatus, a temperature of the process fluid leaving the heat rejection apparatus, a pressure of the process fluid leaving the heat rejection apparatus, and a flow rate of the process fluid.

5. The heat exchanger system of claim 1 wherein the processor circuitry is configured to provide the plurality of potential operating parameters of the cooling system to the machine learning model to estimate energy consumption and water usage based on the potential operating parameters; and

the processor circuitry is configured to determine, based at least in part on the estimated energy consumption and water usage, the optimal operating parameter of the cooling system to satisfy the target optimization criterion.

6. The heat exchanger system of claim 5 wherein the plurality of potential operating parameters includes a first plurality of potential operating parameters and a second plurality of potential operating parameters;

wherein the machine learning model includes a first machine learning model to estimate energy consumption of the cooling system and a second machine learning model to estimate water usage of the cooling system; and

wherein the processor circuitry is configured to provide the first plurality of potential operating parameters to the first machine learning model to estimate energy consumption of the cooling system and provide the second plurality of potential operating parameters to the second machine learning model to estimate water usage of the cooling system.

7. The heat exchanger system of claim 1 wherein the processor circuitry is configured to provide the plurality of potential operating parameters of the cooling system to the machine learning model to estimate chemical consumption based on the potential operating parameters; and

the processor circuitry is configured to determine, based at least in part on the chemical consumption, the optimal operating parameter of the cooling system to satisfy the target optimization criterion.

8. The heat exchanger system of claim 1 wherein the processor circuitry is configured to estimate a future operating condition;

wherein the processor circuitry is configured to provide a plurality of future potential operating parameters of the cooling system associated with the future operating condition to the machine learning model to estimate at least one of future energy consumption, future water usage, and future chemical consumption, based on the future potential operating parameters;

the processor circuitry is further configured to determine the optimal operating parameter of the cooling system to satisfy the target optimization criterion based on at least one of:

energy consumption;
water usage;
chemical consumption;
future energy consumption;
future water usage; and
future chemical consumption.

9. The heat exchanger system of claim 1 wherein the plurality of potential operating parameters provided to the machine learning algorithm include a range of operating parameters within operating constraints of the cooling system.

10. The heat exchanger system of claim 1 wherein the plurality of potential operating parameters include at least one of a fan speed operating parameter and a water usage operating parameter of the heat rejection apparatus.

11. The heat exchanger system of claim 1 wherein the sensor includes a plurality of sensors configured to detect a plurality of variables including:

a water usage variable of the cooling system;

an energy consumption variable of the cooling system; and

at least one of a leaving process fluid temperature variable of the heat rejection apparatus and a leaving process fluid pressure variable of the heat rejection apparatus.

12. The heat exchanger system of claim 1 wherein the sensor includes sensors configured to detect a variable of a process fluid leaving the heat rejection apparatus and a variable of an environment of the cooling system.

13. The heat exchanger system of claim 1 wherein the processor is configured to identify a malfunction of the cooling system, the processor configured to determine the plurality of potential operating parameters to provide to the at least one machine learning model representative based at least in part on the identified malfunction.

14. The heat exchanger system of claim 1 wherein the heat rejection apparatus includes a plurality of cooling towers, wherein at least one of the cooling towers is operable in a dry mode and at least one of the cooling towers is operable in a wet mode or an adiabatic mode.

15. The heat exchanger system of claim 1 wherein the heat rejection apparatus includes a plurality of cooling towers; and

wherein the target operating parameter includes a parameter indicative of whether the cooling towers operate in a series or parallel configuration.

16. The heat exchanger system of claim 1 wherein the heat rejection apparatus includes a thermal energy storage system; and

wherein the target operating parameter includes a parameter indicating whether the thermal energy storage system is charging thermal energy or discharging thermal energy.

17. A method for operating a cooling system, the method comprising:

at a processor associated with a cooling system:

receiving a variable of the cooling system detected by a sensor of the cooling system at a first time;

providing the variable and a plurality of potential operating parameters for operating the cooling system at a second time to the machine learning model representative of

the cooling system to estimate at least one of energy consumption, water usage, and chemical usage of the cooling system for each of the potential operating parameters;

determining, based at least in part on the estimated at least one of energy consumption, water usage, and chemical usage for the potential operating parameters, an optimal operating parameter of the cooling system to satisfy a target optimization criterion; and

effecting utilization of the optimal operating parameter by the cooling system as the cooling system operates at the second time.

18. The method of claim 17 wherein effecting utilization of the optimal operating parameter by the cooling system includes communication circuitry operably coupled to the processor communicating the optimal operating parameter to the cooling system via a network.

19. The method of claim 17 wherein the cooling system includes a cooling tower; and

wherein the optimal operating parameter includes a plurality of optimal operating parameters of the cooling tower.

20. The method of claim 17 wherein the target optimization criterion is minimizing energy consumption, minimizing water usage, minimizing chemical consumption, or minimizing cost.

21. The method of claim 17 wherein the optimal operating parameter includes at least one of an operating mode of a heat rejection apparatus of the cooling system, a temperature of process fluid leaving a heat rejection apparatus of the cooling tower, a pressure of the process fluid leaving the heat rejection apparatus, and a flow rate of the process fluid.

22. The method of claim 17 wherein providing the variable and the plurality of potential operating parameters of the cooling system to the machine learning model includes providing the variable and the plurality of potential operating parameters to the machine

learning model to estimate energy consumption and water usage based on the potential operating parameters;

wherein determining the optimal operating parameter to satisfy the target optimization criterion includes determining the optimal operating parameter based at least in part on the estimated energy consumption and the target optimization criterion.

23. The method of claim 17 wherein providing the plurality of potential operating parameters of the cooling system to the machine learning model includes providing the plurality of potential operating parameters to the machine learning model to estimate chemical usage based on the potential operating parameters;

wherein determining the optimal operating parameter to satisfy the target optimization criterion includes determining the optimal operating parameter based at least in part on the estimated chemical consumption.

24. The method of claim 17 wherein the plurality of potential operating parameters includes a first plurality of potential operating parameters and a second plurality of potential operating parameters;

wherein the machine learning model includes a first machine learning model to estimate energy consumption of the cooling system and a second machine learning model to estimate water usage; and

wherein providing the variable and the plurality of potential operating parameters to the machine learning model includes providing the first plurality of potential operating parameters to the first machine learning model to estimate energy consumption of the cooling system and providing the second plurality of potential operating parameters to the second machine learning model to estimate water usage of the cooling system.

25. The method of claim 17 wherein the plurality of potential operating parameters include at least one of a fan speed operating parameter and a water usage operating parameter of a heat rejection apparatus of the cooling system.

26. The method of claim 17 wherein receiving the variable of the cooling system detected by the sensor of the cooling system includes receiving variables detected by sensors of the cooling system, the variables including:

a water usage variable of the cooling system;

an energy consumption variable of the cooling system; and

at least one of a leaving process fluid temperature variable of a heat rejection apparatus of the cooling system and a leaving process fluid pressure variable of the heat rejection apparatus.

27. The method of claim 17 further comprising:

at the processor associated with the cooling system:

estimating a future operating condition;

providing a plurality of future potential operating parameters of the cooling system associated with the future operating condition to the machine learning model to estimate at least one of future energy consumption, future water usage, and future chemical consumption; and

determining the optimal operating parameter of the cooling system to satisfy the target optimization criterion based on at least one of:

energy consumption;

water usage;

chemical consumption

future energy consumption;

future water usage; and

future chemical consumption.

28. The method of claim 17 further comprising changing the target optimization criterion in response to a predetermined event.

29. The method of claim 17 wherein the plurality of potential operating parameters of the cooling system are determined based at least in part on a detected malfunction in the cooling system.