Further, dry indirect heat exchangers typically increase the static pressure drop seen by air passing through the hybrid evaporative heat exchanger.

SUMMARY OF INVENTION

[0004a] According to a first aspect of the present invention, there is provided a heat exchange apparatus comprising:

an evaporative heat exchanger assembly including an evaporative heat exchanger and an evaporative liquid distribution assembly configured to distribute evaporative liquid onto the evaporative heat exchanger;

a sump configured to collect evaporative liquid from the evaporative heat exchanger;

at least one fan configured to generate airflow relative to the evaporative heat exchanger;

a plume abatement assembly downstream of the evaporative heat exchanger, the plume abatement assembly including at least one heating element configured to increase a temperature of the airflow from the evaporative heat exchanger before the airflow leaves the heat exchange apparatus;

the plume abatement assembly having an operative configuration wherein the airflow travels through the at least one heating element to permit the at least one heating element to raise the temperature of the airflow and a bypass configuration wherein less of the airflow travels through the at least one heating element of the plume abatement assembly;

a control system operatively coupled to the evaporative heat exchanger assembly and the plume abatement assembly, the control system configured to determine plume formation and cause the plume abatement assembly to be in the operative configuration upon determination of plume formation;

wherein the control system is configured to receive either a request to save energy or a request to save water;

wherein, in the absence of the determination of plume formation, the control system is configured to:

operate the evaporative heat exchanger and the plume abatement assembly to limit energy consumption in response to receiving the request to save energy; and

operate the evaporative heat exchanger and the plume abatement assembly to limit evaporative liquid usage in response to receiving the request to save water.

[0004b] According to a second aspect of the present invention, there is provided a hybrid evaporative heat exchange system comprising:

a wet heat exchanger;

at least one fan configured to generate airflow relative to the wet heat exchanger;

a dry heat exchanger assembly downstream of the wet heat exchanger, the dry heat exchanger assembly including a dry heat exchanger configured to raise a temperature of the airflow from the wet heat exchanger;

the dry heat exchanger assembly having an operative configuration wherein the airflow from the wet heat exchanger flows through the dry heat exchanger and a bypass configuration wherein less of the airflow from the wet heat exchanger travels through the dry heat exchanger than when the dry heat exchanger assembly is in the operative configuration;

a control system operatively coupled to the wet heat exchanger, the at least one fan, and the dry heat exchanger assembly, the control system configured to cause the dry heat exchanger assembly to be in the plume abatement configuration in response to a determination of plume formation to permit the dry heat exchanger to raise the temperature of the airflow;

wherein the control system is configured to receive either a request to save energy or a request to save water;

wherein, in the absence of the determination of plume formation, the control system is configured to:

operate the wet heat exchanger and the dry heat exchanger assembly to limit energy consumption in response to receiving the request to save energy; and

operate the wet heat exchanger and the dry heat exchanger assembly to limit evaporative liquid usage in response to receiving the request to save water.

[0004c] According to a third aspect of the present invention, there is provided a method of operating a hybrid evaporative heat exchanger having a wet heat exchanger and a plume abatement assembly downstream of the wet heat exchanger, the plume abatement assembly

including a dry heat exchanger configured to raise a temperature of airflow from the wet heat exchanger, the plume abatement assembly having an operative configuration wherein the airflow from the wet heat exchanger flows through the dry heat exchanger and a bypass configuration wherein less of the airflow from the wet heat exchanger travels through the dry heat exchanger than when the plume abatement assembly is in the operative configuration, the method comprising:

receiving either a request to save energy or a request to save water;

operating the wet heat exchanger;

determining whether there is plume formation;

upon plume formation:

causing the plume abatement assembly to be in the operative configuration; and

raising the temperature of the airflow via the dry heat exchanger of the plume abatement assembly before the airflow leaves the hybrid evaporative heat exchanger to abate plume formation; and

in the absence of plume formation:

operating the wet heat exchanger and the plume abatement assembly to limit energy consumption in response to receiving the request to save energy; and

operating the wet heat exchanger and the plume abatement assembly to limit evaporative liquid usage in response to receiving the request to save water.

BRIEF DESCRIPTION OF THE DRAWINGS

[0005] FIG. 1 shows an embodiment of a hybrid evaporative heat exchanger having at least one wet indirect heat exchanger, at least one dry indirect heat exchanger, and a dry indirect heat exchanger bypass damper.

[0006] FIG. 2A shows the dry indirect heat exchanger bypass damper of FIG. 1 in a fully open position.

[0007] FIG. 2B shows the dry indirect heat exchanger bypass damper of FIG. 1 in a modulated partially open position.

[0008] FIG. 2C shows the dry indirect heat exchanger bypass damper of FIG. 1 in a fully closed position.

[0009] FIG. 3 shows another hybrid evaporative heat exchanger that incorporates dry heat exchanger bypass dampers installed in a side discharge plenum of the unit.

[0010] FIG. 4 shows a damper assembly of the hybrid evaporative heat exchanger of FIG. 3.

[0011] FIG. 5 shows a hybrid evaporative heat exchanger including at least one wet indirect heat exchanger, at least one dry indirect heat exchanger, and a dry indirect heat exchanger bypass damper with independent fans for each side of the hybrid evaporative heat exchanger.

[0012] FIG. 6 is a schematic view of a hybrid evaporative heat exchanger and a control system thereof.

[0013] FIG. 7 shows a hybrid evaporative heat exchanger including a wet indirect heat exchanger, a dry indirect heat exchanger, and a dry indirect heat exchanger bypass damper.

[0014] FIG. 8 shows a hybrid evaporative heat exchanger including a wet indirect heat exchanger, a dry indirect heat exchanger, and a bypass damper.

[0015] FIG. 9 shows a hybrid evaporative heat exchanger including a wet indirect heat exchanger, a dry indirect heat exchanger, and a dry indirect heat exchanger bypass damper

CLAIMS

What is claimed is:

1. A heat exchange apparatus comprising:

an evaporative heat exchanger assembly including an evaporative heat exchanger and an evaporative liquid distribution assembly configured to distribute evaporative liquid onto the evaporative heat exchanger;

a sump configured to collect evaporative liquid from the evaporative heat exchanger;

at least one fan configured to generate airflow relative to the evaporative heat exchanger;

a plume abatement assembly downstream of the evaporative heat exchanger, the plume abatement assembly including at least one heating element configured to increase a temperature of the airflow from the evaporative heat exchanger before the airflow leaves the heat exchange apparatus;

the plume abatement assembly having an operative configuration wherein the airflow travels through the at least one heating element to permit the at least one heating element to raise the temperature of the airflow and a bypass configuration wherein less of the airflow travels through the at least one heating element of the plume abatement assembly;

a control system operatively coupled to the evaporative heat exchanger assembly and the plume abatement assembly, the control system configured to determine plume formation and cause the plume abatement assembly to be in the operative configuration upon determination of plume formation;

wherein the control system is configured to receive either a request to save energy or a request to save water;

wherein, in the absence of the determination of plume formation, the control system is configured to:

operate the evaporative heat exchanger and the plume abatement assembly to limit energy consumption in response to receiving the request to save energy; and

operate the evaporative heat exchanger and the plume abatement assembly to limit evaporative liquid usage in response to receiving the request to save water.

2. The heat exchange apparatus of claim 1 wherein the at least one heating element includes at least one dry indirect heat exchanger configured to receive fluid having a temperature higher than the temperature of the airflow from the evaporative heat exchanger.

3. The heat exchange apparatus of claim 1 wherein the at least one heating element includes at least one dry indirect heat exchanger configured to receive at least one of:

process fluid;

steam;

waste heat; or

a combination thereof.

4. The heat exchange apparatus of claim 1 wherein the plume abatement assembly includes an opening and a closure member movable between open and closed positions relative to the at least one heating element to change a size of the opening and limit airflow through the at least one heating element.

5. The heat exchange apparatus of claim 1 wherein the plume abatement assembly has an opening that is at least partially closed with the plume abatement assembly in the operative configuration and more open with the plume abatement assembly in the bypass configuration to permit more airflow through the opening than when the plume abatement assembly is in the operative configuration.

6. The heat exchange apparatus of claim 1 wherein the plume abatement assembly includes at least one of a damper and a louver; and

wherein the at least one of the damper and the louver are at an at least partially closed position with the plume abatement assembly in the operative configuration and are at a more open position with the plume abatement assembly in the bypass configuration.

7. The heat exchange apparatus of claim 1 further comprising:

a sensor configured to detect at least one parameter relating to operation of the heat exchange apparatus;

wherein the control system is operatively coupled to the sensor, the control system configured to:

determine plume formation based at least in part on the parameter detected by the sensor; and

cause the plume abatement assembly to be in the operative configuration in response to determining plume formation.

8. The heat exchange apparatus of claim 1 further comprising:

a pump configured to pump evaporative fluid from the sump to the evaporative liquid distribution assembly;

wherein the control system is operatively coupled to the pump, the at least one fan, and the plume abatement assembly, the control system having a dry mode of operation wherein the control system:

causes the at least one fan to generate airflow relative to the evaporative heat exchanger;

inhibits the pump from pumping evaporative fluid to the evaporative liquid distribution assembly; and

causes the plume abatement assembly to be in the operative configuration.

9. The heat exchange apparatus of claim 1 further comprising:

a pump configured to pump evaporative fluid from the sump to the evaporative liquid distribution assembly;

wherein the control system is operatively coupled to the pump, the at least one fan, and the plume abatement assembly, the control system having an energy-saving wet mode of operation wherein the control system:

causes the at least one fan to generate airflow relative to the evaporative heat exchanger;

operates the pump to pump evaporative fluid to the evaporative liquid distribution assembly; and

causes the plume abatement assembly to be in the bypass configuration.

10. The heat exchanger apparatus of claim 1 wherein the at least one heating element includes:

a tube and a plurality of fins extending therefrom;

a plurality of serpentine coils;

plate-style heat exchangers; or

a combination thereof.

11. The heat exchanger apparatus of claim 1 wherein the evaporative heat exchanger includes at least one of a direct heat exchanger and an indirect heat exchanger.

12. A hybrid evaporative heat exchange system comprising:

a wet heat exchanger;

at least one fan configured to generate airflow relative to the wet heat exchanger;

a dry heat exchanger assembly downstream of the wet heat exchanger, the dry heat exchanger assembly including a dry heat exchanger configured to raise a temperature of the airflow from the wet heat exchanger;

the dry heat exchanger assembly having an operative configuration wherein the airflow from the wet heat exchanger flows through the dry heat exchanger and a bypass configuration wherein less of the airflow from the wet heat exchanger travels through the dry heat exchanger than when the dry heat exchanger assembly is in the operative configuration;

a control system operatively coupled to the wet heat exchanger, the at least one fan, and the dry heat exchanger assembly, the control system configured to cause the dry heat exchanger assembly to be in the plume abatement configuration in response to a determination of plume formation to permit the dry heat exchanger to raise the temperature of the airflow;

wherein the control system is configured to receive either a request to save energy or a request to save water;

wherein, in the absence of the determination of plume formation, the control system is configured to:

operate the wet heat exchanger and the dry heat exchanger assembly to limit energy consumption in response to receiving the request to save energy; and

operate the wet heat exchanger and the dry heat exchanger assembly to limit evaporative liquid usage in response to receiving the request to save water.

13. The hybrid evaporative heat exchange system of claim 12 wherein the control system has a dry mode wherein the control system limits operation of the wet heat exchanger and a wet mode wherein the control system operates the wet heat exchanger; and

wherein the control system, in the wet mode thereof, is configured to cause the dry heat exchanger assembly to be in the bypass configuration unless there is a plume formation determination.

14. The hybrid evaporative heat exchange system of claim 12 wherein the control system is configured to calculate a first state associated with air upstream of the wet heat exchanger and a second state associated with air downstream of the dry heat exchanger; and

wherein the control system is configured to determine plume formation in response to the first and second states having a predetermined relationship with the ambient air.

15. The hybrid evaporative heat exchanger system of claim 14 wherein the control system is configured to determine the first and second states having the predetermined relationship with ambient air based at least in part upon a plume visibility factor exceeding a threshold.

16. The hybrid evaporative heat exchanger system of claim 14 wherein the control system is configured to determine the first and second states having the predetermined relationship with ambient air based at least in part upon the airflow temperature increase provided by the dry heat exchanger being substantially equal to or exceeding a temperature increase required to

cause the first and second states to no longer have the predetermined relationship with the ambient air.

17. The hybrid evaporative heat exchange system of claim 12 wherein the control system has an input configured to receive data indicative of at least one parameter of air upstream of the wet heat exchanger or downstream of the dry heat exchanger;

wherein the control system is configured to:

determine a first state of the air upstream of the wet heat exchanger and a second state of the air downstream of the dry heat exchanger using psychrometric chart data;

identify a linear relationship connecting the first and second states in the psychrometric chart data and identifying whether the linear relationship is beyond a plume onset line of the psychrometric chart data; and

determine plume formation in response to the identification of the linear relationship being beyond the plume onset line of the psychometric chart data.

18. The hybrid evaporative heat exchange system of claim 12 wherein the control system includes an input configured to receive a request for plume abatement; and

wherein the control system is configured to determine plume formation in response to the input of the control system receiving the request for plume abatement.

19. The hybrid evaporative heat exchange system of claim 12 wherein the dry heat exchanger assembly in the operative configuration has an opening that is closed or partially open; and

wherein, in the bypass configuration, the dry heat exchanger assembly opening is more open than the opening in the operative configuration of the dry heat exchanger assembly.

20. The hybrid evaporative heat exchange system of claim 12 wherein the control system, in response to the determination of plume formation, is configured to cause the dry heat exchanger assembly to be in the plume abatement configuration including:

determining whether the dry heat exchanger assembly is in the operative configuration or the bypass configuration; and

upon the dry heat exchanger assembly being in the bypass configuration, reconfiguring the dry heat exchanger assembly to the operative configuration in response to the plume formation determination.

21. The hybrid evaporative heat exchange system of claim 12 further comprising a sensor configured to detect at least one air parameter; and

the control system configured to use the at least one air parameter to determine plume formation.

22. The hybrid evaporative heat exchange system of claim 12 wherein the control system has a dry mode wherein the control system does not operate the wet heat exchanger and causes the dry heat exchanger assembly to be in the operative configuration thereof.

23. The hybrid evaporative heat exchange system of claim 12 wherein the wet heat exchanger includes at least one of a direct evaporative heat exchanger and an indirect evaporative heat exchanger.

24. The hybrid evaporative heat exchanger system of claim 12 further comprising a plume detector operatively coupled to the control system; and

wherein the control system is configured to determine plume formation in response to a signal from the plume detector indicating a plume.

25. A method of operating a hybrid evaporative heat exchanger having a wet heat exchanger and a plume abatement assembly downstream of the wet heat exchanger, the plume abatement assembly including a dry heat exchanger configured to raise a temperature of airflow from the wet heat exchanger, the plume abatement assembly having an operative configuration wherein the airflow from the wet heat exchanger flows through the dry heat exchanger and a bypass configuration wherein less of the airflow from the wet heat exchanger

travels through the dry heat exchanger than when the plume abatement assembly is in the operative configuration, the method comprising:

receiving either a request to save energy or a request to save water;

operating the wet heat exchanger;

determining whether there is plume formation;

upon plume formation:

causing the plume abatement assembly to be in the operative configuration; and

raising the temperature of the airflow via the dry heat exchanger of the plume abatement assembly before the airflow leaves the hybrid evaporative heat exchanger to abate plume formation; and

in the absence of plume formation:

operating the wet heat exchanger and the plume abatement assembly to limit energy consumption in response to receiving the request to save energy; and

operating the wet heat exchanger and the plume abatement assembly to limit evaporative liquid usage in response to receiving the request to save water.

26. The method of claim 25 further comprising:

calculating a first state associated with air upstream of the wet heat exchanger and a second state of air downstream of the dry heat exchanger; and

determining plume formation in response to the first and second states having a predetermined relationship with the ambient air.

27. The method of claim 26 wherein determining plume formation in response to the first and second states having a predetermined relationship with ambient air includes determining the predetermined relationship based at least in part upon a plume visibility factor exceeding a threshold.

28. The method of claim 26 wherein determining plume formation in response to the first and second states having a predetermined relationship with the ambient air includes:

determining the first and second states having the predetermined relationship with the ambient air based at least in part upon the airflow temperature increase provided by the dry heat exchanger being substantially equal to or exceeding a temperature increase required to cause the first and second states to no longer have the predetermined relationship with the ambient air.

29. The method of claim 25 wherein determining plume formation includes:

receiving data indicative of at least one parameter of air upstream of the wet heat exchanger or downstream of the dry heat exchanger;

determining a first state of the air upstream of the wet heat exchanger and a second state of the air downstream of the dry heat exchanger using psychrometric chart data;

identifying a linear relationship connecting the first and second states in the psychrometric chart data and identifying whether the linear relationship is beyond a plume onset line of the psychrometric chart data; and

determining plume formation in response to the identification of the linear relationship being beyond the plume onset line of the psychometric chart data.

30. The method of claim 25 wherein determining plume formation includes receiving, at a control system of the hybrid evaporative heat exchanger, a request for plume abatement.

31. The method of claim 25 wherein causing the plume abatement assembly to be in the operative configuration includes reconfiguring the plume abatement assembly from the bypass configuration to the operative configuration.

32. The method of claim 31 wherein reconfiguring the plume abatement assembly from the bypass configuration to the operative configuration includes making an opening of the plume abatement assembly smaller than the opening was in the bypass configuration.

33. The method of claim 25 wherein causing the plume abatement assembly to be in the operative configuration includes modulating a closure member of the plume abatement assembly to change the size of an opening of the plume abatement assembly.

34. The hybrid evaporative heat exchanger system of claim 12 wherein the request includes a request to save energy during a first time period and a request to save water during a second time period;

wherein the control system is configured to operate the wet heat exchanger and the dry heat exchanger assembly to limit energy consumption during the first time period; and

wherein the control system is configured to operate the wet heat exchanger and the dry heat exchange assembly to limit evaporative liquid usage during the second time period.

35. The hybrid evaporative heat exchanger system of claim 12 wherein the wet heat exchanger includes an indirect heat exchanger, an evaporative liquid distribution system configured to distribute evaporative liquid onto the indirect heat exchanger, a sump to collect evaporative liquid from the indirect heat exchanger, and a pump configured to pump evaporative liquid from the sump to the evaporative liquid distribution system; and

wherein the control system is configured to operate the wet heat exchanger and the dry heat exchanger assembly to limit evaporative liquid usage including reducing a flow rate of the pump.

36. The hybrid evaporative heat exchanger system of claim 35 wherein the control system is configured to operate the wet heat exchanger and the dry heat exchanger to limit energy usage including increasing the flow rate of the pump.

37. The hybrid evaporative heat exchanger system of claim 12 wherein the control system, in response to the absence of the determination of plume formation and receiving the request to save water, is configured to cause the dry heat exchanger assembly to be in the plume abatement configuration.

38. The hybrid evaporative heat exchanger system of claim 12 wherein the control system is configured to operate the wet heat exchanger and the dry heat exchanger assembly to limit evaporative liquid usage including limiting operation of the wet heat exchanger.

39. The hybrid evaporative heat exchanger system of claim 12 wherein the control system is configured to operate the wet heat exchanger and the dry heat exchanger assembly to limit energy consumption including limiting operation of the dry heat exchanger.

40. The hybrid evaporative heat exchanger system of claim 12 wherein the control system, in response to the absence of the determination of plume formation and receiving the request to save water, is configured to:

reduce usage of evaporative liquid by the wet heat exchanger upon a determination that the hybrid evaporative heat exchanger system is able to meet a process fluid setpoint with reduced evaporative liquid usage by the wet heat exchanger.

41. The method of claim 25 wherein receiving the request includes receiving a request to save energy during a first time period and a request to save water during a second time period; and

wherein operating the wet heat exchanger and the plume abatement assembly to limit energy consumption includes operating the wet heat exchanger and the plume abatement assembly to limit energy consumption during the first time period; and

wherein operating the wet heat exchanger and the plume abatement assembly to limit evaporative liquid usage includes operating the wet heat exchanger and the plume abatement assembly to limit evaporative liquid usage during the second time period.

42. The method of claim 25 wherein the wet heat exchanger includes an indirect heat exchanger, an evaporative liquid distribution system configured to distribute evaporative liquid onto the indirect heat exchanger, a sump to collect evaporative liquid from the indirect heat exchanger, and a pump configured to pump evaporative liquid from the sump to the evaporative liquid distribution system; and

wherein operating the wet heat exchanger and the plume abatement assembly to limit evaporative liquid usage includes reducing a flow rate of the pump.

43. The method of claim 42 wherein operating the wet heat exchanger and the plume abatement assembly to limit energy usage includes increasing the flow rate of the pump.

44. The method of claim 25 further comprising:

determining whether the hybrid evaporative heat exchanger is able to meet a process fluid setpoint with reduced evaporative liquid usage by the wet heat exchanger; and

reducing usage of evaporative liquid by the wet heat exchanger in response to the request to save water, the determination of plume formation, and a determination that the hybrid evaporative heat exchanger is able to meet the process fluid setpoint with reduced evaporative liquid usage by the wet heat exchanger.