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Energy and water recovery using air-handling unit condensate from laboratory HVAC systems

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ABSTRACT

This paper examines ways to reduce energy and water consumption in laboratory HVAC systems. The data add to existing research into reduced potable water consumption derived from air handling unit (AHU) condensate. It also explores and validates the potential for energy recovery.

The literature shows that hot, humid climates can be ideal for AHU condensate to be leveraged as a source for pre-cooling and dehumidifying. The findings also reveal locations best suited for its application, because condensate generation is greatest when pre-cooling and dehumidification are needed most. Psychrometric relationships are used to predict condensate generation based upon ambient meteorological conditions.

Since laboratories require high volumes of 100% outside air, data show they are the perfect candidates to reuse relatively pure, cold condensate. This study analyzes AHU condensate utilization for both energy and water recovery modes; evaporative pre-cooling for sensible energy recovery, and condensate as a source for cooling tower make-up water. An optimization scheme is presented that maximizes energy and water savings based on outside air enthalpy, condensation generation, and energy recovery mode.

1. Introduction

Conservation of finite energy and water resources is one of the most critical challenges facing the planet in the twenty-first century. The energy-water nexus has garnered increasing interest in recent years as researchers and policy makers grapple with mitigation strategies that conserve both energy and water (Hawit & Jaffe, 2017; Hickman, Muzhikyan, & Farid, 2017; Jin, Tang, Feng, & Hook, 2017).

This paper focuses on the enormous potential for energy and water savings by recovering air-handing unit (AHU) condensate generated at cooling coils in 100% outside air heating, ventilating and cooling (HVAC) applications (e.g., laboratories and surgical suites) for sites located in hot and humid climates.

2. Background

In the United States, the commercial building sector accounts for approximately 40% of total energy consumption, including 72% of electricity and 36% of natural gas consumption (U.S. Dept. of Energy, 2008). The U.S. Energy Information Agency's 2012 Commercial Buildings Energy Consumption Survey reported that 7.35 exajoules of site energy was consumed by commercial buildings in the United States during 2012 (U.S. Energy Information Administration, 2015). Additionally, commercial buildings account for 9% of annual U.S. potable water consumption (U.S. Environmental Protection Agency, 2016).

2.1. Laboratories

Laboratories are the most energy-intensive building type, consuming three to four times more energy than the average building (Federspiel, Zhang, & Arens, 2002; Mathew, Sartor, & Bell, 2007). Several factors contribute to excessive laboratory energy consumption: 100% outside air HVAC, required air change rates (typically eight air changes per hour), laboratory equipment plug loads, chemical fume hood and biological safety cabinet ventilation rates, 24/7 operation and humidity requirements.

Laboratory HVAC systems also require tremendous amounts of water during the cooling season. For example, the combined U.S. Environmental Protection Agency/National Institute of Environmental Health Science campus, located in Research Triangle Park, North Carolina (a hot and humid climate), consumed 163,000,000 L of potable water to provide 86,295,985 kW h of cooling to 210,068 m^2 of laboratory, office and data center space in 2015.

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2.2. Laboratory HVAC systems

Outside air is drawn through AHUs by supply air fans. The AHUs are equipped with filter banks, heating and cooling coils, and spray nozzle humidifiers. For laboratories located in hot and humid climates, the AHU discharge air temperature in cooling mode is usually set at 12.8 °C. Selecting this discharge air temperature provides for both cooling and dehumidification.

Supply air is delivered to individual laboratory modules via supply variable air volume (VAV) terminal units. Each supply VAV terminal unit contains a heating coil that is used to reheat the air to an acceptable temperature. Laboratory exhaust VAV terminal units (either fume hoods, biological safety cabinets or general exhaust) are connected to an exhaust fan that removes the air though an exhaust stack.

Many laboratory HVAC systems are equipped with sensible run-around energy recovery loops. The purpose of the energy recovery loop is to first, extract energy from the exhaust airstream that would otherwise be lost to the atmosphere, and then use the energy to pre-heat or pre-cool the supply airstream. Only sensible energy is extracted because extracting latent heat could lead to cross-contamination of the supply and exhaust airstreams. Coils are installed in both supply and exhaust airstreams and a glycol-water mixture is pumped from the exhaust side to the supply side. Fig. 1 depicts a sensible run-around energy recovery loop.

2.2.1. Chiller plant

The chiller plant uses the vapor compression cycle to produce chilled water and remove heat absorbed by AHU cooling coils via the condenser loop. Fig. 2 is a schematic drawing that illustrates chiller plant operations.

The heat contained in the chilled water return piping enters the system as it boils a refrigerant in the evaporator to change the refrigerant's state to a saturated vapor. Work is added to the system to compress the refrigerant to a superheated vapor. The condenser loop removes heat from the system via a direct-contact cooling tower, which causes the refrigerant to change state to a saturated liquid. Finally, an expansion valve reduces pressure, causing the refrigerant to become a saturated mixture.

2.2.2. Cooling Tower

The direct-contact or open-evaporative cooling tower removes heat from the condenser water through evaporative cooling (Fig. 3).

Hot condenser water enters at the top of the tower. As the water droplets fall by gravity, a fan located at the top of the tower draws in ambient make-up air to enhance evaporative cooling. The cooled condenser water exits at the bottom of the tower and returns to the condenser.

Operating a direct-contact cooling tower is a water intensive process. Make-up water, which is typically potable, is used to replace water that is lost through evaporation, drift and blowdown. Blowdown prevents fouling by mineral scale deposits, which negatively impacts the condenser's heat transfer efficiency. Cycles of concentration (COC) are defined as the ratio of dissolved solids in the recirculating water to the dissolved solids in the make-up water (Carrier Air Conditioning Company, 1965). When the cycles of concentration exceed the acceptable number, blowdown occurs.

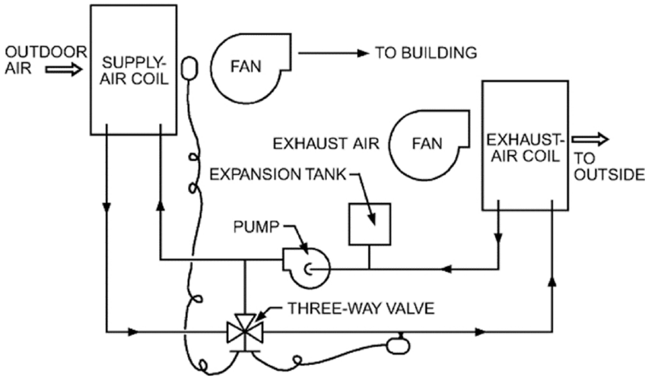

Fig. 1. Sensible Run-Around Energy Recovery Loop (ASHRAE Handbook, 2016).

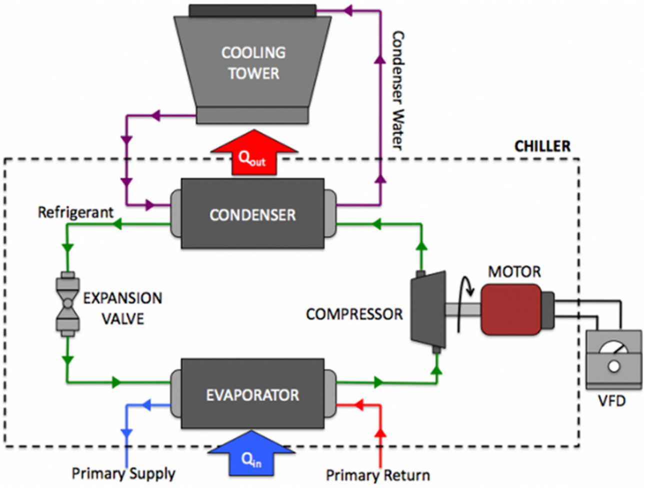

Fig. 2. Chiller Plant Schematic (Baglione, 2016).

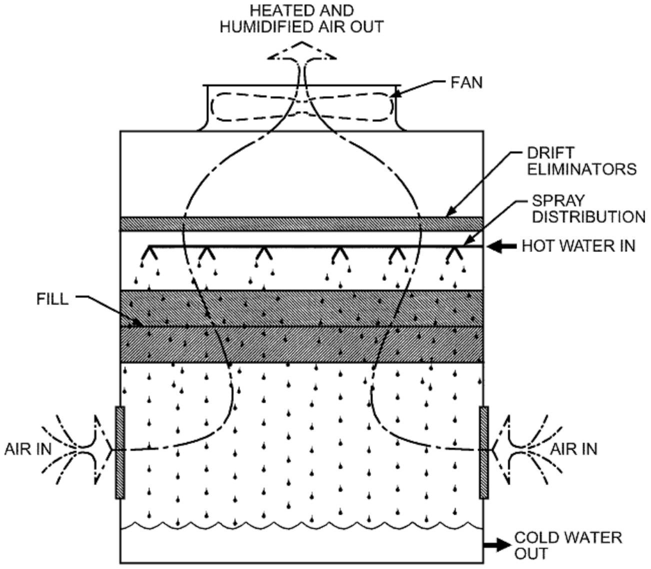

Fig. 3. Direct Contact Cooling Tower Schematic (ASHRAE Handbook, 2016).

2.3. Laboratory AHU condensate energy and water conservation model

Whenever the dew point temperature of the ambient air is greater than the cooling coil dew point temperature, condensate is generated during the cooling and dehumidification process. Instead of the typical practice of directing condensate to a sanitary sewer drain, condensate is directed to one or two alternate locations. In one option, condensate is directed to an air washer to pre-cool exhaust air prior to contacting an energy recovery exhaust coil (condensate assisted energy recovery). The other option utilizes condensate to provide a portion of make-up water for the chiller condenser water loop. Fig. 4 illustrates the model.

2.3.1. Energy recovery

Interest in extracting waste heat for energy recovery purposes can