Performance study of air washer chilled water coil system for a yarn industry

S. Jothyramalingam, D. Mohanlal

Anna University, India

ABSTRACT

This project presents the performance of air washer chilled water coil system for a yarn industry. The basic principles including (1) effectiveness, (2) saturation efficiency and energy consumption for the systems are evaluated. In addition these spray system prevents the contaminants produced in yarn industries entering into the system. This paper also presents the results of direct evaporative cooling processes, energy efficiency ratio and cooling efficiency for the air washer chilled water coil system. At different ambient conditions around India (Delhi, Mumbai, Kolkata, Chennai) against three seasons. This result shows the dry bulb temperatures decrease upto 12°C in arid summer conditions when air washer chilled water coil system is employed. The energy efficiency ratio is high and energy consumption reduces by 22.6% for air washers in Delhi than other cities. The required relative humidity (RH) ranges can be easily achieved when air washer chilled water coil system is employed. It is also one of the eco friendly systems and has less ozone depletion potential.

Keywords: (effectiveness, direct evaporative cooling, saturation efficiency, energy efficiency ratio)

1. INTRODUCTION

Water sprays are extensively used in several engineering applications, such as, dust control, fire fighting, nuclear reactor core cooling, spray drying, air scrubbing and evaporative cooling. In hot and dry climates, such as the summer season in India and other parts of the world, evaporative cooling of air is an attractive energy efficient technique for producing a comfortable indoor environment. Air washers employed in large air-conditioning systems for dust removal can also be optimized for evaporative cooling with appropriate design modifications which can result in energy savings.

In typical air washers, pressurized water travels through the air in which most drops fall to the floor and some drops drift with the air. This drop motion in air causes heat and mass transfer due to evaporation and some sensible cooling. Evaporative cooling operates using induced processes of heat and mass transfer, where water and air are the working fluids. It consists of water evaporation, induced by the passage of air flow, thus decreasing the air temperature. When water evaporates into the air to be cooled, simultaneously cooling and humidifying it, it is called direct evaporative cooling (DEC) and the thermal process is the adiabatic saturation. With direct evaporative cooling, outside air is blown through a water spray and cooled by evaporation. The cooled air is circulated by a blower. DEC adds moisture to the air stream until the air stream is close to saturation. The DBT is reduced, while the WBT stays the same (only when Tw = WBT). The main characteristic of this process is the fact that it is more efficient when the temperatures are higher, that means, when more cooling is necessary for thermal comfort. It has the additional attractiveness of low energy consumption and easy maintenance.

With indirect evaporative cooling (IDEC), a secondary (scavenger) air stream is cooled by water. The cooled secondary air stream goes through a heat exchanger, where it cools the primary air stream. The cooled primary air stream is circulated by blower. IDEC does not add moisture to the primary air stream. Both the DBT and WBT are reduced.

This system is mainly used for spot cooling of the yarn machine. Earlier system used chilled water coil system with 7°C inlet which maintains an inside condition of 24-26°C, 60% RH. In due course the inside condition was not achieved because the supply is through underground trench and lot of dust accumulation is formed in the pre filter section. The fumes produced due to heater in the yarn machine deposited as oily layers over the coil due to which heat transfer is affected. So there arises a need for replacement of chilled water spray system where chilled water at 7°C is sprayed and is circulated with chiller. The air to be supplied in conditioned space is passed inside an insulated room where the water at 7°C is sprayed. Thus overcoming the problem faced by earlier system. This system is an old system operating with a capacity of 150TR and able to maintain an inside condition of 28°C, 65% RH.

A completely different system a new air washer - chilled water coil system is designed for a yarn drawing machine of 250 kW, occupancy 3 people and a room dimension of 27m x 14.5m x 7m. The capacity of the system is 120 TR with 54,000 CFM of conditioned air to maintain an inside condition of 24°C, 60% RH. Considering all the above said factors of the systems, the performances of the systems were studied separately.
2. CHILLED WATER SPRAY SYSTEM

This system consists of mixing room, prefilter section, blower, and spray chamber. In spray chamber chilled water is sprayed at 7° C, which comes in direct contact with air and this spray water is circulated back in to the chiller. This system is used for spot cooling of direct twisting machine. Here supply air is distributed to DT machine through underground RCC trench and airflow through diffuser floor grill for spot cooling of DT machine. Supply RCC trench is at ground level and return duct is at 7.5 m level. Around 90% of the air is recirculated and 10% of air is taken as fresh air from atmosphere into the mixing room. In this system evaporative cooling and dehumidification take place in the spray room. This twisting machine has heaters, which produce oily fumes, and act as main load. These heaters are used to elongate the yarn for number of twist depending up on number of spindle.

Chilled water spray system is operated with vapor absorption chiller. CWSS has a constant load system that works for 20hrs a day with full load.

Figure 3.2 air at Ti inside condition is mixed with outside air O with a proportion of 10% fresh air and 90% recirculated air. At Tm where mixed air passes through spray chamber since the mean water surface temperature is lower than dew point temperature (Ts<Td) of air. Air is simultaneously cooled and dehumidified. The process is exactly similar to that of a cooling and dehumidifying coil. This process is shown as (m-2) s is the point where air is 100% saturated. This conditioned air is passed to maintain the inside condition as designed.

2.1 Experimental Study

From the actual reading measured the various points or various processes are plotted in a psychometrics chart and the following are calculated. 1, Spray chamber saturation efficiency 2, Actual cooling load capacity and Effectiveness of spray chamber.

Condition of air at inlet and outlet of various component of the system is measured.

Inside condition attained 27 ° C DBT 60% RH
Condition of air leaving the Spray chamber: Ts = 15.5° C DBT 14° C WBT
Mixed condition in mixing chamber that is air entering the spray chamber:28° C DBT 22.5° C WBT

2.2 Saturation efficiency of spray chamber

Cooling and dehumidification (Ts<Td) The mean water surface temperature is lower than dew point temperature of air. Air is simultaneously cooled and dehumidified. The process is exactly similar to that of a cooling and dehumidifying coil.

$$\eta = \frac{\omega_s - \omega_m}{\omega_m - \omega_a}$$  \hspace{1cm} (1)

$$\eta = 71.7 \%$$

2.3 Effectiveness Of Spray Chamber:

From the chart

$$C = \frac{(H_m - h_s)}{(H_m - h_a)}$$  \hspace{1cm} (2)

$$= 70.4\%$$

3. AIR WASHER-CHILLED WATER COIL SYSTEM

In this process cooling and humidification followed by cooling and dehumidification take place. This system comprises of an air washer and chilled water coil. In this system, saturation efficiency and effectiveness are subjected to study theoretically. The actual processes are plotted in psychrometric chart and analyzed.
3.1 Description Of The System

This system consists of air handling unit with air washer, which is used for spot cooling of the take-up (yarn drawing) machine. Here supply air is distributed to the take-up machine through under ground RCC trench and delivered through diffuser floor grill for spot cooling. Supply air RCC trench is at ground level and return duct is at 4.5m levels. Around 90% of the air is recirculated and 10% of air is taken as fresh air from atmosphere into the mixing chamber. The various sub system are (1) air handling unit, (2) air washer (3) prefilter, (4) eliminator, (5) chilled water coil and (6) supply fan as Shown in figure 4.1.

3.1.1 Air handling unit

This unit is a thermal break double skin unit, factory assembled and tested. The framework is made up of extruded aluminum and 3D corner joints. The panels are made up of GI Sheet with high polymer polyester coated. The space between the panels is filled with polyurethane foam resulting in high rigidity and thermal insulation. In this the chilled water at 7° C is circulated to cool the air to maintain 24 ° C & 65 % RH

3.1.2 Air washer

Air washer is used to wash the air since there are fumes generated from the machine and dusts since supply air is distributed through underground trench. The spray portion has a SS spray header with bank spray nozzles opposite to each other and with a concrete sump. The spray nozzles are made up of PVC with SS tip. The spray saturation efficiency is designed to be at least 90%.

3.1.3 Prefilter

Filters are washable dry panel filter having an efficiency of 90% down to 20 microns. The filter media is made up of non-woven fabric.

3.1.4 Mist Eliminator

The Mist eliminator is made up of PVC construction.

3.1.5 Chilled water-cooling coil

Cooling coils are made up of the fin and tube type having aluminum fins firmly bonded to copper tubes. Tubes are of 12.5mm O.D and 0.4 mm thickness with 8 fins/in.

3.1.6. Supply air fan

Supply air fans are of centrifugal type with backward curved blades

3.2 Theoretical Calculation For Awewcs

Mixing temperature:

\[ T_m = \frac{(c_{mm})_o \times t_o + (c_{mm})_r \times t_r}{(c_{mm})_d} \]  \hspace{1cm} (3)

\[ (c_{mm})_d = 1529 \]
\[ (c_{mm})_o = 153.4 \]
\[ (c_{mm})_r = 1375.6 \]

\[ T_m = 25.5 ° C \ DBT \]

Temperature of air leaving the coil:

\[ T_s = T_i - RSH/0.0204 \times (c_{mm})_d \]  \hspace{1cm} (4)

\[ T_s = 12.74 ° C \ DBT \]

From figure 4.2 air at Ti inside condition is mixed with outside air O at Tm where mixed air passes through air washer. The mean surface temperature of water is less than the DBT of air but greater than the wet bulb temperature of air and hence the air is cooled, while its enthalpy increases as a result of humidification.

Figure 4.2 Processes On Psychrometric Chart For The Awewcs System

This process is shown as (m-2) and s is the point where air is 100% saturated. Then air passes through chilled water coil where cooling and dehumidification take place along pt 2-s. This conditioned air is passed to maintain the inside condition as designed
3.3 Experimental study:
The reading measured from the various points or various processes are plotted in a psychrometric chart and the following are calculated. 1. Air washer saturation efficiency 2. Actual cooling coil capacity and Effectiveness of the cross flow chilled water coil.
Condition of air at inlet and outlet of various components of the system is measured.
Inside condition: 24 °C DBT, 65% RH
Condition of air leaving the coil: Ts = 18.5 °C DBT, 15.8 °C WBT
Condition before the coil and after air leaving air washer: 21.5 °C DBT, 20.5 °C WBT
Mixed condition in mixing chamber before air washer: 26 °C DBT, 20.5 °C WBT

3.3.1 Air Washer Saturation Efficiency:
The mean surface temperature of water is less than the DBT of air but greater than the wet bulb temperature of air. So the air is cooled and its enthalpy increases as a result of humidification. From figure 4.3
\[ \eta = \frac{(\omega_2 - \omega_1)}{(\omega_S - \omega_1)} \]
\[ \eta = 90.4 \% \]

3.3.2 Cooling Coil Capacity
From Figure 4.3
\[ Q = m (H_{out} - H_{in}) \]  \hspace{1cm} (5)
\[ Q = 468 \text{ kW} \]

3.3.3 Effectiveness Of Chilled Water Coil System
\[ C_{min} = C_p a \times m_a \] \hspace{1cm} (6)
\[ C_{max} = C_p w \times m_w \] \hspace{1cm} (7)
\[ \frac{C_{min}}{C_{max}} = 0.36 \]
\[ \text{NTU} = \frac{A n}{C_{min}} \] \hspace{1cm} (8)
\[ \text{NTU} = 1.1 \]

From chart using NTU and Cmin/ Cmax
We get Effectiveness = 64%.
From the above calculations it is inferred that, in this air washer the air is cooled, from 26 °C DBT to 21.5 °C DBT with a saturation efficiency of 90.4%. The actual process of cooling and humidification, cooling and dehumidification are plotted in a psychrometric chart and shown in figure 4.3. Effectiveness of the air washer cross flow chilled water coil is calculated as 64%.

4. PERFORMANCE STUDY OF DIRECT EVAPORATIVE COOLING AT DIFFERENT LOCATIONS
During summer, there occurs a large difference between the dry bulb temperature and wet bulb temperature, which is termed as wet bulb depression. It is the important feature, which offers an excellent opportunity for evaporative cooling as an alternative to a vapor compression machine. The performance of chilled water spray system is found better based on the effectiveness obtained for the Chennai ambient condition. The evaporative cooling process in the air washer system is not effective for Chennai as the wet bulb depression is not
high. To study this system as an alternative we need performance data on a range of wet bulb depression. Here the ambient conditions of Delhi, Mumbai, Calcutta and Chennai for three seasonal conditions were considered for the study. However Chennai operating parameters were considered as reference for all the locations. The graphs and equations are framed for the months of May, November and September and an hourly temperature profile is plotted and the variations between the four places are pictured.

Here the air washer system performance is calculated for both recirculation system and for 100% fresh air. With 90% saturation efficiency the calculations have been carried out for several sets of weather data for all location (reference. 11) with inside condition 24°C DBT and 65% RH and 1529 cmm.

4.1 Variation Of Wet Bulb Depression
From the table 5.1, during summer there is a large wet bulb depression and it is a special feature of Delhi’s weather when Chennai’s weather is compared. The daily average WBD ranges from 6°C to 15°C during (summer) the month of May in Delhi & for the month of November (winter) the daily average WBD ranges from 1.5°C to 13°C. The hourly variation of WBT in a day for three seasons at Chennai, Delhi, Mumbai and Calcutta are plotted in figure 5.1. WBD for all cities follow the common trend of gradually increasing to maximum at peak hour and then gradually decreasing. This offers an excellent opportunity for evaporative cooling as an alternative to a conventional refrigeration system. Evaporative cooling method for pre-cooling the outdoor air offers the advantages of reduced (i) cooling load for the chiller (ii) peak power demand or the connected load of the building.

4.2 Load Calculation for Awcwcs System at Delhi, Mumbai, Calcutta & Chennai
With the varying outdoor condition for the four cities, the air washer chilled water coil system are psychrometrically ploted for 100% fresh air & for 90% recirculated
Air and 10% fresh air on summer, winter & monsoon. 

Air washer system (100% fresh air) for Chennai during summer at the month May:
Outside condition: 36 °C DBT & 50% RH
Supply temperature: 18.5 °C DBT

From figure 5.2
Air washer saturation efficiency:
\[ \eta = \frac{\omega_2 - \omega_1}{\omega_s - \omega_1} \]
\[ \eta = 90\% \]
\[ \omega_s = 0.0221 \text{ kg/kg of dry air} \]
\[ T_s = 29 \degree C \text{ DBT} \]
Cooling Load: \( m (h_2 - h_1) \)
\[ Q = 343 \text{ TR} \]

Figure 5.2 Psychrometric chart for AWCWCS with 100% Fresh air at Chennai during summer

Figure 5.3 Psychrometric chart for AWCWCS with 100% Fresh air at Chennai during Winter

Figure 5.4 Psychrometric chart for AWCWCS with 100% Fresh air at Chennai during Monsoon

Figure 5.5 Psychrometric chart for AWCWCS with 100% Fresh air at Delhi during Winter

Figure 5.15 Variation Of Load for Air washer chilled water coil system for three seasons in four locations with 100% fresh air
From the figure 5.14 & figure 5.15 it is inferred that for both recirculated AWCWSC system & for 100% fresh AWCWSC system the refrigeration load (TR) required for Delhi in three seasons is found less when compared to other cities. For winter season at Delhi, 77 TR for recirculated air AWCWSC system is required and 50 TR for 100% fresh air system is required. Whereas for other cities we require more load (TR) to cool the 100% fresh air when compared to recirculated air in all seasons. So in Delhi where WBD is high we can see that air washer can be effectively used to cool the ambient air DBT to achieve a decrease up to 12 °C.

4.3 Energy Efficiency Ratio

Energy efficiency ratio (EER) (reference 2) was developed by the industry to evaluate the rate of energy consumption for air conditioning units. The EER represents a measure for rating air conditioning units. The energy efficiency ratio EER is defined as the net thermal energy in watt removed from air for cooling purposes per watt of energy expended.

\[
\text{EER} = \frac{\Delta H}{P}
\]

The enthalpy change in air \(\Delta H\), which can be calculated as follows:

\[
\Delta H = M \cdot c_p \cdot (T_1 - T_2)
\]

where, \(c_p\) is the specific heat of moist air in kJ/kg K; and \(M\) is the air mass flow rate in kg/s

\(T_1\) - DBT of ambient °C

\(T_2\) - DBT of air leaving the air washer °C

Where \(P\) is input electrical power in kW of the fan and water pump. The value of EER is calculated by determining the difference in the enthalpy of the inlet and outlet airstreams through the air washer and the input power.

**Figure 5.16 EER of Air washer chilled water coil system for three seasons in four locations with 100% fresh air**

4.4 Total Power Consumption

Fig 5.17 Energy consumption of Air washer chilled water coil system for three seasons in four locations with 90% recirculated air and 10% fresh

**Figure 5.17** Energy consumption of Air washer chilled water coil system for three seasons in four locations with 90% recirculated air and 10% fresh

**Figure 5.18** Energy consumption of Air washer chilled water coil system for three seasons in four locations with 100% fresh air

Figure 5.17 & fig 5.18 depict the seasonal power consumption for the considered system operating at the different locations. It is observed that the power consumption during summer in Delhi is 9% and 22.6% lower than those in Chennai for the 90% recirculated air system and 100% fresh air system respectively. Since the reduction in power consumption is more for 100% fresh air system it is advisable to go in for such systems even from the viewpoint of power consumption. Needless to say that the air quality also will be good.
5. SUMMARY AND CONCLUSIONS

The chilled water spray system and Air washer chilled water coil systems have been studied. The first system is found to be not suitable for the yarn industry. Hence the latter system alone has been analyzed in detail with specific reference to the geographic location (namely Delhi, Chennai, Mumbai and Calcutta) and seasonal variation in the ambient. Based on the analysis the following conclusions are drawn.

At Chennai Air washer saturation efficiency is found to be 90.4%.

Effectiveness of air washer chilled water coil system is found to be 64% at Chennai condition.

The air washer chilled water coil system is found more efficient at Delhi where the wet bulb depression is high. Evaporative cooling is an attractive energy conservation measure to pre-cool the supply air in air-conditioned buildings where wet bulb depression is high. Evaporative cooling performance differs drastically from place to place depending on the ambient conditions.

The drop in dry bulb temperature from ambient was 12°C in arid summer conditions when air washer system is employed at Delhi.

Power consumption for the AWCWC system employed in Delhi condition was found 22.6% lower than those in Chennai for 100% fresh air during summer.

EER of air washer for Delhi is 7.6 followed by Calcutta, Mumbai and Chennai.

In the manufacture of yarn and in processes such as spot cooling, direct evaporative coolers can provide the required accurate relative humidity control. For example, textile manufacturing requires relatively high humidity and the machinery load is heavy, so evaporative cooling can be effectively employed with the conventional air conditioning system to provide required condition.

In the yarn industry where fumes and gaseous contaminants are released from the machines, evaporative coolers, which function as scrubbers and reduce this contaminants found in air.

Nomenclature

\[ T_{m} \] - Mixing temperature in °C
\[ T_{o} \] - Outside air temperature in °C
\[ T_{r} \] - Return air temperature in °C
\[ cmm \] - Cubic meter per minute
\[ cmm_{o} \] - Outside air Cubic meter per minute
\[ cmm_{r} \] - Return air Cubic meter per minute
\[ RSH \] - Room sensible heat in kW
\[ RLH \] - Room Latent heat in kW
\[ T_{s} \] - Supply temperature in °C
\[ T_{i} \] - Inside temperature in °C
\[ \omega \] - Specific humidity g / kg dry air
\[ \eta \] - Saturation efficiency
\[ H_{aw} \] - Enthalpy of air leaving air washer kJ / kg
\[ H_{l} \] - Enthalpy of air leaving coil kJ / kg
\[ V_{n} \] - Velocity of water flow in m/s
\[ R_{e} \] - Reynold number
\[ N_{s} \] - Nusselt number
\[ h_{s} \] - Water side heat transfer coefficient W / m² K
\[ K \] - Thermal conductivity W/m K
\[ D_{t} \] - Inside tube diameter in m
\[ \nu \] - Kinematic viscosity in m²/s
\[ h_{a} \] - Air side heat transfer coefficient in W / m²
\[ U_{o} \] - Overall heat transfer coefficient in W / m²
\[ NTU \] - Number of transfer unit
\[ \epsilon \] - Effectiveness
\[ H_{es} \] - Enthalpy of air entering spray chamber kJ / kg
\[ H_{s} \] - Supply enthalpy in kJ / kg
\[ VAM \] - vapor absorption machine
\[ WBD \] - Wet bulb depression in °C
\[ KWR \] - Kilowatt per ton of refrigeration
\[ AWCWCS \] - Air washer chilled water coil system
\[ CWSS \] - Chilled water spray system
\[ DEC \] - Direct evaporative cooling
\[ IDEC \] - Indirect evaporative cooling

REFERENCES


Weather Data for India by “Climate Data ISHRAE”

Weather Data for India by “Climate Data ISHRAE”