EXPERIMENTAL STUDY OF AIR FLOW RATE EFFECTS ON HUMIDIFICATION PARAMETERS WITH PREHEATING AND DEHUMIDIFICATION PROCESS CHANGING

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ABSTRACT

The objective of this research is to study experimentally the effect of air flow rate on humidification process parameters. Experimental data are obtained from air conditioning study unit T110D. Results obtained from experimental test, calculations and psychometrics software are discussed. The effect of air flow rate on steam humidification process parameters as a part of air-conditioning processes can be explain in results obtained. Results of the steam humidification process with and without preheating with 5A and 7.5A shows decreasing in dry bulb temperature, humidity ratio, and heat add to moist air with increasing air flow rate, but humidification load, and total energy of moist air increase with increasing air flow rate in the testing tunnel. The steam humidification process with dehumidifying coil shows increase in dry bulb temperature, humidity ratio, humidification load, and heat add to moist air with increasing air flow rate in the testing tunnel, but the total energy decrease as air flow rate increase. These results obtained can be beneficial for controlling comfort air-conditioning processes in buildings.

Keywords: humidification process, air flow rate, total energy, preheating, dehumidifying coil.

INTRODUCTION

The indoor air environment of modern buildings is customarily extremely airtight and highly controlled, though may still exhibit inadequate ventilation. The controlling system must regulate temperature, relative humidity (RH), air flow, and concentration of dusts. The air flow rate in air conditioning system must change due to changing of temperature and relative humidity (RH) between summer and winter.

The humidity parameters contains Humidity ratio (W) (alternatively, the moisture content or mixing ratio) of a given moist air sample is defined as the ratio of the mass of water vapor to the mass of dry air contained in the sample:

$$W=M_w / M_{da}$$

The humidity ratio (W) is equal to the mole fraction ratio x_w/x_{da} multiplied by the ratio of molecular masses, namely, 18.01528/28.9645 = 0.62198:

$$W = 0.62198X_w /X_{da}$$

Relative humidity (Φ) is the ratio of the mole fraction of water vapor X_w in a given moist air sample to the mole fraction X_{ws} in an air sample saturated at the same temperature and pressure:

$$\Phi= (X_w/X_{ws})_{t.p}$$

Thermodynamic wet-bulb temperature $t*$ is the temperature at which water (liquid or solid), by evaporating into moist air at a given dry-bulb temperature Td and humidity ratio W, can bring air to saturation adiabatically at the same temperature $t*$ while the total pressure p is maintained constant. Dew-point temperature (t_d) is a temperature of saturated moist air at the same pressure and humidity ratio as the given mixture [ASHRAE - 2009].

Humidification processes is the transfer (addition) of water vapor to air. This process is usually accomplished by introducing water vapor or by spraying fine droplets of water that evaporate into the circulating air stream. Moisture can be added to air by injecting steam, i.e., water which is already in vapor form and does not require the addition of latent heat. Under these conditions, the air will not be cooled and will stay at about the same dry bulb temperature. The steam will be at 100°C when released to the atmosphere (or may be slightly superheated), and so raises the final temperature of the mixture [A. R. Trott and T. Welch - 2000].

A natural concomitant of dropping the temperature of the air is removing moisture from it. In cooling the air in a low-temperature refrigerated warehouse the dehumidification process form frost on the coil, which is usually an undesirable by product of the temperature-reduction process. In a comfort or industrial air-conditioning application the dehumidification is usually a desirable objective [Stoeker W.F. - 1982].

Humidification processes with air flow, preheating, and a dehumidification effect has been the subject of various previously experimental studies:

S.A. El-Agouz, M. Abugderah (2008) presented an experimental investigation of humidification process by air passing through seawater. The main objective of their work was to determine the humid air behavior through single-stage of heating-humidifying processes. Two cases of different inlet conditions of ambient and heated air cases are studied. The experimental results show that, the vapor content difference and the humidification efficiency of the system is strongly affected by the saline water temperature in the evaporator chamber, headwater difference and the air velocity.

Hongbin Zhao, Pengxiu Yue *et al*., (2009) showed a new humid air turbine cycle that uses low- or medium-temperature solar energy as assistant heat source was proposed for increasing the mass flow rate of humid air. The effects of some parameters such as pressure ratio, turbine inlet temperature, and solar collector efficiency, specific work, and solar energy to electricity efficiency were discussed.

Compared with the conventional HAT cycle, because of the increased humid air mass flow rate in the new system, the humidity and the specific work of the new system were increased.

Mikiya Sato, Shingo Fukayo *et al*., (2003) Explained that relative humidity (RH) shows the lowest achievement rate among the various general air quality standards for work environment. It has been mainly contributed by airtight design of modern buildings and occurrence of dry outdoor air in winter.

Furthermore, an ultra-dry air environment of nearly 0% RH is often required in sophisticated industries. In order to assess the adverse health effects of the ultra-dry air environment, using a self-reported questionnaire, we have undertaken a study of over 200 employees of a high-tech device developing laboratory having a room at 2.5% RH (ultra-dry room).

Paraya A., Faud M. B. *et al*., (2000) Showed a developed method for measuring the temperature and relative humidity of air prior to and after nasal conditioning and used it to study the effect of treatment with ipratropium bromide on the ability of the nose to condition cold, dry air.

Anton Ten Wolde, lain S. Walker (2001) Focuses in their paper on interior moisture design loads for residences and proposes a procedure to estimate the design indoor humidity for both winter and summer conditions. The interior humidity is a function of moisture release, ventilation, dehumidification, and moisture storage in the materials in the building. If the home is not air conditioned or dehumidified, the weekly or monthly average design indoor humidity can be calculated from design ventilation and moisture release.

Tony Evans (2008) showed the control of humidity in information technology environments is essential to achieving high availability. His paper explains how humidity affects equipment and why humidity control is required.

Mohamed Mahmoud Gouda (2005) showed that the fuzzy ventilation control strategy aims to use the free cooling and dehumidification available due to differences in zone and ambient conditions. This can achieve by changing the proportion of fresh air entering the heating, ventilation and air conditioning (HVAC) system and hence the controlled zone.

The goal of this work is to study experimentally the effect of air flow rate on humidification process parameters; dry bulb temperature, humidity ratio, relative humidity, humidification load, heat added and total energy of the processes.

EXPERIMENTAL WORK

The operating principle of air conditioning study unit T110D is as follows: a stream of air generated by a centrifugal fan is made to pass through a tunnel via a fluid thread rectifier. As it goes through the tunnel the air undergoes a series of treatments until it reaches a final chamber representing the environment to be conditioned. The air is initially preheated then humidified by means of steam diffusers then cooled by means of the R22 evaporator and finally conveyed into the end chamber which enabling to vary the greatest possible quantity of parameter for through understanding of climate control, Figure-1 describe the parts of the study unit.

The test procedure of steam humidification processes consists of turning the centrifugal fan on with mass flow rate (1) of steam humidifier, test air velocity inside circular testing tunnel vary from 2.6 m/s to 21 m/s, and test RH and Td after steam humidifier for each velocity. By using manual control valve over the steam boiler, the prior steps be repeated for mass flow rate (2) of humidification steam which is double mass of flow rate (1).

Before each test read the ambient RH and Td entering the testing tunnel, as well as turning the preheated on for 5A and 7.5A current individually for preheating and steam humidification processes with mass flow rate (1, 2) of steam, and finally turning dehumidifying coil (evaporator) on for the process of steam humidification and dehumidifying coil with mass flow rate (1) of steam. Individual steam humidification processes, preheating with steam humidification processes, and steam humidification with dehumidifying coil processes be achieved all in a space consider great enough to prevent mixing between outlet conditions and inlet conditions for any process.

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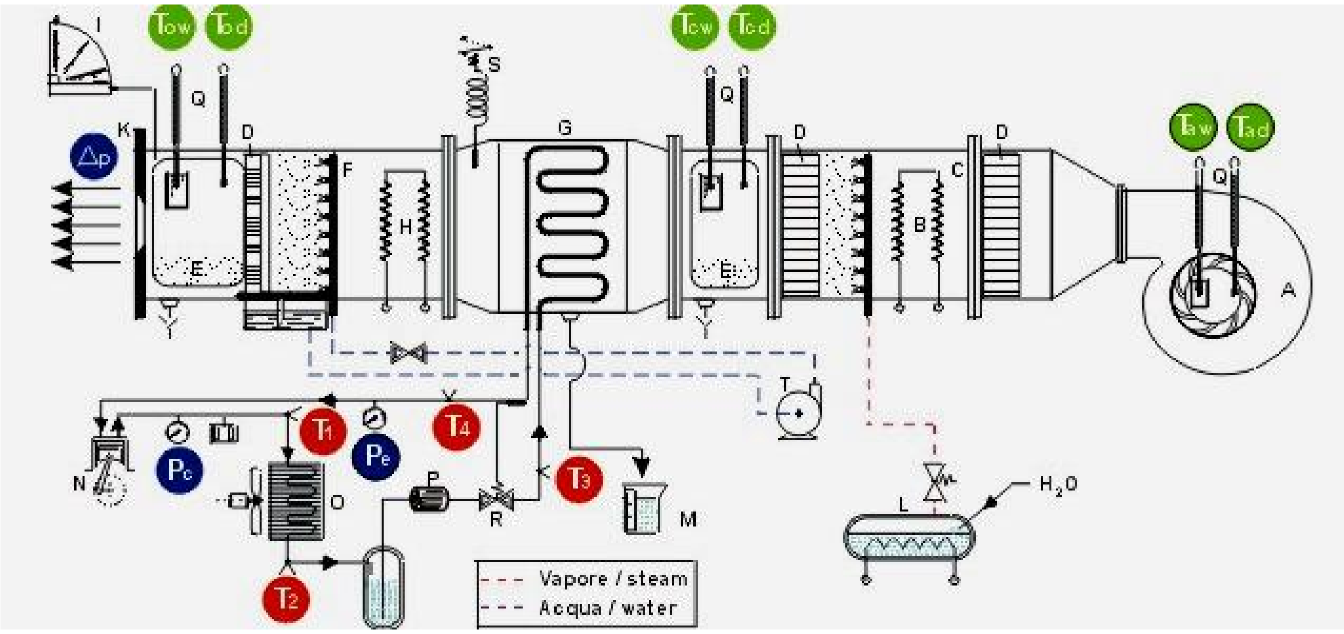

Figure-1. Schematic diagram of air-conditioning study unit T110D.

Keys for study unit T110D

A. Variable speed centrifugal fan
B. Variable power pre-heater
C. Steam diffuser
D. Fluid thread rectifier
E. Inspection window
F. Water diffuser
G. R22/air evaporator
H. Variable power heater
I. Tilting scale differential micro manometer
K. Calibrated diaphragm
L. Automatic steam boiler
M. Extracted moisture measuring Device
N. Close type compressor
O. Ventilated R22/air condenser
P. Dehydrating filter
Q. Dry and wet bulb psychomotor
R. Isenthalpic thermostatic expansion valve
S. Electronic thermostat
T. Water circulation electro pump

Test Meters

1-Humidity and Temperature Meter

- **Specifications**

Temperature range: -10 °C to 50 °C
Relative humidity range: 5.0% RH to 98%RH

- **Accuracy**

Temperature: ±1°C
Relative humidity: ±3.5%RH

2-Remote Vane Digital Anemometer

- **Specifications**

Air flow range: 0.4 m/s to 35 m/s
Temperature: -10 °C to 50 °C
Fan diameter: 70 mm

- **Accuracy**

Air flow range: ±2%
Temperature: ±0.6°C

THEORY

The readings were obtained from the experimental work which is relative humidity and dry bulb temperature with various air velocities would be used in calculations, the calculations of humidification parameters are:

a) Humidity ratio difference between air entering and air leaving the processes (W_o-W_i).
b) The amount of heat added in each process per kilogram of dry air is

Heat added = $(h_o - h_i)$ (1)

OR Heat added = $C_p\,(T_o - T_i)$

c) Humidification load which is given by

Humidification load = $m_{air}\,(W_o - W_i)$ (2)

Where
$m_{air} = \rho\, V\, A$

ρ = density of air at entering the process
V = velocity of air at entering the process
A = cross suction area of the tunnel ($A=\pi d^2/4$)
d = diameter of tunnel ($d = 0.1$ m)

d) Total energy for each process could obtain from the difference between outlet conditions and inlet conditions for individual steam humidification and compound steam humidification processes. At first, the total energy of steam humidification process calculated by the summation of sensible and latent energy through the process from psychrometrics software which equal

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to air mass flow rate multiplying by enthalpy difference at same process, as well as for steam humidification with preheating processes and steam humidification with dehumidifying coil processes.

The Psychrometrics software has complete properties of psychrometrics chart of dry and wet bulb temperatures, relative humidity, humidity ratio, specific volume, and enthalpy. The software have ability of getting the total properties of moist air from two properties only, and calculate the sensible and latent energy for the total process which can drawn on the psychrometrics chart, then the total energy of the process can be achieved. The processes performed at psychrometrics software are; steam humidification process (1), steam humidification process (2), steam humidification process (1) with preheating of 5A, steam humidification process (2) with preheating of 5A, steam humidification process (1) with preheating of 7.5A, steam humidification process (2) with preheating of 7.5A, and steam humidification process (1) with dehumidifying coil, the seven processes have ten calculation points for each and the software used seventy time.

RESULTS AND DISCUSSIONS

Air properties

Figure-2 shows the variation of air dry bulb temperature leaving the humidification process with air flow rate.

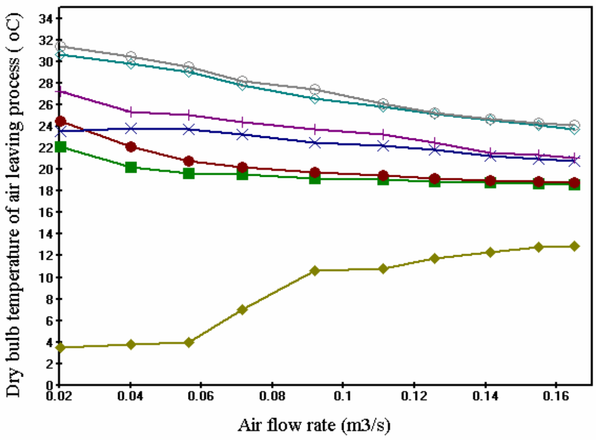

Figure-2. The variation of dry bulb air temperature leaving the processes with air flow rate.

The results show that when steam humidification (1, 2) decrease, air flow rate increase. Furthermore, steam humidification (1, 2) with 5A and 7.5A preheating decrease when air flow rate increase because of increasing of air velocity and heat loss which leads to a decrease in dry bulb temperature. For steam humidification (1) with dehumidifying coil the dry bulb temperature of air increases with air flow rate because of the increase in heat gain from the surrounding to the moist air in the testing tunnel.

Figure-3 shows the variation of relative humidity of air leaving humidification process with air flow rate.

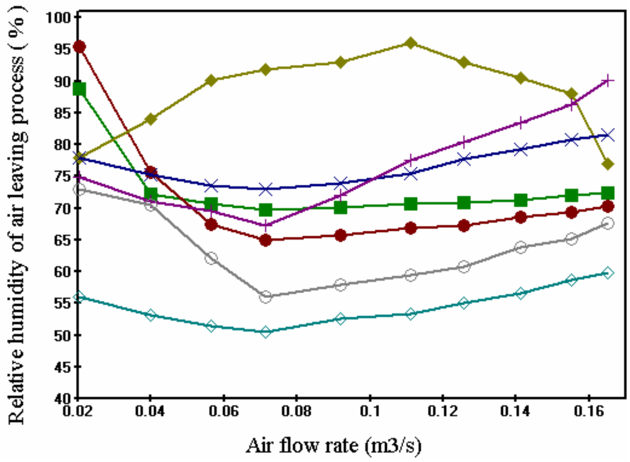

Figure-3. The variation of relative humidity of air leaving the processes with air flow rate.

The relative humidity of steam humidification (1, 2) with and without 5A and 7.5A preheating decrease with an increase in the air flow rate till a value of (0.071) m^3/s after which the relative humidity increase with air flow rate. The relative humidity of steam humidification (1, 2) with 5A preheating is greater than that with 7.5A preheating because of heating the air then decreases RH. Relative humidity of steam humidification (1) with dehumidifying coil increase with air flow rate till a value of (0.111) m^3/s; after which it decreases with air flow rate because of comparatively fixed humidity ratio with an increase in dry bulb temperature. This is in contrast to the steam humidification (1, 2) with and without preheating because of the difference between heat added and heat removed at humidification process. The steam humidification (1, 2) with and without preheating leads to an increase in the air temperature and decrease in relative humidity for low air flow rate then they increase with air flow rate. The steam humidification with dehumidifying coil cause an increase in relative humidity for low air flow rate then it decreases with air flow rate. Steam humidification (2) with dehumidifying coil could not be performed because the relative humidity reached a value of 100% because of double mass of steam humidification with heat removed.

Humidification load

Figure-4 shows the variation of humidity ratio of air leaving the process with air flow rate. The humidity ratio of steam humidification (1,2) with and without preheating decrease as the air flow rate increases, but steam humidification (1) with dehumidifying coil increase as the air flow rate increases because of increase in the mole fraction ratio of humidity, which is in contrast to steam humidification with preheating.

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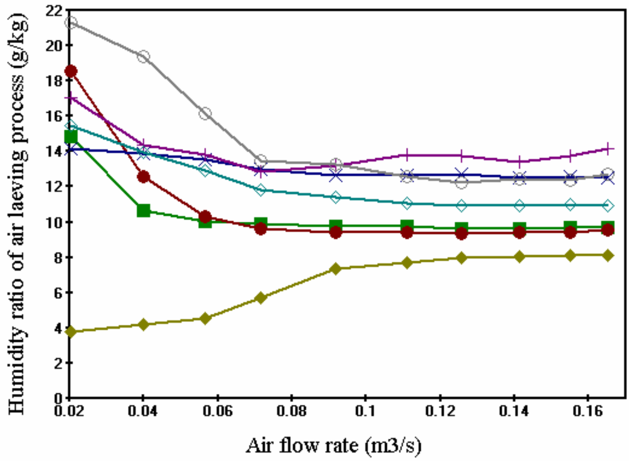


Figure-4. The variation of humidity ratio of air leaving the processes with air flow rate.

Figure-5 shows the variation of humidification load with the air flow rate calculated from equation (2). The humidification load of steam carried out with air flow rate shows increase in the ability of carrying steam with increasing the flow rate of air. The negative values of humidification load for dehumidifying coil means a decrease in the humidity ratio of air leaving the process with respect to entering air because of dehumidifying coil use.

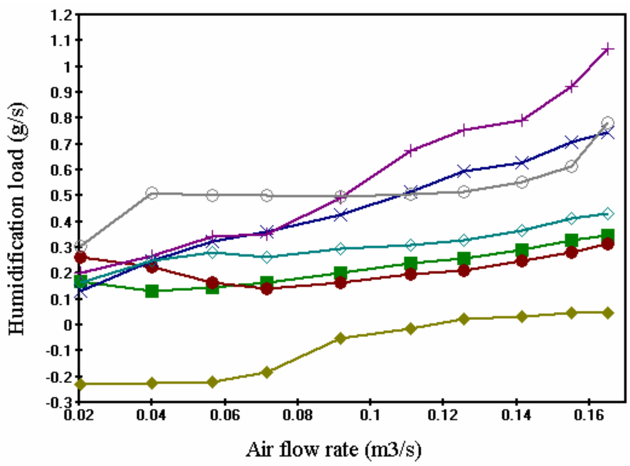


Figure-5. The variation of humidification load of the processes with air flow rate.

Heat added and total energy

Figure-6 shows the variation of heat added by the processes with air flow rate which is calculated from equation (1). The heat added of steam humidification (1,2) with and without preheating decrease as air flow rate increases because of the increase in air velocity while heat exchange decrease as the air flow rate increases from a value of (0.071) m^3/s to (0.165) m^3/s. The heat added at steam humidification (1) and (2) processes become very close after a flow rate of (0.071) m^3/s. Heat added at steam humidification process (1) with dehumidifying coil increase as air flow rate increases. The negative values of heat added are caused by using of dehumidifying coil.

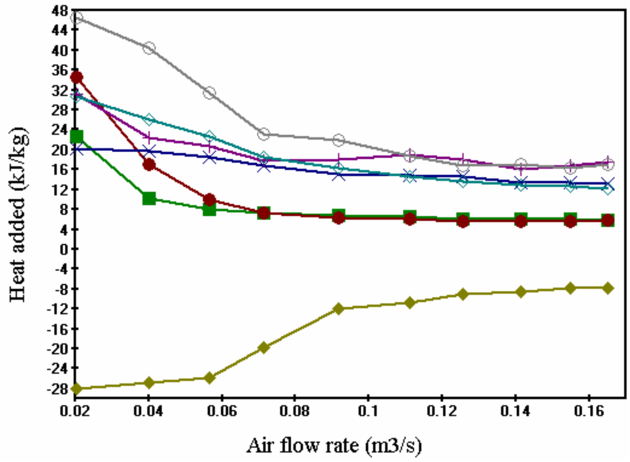


Figure-6. The variation of heat added at the processes with air flow rate.

Figure-7 shows the variation of total energy of the processes with air flow rate which is the sum of the sensible energy and the latent energy for each part participate in these processes. The total energy for steam humidification (1,2) without preheating increase slightly with air flow rate, but the total energy for steam humidification (1,2) with preheating increase strongly with air flow rate. This clearly means that the energy of steam with heating increase as air flow rate increases. The total energy of the process with dehumidifying coil decrease slightly as air flow rate increases; because of varying the sensible and latent energy between steam added in humidification process and steam removed in dehumidifying coil with increase in the air flow rate.

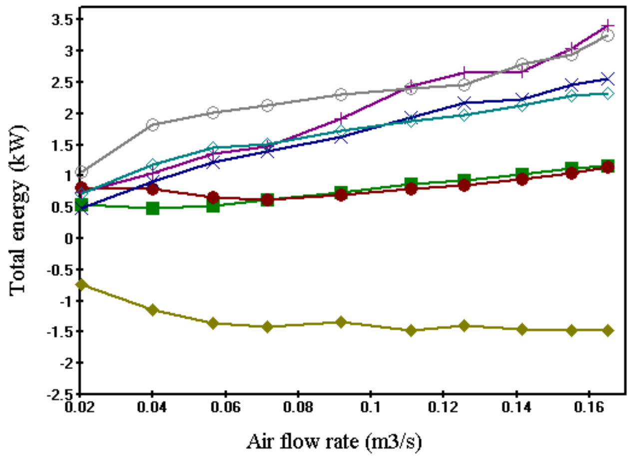


Figure-7. The variation of total energy of the processes with air flow rate.

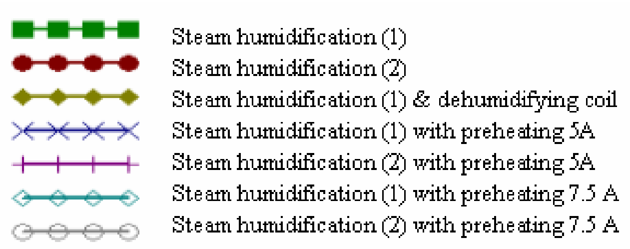
CONCLUSIONS

The following conclusions may be drawn from this study:

- The steam humidification process with and without preheating with 5A and 7.5A shows decreasing in dry bulb temperature, humidity ratio, and heat add to moist air with increasing air flow rate, but humidification load, and total energy of moist air increase with increasing air flow rate in the testing tunnel;

- The steam humidification process with dehumidifying coil shows increase in dry bulb temperature, humidity ratio, humidification load, and heat add to moist air with increasing air flow rate in the testing tunnel, but the total energy decrease as air flow rate increase;
- The relative humidity shows a different variation with increasing air flow rate. For low air flow rate, steam humidification process with and without preheating decrease till 0.071 m^3/s then increase for high flow rate; and steam humidification process with dehumidifying coil increase till 0.111 m^3/s then decrease for high flow rate; and
- Humidification load, relative humidity, dry bulb temperature, and air velocity are the main parameters for controlling comfort air-conditioning processes in buildings.

Figures legend



Nomenclature

A cross section area of the tunnel (m^2)
C_p specific heat of moist air (kJ/kg.K)
d diameter of the tunnel (m)
h_i ambient air enthalpy entering process (kJ/kg)
h_o enthalpy of air leaving the process (kJ/kg)
m_{air} mass flow rate of air
$\dot{m}_{da}$ mass flow of dry air, per unit time
$\dot{m}_w$ mass flow of water (any phase), per unit time
M_{da} mass of dry air in moist air sample
M_w mass of water vapor in moist air sample
RH relative humidity (%)
Td dry bulb temperature (^oC)
t^* thermodynamic wet-bulb temperature (^oC)
t_d dew-point temperature of moist air (^oC)
T_i temperature of air entering process (^oC)
T_o temperature of air leaving the process (^oC)
V air velocity (m/s)
W humidity ratio of moist air (g/kg)
W_i ambient air humidity ratio (g/kg)
W_o humidity ratio of air leaving process (g/kg)
x_{da} mole-fraction of dry air, moles of dry air per mole of mixture
da dry air (^oC)

Greek symbols

Φ relative humidity
ρ air density (kg/m^3)

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