5. Type 334 Air handling unit with sensible and latent heat recovery

5.1. General description

An air handling unit (AHU) is used to calculate the energy consumption of heating and/or cooling (outside) air to a certain setpoint. This type is considered to be mainly used in combination with type 56 (multizone building) for ventilation. By specifying different parameters the AHU can act as a (air) heat recovery unit only, or as a full HVAC component where the air is heated, cooled, humidified and dehumidified. In addition, a frost protection temperature setting at the heat recovery device and a bypass mode can be specified. The following modes are available:

- Sensible and/or latent heat recovery
- Frost protection
- (Re-)heating and (re-)cooling
- Humidification and/or dehumidification
- Bypass of heat recovery
- Adiabatic cooling of exhaust air by humidification
- Recirculation

5.2. Nomenclature

A_{ref}	m²	Reference area for calculation of specific outputs
$c_{p,Air}$	kJ/kgK	Specific heat capacity of air at approx. inlet/outlet air temp. conditions
ModeHTCL	-	Mode for heating and/or cooling humidification/dehumidification
ModeFP	-	Mode for frost protection
ModeBP	-	Mode for bypass
$\dot{m}_{RA}$	kg/h	Return air mass flowrate
$\dot{m}_{OA}$	kg/h	Outdoor air mass flowrate
$\dot{m}_{SA}$	kg/h	Supply air mass flowrate
$\dot{m}_{EA}$	kg/h	Exhaust air mass flowrate
$\dot{Q}_{cl,AD}$	kJ/h	Possible adiabatic cooling power by humidification of the return air
$\dot{Q}_{cl,DEHUM}$	kJ/h	Required cooling power demand for dehumidification
$\dot{Q}_{cl,CC}$	kJ/h	Required cooling power by cooling coil
$\dot{Q}_{HT,DEHUM}$	kJ/h	Required heat after dehumidification to reach the wanted zone input temperature
$\dot{Q}_{HT,PHC}$	kJ/h	Required heating power by pre-heating coil
V	m³	Volume of thermal zone for calculation of air change rate

w_{RA}	kg/kg	Return air humidity ratio
w_{OA}	kg/kg	Outdoor air humidity ratio
w_{SA}	kg/kg	Supply air humidity ratio
w_{EA}	kg/kg	Exhaust air humidity ratio
w_{HR}	kg/kg	Humidity ratio of supply air after humidity recovery
$w_{SA,min,HUM}$	kg/kg	Minimum supply air humidity ratio after humidification
$w_{SA,max,DEHUM}$	kg/kg	Maximum supply air humidity ratio after dehumidification
Δh_v	kJ/kg	Specific enthalpy for the vaporization of water
η_{lat}	-	Latent air heat exchanger efficiency
$\eta_{lat,eff}$	-	Effective latent air heat exchanger efficiency
η_{sens}	-	Sensible air heat exchanger efficiency
$\eta_{sens,eff}$	-	Effective sensible air heat exchanger efficiency
ρ_{Air}	kg/m^3	Density of air
ϑ_{RA}	°C	Return air temperature
ϑ_{OA}	°C	Outdoor air temperature (e.g. outside air temperature)
ϑ_{SA}	°C	Supply air temperature
ϑ_{EA}	°C	Exhaust air temperature
$\vartheta_{EA,min}$	°C	Minimum exhaust air temperature for frost protection
$\vartheta_{WB,RA}$	°C	Wet bulb return air temperature
ϑ_{HR}	°C	Temperature of the outdoor air after heat recovery
$\vartheta_{SA,set}$	°C	Supply air setpoint temperature after heating / cooling

5.3. Mathematical Description

The air handling unit offers many different operating modes. A description of the different modes, their fundamental equations, and their associated variables are given in the following text. A schematic sketch of the AHU is shown in Figure 5.3-1.

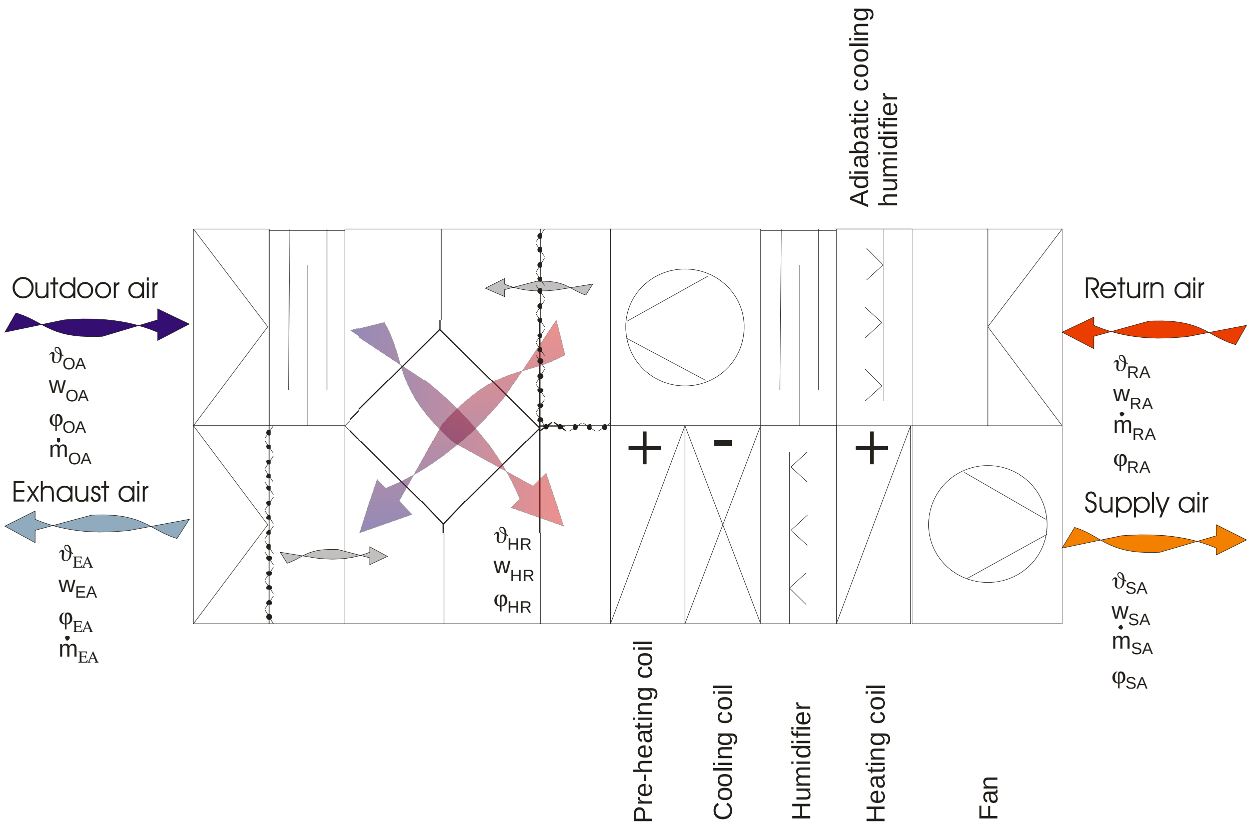

Figure 5.3-1: AHU Schematic

The equations describe how the efficiency of the heat recovery is calculated. Due to the fact that the exhaust air flow rate is not necessarily identical to the delivery air flow rate, the specified sensible and latent efficiency is replaced by an effective efficiency. This effective efficiency is calculated related to the mass flow rate relation between both air streams.

$$\eta_{sens,eff} = \frac{\dot{m}_{RA}}{\dot{m}_{OA}} \cdot \eta_{sens} \tag{5-1}$$

$$\eta_{lat,eff} = \frac{\dot{m}_{SA}}{\dot{m}_{OA}} \cdot \eta_{lat} \tag{5-2}$$

These efficiencies are characteristic for both the heat exchange and the humidity recovery behavior between both air streams. Resulting from the definition of the effective sensible efficiency the temperature of the delivery air after the heat exchanger is calculated by the following equation:

$$\vartheta_{HR} = \eta_{sens,eff}\left(\vartheta_{RA} - \vartheta_{OA}\right) + \vartheta_{OA} \qquad \textbf{(5-3)}$$

5.4. Frost protection

In order to avoid icing of the heat exchanger from the AHU it can be important to protect the heat exchanger from very low temperatures. For this case, Type334 offers the function of frost protection to define a minimum exhaust air temperature by $\vartheta_{EA,min}$. This leads to the calculation of the supply air as in eq. (5-4).

$\vartheta_{EA,min}$ = minimum exhaust air temperature of the AHU output for frost protection

$$\vartheta_{HR} = \mathrm{Min}\left(\eta_{sens,eff} \cdot \left(\vartheta_{RA} - \vartheta_{OA}\right), \vartheta_{RA} - \vartheta_{EA,min}\right) + \vartheta_{OA} \qquad \textbf{(5-4)}$$

5.5. Humidity recovery

Type334 offers the possibility to use humidity recovery from the return air to the supply air. The integrated simple model requires only the humidity recovery efficiency as an input. The absolute humidity of the supply air stream after humidity recovery is calculated as:

$$w_{HUM,HR} = \eta_{lat,eff}\left(w_{RA} - w_{OA}\right) + w_{OA} \qquad \textbf{(5-5)}$$

5.6. Air conditioning modes after heat recovery

After the heat exchange/humidity recovery unit, the supply air can be conditioned by the following options.

5.6.1. Heating

If the heating mode is activated (modeHzCl=1 or modeHzCl=3) the supply air is heated up to the defined setpoint temperature, if necessary.

$$\vartheta_{SA,set} - \vartheta_{HR} > 0 \Rightarrow \qquad \dot{Q}_{HT,PHC} = \dot{m}_{OA} \cdot c_{p,Air} \cdot \left(\vartheta_{SA,set} - \vartheta_{HR}\right) \qquad \textbf{(5-6)}$$

In addition if $w_{HR} < w_{SA,min,HUM}$ the supply air can be humidified to the defined setpoint humidity (NOTE: humidification is only possible in combination with re-heating). For this case the heat required for the water evaporation is calculated as in equation 5-7.

$$\dot{Q}_{HUM} = \dot{m}_{OA} \cdot \Delta h_v \cdot \left(w_{SA,min,HUM} - w_{HR}\right) \quad \textbf{(5-7)}$$

5.6.2. Cooling

If the cooling mode is active (modeHzCl=2 or modeHzCl=3) the supply air is cooled down to the defined set-point temperature if necessary.

$$\vartheta_{SA,set} - \vartheta_{HR} < 0 \Rightarrow \qquad \dot{Q}_{cl,CC} = \dot{m}_{OA} \cdot c_{p,Air} \cdot \left(\vartheta_{SA,set} - \vartheta_{HR}\right) \quad \textbf{(5-8)}$$

In addition the supplied air can be dehumidified if $w_{HR} > w_{SA,max,DEHUM}$ to a defined setpoint humidity (NOTE: dehumidification is only possible in combination with cooling). For this mode, the delivery air stream after passing the heat or humidity recovery unit is cooled in the cooling coil (eq.(5-9)) to the dew point temperature and then the additional cooling power for dehumidification (eq.(5-10)) is calculated. See the following two equations for explanations:

$$\dot{Q}_{cl,DEHUM} = \dot{m}_{OA} \cdot c_{p,Air} \cdot \left(\vartheta_{DP} - \vartheta_{HR}\right) \quad \textbf{(5-9)}$$

$$\dot{Q}_{DEHUM} = -\dot{m}_{OA} \cdot \Delta h_v \cdot \left(w_{HR} - w_{SA,max,DEHUM}\right) \quad \textbf{(5-10)}$$

After the dehumidification is done the last step is to re-heat the air to achieve the required supply air temperature. This is done by a heating coil where the required sensible heat is calculated according to the previous required dehumidification and cool down power (see eq. (5-11)) plus the power required to reach the set-point temperature.

$$\dot{Q}_{HT,DEHUM} = -\dot{Q}_{cl,DEHUM} + \dot{m}_{OA} \cdot c_{p,Air} \cdot \left(\vartheta_{SA,set} - \vartheta_{HR}\right) \quad \textbf{(5-11)}$$

5.7. Bypass

For avoiding overheating/overcooling of the supply air by the heat exchanger, a bypass mode is integrated in Type333. If the bypass mode is activated (modeBP=1) only the mass flow of the return air required for reaching the set-point supply air temperature flows through the heat recovery unit; the rest is sent through the bypass.

5.8. Special Mode: Adiabatic cooling of the return air

Adiabatic cooling can be activated by a hidden switch, setting latent efficiency < 0. The return air is cooled down by humidification to the minimum wet bulb temperature before entering the heat recovery unit.

Followed by this ϑ_{WRG} can be reduced to the required supply air temperature to the zone. !!Note: By using this mode it is not possible to use humidity recovery and bypass mode.!! The calculation works as follows:

1) The new required return air temperature is calculated according to $\vartheta_{HR} = \vartheta_{SA,set}$ by recalculating from the effective sensible efficiency

$$\vartheta_{RA,NEW} = MAX\left(\left(\vartheta_{SA,set} - \vartheta_{OA}\right)/\eta_{sens,eff} + \vartheta_{OA}, \vartheta_{WB,RA}\right) \quad \textbf{(5-12)}$$

2) From this the adiabatic cooling power is calculated depending on the ϑ_{WRG} change before and after the use of adiabatic cooling.

$$\dot{Q}_{cl,AD} = \dot{m}_{SA} \cdot c_{p,Air} \cdot \left(\vartheta_{WAD} - \vartheta_{HR,OAD}\right) \quad \textbf{(5-13)}$$

WAD = with adiabatic cooling

OAD = without adiabatic cooling

5.9. Fan Power

The total power of both the supply and exhaust fans is calculated based on the actual supply and return air flowrates, $\dot{m}_{SA}$ and $\dot{m}_{RA}$, and the maximum supply fan flowrate, pressure drops, and fan efficiency given as parameters. Note that the impact of heat generated by the fan and motor on either airstream is not considered; this calculation is for determination of electrical power only. The total fan power is calculated as:

$$\Delta P_{SA} = 0.3\Delta P_{SA,Max} + 0.7\Delta P_{SA,Max}\left(\frac{\dot{m}_{SA}}{\dot{m}_{max}}\right)^3 \quad \textbf{(5-14)}$$

$$\Delta P_{RA} = 0.3\Delta P_{RA,Max} + 0.7\Delta P_{RA,Max}\left(\frac{\dot{m}_{RA}}{\dot{m}_{max}}\right)^3 \quad \textbf{(5-145)}$$

$$\dot{Q}_{el,Fan} = \frac{\Delta P_{SA} \cdot \dot{m}_{SA}}{\rho_{air} \cdot \eta_{vent}} \cdot + \frac{\Delta P_{RA} \cdot \dot{m}_{RA}}{\rho_{air} \cdot \eta_{vent}} \quad \textbf{(5-156)}$$

5.10. Recirculation Fraction

The user has the option of setting a recirculation fraction as an input. This fraction is normally 0 when the unit is operating in 100% outside air mode. To simulate a morning warm-up period or other operation where no outside air is required, this fraction may be set to 1. In this mode the return air becomes the supply air and there is no use of the heat exchanger.

5.11. Description of Inputs

The following input values are used for calculating the thermal performance of the AHU:

Input no	Symbol	Description	Unit
1	ϑ_{OA}	Outdoor air temperature	°C
2	w_{OA}	Absolute water content of outdoor air	kg/kg
3	$\dot{m}_{OA}$	Mass flow rate of outdoor air	kg/h
4	ϑ_{RA}	Return air temperature (to AHU from zone)	°C
5	w_{RA}	Absolute water content of return air (to AHU from zone)	kg/kg
6	$\dot{m}_{RA}$	Mass flow rate of return air (to AHU from zone)	kg/h
7	η_{Sens}	Sensible efficiency of heat recovery	-
8	η_{Lat}	Latent efficiency of humidity recovery	-
		Two different AHU operating modes can be set by η_{Lat}: =0 => no humidity recovery between exhaust and delivery air stream >0 => Humidity recovery enabled	
9	$\vartheta_{EA,min}$	Exhaust air, minimum temperature for frost protection	°C
10	$\vartheta_{HR,set}$	Supply air temperature setpoint after heat recovery	°C
11	$\vartheta_{SA,set}$	Supply air temperature setpoint after the AHU (from AHU to zone)	°C
12	$w_{SA,min,hum}$	Absolute water content of the supply air after humidification (min setp.)	kg/kg
13	$w_{SA,max,dehum}$	Absolute water content of the supply air after dehum.(max. setpoint)	kg/kg
14	γ_{recirc}	Fraction of return air to be recirculated	

5.12. Description of Parameters

Par. no.	Symbol	Description	Unit
1	modeHTCL	Operation mode heating and/or cooling	-
		0 = No heating/cooling and no humidification/dehumidification 1 = Heating and humidification; no cooling/dehumidification 2 = Cooling and dehumidification; no heating/humidification 3 = Heating, cooling, humidification and dehumidification	
2	modeFP	Frost protection Yes/No	-
		0 = no frost protection 1 = minimum exhaust air temperature is user-defined	
3	modeBP	Bypass Yes/No	-
		0 = no bypass 1 = bypass if necessary	
4	ρ_{Air}	Density of Air	kg/m^3
5	$c_{p,Air}$	Spec. heat capacity of Air	kJ/(kg*K)
6	Δh_v	Enthalpy of vaporization of water	kJ/kg
7	A_{ref}	Reference area for specific power calculation	m^2
8	V	Zone volume for air change rate calculation	m^3
9	$\Delta P_{SA,max}$	Maximum supply side pressure drop	Pa
10	$\Delta P_{RA,max}$	Maximum return side pressure drop	Pa
11	η_{vent}	Overall efficiency of fan and motor	-
12	$\dot{m}_{Max}$	Maximum fan mass flowrate	kg/h

5.13. Description of Outputs

The cooling power outputs are all negative.

Out. no.	Symbol	Description	Unit
1	ϑ_{SA}	Temperature of supply air after heating coil	°C
2	ACH	Air change rate	1/h
3	φ_{SA}	Relative humidity of the supply air after heating coil	%
4	w_{SA}	Absolute water content of the supply air	kg/kg
5	h_{SA}	Enthalpy of supply air	kJ/kg
6	$\dot{m}_{SA}$	Mass flow rate of the supply air	kg/h
7	$\vartheta_{DP,SA}$	Dewpoint temperature of supply air	°C
8	ϑ_{HR}	Temperature of supply air after heat recovery	°C
9	φ_{HR}	Relative humidity of supply air after heat recovery	%
10	w_{HR}	Absolute water content of supply air after heat recovery	kg/kg
11	h_{HR}	Enthalpy of supply air after heat recovery	
12	ϑ_{EA}	Exhaust air temperature after AHU	°C
13	φ_{EA}	Relative humidity of exhaust air after AHU	%
14	w_{EA}	Absolute water content of exhaust air after AHU	kg/kg
15	$\dot{m}_{EA}$	Mass flow rate of exhaust air after AHU	kg/h
16	h_{EA}	Enthalpy of exhaust air after AHU	kJ/kg
17	$\dot{m}_{AD,CL}$	Mass flow rate of water for adiabatic cooling	kg/h
18	ϑ_{OA}	Outdoor air temperature (=Input 1)	°C
19	φ_{OA}	Relative humidity of outdoor air	%
20	w_{OA}	Absolute water content of outdoor air (=Input 2)	kg/kg
21	h_{OA}	Enthalpy of outdoor air	kJ/kg
22	ϑ_{RA}	Temperature of return air to AHU (=Input 4)	°C
23	φ_{RA}	Relative humidity of return air to AHU	%
24	w_{RA}	Absolute water content of return air to AHU (=Input 5)	kg/kg
25	h_{RA}	Enthalpy of return air to AHU	kJ/kg
26	$\eta_{sens,eff}$	Effective sensible efficiency	-
27	$\eta_{lat,eff}$	Effective latent efficiency	-
28	$\eta_{sens,eff\ -\%}$	Effective sensible efficiency, percent	%
29	$\eta_{lat,eff\ -\ \%}$	Effective latent efficiency, percent	%
30	$Y_{BP,HR}$	Switch for bypass ON/OFF	
31	$\vartheta_{HR,WOBP}$	Temperature of supply air without bypass	-
32	$\vartheta_{HT,WOFP}$	Temperature of supply air without frost protection	-
40	$\dot{Q}_{HR,Without}$	Sensible heat demand without air heat recovery	kJ/h
41	$\dot{Q}_{HR}$	Heat exchanged by heat recovery (saved demand for heating)	kJ/h
42	$\dot{Q}_{HT,PHC}$	Required heat for pre-heating coil	kJ/h
43	$\dot{Q}_{HT,DEHUM}$	Required heat for heating coil after dehumidification	kJ/h
44	$\dot{Q}_{HT,HC,tot}$	Total required heat after heat recovery using dehum.	kJ/h
45	$\dot{Q}_{HUM}$	Latent heat demand for humidification	kJ/h
46	$\dot{Q}_{HT,tot}$	Total latent and sensible heat demand	kJ/h

47	$\dot{Q}_{HUM,HR}$	Saved latent heat demand for hum. using humidity recovery	kJ/h
48	$\dot{Q}_{HUM,FP}$	Heat recovery heat demand loss by using frost protection	kJ/h
49	$\dot{Q}_{HT,Recirc}$	Required heat for recirculated air	kJ/h
50	$\dot{Q}_{cl,Without}$	Sensible cooling heat demand without air heat recovery and with dehumidification	kJ/h
51	$\dot{Q}_{cl,HR}$	Heat exchanged by heat recovery (saved heat demand for cooling)	kJ/h
52	$\dot{Q}_{cl,CC}$	Sensible cooling capacity required after heat recovery	kJ/h
53	$\dot{Q}_{cl,DEHUM}$	Additional sensible cooling capacity to reach the dew point temperature	kJ/h
54	$\dot{Q}_{cl,CC,tot}$	Total required sensible and latent cooling capacity with dehumidification	kJ/h
55	$\dot{Q}_{DEHUM}$	Latent cooling capacity for dehumidification	kJ/h
56	$\dot{Q}_{cl,tot}$	Total cooling capacity for latent and sensible demands	kJ/h
57	$\dot{Q}_{DEHUM,HUM,HR}$	Saved latent cooling capacity by humidity recovery	kJ/h
58	$\dot{Q}_{cl,AD}$	Adiabatic cooling capacity	kJ/h
59	$\dot{Q}_{el,Fan}$	Required fan power	kJ/h
60	$\dot{Q}_{HT,Without}$	Spec sensible heat demand without air heat recovery	W/m^2
61	$\dot{Q}_{HT,HR}$	Spec. heat exchanged by heat recovery (saved heat demand for heating)	W/m^2
62	$\dot{Q}_{HT,PHC}$	Required spec. heat for pre-heating coil	W/m^2
63	$\dot{Q}_{HT,DEHUM}$	Required spec. heat for heating coil after dehumidification	W/m^2
64	$\dot{Q}_{HT,HC,tot}$	Total required spec. heat after heat recovery using dehum.	W/m^2
65	$\dot{Q}_{HUM}$	Spec. latent heat demand for humidification	W/m^2
66	$\dot{Q}_{HT,tot}$	Total spec. latent and sensible heat demand	W/m^2
67	$\dot{Q}_{HUM,HR}$	Saved spec. latent heat demand for hum. using humidity recovery	W/m^2
68	$\dot{Q}_{HUM,FP}$	Heat recovery spec. heat demand loss by using frost protection	W/m^2
70	$\dot{Q}_{cl,Without}$	Sensible required spec. cooling capacity without air heat recovery and with dehumidification	W/m^2
71	$\dot{Q}_{cl,HR}$	Spec. heat exchanged by heat recovery (saved heat demand for cooling)	W/m^2
72	$\dot{Q}_{cl,CC}$	Spec. sensible cooling capacity required after heat recovery	W/m^2
73	$\dot{Q}_{cl,DEHUM}$	Additional spec. sensible cooling capacity to reach the dew point temperature	W/m^2

74	$\dot{Q}_{cl,CC,tot}$	Total required spec. sensible and latent cooling capacity with dehumidification	W/m^2
75	$\dot{Q}_{DEHUM}$	Spec. latent cooling capacity for dehumidification	W/m^2
76	$\dot{Q}_{cl,tot}$	Total spec. cooling capacity for latent and sensible demands	W/m^2
77	$\dot{Q}_{DEHUM,HUM,HR}$	Saved spec. latent cooling capacity by humidity recovery	W/m^2
78	$\dot{Q}_{cl,AD}$	Spec. adiabatic cooling capacity	W/m^2
79	$\dot{Q}_{el,Fan}$	Required spec. fan power	W/m^2
80	w_{OA}*1000	Absolute water content of outdoor air	g/kg
81	w_{SA}*1000	Absolute water content of supply air	g/kg
82	w_{RA}*1000	Absolute water content of return air	g/kg
83	w_{EA}*1000	Absolute water content of exhaust air	g/kg
84	w_{HR} * 1000	Absolute water content of supply air after heat recovery	g/kg
85	$dw_{HUM,HR}$*1000	Recovered water by humidity recovery	g/kg
86	dw_{HUM}*1000	Required water by humidification	g/kg
87	dw_{DEHUM}*1000	Required water by dehumidification	g/kg