CO_2 MITIGATION USING HEAT PUMP AND EVAPORATIVE HUMIDIFER IN MAKEUP AIR-HADLING UNIT

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Abstract: It is popular to use steam heater and steam humidifier in makeup air-handling unit in Japan. But the coefficient of performance (COP) of steam generating and humidifying by fossil fuel is less 1. And it generates a lot of CO_2. We introduce the heating and humidifying system by “heat pump and evaporative humidifier” in makeup air-handling unit, for new painting facility. This system contributes greatly to the CO_2 mitigation than ever steam heater and steam humidifier system. We report this heat pump warm water heating and evaporative humidifier system at makeup air-handling unit, COP of system, and CO_2 mitigation effect.

Key Words: *air source heat pump, paint booth, makeup air-handling unit, evaporative humidifier, COP*

1 INTRODUCTION

Conventionally, direct combustion of fossil fuels or steam has been used as heat sources for heating and humidifying in makeup air-handling units for paint booths in winter season. Using a “warm water heated by heat pump + evaporative humidifier” system as a heat source for heating and humidifying in these makeup air-handling units would make it possible to vastly save energy consumption and CO_2 mitigation compared to the conventional system. Because the heat pumps have a high COP and the evaporative humidifiers have the energy-saving characteristics. In this study, we used an “air source heat pump warm water heating + evaporative humidifier” in makeup air-handling unit for a paint booth and confirmed its energy-saving characteristics and CO_2 emission mitigation effect, with the results reported below. Photo 1 shows the typical paint booth.

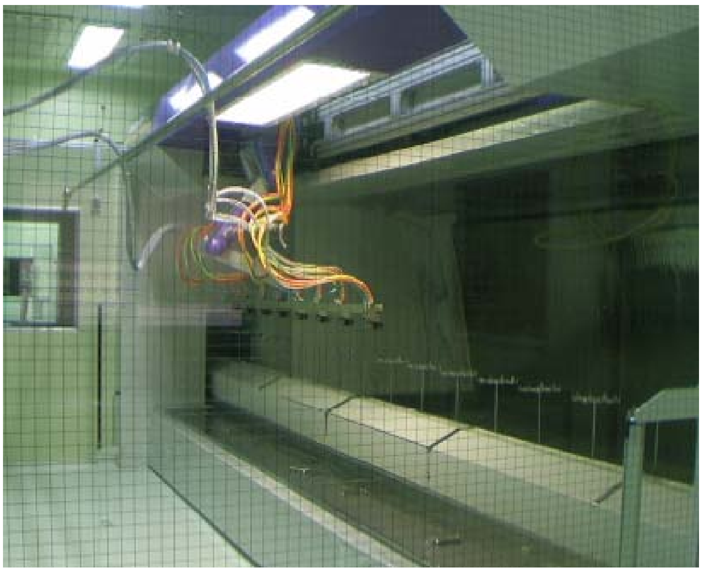


Photo 1: Paint booth

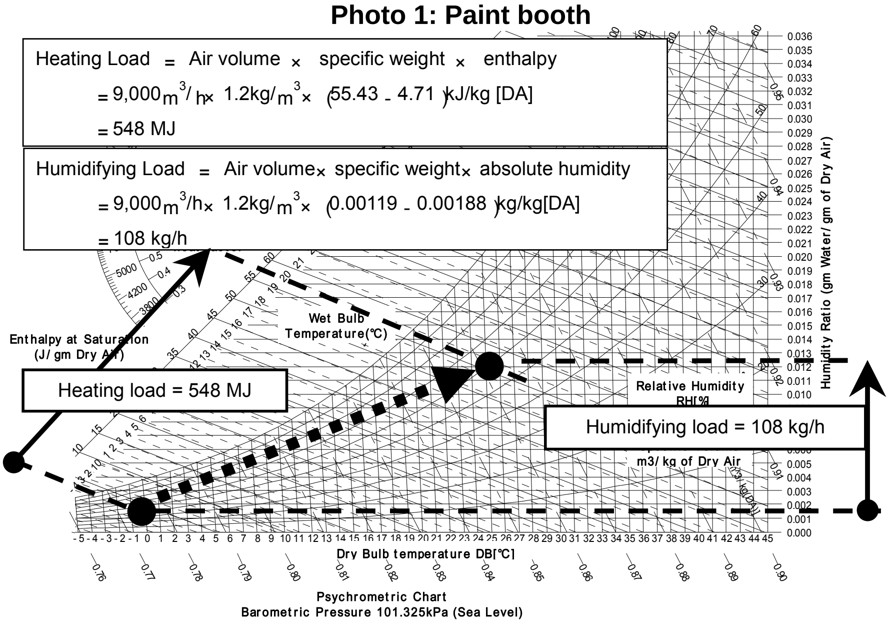


Figure 1: Design temperature and humidity conditions in paint booth

2 CHARACTERITICS OF PAINT BOOTHS AND DESIGN AIR CONDITION

To ensure a high quality of paint finish, paint booths need to be kept in a constant environment of temperature and humidity at all times. And paint booths are local exhaust devices for discharging organic solvents. So the air-conditioning system for paint booth needs all outdoor air, i.e. needs makeup air-handling units. Namely the air-conditioning systems for paint booths must be fully outside air-conditioning system. And it consumes quantity of energy, because this system needs to have constantly controlled temperature and humidity throughout the year, and it is an energy-intensive fully outside air-conditioning system. Conventionally, direct combustion of fossil fuels or steam has been used as the heating source, and steam as the humidifying source. Namely, combustion heat from fossil fuels at 1,000°C or more and steam at 100°C or more have been used for heating and humidifying for air-conditioning at around 40~50°C.[*1] And the combustion efficiency and the steam generation thermal efficiency are less than 1 (COP < 1), which is lower than the COP of heat pump. The paint booth design temperature and humidity conditions used in this study were a constant year-round 25±2°CDB/60±5%RH, while the winter design outside air conditions (Tokyo, Japan) were 0°CDB/50%RH. This paint booth needs 9000 m^3/h of outside air. Therefore, the design heating load of the makeup air-handling unit for this paint booth was 548MJ (163kW･h), while the design humidifying load was 108kg/h. Fig. 1 shows psychrometric chart of design temperature and humidity conditions in this paint booth.

3 AIR MOVEMENT ON PSYCHROMETRIC CHART

3.1 CONVENTIONAL SYSTEM

Fig. 2 shows the equipment configuration of the makeup air-handling unit, boiler and other equipment using the conventional system. Fig. 3 shows movement on the psychrometric chart during heating and humidifying using the conventional system.
Outside air is heated to around 25°C by a steam heating coil. Then it is humidified using a steam atomizer to create the temperature and humidity conditions for the paint booth, and is finally blown into the booth. The same sequence applies using directly combusting fossil

fuels as a heat source. The calorific value needed to heat outside air to 25°CDB is 262MJ (73kW･h), while the steam required for humidification is 108kg/h and the calorific value is 286MJ. Table 1 shows the input power required when using steam for this purpose.

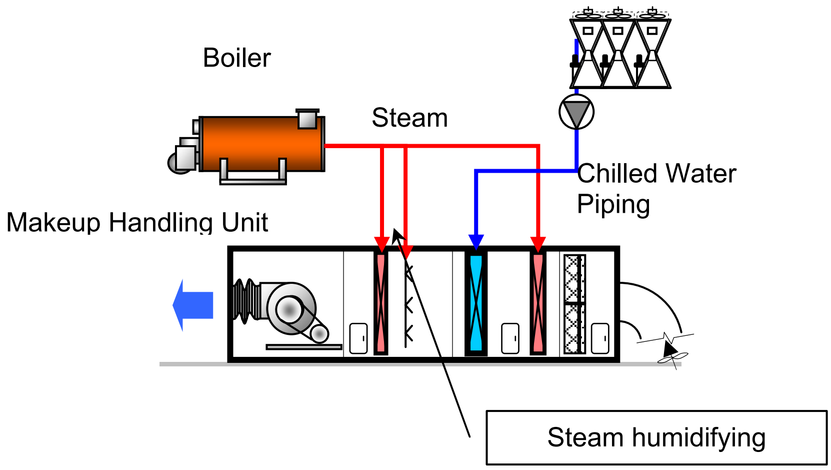


Figure 2:Equipment configuration of conventional system

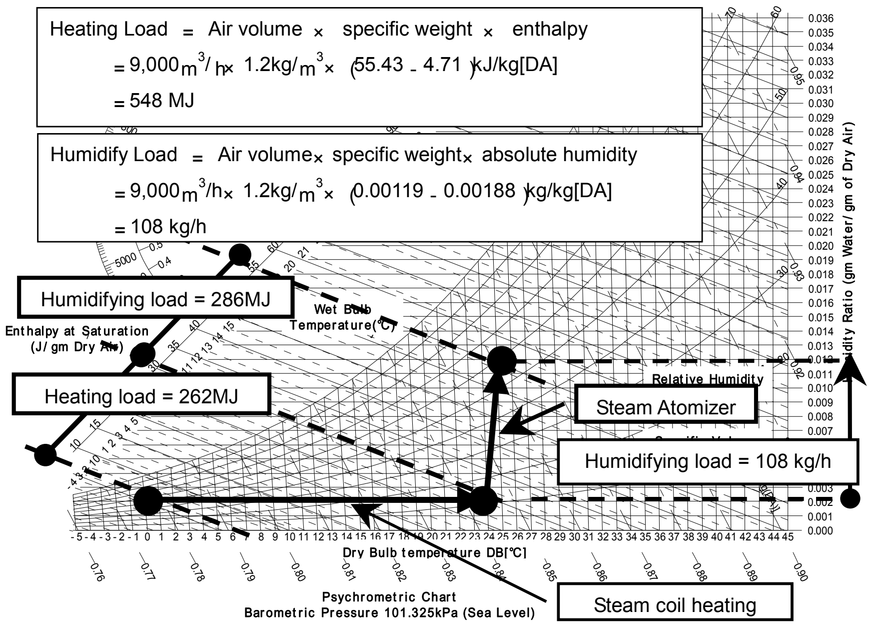


Figure 3: Movement caused by heating and humidifying in the conventional system

3.2 HEAT PUMP SYSTEM

Fig. 4 shows the equipment configuration for the “heat pump warm water heating + evaporative humidifier” system. There are two differences in this equipment configuration compared to the conventional system. The first is that a pump is required to convey the warm water generated by the air-source heat pump. The second is that the makeup air-handling unit requires additional fan power for the increased pressure loss inside the air-handling unit due to the addition of the evaporative humidifier. The power needed for each of these is shown in Table 1. Fig. 5 shows the movements of air condition on the psychrometric chart. Outside air is heated to 42°C by a warm water coil that supplied warm water generated by an air-source heat pump. It is then cooled and humidified by the evaporative humidifier, and finally, after fine adjustment of the air blower temperature by a re-heating coil, is blown into the paint booth. Of course, the warm water for the re-heating coil is also generated by the same air-source heat pump. The calorific value for heating is 548MJ (163kW･h), while the water required for humidification is 108kg/h. Table 1 shows the input power required when the temperature of warm water generated by the heat pump and supplied to the makeup air-handling unit is 45°C.

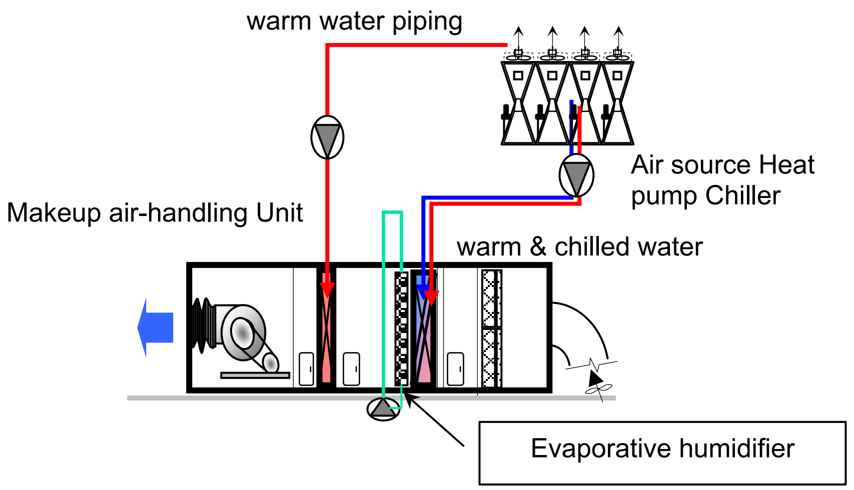


Figure 4: Equipment configuration using the “heat pump + evaporative humidifier” system

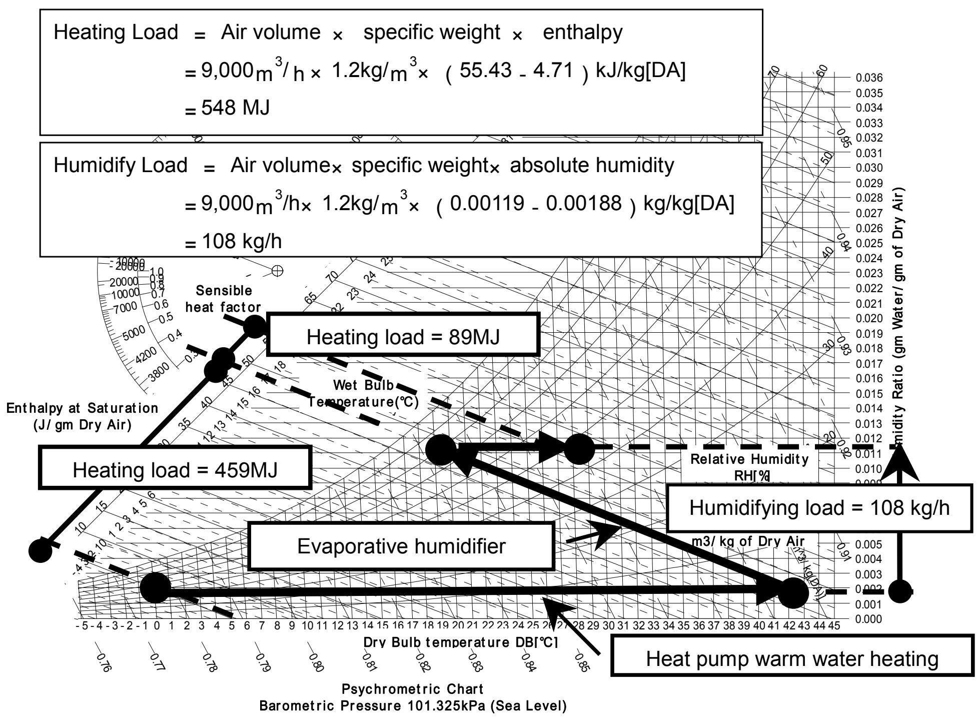
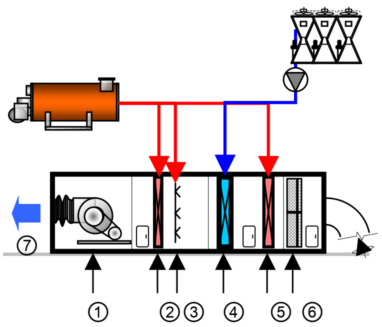
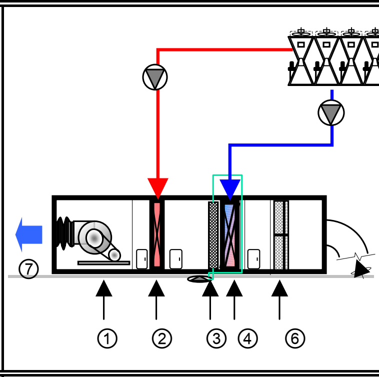


Figure 5: Movement along air lines using the “heat pump + evaporative humidifier” system

Tabel 1: Comparison of axial power of Makeup air-handling fans

		Steam Heating + Steam Humidifying		Heat Pump warm water heating + Evaporative Humidifying	
Equipment Configuration					
Makeup Handling Unit			Pa		Pa
Static Pressure	①Fan Air volume	9,000 m^3/h		9,000 m^3/h	
	②Reheater	25 kW steam volume = 43kg/h Coil Number = 2	5	25 kW warm temperature 45→40℃ water volume 72ℓ /min Coil Number = 3	20
	③Humidifier	Steam Jet 102kg/h	0	Evaporative 102kg/h	78
	④Cooling coil	122 kW chilled water 7→12℃ water volume 350ℓ /min coil number = 6	60	122 kW chilled water 7→12℃ water volume 350ℓ /min coil number = 6	60
	⑤Preheater	70 kW steam volume = 136kg/h coil number = 1	7	—	-
	⑥Air filter	Medium Efficiency Pre Pressure up	98 49 98	Medium Efficiency Pre Pressure up	98 49 98
	⑦Others	Casing loss Duct pressure drop	49 294	Casing loss Duct pressure drop	49 294
	∑(①~⑦)		660		746
Fan shaft power kW		2.7		3.1	

4 HUMIDIFYIERS

In this chapter, the system of humidification, a major difference compared to the conventional system, will be explained.

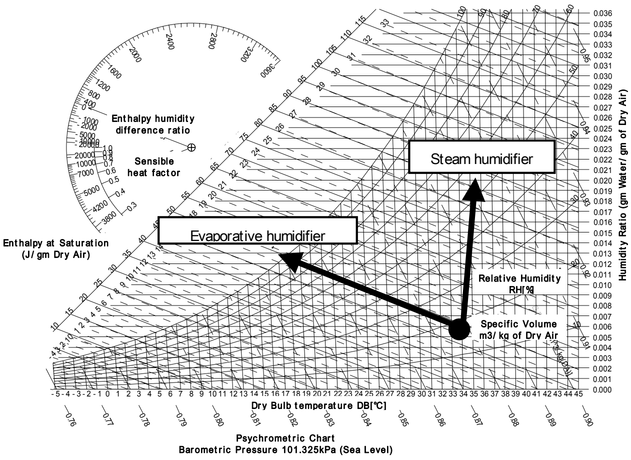
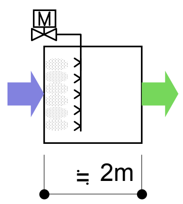
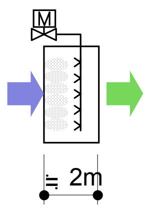
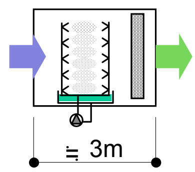
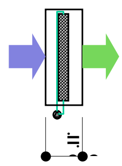
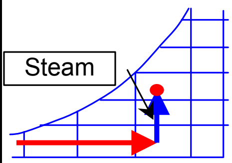
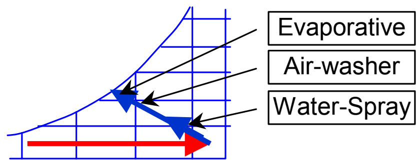


Figure 6: Movement on the psychometric chart steam and evaporative humidifier

4.1 STEAM HUMIDIFYING AND WATER HUMIDIFYING

There are generally two systems of humidification, one using steam and the other using water. Fig. 6 shows the psychrometric chart and the air condition movement of both humidification systems. Steam humidification rises almost vertically along the same dry-bulb temperature line while being humidified. Because steam has a high enthalpy when it is generated, and the enthalpy of the air sprayed from this steam increases as shown. On the other hand, water humidification moves from the bottom right to the top left along wet-bulb temperature lines on the psychrometric chart, and the dry-bulb temperature decreases while the absolute humidity in the air increases. In the psychrometric chart, wet-bulb temperature lines and specific enthalpy lines are more or less parallel, and the enthalpy difference before and after water humidification is virtually zero. In other words, water humidification may be seen as a system of humidification that requires no particular energy and is therefore energy-saving system.

Table 2: Comparison of humidifiers

	Steam spray	Water		
		Water-Spray	Air-washer	Evaporative
Required Length				
Movement on psychro -metric chart				
Saturation efficiency	90～95%	≒ 30%	≒ 85%	≒ 90%
Pressure loss	0	0	30mmAq	8mmAq
Spray /Humidify	1.2	≒ 3	≒ 1.5	≒ 2

4.2 COMPARISON OF HUMIDIFIERS

The main humidifiers are compared in Table 2. In the water humidification system, evaporative humidifiers were the last to arrive on the market. Compared to conventional water humidifiers such as the water spray or air washer types, evaporative humidifier is characterized by requiring less space to install and having higher humidification efficiency (saturation efficiency).

5 STRUCTURAL COMPARISON OF MAKEUP AIR-HANDLING UNIT

Table 1 shows a structural comparison of a makeup air-handling unit for a paint booth, as well as the pressure loss due to the configuration of the unit, and the axial power of the fan.

Compared to the conventional system, the “heat pump warm water heating + evaporative humidifier” system requires an increase of about 0.4kW in the axial power of the air-conditioning fan (an increase of about 15% compared to the conventional system) to cope with an increased pressure loss of about 78Pa in the evaporative humidifier.

Table 3: Crude oil conversion of energy needed and CO_2 generation

Air volume = 9,000m^3/h

		Steam Heating + Steam Humidifying		Heat Pump warm water heating + Evaporative Humidifying	
Heating load		75 kW	163 kW	163 kW	163 kW
Humidifying load		88 kW		—	
COP		boiler	0.9	Heat pump (Air sources)	3.5
Input for heating load	①	83 kW	181 kW	47 kW	47 kW
Input for humidifying load		98 kW		—	
Fan shaft power ②			2.7 kW		3.1 kW
Water pump shaft power ③			—		2.5 kW
Σ ①+②+③		184 kW		52 kW	
energy	LPG	7.2 kg/h	15.6 kg/h	—	—
		8.4 kg/h		—	
	Electric Power		2.7 kW		52 kW
Crude Oil KJ	Heating	391	849	455	455
	Humidifying	458		—	
	Fan shaft power		27		30
	pump shaft power		-		25
	Σ	876		510	
CO_2 kg-CO_2/h	Heating	19.4	42.1	15.8	15.8
	Humidifying	22.7			
	Fan shaft power		0.9		1.1
	pump shaft power		-		0.9
	Σ	43.0		16.8	

	Convert to Crude oil	CO2 generate
LNG	54.5 MJ/ℓ	2.7 kg-CO2/kWh
Electric Power*	9.76 MJ/kWh	0.339 kg-CO2/kWh

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6 COMPARISON OF CO_2 GENERATION

Table 3 shows a comparison of energy needed by the conventional system and the “heat pump warm water heating + evaporative humidifier” system. The total thermal load for heating and humidification is the same for both systems, although their respective proportions of load for heating and humidification are different. However, the energy input values are very different. The reason for this is that, with the “heat pump warm water heating + evaporative humidifier” system, all of the thermal load can be heated using warm water generated by an air-source heat pump with a COP of 3.5. On the other hand, the COP of boiler is less than 1.0, meaning that the input energy is greater than the thermal load when loss increases. The boiler fuel assumed for the conventional system is LPG. This result is the same even if we include the increase of about 0.4kW in the axial power of the air-conditioning fan and pump power of about 2.5kW, these being necessary for the “heat pump warm water heating + evaporative humidifier” system. In this study, they were about 6% of input thermal energy. Fig. 8 shows a comparison of energy conservation, with the necessary input energy converted to crude oil. Fig. 9 shows a comparison of CO_2 generation. These figures show that, compared to the conventional system, an energy saving of about 40% and a reduction of about 60% in CO_2 generation can be achieved using the “heat pump warm water heating + evaporative humidifier” system.

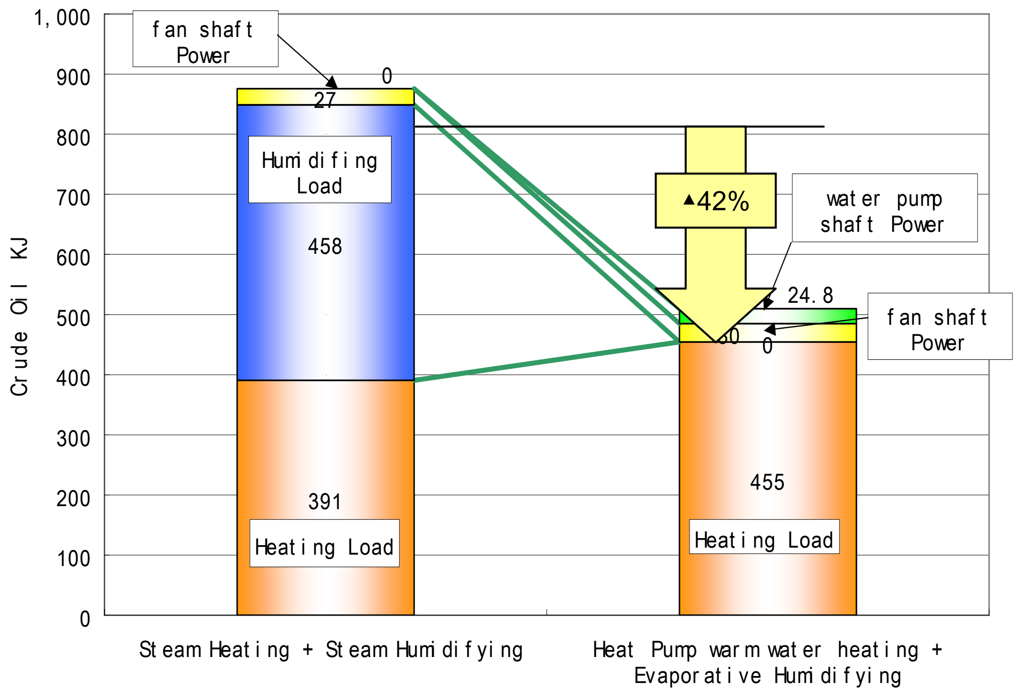

Figure 8: Comparison of crude oil conversion

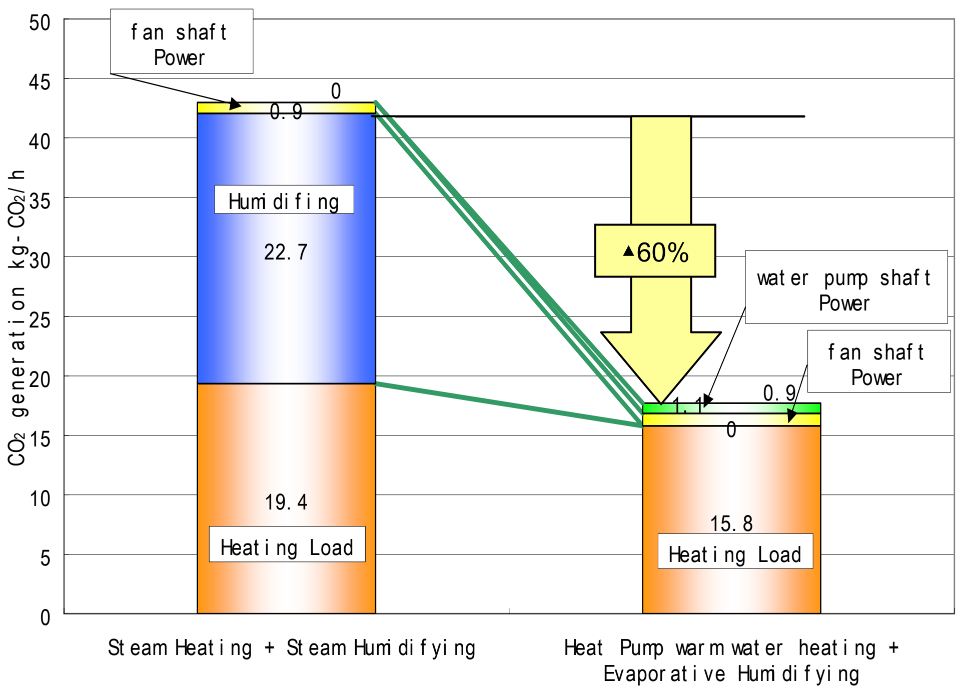

Figure 9: Comparison of CO_2 generation

7 CONCLUSION

Compared to the conventional system, using the “heat pump warm water heating + evaporative humidifier” system as a heating source in makeup air-handling units for paint booths results in the following.

1) Reduction in energy needed for heating and humidifying outside air:
- About 40% mitigation at crude oil conversion
- About 60% mitigation at CO_2 generation

2) Although input energy for conveyance power rises by about 6%, the impact of this is small.
- An increase of about 0.4kW in the axial power of the air-conditioning fan (about 15% higher than with the conventional system)
- An increase of about 2.5kW in pump power for warm water conveyance

Systems of heating and humidifying in makeup air-handling units have conventionally relied on steam (COP<1). By changing this to the “heat pump warm water + evaporative humidifier” system, a vast reduction in CO_2 generation can be achieved.
In future, we would like to make more use of heat pump technology, which is efficient and can contribute to reducing CO_2 generation. We would thereby hope to contribute to CO_2 mitigation in many heat-using applications.

REFERENCES

[*1] : Masanosuke Yanagimachi, 1974, “Heating and Air-conditioning system by Heat pump”, Tokyo, Japan