# CO$_2$ EMISSION MITIGATION EFFECT
# BY HEAT PUMP AND EVAPORATIVE HUMIDIFIER

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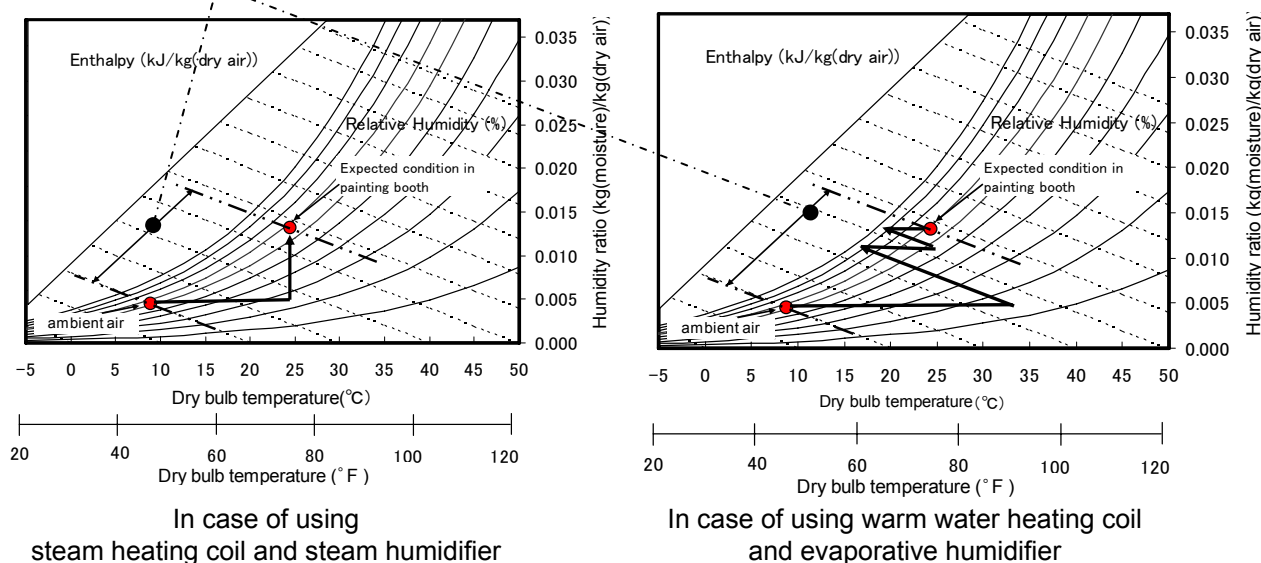*Toshihiko Kitamura, Tokyo Electric Power Company, Tokyo, Japan*

**Abstract:** It is popular to use direct combustion to generate heat or steam for a heating coil and a steam humidifier in an air makeup unit for a painting booth. However, using the combination of a heat pump and an evaporative humidifier instead of using the combination of a boiler and a steam humidifier can contribute to mitigate CO$_2$ emission. It was announced on the 1st report about the effectiveness of CO$_2$ emission reduction by an air makeup unit with the heat pumps and evaporative humidifiers on the 9th IEA Heat Pump Conference in Zurich, 2008. A new painting booth of supply airflow volume of around 30,000m$^3$/h with heat pumps and evaporative humidifiers in an air makeup unit, was constructed in Kanto area by a leading automobile parts manufacturer. In this report, the effectiveness of CO$_2$ emission reduction by the air conditioning system installed is evaluated, comparing with CO$_2$ emission by an assumed air conditioning system using the combination of a boiler and a steam humidifier. Also, the coefficient of performance (COP) of the heat pump is evaluated.

**Key Words: heat pump, evaporative humidifier, painting booth, CO$_2$ emission**


## 1        INTRODUCTION

The high quality of exterior finish of automobile parts is achieved under stringent quality control. The environment inside a painting booth for automobile parts is a key to ensure high quality of exterior finish. Fresh ambient air is drawn from outside environment into a painting booth. The air is generally heated and humidified particularly during winter season. At many of industrial painting booths, ambient air supplied has been warmed and humidified by direct combustion, a steam heating coil or a steam humidifier in an air makeup unit. Thermal efficiency of the air conditioning system using steam decreases, as heat loss such as heat transfer and heat radiation at surface of steam pipes, and leakage from steam pipes, occurs. Therefore, the thermal efficiency of the air conditioning system using steam is not so high. On the other hand, the heat pump is more efficient than direct combustion or the conventional boiler, because it uses renewable energy. The amount of  the enthalpy change of air from ambient air condition to the designed condition inside a painting booth is the same by either steam humidification or evaporative humidification, as can be seen in figure 1. In the case of evaporative humidification, it is possible for air to be warmed and humidified without steam. Comparing the thermal efficiency of the conventional boiler with the COP of the heat pump, it is understandable that to obtain the same amount of enthalpy change of air, the heat pump should be used for not only warming but also humidifying air from a point of view of reduction of CO$_2$ emission. In addition, the painting booth has local exhaust devices for discharging organic solvents. The air conditioning system for the painting booth uses outdoor air only. So, the production process at the painting booth is seemed to be more energy consuming than other production processes. Therefore, it is significant to take measures to reduce CO$_2$ emission against the painting booth.
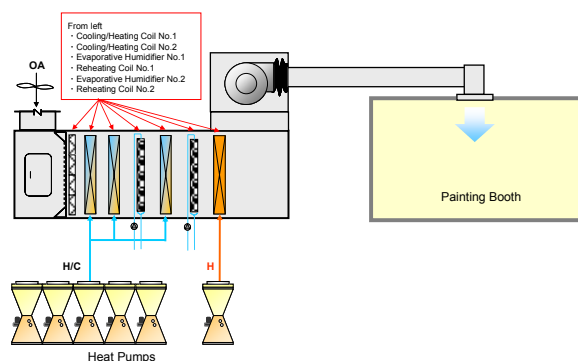
Both amounts of enthalpy change are the same value.

In case of using
steam heating coil and steam humidifier

In case of using warm water heating coil
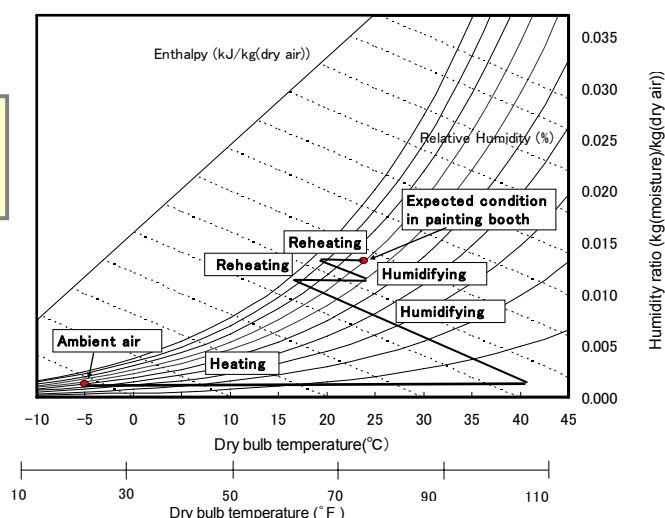and evaporative humidifier

**Figure 1 Change of state of air on psychrometric chart**

## 2    CONFIGURATION OF AIR CONDITIONING SYSTEM OF PAINTING BOOTH

Figure 2 shows the schematic diagram of the air conditioning system installed. The airflow volume is set at around 30,000m³/h.   The painting booth needs to be kept at the constant environmental condition by air supplied via the air makeup unit at all times to ensure high quality of painting finish. The figure 3 shows a change of state of air from outdoor condition to the expected condition (24 ℃DB, 70 %RH) in the painting booth on a psychrometric chart.
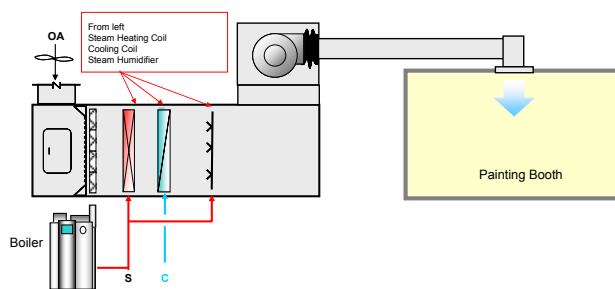
**Figure 2 Schematic diagram of
installed air conditioning system**

**Figure 3 Expected movement of
state of air on psychrometric chart**

In order to evaluate the reduction effect of the amount of $CO_2$ emission by the system installed, we assume the air conditioning system using steam shown in figure 4 for comparison.

**Figure 4 Schematic diagram of assumed air conditioning system for comparison**

## 3      EVALUATION METHOD

### 3.1     Data Used For Evaluation

The parameters of the system installed have been monitored and recorded by the central monitor device: they are temperature and relative humidity of ambient air, the total power consumption of the system, the temperature and relative humidity in the painting booth, etc..

### 3.2     Evaluation Method For System COP And COP Of Heat Pumps

The system COP and the COP of the heat pumps installed are calculated by using the parameters mentioned above. The rated airflow volume and the signal output to control the rotation speed of the fan are taken into consideration to calculate the airflow volume to obtain the heat load. In addition, the deference between the enthalpy of ambient air and the enthalpy at the painting booth air inlet is used as well.  To calculate those COPs the heat load is divided by the input energy defined later on.

As the total power consumption includes auxiliary machine's power consumption, to obtain the COP, 70% of the rated power consumption of each auxiliary machine as actual power consumption is assumed respectively. The input energy into the system is calculated by reducing the estimated power consumption of the fan from the total power consumption to obtain the system COP: the input energy is calculated by reducing the estimated summation of power consumption of each auxiliary machine from the total power consumption to calculate the COP of the heat pumps.

### 3.3     Evaluation Method For Amount Of $CO_2$ Emission

Once the COP of the heat pumps is decided, a comparison between the decided COP and the COP written in the technical specification of the heat pumps will be made. After the confirmation of the good match between them, the set of the COP at a given dry bulb temperature written in the technical specification will be used to calculate the COP during operation in a recent year. The COP at the monthly average dry bulb temperature during operation will be calculated by interpolation from the set. And the calculation will be done based on the meteorological data at the point close to the area in which the painting booth was constructed. Also, to compare with the air conditioning system using the boiler, we conservatively assume 90% of the thermal efficiency of the system using the boiler. The heat load per one hour is calculated:

$$H = \rho Q\ (h_2 - h_1). \tag{1}$$

Hence H is the heat load per one hour, $\rho$ the density of air, Q the airflow volume, $h_1$ the enthalpy of ambient air, and $h_2$ the enthalpy at the painting booth air inlet. We compare the

amounts of $CO_2$ emission of two cases, i.e. using steam of the boiler, indicated by the subscript s, and using the heat pumps, indicated by the subscript h. The amount of $CO_2$ emission per one hour is calculated:

$$A_i = (H \cdot b_i) \diagup (a_i \cdot c_i) + bi \cdot di. \tag{2}$$

The subscript i is either s or h. Hence $a_i$ is the thermal efficiency (or the COP of heat pumps), $b_i$ the $CO_2$ emission intensity, $c_i$ the unit conversion factor for electricity or the net calorific value of fuel used at the boiler, and di the assumed power consumption per one hour of the auxiliary machine. The amount of $CO_2$ emission per one hour is accumulated to obtain the heat load for every month and the annual heat load. And liquidized natural gas (LNG) is assumed as fuel used at the boiler. For calculation of the amount of $CO_2$ emission we use $CO_2$ emission intensities of 2.69 kg-$CO_2$/kg for LNG and 0.339 kg-$CO_2$/kWh for electricity. The $CO_2$ emission intensity for electricity is the actual value of the fiscal year 2006 provided by the Tokyo Electric Power Company Incorporated.

## 4 EVALUATION

### 4.1 Evaluation Of  System COP And COP Of Heat Pumps

Figure 5 shows an example of changes in the parameters from 9:00 a.m. through 21:00 p.m. on October 19th, 2010 as following: ambient air temperature, the system COP, and the COP of the heat pumps. In figure 5, the system COP was 3.5 and the COP of the heat pumps was 3.9, at least respectively. The average temperature during this period was about 17 ℃. The COP of the heat pump depends on ambient air condition: especially dry bulb temperature is important to estimate the COP. The estimation shows that the COP of the heat pumps at 17 ℃ was 4.43, which would be a comparable value with the COPs of the heat pumps in figure 5.
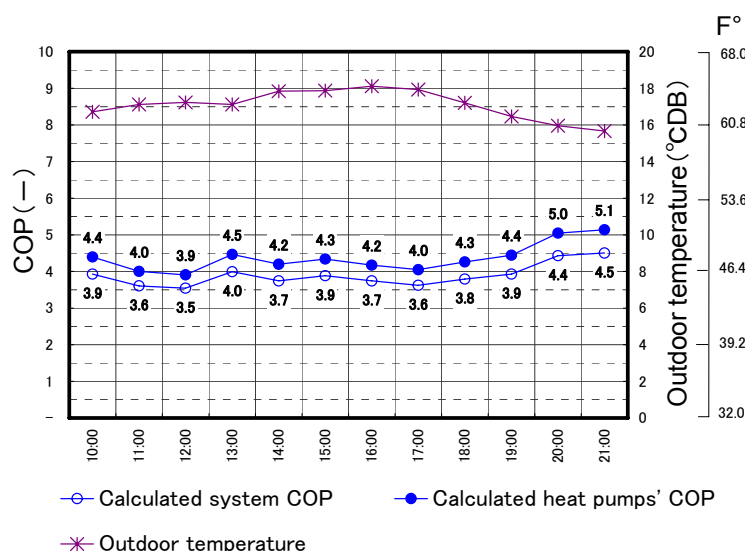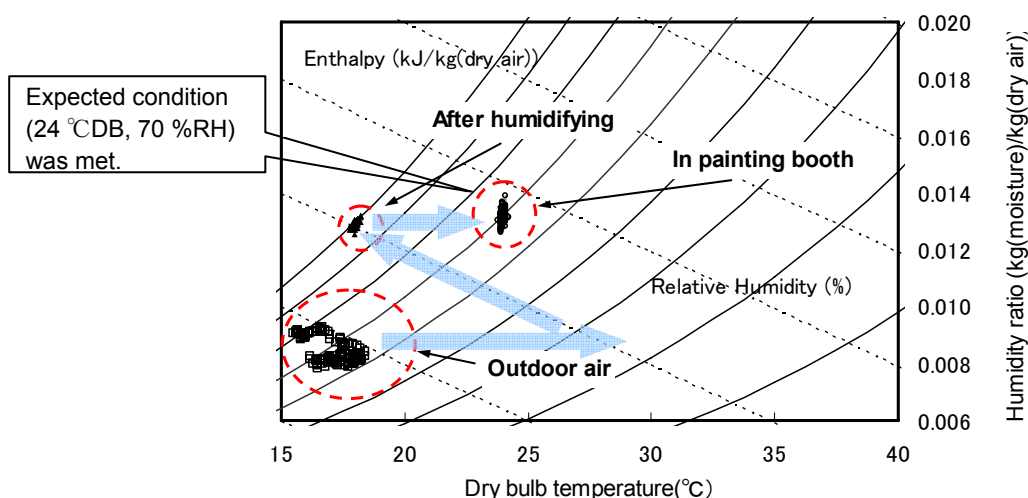


**Figure 5 Changes in parameters on October 19th, 2010**

### 4.2 Evaluation Of System Operation

Figure 6 shows an example of sampling data on a psychrometirc chart. In figure 6, it is shown that conditioning air by the air conditioning system installed was very successful, because the conditioned air state in the painting booth met the expected condition. In

addition to the high controllability of state of air, the high relative humidity expected was achieved, which means that the vapour type humidifier attained high applicable saturation efficiency.
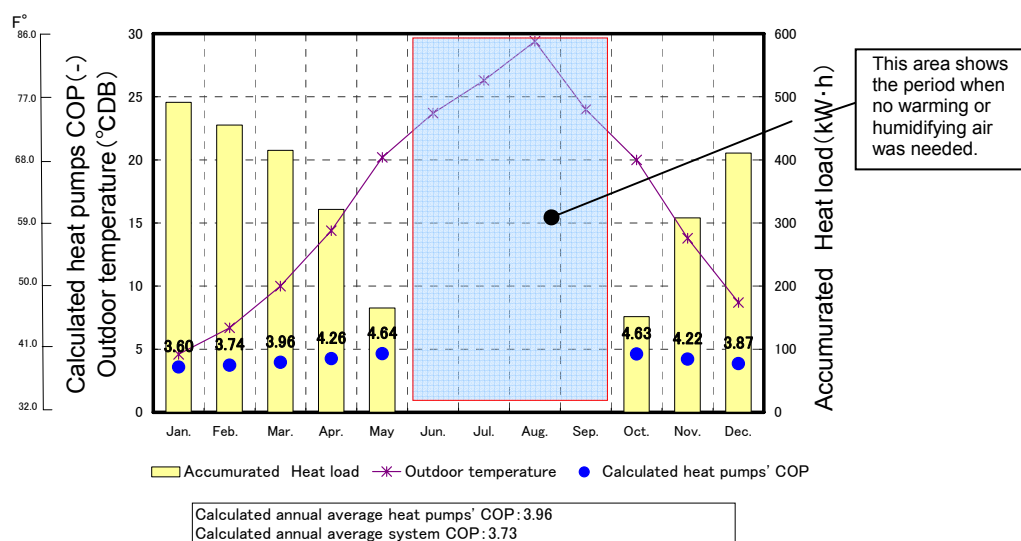


**Figure 6 Sampling data on psychrometric chart**
(Time period is from 9:00 a.m. through 21:00 p.m. on October 19th, 2010.  Sampling frequency is 5 min.)
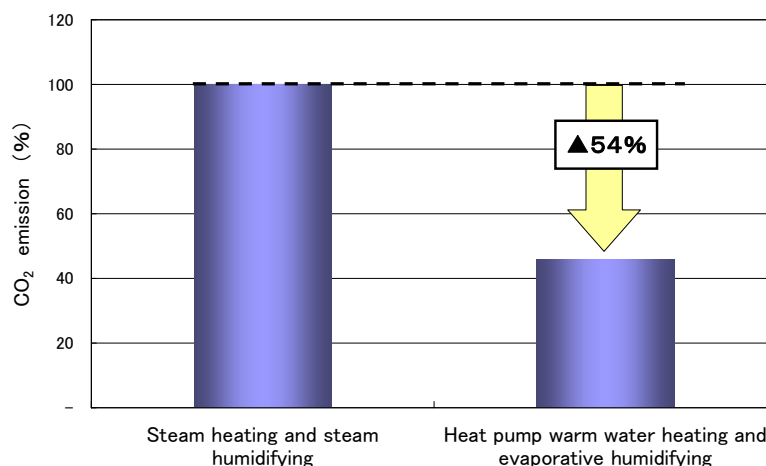

## 4.3    Evaluation Of Amount Of $CO_2$ Emission

Before calculating the amount of $CO_2$ emission in a recent year, the monthly average COPs during operation and the accumulated heat loads of warming and humidifying air per one month were estimated. Figure 7 shows the result.

A comparison of the amount of $CO_2$ emission in the case of the assumed air conditioning system using steam with that in the case of the installed system using the combination of the heat pumps and the evaporative humidifiers is shown in figure 8. As can be seen in figure 8, the amount of $CO_2$ emission from the air conditioning system using the combination of the heat pumps and the evaporative humidifiers is lower than that from the air conditioning system using steam by 54% in the period when warming and humidifying air was needed.



**Figure 7 Estimated COP and accumulated heat load**

**Figure 8 Comparison of amount of $CO_2$ emissions from air conditioning system using steam with using combination of heat pumps and evaporative humidifiers**

## 5    CONCLUSION

・   In terms of the period when warming and humidifying air was needed in a recent year, 54% of the amount of $CO_2$ emission by the assumed air conditioning system using steam for the painting booth was estimated to have been reduced by the installed air conditioning system using the combination of the heat pumps and the evaporative humidifiers.

・   The air conditioning system for painting booth was well designed and operated to keep a constant environment, even the expected relative humidity was relatively high.

## 6    REFERENCES

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