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A STUDY ON IMPROVEMENT OF INDOOR HUMIDITY IN OFFICE BUILDING DURING HEATING OPERATION IN WINTER

Shigehiro ICHINOSE[1], Kazunobu SAGARA[2], Yukio ISHIKAWA[3], Toshihumi KOBAYASHI[1], Genzaburou FUKAYA[1] and Ikuya KAWAKAMI[4]

[1] Building Facilities Section, Civil & Architectural Engineering Department, Chubu Electric Power Co., Inc, 1,Toshin-cho, Higashi-ku, Nagoya, 461-8680, Japan, e-mail: Ichinose.Shigehiro@chuden.co.jp
[2] Department of Architectural Engineering, Graduate School of Engineering, Osaka University, 2-1 Yamadaoka, Suita, Osaka, 565-0871, Japan
[3] Department of Architecture, Faculty of Engineering, Mie University, 1515 Kamihama-cho, Tsu, 514-8507, Japan
[4] Toenec corporation, 1-79, Chitose, Minami-ku, Nagoya, 457-0819, Japan

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Summary

Indoor relative humidity is prescribed for an important control point in indoor environment regulations such as Building Control Code and Industrial Safety and Health Code. But from the findings of the survey, which is carried out during winter, we can see that relative humidity is lower than the standard in many buildings. The factors that deteriorate indoor relative humidity is divided into building side such as infiltration and humidifier side such as low performance under low indoor temperature. It is essential to control these factors to improve indoor relative humidity. Aiming to improve indoor relative humidity, we have developed a high efficiency humidifier that is using two-phase flow nozzle and installed it in an office building in Ise-City, Mie prefecture in 2004. We carried out a field test and evaluated the operational state. In this report, results of the field test are presented. It was found that the humidifier using two-phase flow nozzle is more efficient than popular humidifier which is frequently used for air-conditioning systems.

1. Introduction

An Office building, its total floor area beyond 3,000m^2 is prescribed as controlled buildings in Building Control Code and we must maintain its relative humidity beyond 40% in Japan. But according to the indoor environment survey which was carried out during winter, almost 80% of office buildings can't meet its standard (S. Ichinose et al., 2004). Although you can find a lot of studies have made on indoor air pollutants (Dong-Won, Yoon et al., 1996) there is few studies on indoor relative humidity during winter. It is said that relative humidity during winter is not good condition. However, there seems to be no established technology to improve it. Considering these backgrounds, we have developed a high efficiency humidifier using two-phase flow nozzle. Two-phase flow nozzle is frequently used for industrial installation and we arranged it for air-conditioning use. As its atomized particle size is smaller than popular humidifiers such as a high pressure water type, it could keep its performance under low indoor temperature. Especially, because heating load in office buildings tends to decrease because of improvement of building insulation and increasing OA instrument in office buildings, heating operation during winter is more and more decreasing. And because the temperature at the front of a humidifier tend to drop, popular humidifier such as high pressure water type and vaporizing type deteriorate its performance. The purpose of this study is to verify the practicability of the humidifier using two-phase flow nozzle in actual field. Through this study, we confirm its high performance.

2. Outline of office building and its air-conditioning system

Table 1 shows outline of the building and its humidifier system. Figure 1 shows 2nd floor plan of the building. When the remodel of air-conditioning system was carried out in 2004, the air-conditioner equipped with humidifier using two-phase flow nozzle is installed in the second floor. Its air-conditioning area is shown in Figure 1 (2F South office). The air-conditioner equipped with vaporizing type humidifier is installed in the first floor and third floor at the same time. Their air-conditioning areas is also south office in the first floor and third floor respectively. Air-conditioner takes CAV (Constant Air Volume) system and cope with fluctuating load by proportional control using two-way outlet valve. There is no humidifier in the north office in the second floor. The humidifier using two-phase flow nozzle can vary its atomizing capacity in two steps in accordance with moistening load. On the other hand, vaporizing type humidifier can't vary its capacity because it depends on air temperature at the front of humidifier. From the point of convenience for

Table 1 Outline of humidifier system in the office building[†1]

Office	Air volume (m^3/h)	Humidifier type
1F	1,500	Vaporizing Type (6.6(kg/h))[†2]
2F South	9,300	Two-phase flow nozzle (13.8(kg/h))[†]
2F North	-(Fan-coil unit)	No humidifier
3F	9,700	Vaporizing Type(12.6(kg/h))[†2]

[†1] Total floor area is 2,665m^2. [†2] Effective moistening quantity

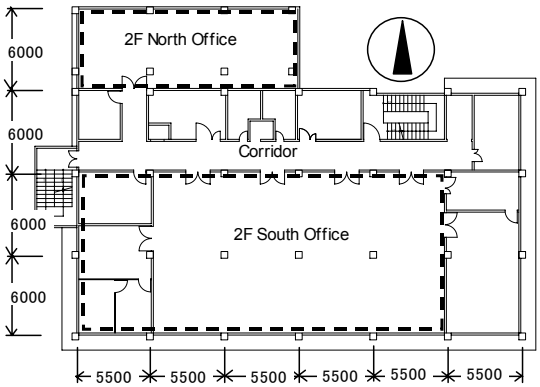


Figure 1 2nd floor plan of the building

Table 2 Set point of air-conditioner

Control Point / Office	1F	2F South	2F North	3F
Temperature (°C)	22	22	22	22
Relative humidity (%)	50	-	-	50
Dew-point temperature(°C)	-	10.5	-	-

occupants, the doors facing the corridor open all the time except north office in the second floor and south office in the third floor. Especially there are many visitors in the first floor because it has sales counter. And plenty of infiltration is likely to flow into the first floor. Table 2 shows the set point of air-conditioner. As for humidity, considering indoor temperature tends to rise during winter owing to increase of OA instruments, which causes deterioration of relative humidity, we must set its set point rather high to make relative humidity in standard. We control indoor temperature 22°C and relative humidity 50% or dew-point temperature 10.5 °C. These set points are equivalent to absolute humidity approximately 0.008kg/kg(DA). To verify the practicability of the humidity using two-phase flow nozzle and improvement of relative humidity in this office building, measuring instrument such as watt-hour meters and hygrothermographs were installed at several point around air-conditioners and office. These data were measured every ten minutes. Moistening quantity and absolute humidity were calculated from these data in order to verify the operational state of humidifier. Field test was carried out in January, 2005.

3. Improvement of relative humidity

Figure 2 shows improvement of relative humidity in the every floor. The data before remodel was measured on February 13, 2003 and we could see that this data couldn't meet relative humidity standard which is prescribed in Building Control Code. As this figure indicates that relative humidity was improved after remodel except 1F office and 2F North office. In 2F south office where the humidifier using two-phase flow nozzle was installed, relative humidity was high sufficiently.

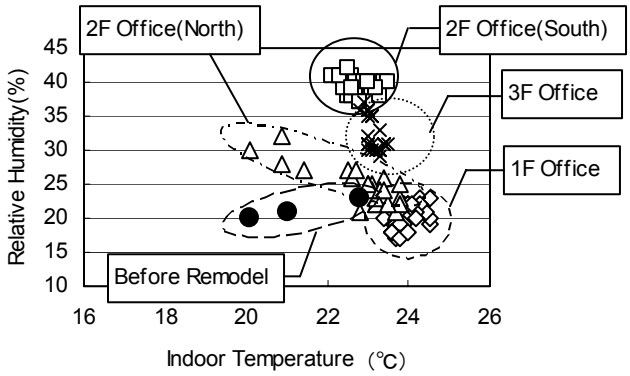


Figure 2 Improvement of relative humidity (January 20,2005 (8:00-18:00))

4. Factors deteriorating relative humidity

4.1 Factor in the building side

If the doors or windows which should be closed all the time are opened during winter, the infiltration beyond designed values flow into room and deteriorate relative humidity in the office buildings. Especially doors tend to be opened for convenience. Figure 3 shows time change of absolute humidity. I have mentioned earlier service condition of this office building. As this figure indicates, absolute humidity during day time (8:00 to 18:00), except 2F south office decline in accordance with time and approach absolute humidity in the outdoor. In terms of these results, it is quite likely that plenty of infiltration beyond designed value flow into the office. Especially as absolute humidity in the 1F office is lower than 2F north office where there is no humidifier, we can say that there is plenty of infiltration flow into 1F office in comparison with another floor. The absolute humidity in the 2F north office is uncontrolled because there is no humidifier. Therefore tendency of time change is similar to that of the outdoor. Although there is no humidifier in the 2F north office, a big fluctuation of the absolute humidity is not observed. This is because that the door of the 2F north office facing corridor is closed all the time and there is less infiltration in comparison with 1F office. Though the doors in the 3F office is closed all the time, absolute humidity decline in accordance with time. The result indicates that the vaporizing type humidifier which is installed in the third floor could not meet the humidity loss predicted in a design phase. As for this point, we can say that its predict method and the performance of the humidifier need to be examined in detail. The doors in the 2F south office is opened all the time, therefore we can say that infiltration flows into the office during daytime operation. While it could not meet absolute humidity set point (0.008(kg/kg(DA)), it keeps about 0.007(kg/kg(DA)). For the reason mentioned above, the humidifier using two-phase flow nozzle could meet the humidity loss. It was found from the results given above that the measures which keep infiltration out in the building side is close doors or windows which is opened all the time for convenience. Furthermore setting double door space at the entrance can be effective to keep it out.

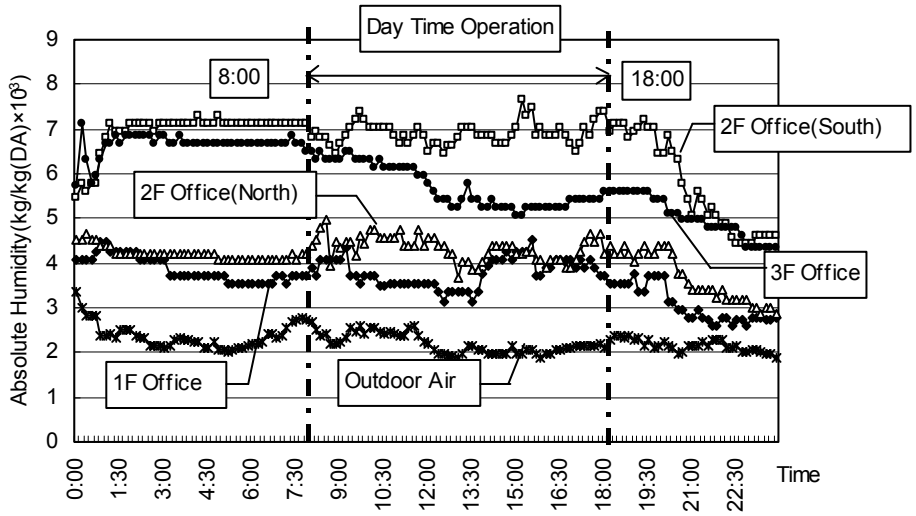


Figure 3 Time change of absolute humidity (January 20,2005 (0:00-24:00))

4.2 Change of winter heating load in office building and humidity design method

Winter heating load in office building tends to decrease because introduction of heating element such as OA instrument is increasing these days. Under these circumstances, heating operation during winter is decreasing. On the contrary, fan operation without heating is increasing. As fan operation without heating consists of outdoor air and return air, its air temperature is lower than that of heating operation. During fan operation without heating the temperature at the front of a humidifier is also lower than that of heating operation and popular humidifier such as high pressure water type and vaporizing type deteriorate their performance. Figure 4 shows the day time operational state of air-conditioner which is installed second and third floor. To analyze the incidence of heating operation or fan operation without heating, temperature of return air and behind heating and cooling coil were measured respectively. You can see that almost all the return air temperatures were higher than designed value, 22°C in Figure 4. The ratio of heating operation during daytime on January 20th (8:00-18:00) is 10% in the second floor and 0% in the third floor. The temperature behind heating and cooling coil is under 30°C continuously and also lower than designed values 39°C in Figure 4. The result clearly shows that almost all the daytime operation on January 20th, 2004 is fan operation without heating. The humidifier using binary cycle could keep its performance under low

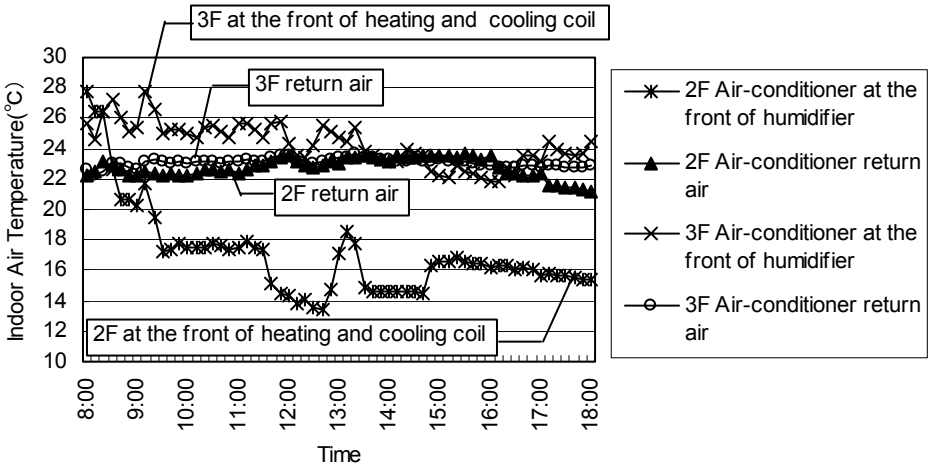


Figure 4 Operational state of air-conditioner installed at the second and third floor

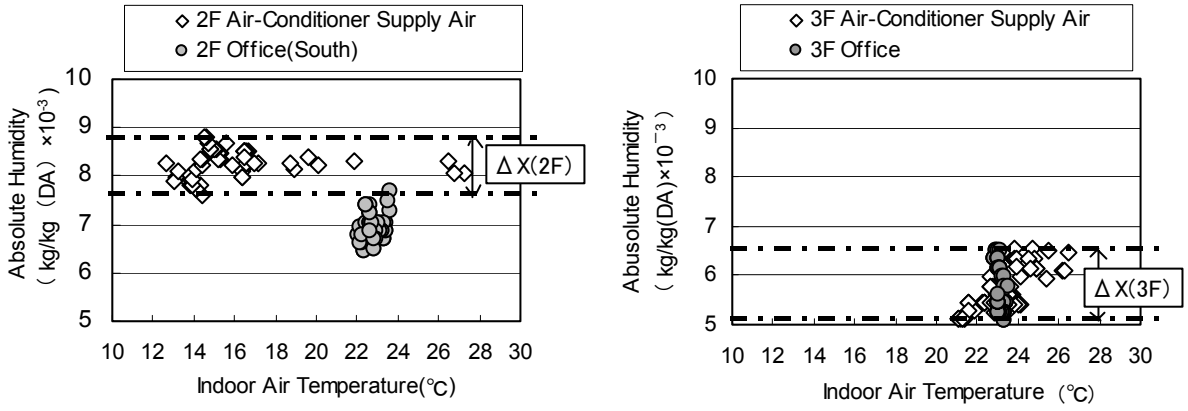
(January 20,2005 (8:00-18:00))

temperature, because its atomized particle is very small and vaporizes easily. On the other hand, as performance of vaporizing type humidifier depend on the temperature at the front of humidifier, its performance goes down during fan operation without heating. Especially, as the vaporizing type humidifier which was installed at the third floor was designed under the condition of heating operation, it takes an open type which covers only half of heating and cooling coil and has fewer humidifier elements. Open type is easily affected by temperature at the front of the humidifier because its humidifier element area is small. To prevent relative humidity go down during fan operation without heating, vaporizing type humidifier should be a closed type which cover the whole of heating and cooling coil. It could keep its performance even if the temperature in front of humidifier goes down, because its humidifier element area is two times as large as that of open type. It was found from the results given above that we should design humidifier taking fan operation without heating into consideration.

5. Operational state of humidifier using two-phase flow nozzle and vaporizing type humidifier

5.1 Controllability

Figure 6 shows humidity control state in the office room air and supply air during daytime. Humidity in the second floor was controled by dew-point temperature at the supply air, while humidity in the third floor was controled by relative humidity at the return air. As you see from Figure 6 that supply air temperature in the second floor and third floor always under 30℃, which is lower than designed value 36.5℃, we could say almost all the daytime operation is fan operation without heating. Although under the situation as stated above, absolute humidity of the second floor was maintained about 8.0×10^{-3}(kg/kg(DA)), which is set point.



a) Second floor b) Third floor

Figure 6 Control state of humidity during daytime operation(January 20, 2005 8:00-18:00)

On the other hand, absolute humidity of the third floor was distributed from 5.0×10^{-3}(kg/kg(DA)) to 7.0×10^{-3}(kg/kg(DA)), in spite of its supply air temperature was maintained beyond 20°C which is higher than second floor. $\Delta X(2F)$ and $\Delta X(3F)$ in the Figure 6 means the difference of absolute humidity between maximum value and minimum value during daytime operation in the second floor and third floor respectively. The difference in the $\Delta X(3F)$ becomes 1.42×10^{-3}(kg/kg(DA)) which is bigger than that of $\Delta X(2F)$, 1.17×10^{-3}(kg/kg(DA)). As the humidifier installed in the third floor is a vaporizing type, its performance is easily affected by the temperature at the front of the humidifier and it goes to be uncontrolled. That is the reason why $\Delta X(3F)$ is bigger than $\Delta X(2F)$. You can also see from Figure 6 that while absolute humidity of supply air and office in the third floor is almost same (Figure 6 b)), that of office in the second floor is almost 1.0×10^{-3}(kg/kg(DA)) lower than that of supply air. As the reasons mentioned in the chapter 2, the doors facing the corridor in the second floor was opened all the time for convenience, large amount of infiltration flow into the office in comparison with the third floor. That is the reason why this difference in the second floor is happened. It was found from the result that the controllability of humidifier using two-phase flow nozzle is superior to vaporizing type humidifier except the infiltration factor which causes deterioration of humidity.

5.2 Moistening quantity during daytime operation

Figure 7 shows time change of moistening quantity in the second and third floor during daytime operation. Moistening quantity is calculated from absolute humidity between air at the front of heating and cooling coil and supply air every an hour. Table 4 shows difference of condition of humidifier. When we select the humidifier using two-phase flow nozzle, we take safety factor and humidifier performance into consideration in addition to effective moistening quantity (Table 1). On the other hand, we don't consider these factors when we select the vaporizing type humidifier. We can see from Figure 7 that moistening quantity in the second floor, where the humidifier using two-phase flow nozzle is installed in, become almost 30(kg/h) in every time steps. It performs almost 100% of its design condition and is over effective moistening quantity. As for this result, owing to continuous moistening load which is caused by infiltration and evaporation of condensed water which is caught by eliminator set behind the humidifier in the air-conditioner, it is likely that the humidifier perform such a large amount of moistening quantity. To the contrary, we also see from Figure 7 that moistening quantity in the third floor where the vaporizing type humidifier is installed in, become below effective moistening quantity all the time. While it is selected under the heating operation, almost all the daytime operation is fan operation without heating as we can see in Figure 4. Furthermore, as the temperature at the front of the humidifier is 10°C lower than that of condition in Table 4, it is likely that the

Table 4 Humidifier's design condition of the second floor and third floor

Floor	Humidifier' specification	Remark
2F Office(South)	Two-phase flow nozzle 4.3(kg/h)×7 pieces	Performance efficiency; 60% Safety factor 30%
3F Office	Vaporizing type (open type) 15.4kg/h	Performance efficiency; 100% Condition† ; Temperature 39°C, Relative humidity 17%

† Condition in front of the humidifier

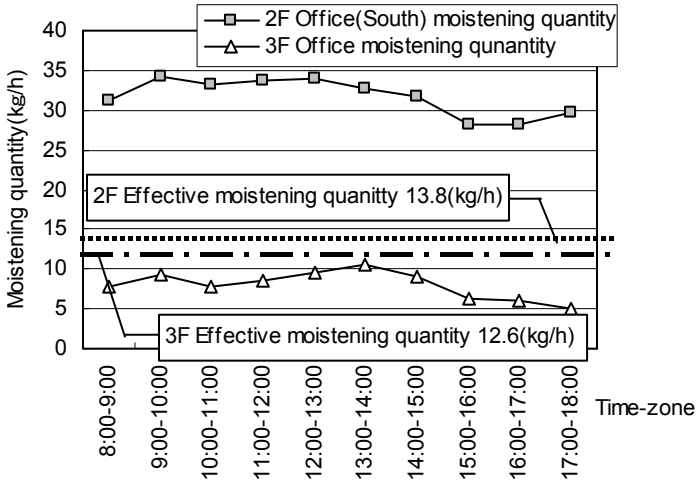


Figure 7 Time change of moistening quantity in the second floor and third floor

(January 20, 2005 8:00-18:00)

humidifier couldn't perform its designed capacity. As for total moistening quantity in the second floor during daytime operation become 316.8(kg), while total moistening quantity in the third floor become 80.3(kg). Electrical power consumption per moistening quantity of the humidifier using two-phase flow nozzle becomes 69(W/kg). This is almost equal to electrical power consumption of popular humidifier such as supersonic type. It was found from the results that the humidifier using two-phase flow nozzle is equal to popular humidifier in terms of its performance.

6. Result of research on comfortability of office worker

Figure 8 shows result of research on comfortability that is intended for office workers in the second floor (south) and third floor. Relative humidity was improved after remodel in comparison with before remodel, and as you can see from Figure 8, the ratio of comfortable or rather comfortable is increasing, while that of uncomfortable or uncomfortable is decreasing in comparison with before remodel. We can say that the comfortability of the office worker was improved by improvement of humidity.

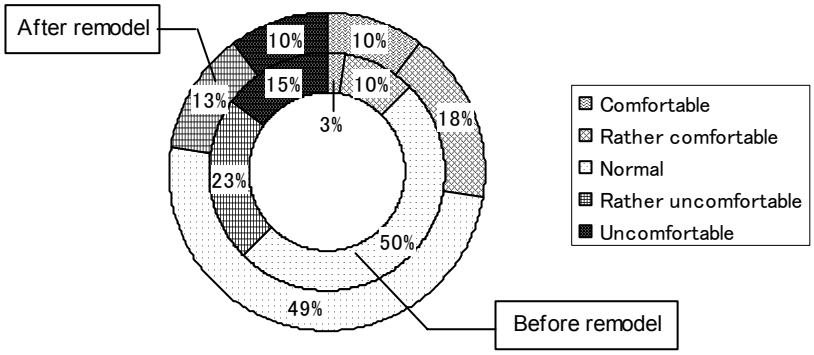


Figure 8 Result of research on comfortability in the second and third floor (Total answers 40)

7. Conclusions

Through the field test of humidifier using two-phase flow nozzle, the following results are obtained.

Owing to remodel of air-conditioning system, relative humidity was improved except second floor (north) and first floor where a plenty of infiltration was flown in. Especially, relative humidity of second floor (south) where the humidifier using two-phase flow nozzle was installed in was improved remarkably.

We could see the absolute humidity during daytime (8:00 to 18:00), except second floor (south) office, declines in accordance with time and approaches absolute humidity in the outdoor. From the point of keeping indoor environment proper, we should take measures in the building side such as setting double door space at the entrance can be effective to keep infiltration out.

We must design humidifier system considering almost all the daytime operation during winter is fan operation without heating. Especially, if we use vaporizing type humidifier, this consideration is important.

The humidifier using two-phase flow nozzle is equal to popular humidifier in terms of energy consumption and its performance. Further direction of this study will be development of a humidifier which can improve relative humidity in an unit type air-conditioning system which is applied to rather small buildings.

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