INVESTIGATION ON INDOOR ENVIRONMENT AT OFFICES LOCATED IN HOT HUMID REGION IN JAPAN UNDER THE CONDITION OF POWER SAVING

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According to a research result handled by Ministry of Health, Labour and Welfare, measurement values of temperature, relative humidity and concentration of carbon dioxide (CO_2 concentration), which had been obtained at large buildings, have not met partly the reference values of the Act on Maintenance of Sanitation in Buildings in Japan recently. At the same time, the government has been requiring power saving activities for the public after the Great East Japan Earthquake in 2011.

This paper describes the present state of temperature, relative humidity, and CO_2 concentration by using result of continuous measurement at four office rooms located in hot humid region in Japan. Additionally, result of questionnaire survey about power saving action in each target office room is shown. At one office room, at which the air conditioning's setting temperature was as same as the upper limit of the reference of the Act, mean value of temperature was higher than the reference value in cooling period. In heating period, the mean value of the measurement result of relative humidity was approximately 30%RH, which is lower than the lower limit of the reference value of the Act. CO_2 concentration was influenced by the power saving action. The measurement value of the concentration was proportionate to the strength of the power saving activities. Moreover, the measurement values are compared with Japan wide data obtained before the earthquake. The result of the comparison derives that the measured indoor environment are poorer quality. The quality seems that it was caused by the energy saving actions by analysing questionnaire survey results.

KEYWORDS: temperature, relative humidity, CO_2 concentration, office, energy saving

1. INTRODUCTION

1.1 Trends of the indoor environment in buildings

The Act on Maintenance of Sanitation in Buildings requires measuring indoor hygiene environment in the every single *large building*[1] more than once in two months in Japan. The Act has seven measuring items and the reference values as shown in table 1. However, according to a research result handled by Ministry of Health, Labour and Welfare, measurement values of temperature, relative humidity and concentration of carbon dioxide (CO_2 concentration) have not met the reference values partly recently. Moreover the trend of the inadequate has been increasing for these years and the inadequate rate obtained in FY2011 was the highest[1] in the past. The situation is considered as being influenced by the power saving requirement by government[2] after the Great East Japan Earthquake in 2011.

[1] The buildings larger than 3000m^2 and grouped into categories such as department stores, auditoriums, libraries, museums, retail stores and offices, and buildings larger than 8000m^2 and grouped into schools, are classified as the large buildings in the Act on Maintenance of Sanitation in Buildings.

Table 1. Measuring items of the Act on Maintenance of Sanitation in Buildings in Japan

measuring item	reference value
Airborne Particles	0.15 mg/m^3
CO	10 ppm
CO_2 concentration	1000 ppm
Temperature	17 ºC - 28 ºC
Relative Humidity	40 %RH – 70 %RH
Air Velocity	0.5 m/s
Formaldehyde	0.1 mg/m^3

1.2 The Energy Saving Code

The Energy Saving Code for Building in Japan was amended in 2013. The amended code is intended not only to decrease heating and cooling load by employing insulation and solar shading but also to estimate primary energy consumption in buildings. Additionally, the Code requires applying to the standard values, like as insulation performance and primary energy consumption, for each region divided whole of Japan into 8 areas as shown in Figure 1. Kochi prefecture, called as hot humid region and 95% of the populations live in the area6 and the area7, has approximately 750,000 populations, which means only 0.6% of total population of Japan live in the prefecture. Therefore, very few data on energy consumption and indoor environment are available.

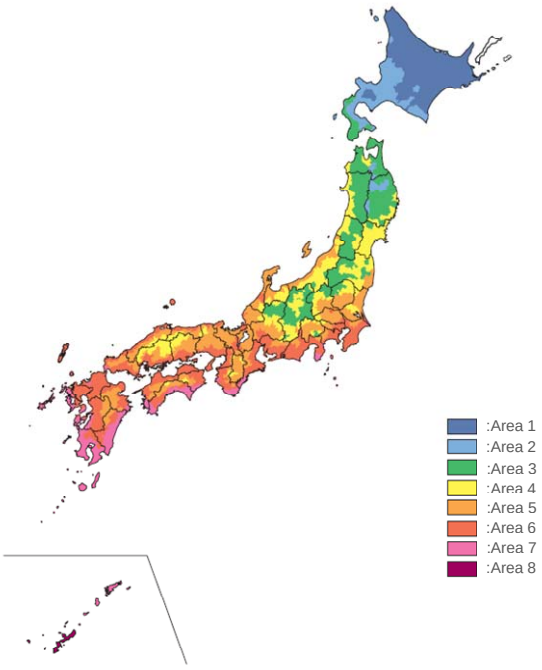

Figure 1. Areas in the Energy saving code [3]

2. METHODOLOGY

This research aims at to grasp the present state of temperature, relative humidity, and CO_2 concentration by real measurement at four office rooms (shown in table 3) located in hot humid region in Japan. Additionally, not only the measurement but also questionnaire related in power saving activities was conducted to obtain the relationships between the indoor environment and the energy saving activities. In table 3, the controlling way for the HVAC (heating, ventilation, and air conditioning) systems and the area in the Code are also shown.

The measurement, whose items are temperature, relative humidity, and CO_2 concentration, was executed during both cooling period and heating period as shown in table 2. The measurement instruments for temperature and relative humidity were set at the centre of the rooms and the height from the floor level at 75cm - 150cm. The measuring instruments for CO_2 concentration were also set at the centre of the rooms. The location of the instruments was decided by respecting the measurement procedure of the Act. In the procedure of the Act, once or few times measurement are required for each measuring point in a day. However, the measurement interval in this research is set as 15 minutes to know the environment in more detail by continuous measurement. The measurement data are sampled as only office hours (AM8-PM6) for analysing.

The survey for the power saving activities at the office was conducted by asking for an office worker of each target room. *Quantitative understanding of the effects and power-saving measures of small and medium-sized commercial building* [4] is used as reference for the question items in the questionnaire.

Table 2. Measuring period

Cooling period	August 23, 2012 - September 10, 2012
Heating period	December 21, 2012 - January 21, 2013

Table 3. Outline of the target office rooms

room	HVAC control	area in the Energy Saving Code
#A	central	7
#B	individual	6
#C	generally central *	6
#D	individual	6

*only ventilation fan is controlled by individually

3. RESULT

3.1 Cooling period

The measuring results for temperature, relative humidity and CO_2 concentration obtained during the cooling period of each room are shown in Figure 3, 4 and 5 (Figure 2 indicates the legend of box plots). The grey areas in the diagrams indicate the range of the reference value of the Act.

Only the mean temperature of the room #A exceeds the reference value. It is believed to be due to the setting temperature for the HVAC system is higher than usual out of respect for the power saving requirement.

The measuring relative humidity of the all locations approximately meets the reference value of the Act. The values obtained at room #A and room #C which employ central controlling are lower than the others, which means better thermal comfort.

Most of the CO_2 concentration of the room #C indicates higher than 1000ppm. At the same time, the mean value is higher than 2000ppm also. By an interview with an occupants, it was indicated that the ventilation system employed at the room was often deactivated from the view point of the power saving. The deactivation has been dane easily because its ventilation system employs individual control.

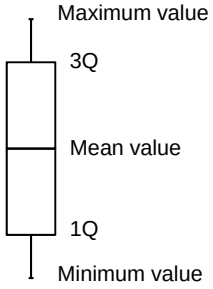

Figure 2. Legend for box plots (for Figure 3-8)

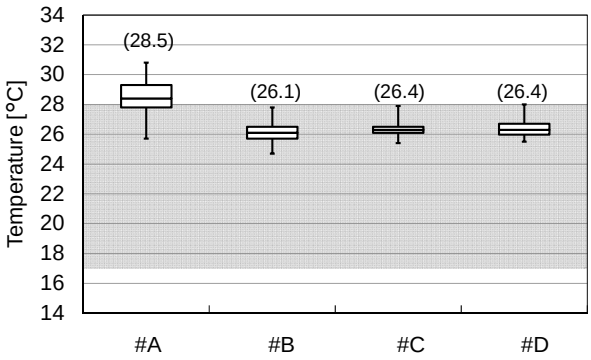

Figure 3. Temperature in office hours, cooling period ( )indicates mean value

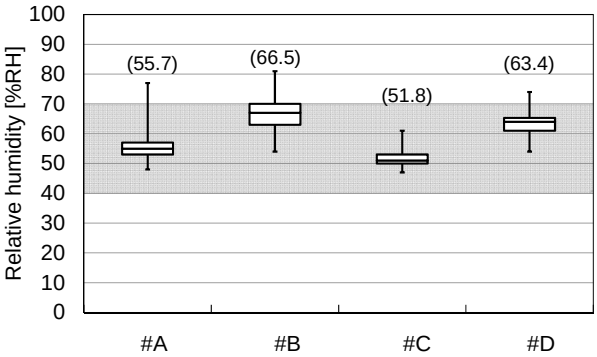

Figure 4. Relative humidity in office hours, cooling period ( )indicates mean value

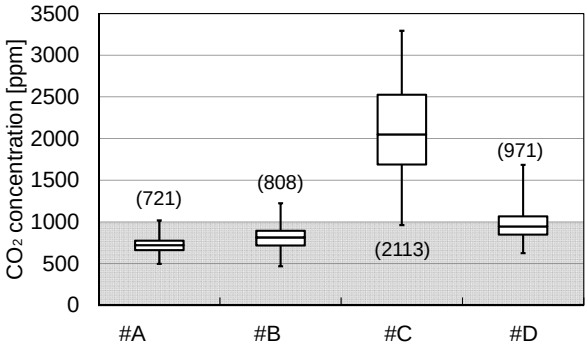

Figure 5. CO_2 concentration in office hours, during cooling period ( )indicates mean value

3.2 Heating period

The measuring results for temperature, relative humidity and CO_2 concentration obtained during the cooling period of each room are shown in Figure 6, 7 and 8.

Most of the temperature data approximately meet the reference value of the Act. Only some data, which are obtained in the start-up time in the morning, are lower than the reference value.

Most of the measuring relative humidity data are inadequate the reference value of the Act.

Especially, the mean value of the room #A is the lowest and some data are found as lower than 20%RH. This means the office room has a certain risk of catching a cold for the occupants.

Approximately, half of the CO_2 concentration data taken at the room #C is higher than the reference value. However, the adequate rate is improved compared with in the cooling period. This improvement, 1000ppm descend of the mean value, is considered to be led by informing the measurement result of the cooling period for the occupants at the office room before the period by the authors.

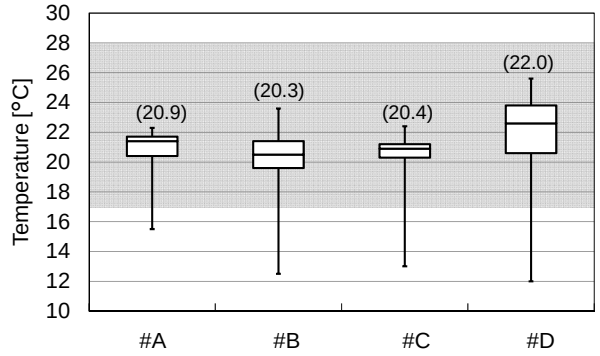

Figure 6. Temperature in office hours, heating period ( )indicates mean value

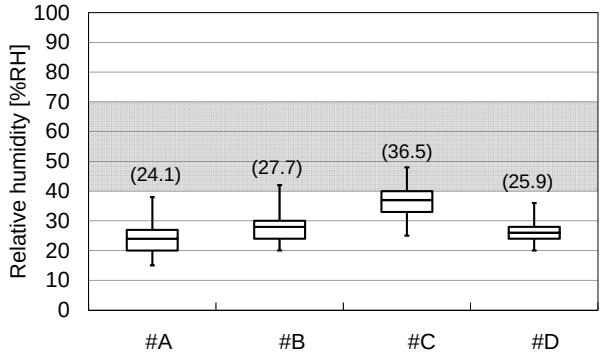

Figure 7. Relative humidity in office hours, heating period ( )indicates mean value

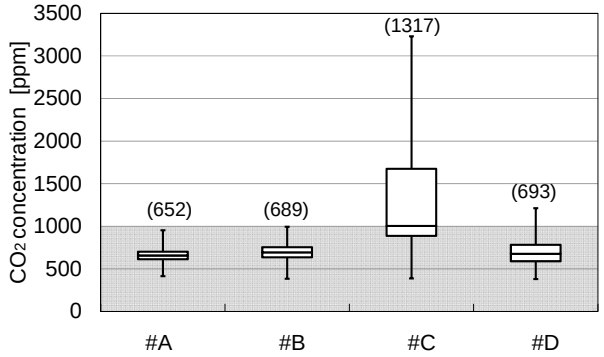

Figure 8. CO_2 concentration in office hours, heating period ( )indicates mean value

3.3 Comparison with Japan wide data

The measured data is compared with Japan wide data[5], which is obtained indoor environment data at more than 4000 office rooms (cooling period: 4922 rooms, heating period: 4023 rooms) in all over Japan by following the procedure of the Act before the requiring power saving activities and the Great East Japan Earthquake.

Table 4 and 6 represent the mean value of the taken data of temperature, relative humidity and CO_2 concentration of the rooms in the office hours during cooling period and heating period. Figures 9 and 10 represent the relationships between the measuring data and the Japan wide data with using temperature data and relative humidity data. Tables 5 and 7 represent relative ranking of the mean value of the measuring by fitting into the Japan wide data. The relative ranking equals to the cumulative frequency of each measuring item shown in Figure 9 and 10.

In the cooling period, the mean temperature of the room #A is higher than the reference value and at the same time the relative ranking is 0.976. Therefore, the mean value represents almost the highest value fitting into the Japan wide data obtained before the requiring power saving. The relative rankings of the relative humidity indicate moderate rank, at the same time every mean value meets the reference value. Every relative ranking of CO_2 concentration is low (generally larger than 0.7) and the result is considered that there is a certain influence of the power saving activities like as deactivation of ventilation system or reducing the ventilation rate. Especially, the mean value of the room #C shows almost the lowest relative ranking.

In the heating period, the relative rankings of both the temperature and the relative humidity are approximately less than 0.3. There can be some problems for managing the relative humidity since not only the mean values are inadequate the reference value of the Act but also the most of the

relative rankings indicate almost 0. The relative ranking of CO_2 concentration taken in the room #C is close to 1 even the improvement of ventilation operating has occurred.

3.4 Questionnaire survey on power saving

The estimated power saving efficiency by utilising the questionnaires result is called as the theoretical power saving rate in this research, because the rate is not obtained by measurement. Figure 11 shows the theoretical power saving rate of each office rooms within the starting period of the power saving activities also. At the room #C it has been carried out the power saving activities before the requiring of power saving. The room #A and #B has employed some energy saving activities since 2012, this can indicate some influences of the power saving.

The relationship between the theoretical power saving rate and the measured indoor environment items is analysed as shown in Figure 12. The dot plots in the diagram represent the mean value of the measured CO_2 concentration obtained in the each office room during both of the heating and the cooling period. The mean value of the CO_2 concentration is estimated to be proportional to the theoretical power saving rate. It is considered that poor indoor environment can be led by the power saving activities.

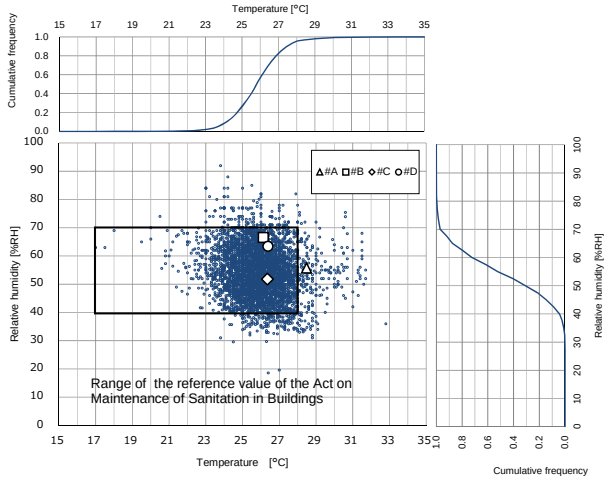

Figure 9. Mean value of the temperature and the relative humidity taken in the each office rooms comparing to Japan wide data in cooling period

Table 4. Mean value of the measuring items and the Japan wide data in cooling period

room	Temperature [°C]	Relative humidity [%RH]	CO_2 concentration [ppm]
#A	28.5	55.7	721.0
#B	26.2	66.5	808.0
#C	26.4	51.8	2112.9
#D	26.4	63.4	971.2
Japan wide data	25.9	54.8	643.0

Table 5. Relative ranking of the measuring items in cooling period

room	Temperature [°C]	Relative humidity [%RH]	CO_2 concentration [ppm]
#A	0.976*	0.543	0.720
#B	0.584	0.904	0.845
#C	0.641	0.373	0.999*
#D	0.641	0.826	0.954

* inadequate the reference value

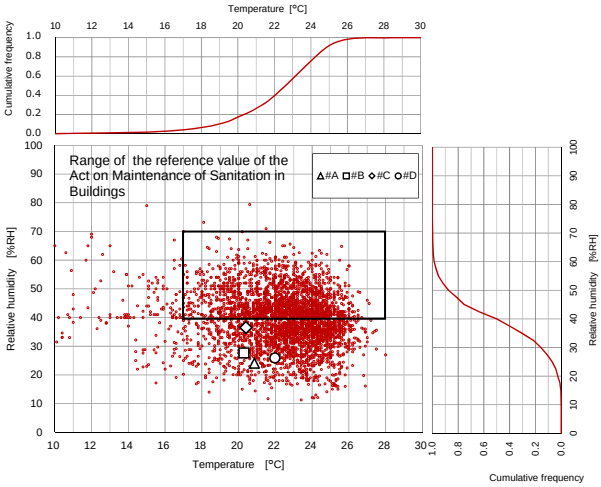

Figure 10. Mean value of the temperature and the relative humidity taken in the each office rooms comparing to Japan wide data in heating period

Table 6. Mean value of the measuring items and the Japan wide data in heating period

name	Temperature [°C]	Relative humidity [%RH]	CO_2 concentration [ppm]
#A	20.9	24.1	652.0
#B	20.3	27.7	689.2
#C	20.4	36.5	1317.4
#D	22.0	25.9	692.8
Japan wide data	22.3	39.7	685.4

Table 7. Relative ranking of the measuring items in heating period

name	Temperature [°C]	Relative humidity [%RH]	CO_2 concentration [ppm]
#A	0.228	0.054*	0.544
#B	0.178	0.104*	0.593
#C	0.186	0.360*	0.983*
#D	0.352	0.075*	0.598

* inadequate the reference value

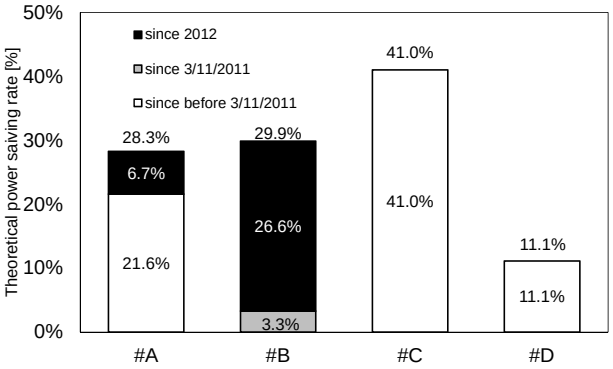

Figure 11. Theoretical power savings rate of rooms

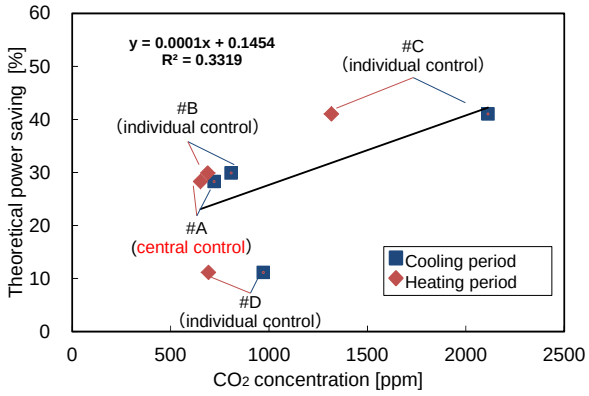

Figure 12. Relationship of theoretical power savings and mean value of the CO_2 concentration

4. CONCLUSIONS

A continuous measurement for temperature, relative humidity and CO_2 concentration, and questioner survey about power saving activities in four office rooms located in hot humid region in Japan have been executed in order to take the present state of indoor environment in hot humid region in Japan. The followings are the conclusions.

In the cooling period, there is a room whose mean temperature is higher than the reference value of the Act on Maintenance of Sanitation in Buildings. It is believed to be due to the setting temperature for the HVAC system is higher than usual out of respect for the power saving requirement.

In the heating period, most of the measuring relative humidity data are inadequate the reference value of the Act. This means the office room has a certain risk of catching a cold for the occupants. The relative rankings of both the temperature and the relative humidity are approximately less than 0.3. From the view point of the hygiene, the management of the humidity in winter under the power saving condition is one of the most important issues.

The mean value of the CO_2 concentration is estimated to be proportional to the theoretical power saving rate. It is considered that higher CO_2 concentration can be led by the power saving activities if the ventilation system employs individual control.

This study uses four sites' data, therefore it will be required to obtain data in more sites for understanding in more details. However some problems are indicated caused by activities for the power saving or HVAC control way. These results will be useful for balancing the indoor environment with energy saving.

5. ACKNOWLEDGEMENT

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