Temperature, Relative humidity and Indoor Air Quality in office buildings and their subjective evaluation

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ABSTRACT

Long-term continuous measurements of temperature, humidity and CO_2 concentrations were conducted in offices in three buildings of over 3,000 m^2 and three non-specified buildings of less than 3,000 m^2. These measurements were carried out to investigate the effect of the hygrothermal environment in winter and summer, with a particular focus on the impact of humidity in winter and the hot and humid environment when air conditioning is turned off in summer, on microbial contamination. The impact of temperature and humidity conditions in winter and summer, particularly winter humidity and the high temperature and humidity environment in summer, on microbial contamination was examined.
Regarding relative humidity, the specified buildings A, B and C, which are humidified, are humidified to a sufficient degree to create an average absolute humidity difference of 2.75-6.10 g/kgDA with respect to the outdoor air. However, the percentage of time meeting the standard is not necessarily high: A: 58.9%, B: 9.3% and C: 3.9%. In contrast, non-specified building D exhibits a relative humidity below 40% (with an average of 15.7 ± 6.2%), while non-specified buildings E and F also meet the standard at a rate of 7.8% and 3.4%, respectively. In the subjective evaluation of the office workers, there was no statistically significant difference in the perceived relative humidity between those who reported feeling dry and those who did not. Conversely, the perception of dryness was found to be less pronounced in areas with higher absolute outdoor humidity.
Regarding microbiological contamination when air conditioning is turned off in the summer, in the specified building C, which has a high proportion of I/O ratios exceeding 1, there was no odour when arriving at work. In other buildings, 10-15% of office workers perceived some kind of odour. Buildings A, B and D also reported a mouldy odour. Furthermore, during normal office hours, 10-15% of employees reported an olfactory sensation, except for building B, which exhibited a mouldy odour. There were notable discrepancies between the specified buildings subject to the law and the non-specified buildings that were not obliged to comply, particularly regarding the humidification control. Additionally, significant differences were observed in the indoor relative humidity. Furthermore, differences were identified due to differences in building size, particularly regarding HVAC controls and the stability of non-steady-state temperature and humidity.

KEYWORDS

Office buildings, Relative humidity, Subjective evaluation, Act on Maintenance of Sanitation in Buildings

1 INTRODUCTION

The temperature, humidity, and air quality of a building are affected by the type of air conditioning and ventilation unit and their operation. In addition, the thermal performance, airtightness, thermal capacity, and moisture capacity of a building play an important role. Humidification control is implemented by law regardless of building use. Dehumidification,

on the other hand, is performed simultaneously during cooling operation in conjunction with the cooling load.
The primary distinction between specified and non-specified buildings pertains to the regulation of humidity, which is subject to different stipulations depending on the applicability of legal obligations. In most cases, humidification units for packaged air conditioning systems are optional. However, the adoption rate remains relatively low due to the necessity for water supply pipes and the implementation of leakage prevention measures. The objective of this study is to elucidate the characteristics of office room temperature and humidity conditions in office buildings during winter and summer based on the results of long-term continuous measurements of temperature, humidity, and CO_2 concentration in office rooms of three specified buildings and three non-specified buildings.

2 METHODS

2.1 The Surveyed Buildings

Table 1 provides an overview of the surveyed buildings. Buildings A, B, and C are tenant buildings with a total floor area of 3000 m^2 or more and fall under the category of specified buildings as defined in the Act on Maintenance of Sanitation in Buildings. A building maintenance company provides comprehensive management, including air conditioning operation, building automation operation monitoring, and cleaning. Buildings D, E, and F, on the other hand, are equipped with a combination of packaged air conditioners and ventilation systems. The heating and cooling operations are controlled by switches and operation panels installed in each room. The buildings A to C operate on a Monday to Friday schedule, with the air conditioning system typically turned off on Saturdays and Sundays. Buildings D to F are off on Wednesdays, with another day off on Tuesdays, Saturdays, or Sundays.

Table 1: Discription of surveyed buildings

	Location	Total Floor Area (m^2)	Tenant (m^2)	Floor Level	AC	Ventilaiton
A	Sapporo	25289	247	10F /16F	AHU(CAV)+FCU	AHU+HEX
B	Sendai	6800	142	7F /8F	PAC	OHU
C	Tokyo	93997	209	22F /35F	AHU(VAV)	AHU(VAV)
D	Sapporo	1373	325	2F /3F	PAC	HEX
E	Kumamoto	973	156	3F /3F	PAC	Exhaust Fan
F	Kanazawa	806	235	1F /1F	PAC	Exhaust Fan

2.2 Measurement

Temperature, humidity, and CO_2 measurements were logged at 10-minute intervals using a T&D TR-76Ui temperature/humidity/CO_2 logger. Continuous measurements commenced in October 2022 and are ongoing. The period from 1 October 2022 to 20 February 2023 was designated as the winter period, while the period from 26 June 2023 to 6 August 2023 was designated as the summer period. On one specific day during each season, suspended microorganisms (fungi and bacteria) were sampled. The suspended microorganisms were incubated with DG18 medium for fungi and SCD medium for bacteria at a specified temperature and time after the aspiration of 100 litters each was conducted using a bio sampler.

3 RESULTS

3.1 Results of Ventilation Rate Estimation During HVAC are not in Operation

The ventilation rate during the time that air conditioning was not in operation was estimated from the CO_2 concentration decay after working hours. In A to C, ventilation is also out of operation along with the air conditioning, while in D to F, the ventilation system is in continuous operation even when the air conditioning is off. The results for winter and summer are presented in Figure 1. The air change rate for A-F was 0.37, 0.11, 0.28, 0.45, and 0.4, respectively. The respective values were 0.8 and 0.55 for winter, and 0.25, 0.12, 0.17, 0.4, 0.45, and 0.53 for summer. The estimated results for winter demonstrated greater variability, yet on average, no significant difference was observed between winter and summer. These findings suggest that the stack effect has a minimal impact. The amount of ventilation air during working hours was estimated based on the number of individuals in the room on specific days in winter and summer, the estimated amount of CO_2 exhalation for each, and the variation in CO_2 concentration. The results are presented in Table 2.

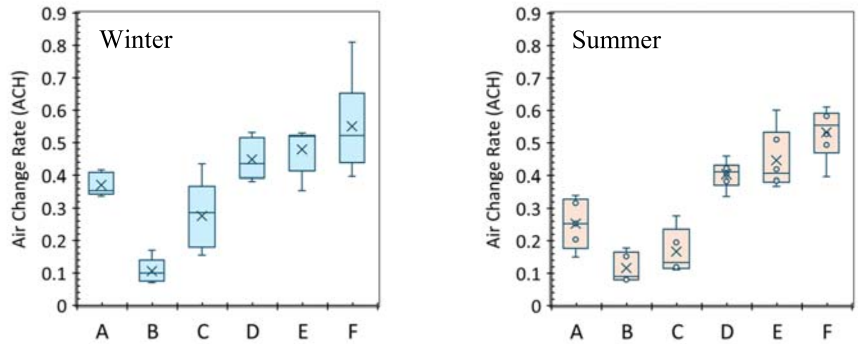


Figure 1: Estimation of ventilation rate during HVAC is out of service based on CO_2 concentration decay (Left figure is in winter, Right figure is in summer)

Table 2: Estimated ventilation rate during working hours

Measured Ventilation Rate (Estimation)						
	Winter		Summer		Density (person/m^2)	Floor Area (m^2)
	m3/h/p	ACH	m3/h/p	ACH		
A	100.5	1.04	65.7	0.68	0.031	247.5
B	40.7	0.85	23.1	0.49	0.063	142.2
C	69.1	1.5	63.9	1.38	0.065	208.8
D	63	1.34	62.2	1.33	0.064	325.1
E	75.9	1.11	103.6	1.52	0.044	156
F	141.7	3.12	108	2.38	0.066	805.5

3.2 Temperature and humidity conditions in the office during winter

The mean values and standard deviations of CO_2 concentration, temperature, relative humidity, and absolute humidity from 10/01/2023 to 20/02/2023 are shown in Table 3. Office hours (9-17) and out of office hours (18-8) are calculated for each office. The temperature histograms for each office are presented in Table 4, the relative humidity histograms in Table 5, and the differences in absolute humidity between indoor and outdoor are illustrated in Figure 2. The specified buildings are maintained at a temperature range of approximately 24.7-25.0°C ± 1.0-1.8°C. In contrast, the temperatures in non-specified buildings A, B, and C range from 23.3 to 26.6°C ± 2.4 to 3.6°C, exhibiting a more pronounced variation compared to the specified buildings. Non-specified buildings D, E, and F display a notable decline in temperature during the winter months when the package air conditioning systems are deactivated. The continuous ventilation and thermal performance of the building play a role in this phenomenon. Regarding relative humidity, the specified buildings A, B, and C, which employ humidification, achieve an average absolute humidity difference of 2.75 to 6.10 g/kgDA relative to outdoor air. However, the percentages of relative humidity below 40% are relatively low: A: 41.1%, B: 90.7%, C: 96.1%. The percentage of non-specified buildings D is well below 40% relative humidity (15.7 ± 6.2%RH), and the percentage of buildings E and F which is less than 40% relative humidity is 7.8% and 3.4%, respectively. This is due to the lack of humidification in the facility and the lack of continuous ventilation.

Table 3: The mean values and standard deviations of CO_2, temperature, RH and AH in winter

		Working hours (9-17)				Out of Working hours (18-8)			
		CO_2 ppm	Temperature deg.C.	RH %	AH g/kgDA	CO_2 ppm	Temperature deg.C.	RH %	AH g/kgDA
A	average	691	25.0	41.0	8.10	530	21.5	41.4	6.66
	S.D.	60	0.7	3.4	0.56	75	1.3	3.8	0.97
B	average	819	24.7	29.4	5.70	601	20.2	38.0	5.64
	S.D.	111	0.9	6.2	1.24	158	1.9	3.1	0.93
C	average	904	24.8	35.0	6.81	614	21.2	36.8	5.75
	S.D.	73	0.5	2.1	0.42	140	1.8	2.5	0.72
D	average	797	26.6	15.7	3.40	496	21.3	15.6	2.51
	S.D.	119	1.8	3.1	0.74	131	3.1	4.2	0.91
E	average	634	25.8	27.7	5.74	453	22.9	30.8	5.47
	S.D.	84	1.2	6.8	1.50	87	2.8	7.7	1.83
F	average	610	23.3	28.2	5.01	451	16.9	34.3	4.11
	S.D.	60	1.3	4.7	0.91	79	5.0	8.2	1.22

Table 4: Temperature histograms for each office in winter
(Left is in working hours:9-17, Right is out of working hours:18-8)

	A	B	C	D	E	F
<18℃	0	0	0	0.8	0	0.1
18℃<=,<18.5℃	0	0	0	0.1	0	0.1
18.5℃<=,<19℃	0	0	0	0.2	0	0.3
19℃<=,<19.5℃	0	0	0	0	0.1	0.5
19.5℃<=,<20℃	0	0	0	0	0.1	1.3
20℃<=,<20.5℃	0	0	0	0.1	0.1	1.3
20.5℃<=,<21℃	0	0	0	0	0.1	2
21℃<=,<21.5℃	0	0.1	0	0.4	0.1	4.6
21.5℃<=,<22℃	0	0.8	0	1.2	0.2	6.5
22℃<=,<22.5℃	0.1	1.1	0	0.6	0.5	6.4
22.5℃<=,<23℃	0.8	1.7	0	0.1	1.2	11.6
23℃<=,<23.5℃	3	4.7	0.1	0.4	2.1	12.4
23.5℃<=,<24℃	5.3	12.7	3.1	0.5	3	16.7
24℃<=,<24.5℃	7.4	14.1	24.6	1.1	3.7	17.7
24.5℃<=,<25℃	16.8	17.9	29.8	4.2	7.2	13.2
25℃<=,<25.5℃	38.9	24.3	35	6.8	12.9	4
25.5℃<=,<26℃	23.5	16	7.5	10.9	15.1	1.1
26℃<=,<26.5℃	4	6.1	0	12.4	20.3	0.2
26.5℃<=,<27℃	0.2	0.4	0	12	16.5	0
27℃<=,<27.5℃	0	0.1	0	14.4	13.5	0
27.5℃<=,<28℃	0	0.1	0	16	2.7	0
28℃<=,<28.5℃	0	0	0	8.6	0.6	0
28.5℃<=,<29℃	0	0	0	5.8	0	0
29℃<=,<29.5℃	0	0	0	2.3	0	0
29.5℃<=,<30℃	0	0	0	1.1	0	0
30℃<=,<30.5℃	0	0	0	0.1	0	0
30.5℃<=,<31℃	0	0	0	0	0	0
31℃<=,<31.5℃	0	0	0	0	0	0
31.5℃<=,<32℃	0	0	0	0	0	0
32℃<=,<32.5℃	0	0	0	0	0	0
32.5℃<=	0	0	0	0	0	0
18-28℃	100	100	100	81.4	99.4	99.9

	A	B	C	D	E	F
<13℃	0	0	0	0.7	0	22
13℃<=,<13.5℃	0	0	0	0.6	0	3.4
13.5℃<=,<14℃	0	0	0	0.5	0	3.5
14℃<=,<14.5℃	0	0	0	0.4	0.3	2.8
14.5℃<=,<15℃	0	0.6	0	0.7	0.5	3.4
15℃<=,<15.5℃	0	1.2	0	0.7	0.4	3.2
15.5℃<=,<16℃	0	1	0	0.5	0.4	3.8
16℃<=,<16.5℃	0	0.7	0	0.5	0.6	4.5
16.5℃<=,<17℃	0	2.2	0.6	0.9	0.5	3.6
17℃<=,<17.5℃	0	2.5	0.9	1.4	0.6	3.8
17.5℃<=,<18℃	0	4.1	1.8	1.9	0.8	3.4
18℃<=,<18.5℃	0	5.5	3.8	2.3	1.1	2.9
18.5℃<=,<19℃	0.3	7.5	4.1	5.2	1.7	3.1
19℃<=,<19.5℃	3	8.8	7.4	6.8	2.4	2.8
19.5℃<=,<20℃	8.2	9.9	10.9	7.1	3.2	3.5
20℃<=,<20.5℃	10	12.8	11.5	5.9	4.3	2.8
20.5℃<=,<21℃	15.7	11.4	11.6	6.4	4.1	1.2
21℃<=,<21.5℃	15.9	9.1	12.5	6.2	4	1.1
21.5℃<=,<22℃	15.7	7.4	8.4	6.7	4	1
22℃<=,<22.5℃	10.5	5.1	6.4	5.3	4.3	0.8
22.5℃<=,<23℃	8	3.7	5.2	4.3	5.6	1.8
23℃<=,<23.5℃	4.9	2.7	3.7	4.6	7.6	2.8
23.5℃<=,<24℃	3.6	1.7	3.1	4.3	8.2	6
24℃<=,<24.5℃	2.4	0.9	3.1	3.8	7.5	5.6
24.5℃<=,<25℃	1.6	0.6	3.5	4.3	7.6	4.3
25℃<=,<25.5℃	0.3	0.2	1.3	4.4	9.4	2.3
25.5℃<=,<26℃	0	0.2	0.1	3.9	8.8	0.2
26℃<=,<26.5℃	0	0	0	2.8	7	0.3
26.5℃<=,<27℃	0	0	0	2.5	3.5	0.2
27℃<=,<27.5℃	0	0	0	2	1.1	0
27.5℃<=	0	0	0	2.4	0.4	0
18-28℃	100	87.5	96.6	91.2	95.8	42.7

Table 5: Relative humidity histograms for each office in winter
(Left is in working hours:9-17, Right is out of working hours:18-8)

	A	B	C	D	E	F
<10%	0	0	0	2.4	0	0
10%<=,<15%	0	0	0	32.6	0	0
15%<=,<20%	0	0.4	0	56.3	2.2	0.1
20%<=,<25%	0	20.3	0	8.5	36.8	15.8
25%<=,<30%	0	40.7	0	0.2	33.4	52.2
30%<=,<35%	0	13.3	53.3	0	10.6	26.1
35%<=,<40%	41	16	42.8	0	9.6	2.3
40%<=,<45%	40.7	8.7	3.9	0	4.1	0.6
45%<=,<50%	17.5	0.6	0	0	2.5	2.8
50%<=,<55%	0.7	0	0	0	1	0
55%<=,<60%	0	0	0	0	0	0
60%<=,<65%	0	0	0	0	0	0
65%<=,<70%	0	0	0	0	0	0
70%<=	0	0	0	0	0	0
40-70%	58.9	9.3	3.9	0	7.6	3.4

	A	B	C	D	E	F
<10%	0	0	0	6.8	0	0
10%<=,<15%	0	0	0	37.6	0	0
15%<=,<20%	0	0	0	46.8	2.9	1.3
20%<=,<25%	0	0.8	0	7.5	21.8	15.5
25%<=,<30%	0.8	41.3	1.4	1.4	31.5	24.2
30%<=,<35%	10.2	23.6	38.3	0	24.5	23.8
35%<=,<40%	8.7	22.2	54.5	0	10.3	15.6
40%<=,<45%	77	12.1	5.8	0	5.4	11.3
45%<=,<50%	3.3	0.1	0	0	2.1	4.1
50%<=,<55%	0	0	0	0	0.6	3.4
55%<=,<60%	0	0	0	0	0.9	0.4
60%<=,<65%	0	0	0	0	0	0.3
65%<=,<70%	0	0	0	0	0	0
70%<=	0	0	0	0	0	0
40-70%範囲	80.3	12.2	5.8	0	9	19.5

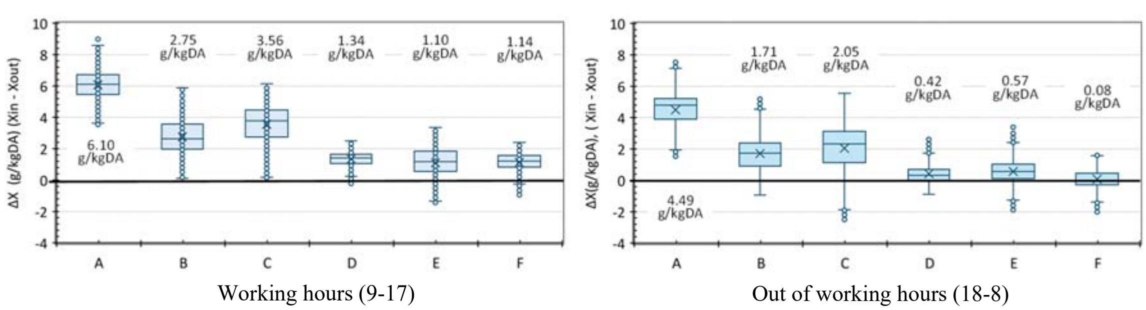
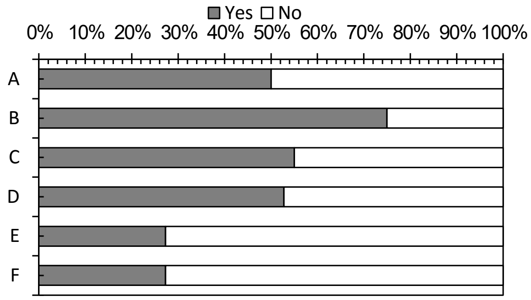


Figure 2: Boxplot of the differences in absolute humidity between indoor and outdoor in winter ((Left is in working hours:9-17, Right is out of working hours:18-8)

The reason for this is that in the specified buildings A, B, and C, ventilation is stopped when the air conditioning system is off, allowing the next operation of the air conditioning to commence from a relatively high indoor absolute humidity. In contrast, in the non-specified buildings D, E, and F, ventilation is continuous, resulting in the absolute humidity level dropping to the same level as the outdoor air during the night. However, in the subjective evaluation, many office workers report a sensation of dryness in the specified buildings A, B, and C, where a humidifier is used (Figure 3). The presence or absence of a feeling of dryness appears to be influenced by the absolute humidity of the outdoor air rather than the indoor relative humidity or absolute humidity.



Questionnaire
Is there currently a feeling of dryness?

Choices
1. Yes
2. No

Figure 3: Subjective evaluation of dryness during working hours in winter

3.3 Self-reported winter relative humidity and dryness

The standard setting of 40% relative humidity in the Building Sanitation Law has not been changed since 1970. This value has not been changed as it is still effective as a countermeasure against influenza. Figure 4 shows the results of the subjective evaluation of dryness and the perceived relative humidity in each office. In many cases, the relative humidity experienced by those who indicated that they felt dry (respondent groups A1, B1, C1, D1, E1, and F1) was lower than that reported by those who did not feel dry (respondent groups A2, B2, C2, D2, E2, and F2). Furthermore, there was no significant discrepancy between the actual measured relative humidity and the reported perception. Nevertheless, no statistically significant difference was observed between the presence or absence of a feeling of dryness and the perceived relative humidity.

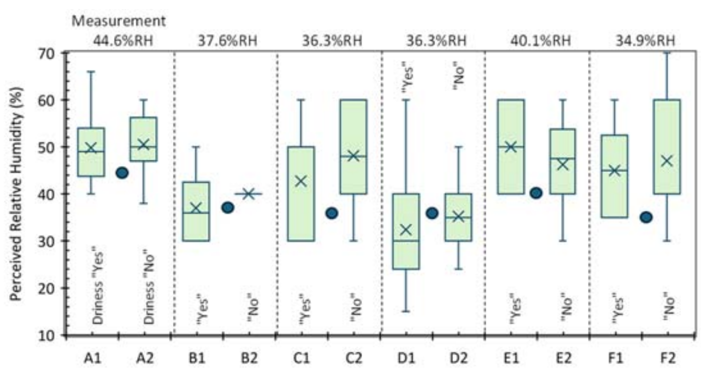


Figure 4: Subjective evaluation of dryness, perceived relative humidity and measured relative humidity during working hours in winter

3.4 Temperature and humidity conditions in the office during summer

The mean values and standard deviations of CO_2 concentration, temperature, relative humidity, and absolute humidity from 26/06/2023 to 06/08/2023 are shown in Table 6. The temperature histograms for each office during the summer season are presented in Table 7, the relative humidity histograms in Table 8, and the differences in absolute humidity between the indoor and outdoor environments during the summer season are illustrated in Figure 5. It is notable that the average temperature in specific buildings A, B, and C is consistent with that observed during the winter season, ranging from 25.2 to 25.6 degrees Celsius. However, the variation is smaller than in winter, with a range of ±0.6 to 1.0 deg.C. As the effect of solar radiation at the openings is minimal, the resulting cooling load fluctuation is also small and is more stable than in winter. Nevertheless, room temperature rises occur after the cooling operation has ceased. For building B, the temperature exceeds 28 deg.C. in 49% of periods. The mean temperatures of the non-specified buildings (D, E, and F) are also higher (25.9-26.6 deg.C.) due to their increased susceptibility to solar radiation at the openings. The variation is considerable, ranging from 1.2 to 2.8 deg.C. (2σ= 2.8 deg.C. for F, which is largely attributable to window opening). Regarding relative humidity, both specified buildings A, B, and C are dehumidified (on average, minus 2.37 to 4.65 g/kgDA of outdoor air). Furthermore, the relative humidity exceeds 70% very infrequently, including when air conditioning is off. Conversely, for non-specified buildings D and E, the relative humidity is consistently below 70% RH during working hours. However, for all but non-specified building D, the relative humidity exceeds 70% at night (E: 5.3%, F: 66.9% of the time, the relative humidity is higher than 70%). In the case of E, the absolute humidity of the outdoor air is a determining factor since it is an exhaust-only mechanical ventilation system. Although packaged air conditioners only dehumidify according to the cooling load, the load factor is high due to the low thermal performance of the building, which results in a high air flow rate for the packaged air conditioners. Therefore, it is assumed that the amount of condensation water is also high.

3.5 Microbial contamination in summer

The Japanese climate is characterized by high humidity, and therefore, attention should be paid to microbial contamination when air conditioning is turned off. Furthermore, airborne fungi and bacteria were sampled in offices, common areas, and outside air on specific days in August and September 2023.

The maintenance and management standard (Architectural Institute of Japan) for the interior of office buildings is 50 CFU/m^3 or less for fungi and 500 CFU/m^3 or less for bacteria. These standards were exceeded in B, D, E, and F (Figure 6) for fungi and F for bacteria (Figure 7). In terms of both fungi and bacteria, many of the I/O ratios in the office did not exceed 1. However, only C exceeded 1 (bacteria 1.44). The concentrations of suspended microorganisms in common areas such as corridors were higher than those in the offices, with I/O ratios of E: fungi 1.04 and C: bacteria 3.56. Given that the relative humidity in the offices of buildings A, B, and C never exceeded 70% RH, including nights and holidays, there is a concern regarding bacterial proliferation in the air conditioning system or ducts in the common area of C. In contrast, among the non-specified buildings, the relative humidity in the offices of F exceeded 70% on many days (especially at night and on holidays), resulting in airborne microorganisms' concentration.

It can be reasonably assumed that the odours observed during the summer months are the result of microbial contamination. If the odour is present just after the start of the air conditioning operation, it is likely that it is growing inside the air handling unit or in the duct. However, C, with a high percentage of I/O ratio exceeding 1.0, reported no "bothersome odour" at the time of arrival at work. Ten to fifteen percent of the workers, aside from C, reported some kind of odour. A, B, and D reported a mouldy odour (Figure8). Furthermore, during normal office hours, ten to fifteen percent of the office workers felt some odour, except for B, and mouldy odour was reported by A and F (Figure 9).

Table 6: The mean values and standard deviations of CO_2, temperature, RH and AH in summer

		Working hours (9-17)				Out of Working hours (18-8)			
		CO_2 ppm	Temperature deg.C.	RH %	AH g/kgDA	CO_2 ppm	Temperature deg.C.	RH %	AH g/kgDA
A	average	656	25.2	57.0	11.46	532	25.8	55.2	11.45
	S.D.	51	0.3	2.7	0.49	64	0.5	3.0	0.72
B	average	859	25.4	51.4	10.43	617	27.6	51.8	11.98
	S.D.	139	0.5	3.8	0.89	162	0.7	3.0	0.97
C	average	849	25.6	61.2	12.56	641	26.6	60.1	13.13
	S.D.	45	0.3	1.8	0.47	109	0.6	2.1	0.66
D	average	775	26.2	51.0	10.86	479	26.1	53.4	11.30
	S.D.	128	0.6	3.8	0.85	104	0.7	4.8	1.21
E	average	659	25.9	52.2	10.87	489	27.3	63.7	14.61
	S.D.	88	0.7	5.4	1.09	105	1.3	5.2	2.07
F	average	553	26.6	68.0	14.86	456	25.4	73.9	15.11
	S.D.	75	1.4	6.2	1.29	61	0.8	5.7	1.31

Table 7: Temperature histograms for each office in summer
(Left is in working hours:9-17, Right is out of working hours:18-8)

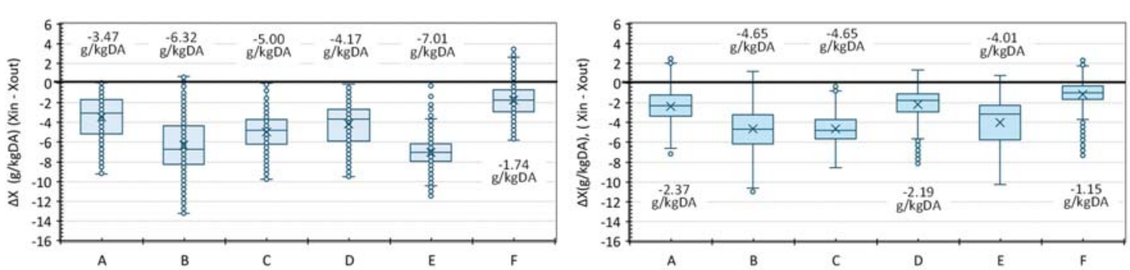
	A	B	C	D	E	F
<18℃	0	0	0	0	0	0
18℃<=,<18.5℃	0	0	0	0	0	0
18.5℃<=,<19℃	0	0	0	0	0	0
19℃<=,<19.5℃	0	0	0	0	0	0
19.5℃<=,<20℃	0	0	0	0	0	0
20℃<=,<20.5℃	0	0	0	0	0	0
20.5℃<=,<21℃	0	0	0	0	0	0
21℃<=,<21.5℃	0	0	0	0	0	0
21.5℃<=,<22℃	0	0	0	0	0	0
22℃<=,<22.5℃	0	0	0	0	0	0
22.5℃<=,<23℃	0	0	0	0	0	0
23℃<=,<23.5℃	0	0	0	0	0	0
23.5℃<=,<24℃	0	0.4	0	0.1	0	0
24℃<=,<24.5℃	0	3.3	0	0.5	0.5	1.1
24.5℃<=,<25℃	16.3	12.5	0.8	1.7	11.1	3.5
25℃<=,<25.5℃	61.4	30	36.7	5	11.2	10
25.5℃<=,<26℃	22	44.2	55.8	25.1	41.9	14.4
26℃<=,<26.5℃	0.2	8.7	6.6	28.7	17.6	24.8
26.5℃<=,<27℃	0.1	0.6	0	30.7	9.6	22.9
27℃<=,<27.5℃	0	0.1	0	7.7	5.5	10.7
27.5℃<=,<28℃	0	0	0	0.5	2	4.8
28℃<=,<28.5℃	0	0.1	0	0	0.4	0.9
28.5℃<=,<29℃	0	0	0	0	0.2	0.6
29℃<=,<29.5℃	0	0	0	0	0	0.7
29.5℃<=,<30℃	0	0	0	0	0	0.7
30℃<=,<30.5℃	0	0	0	0	0	0.8
30.5℃<=,<31℃	0	0	0	0	0	1
31℃<=,<31.5℃	0	0	0	0	0	1.4
31.5℃<=,<32℃	0	0	0	0	0	0.4
32℃<=,<32.5℃	0	0	0	0	0	0.4
32.5℃<=	0	0	0	0	0	0.8
18-28℃	100	99.8	99.9	100	99.4	92.2

	A	B	C	D	E	F
<18℃	0	0	0	0	0	0
18℃<=,<18.5℃	0	0	0	0	0	0
18.5℃<=,<19℃	0	0	0	0	0	0
19℃<=,<19.5℃	0	0	0	0	0	0
19.5℃<=,<20℃	0	0	0	0	0	0
20℃<=,<20.5℃	0	0	0	0	0	0
20.5℃<=,<21℃	0	0	0	0	0	0
21℃<=,<21.5℃	0	0	0	0	0	0
21.5℃<=,<22℃	0	0	0	0	0	0
22℃<=,<22.5℃	0	0	0	0	0	0
22.5℃<=,<23℃	0	0	0	0	0	0
23℃<=,<23.5℃	0	0	0	0	0	0
23.5℃<=,<24℃	0	0	0	0	0.2	0.9
24℃<=,<24.5℃	0	0	0	0.1	0.8	3.4
24.5℃<=,<25℃	4.4	0	0.1	2.7	3.3	8.9
25℃<=,<25.5℃	11	0.2	4.8	5.9	5.3	18.2
25.5℃<=,<26℃	39.9	0.3	3.6	21	7.7	18.7
26℃<=,<26.5℃	32.4	0.8	12.3	25	6.9	10.2
26.5℃<=,<27℃	4.1	4.1	35.6	21.5	5.1	11.2
27℃<=,<27.5℃	6.9	19.1	26	12.2	9.1	9.5
27.5℃<=,<28℃	1	24.5	9.7	7.2	10.7	9
28℃<=,<28.5℃	0.4	13.5	3.1	2.7	10.6	4.3
28.5℃<=,<29℃	0	16.1	3.2	1.8	16.9	1.8
29℃<=,<29.5℃	0	4.3	0.1	0	9.1	1
29.5℃<=,<30℃	0	5.3	1.2	0	8.4	0.6
30℃<=,<30.5℃	0	2.6	0.2	0	3.1	0.5
30.5℃<=,<31℃	0	2.9	0	0	1.9	0.5
31℃<=,<31.5℃	0	2.1	0	0	0.7	0.6
31.5℃<=,<32℃	0	2.7	0	0	0.1	0.2
32℃<=,<32.5℃	0	1.1	0	0	0.1	0.1
32.5℃<=	0	0.5	0	0	0	0.3
18-28℃	99.7	49	92.1	95.6	49.1	90

Table 8: Relative humidity histograms for each office in summer
(Left is in working hours:9-17, Right is out of working hours:18-8)

	A	B	C	D	E	F
<10%	0	0	0	0	0	0
10%<=,<15%	0	0	0	0	0	0
15%<=,<20%	0	0	0	0	0	0
20%<=,<25%	0	0	0	0	0	0
25%<=,<30%	0	0	0	0	0	0
30%<=,<35%	0	0	0	0	0	0
35%<=,<40%	0	0	0	0	0.1	0
40%<=,<45%	0	3.1	0	1	8.7	0
45%<=,<50%	0	29.6	0	38.3	22.3	0
50%<=,<55%	20.7	44.6	0	43.1	35.6	1.8
55%<=,<60%	61.3	21.2	18.3	15.7	24.3	3.2
60%<=,<65%	18	1.5	79.6	1.7	8.2	23.9
65%<=,<70%	0	0	2.1	0.2	0.8	35.1
70%<=	0	0	0	0	0	35.9
40-70%	100	100	100	100	99.9	64

	A	B	C	D	E	F
<10%	0	0	0	0	0	0
10%<=,<15%	0	0	0	0	0	0
15%<=,<20%	0	0	0	0	0	0
20%<=,<25%	0	0	0	0	0	0
25%<=,<30%	0	0	0	0	0	0
30%<=,<35%	0	0	0	0	0	0
35%<=,<40%	0	1.2	0	0	0	0
40%<=,<45%	0	8.9	0	1.1	0.2	0
45%<=,<50%	2.1	24.7	0	12.7	5.3	0.1
50%<=,<55%	25.5	50.3	2.2	29.4	11.8	0.3
55%<=,<60%	56.1	14.6	67.8	30.4	27.6	1
60%<=,<65%	14.9	0.3	29.6	21.4	26.1	7.6
65%<=,<70%	1.3	0	0.4	4.9	23.7	24.1
70%<=	0	0	0	0.1	5.4	66.9
40-70%	99.9	98.8	100	99.9	94.7	33.1



Working hours (9-17)

Out of working hours (18-8)

Figure 5: Boxplot of the differences in absolute humidity between indoor and outdoor in summer ((Left is in working hours:9-17, Right is out of working hours:18-8)

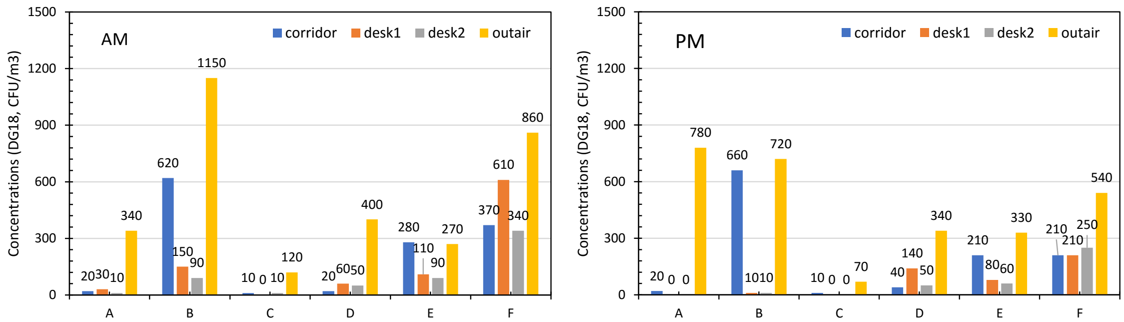


Figure 6: Concentration of airborne fungi in summer (Left is in AM, Right is in PM)

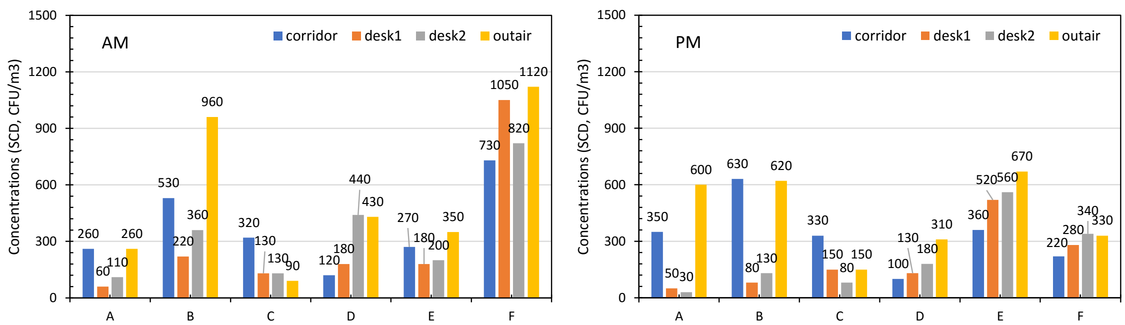
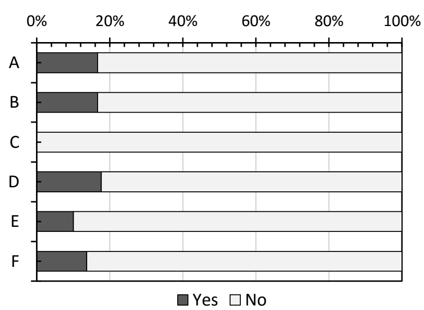


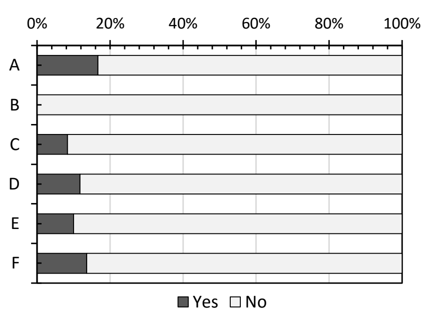
Figure 7: Concentration of airborne bacteria in summer (Left is in AM, Right is in PM)



Questionnaire
Is there an odour in the office when you arrive? This odour is noticeable when you arrive, but it becomes less noticeable over time.

Choices
1. Yes
2. No

Figure 8: Subjective evaluation of odour problems in the office on arrival at work in summer



Questionnaire
Are there any odours of concern in the space you are currently in?

Choices
1. Yes
2. No

Figure 9: Subjective evaluation of current odour problems in the office in summer

4 DISCUSSION

A, B, and C are specific buildings of more than 3000 m^2 and are designed in accordance with the standards of air management. In case B, where air conditioning is intermittently operated to reduce energy costs by stopping air conditioning during lunch break and ending operation at 15:00, the percentage of temperature and relative humidity exceeding the standard values increased compared to A and C. Furthermore, there were complaints from workers about the heat and cold. Regarding the perception of winter dryness, the sense of dryness was higher in buildings A, B, and C, where humidification was employed, while there was no statistically significant difference in the relative humidity experienced by office workers who complained of dryness and those who did not. Furthermore, buildings A and D (both located in Sapporo), although there was a significant difference in the measured indoor relative humidity, there was no significant difference in the perception of dryness.

5 CONCLUSIONS

A comparative analysis of buildings A, B, and C, which have a central HVAC unit, and buildings D, E, and F, which are not obliged to meet the requirements of the Act on Maintenance of Sanitation in Buildings, revealed that the temperature and humidity environments formed are completely different due to differences in building performance and operating methods. A summary is given below.

- It was found that buildings with a larger area scale exhibited greater stability in terms of temperature. Furthermore, it was verified that the air conditioning system maintains relatively stable conditions throughout the year, as there is no outside air introduced when the air conditioning unit is turned off.
- It was found that non-specified buildings were significantly affected by outside air due to separate control of air conditioning systems and ventilation systems, as well as continuous ventilation during the night. The colder the weather, the lower the absolute outdoor humidity, and thus the more humidification is required. However, the office workers do not experience the benefits of this humidification.

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