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The Necessity of Improving the Standard for Thermal Environment in Korean Public Facilities

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Abstract: As one of the energy saving policies, the Korean government has been regulating the indoor thermal environment of public office facilities in Korea, starting with energy conservation measures in 1980. This policy, which is above 28 °C in summer and below 18 °C in winter, is causing discomfort among the occupants. The purpose of this study is to support the need to improve temperature limitation standards of the Korean public office facilities. For this purpose, the standards for the thermal environment in offices of major countries and associations were examined. Subsequently, they were compared with the Korean standards. Additionally, nine buildings of public office facilities in Korea were surveyed on the thermal environment, and PMV measurement was carried out. As a result, most of the buildings that complied with the cooling temperature standard as well as most of the buildings that did not comply were found to be uncomfortable. In conclusion, to improve the comfort of Korean public office facilities in the heating and cooling period, it is necessary to mitigate temperature regulation and regulate additional environmental factors.

Keywords: public office facility; thermal environment; PMV (predicted mean vote); standard comparison

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1. Introduction

According to the Energy Consumption Survey of South Korea [1], public office facilities in Korea consumed about 395 million TOES in 2016, a mere 1.84% of the total energy demand. Public office facilities consume about 1.84 percent of the total energy in the demand sector, not much. However, according to the Korea Environmental Industry & Technology Institute [2], public buildings are symbolized as public buildings owned by public institutions and affect the determination of civil life and urban image, so they are applied first in terms of the government's energy policies and standards. The Korean government has regulated energy consumption of public office facilities since 1980 by having government organizations and their affiliated organizations take energy conservation measures. Now in 2019, it has come up with energy use regulations: the energy use rationalization of public facilities [3]. Especially, the regulation of the indoor thermal environment is enhanced in summer and in winter under Article 14 (the observance of the optimal indoor temperature) of regulations of the energy use rationalization of public facilities.

Because of these regulations, the discomfort of the occupants caused by the cooling temperature standard is reported on the news every year. Among the discomfort reports were the extra use of individual heating and cooling systems due to the performance degradation of insulation and airtightness, a thermal trapping phenomenon caused by the atrium configuration, excessive solar radiation with the curtain wall structure and unpleasantness caused by low indoor temperatures in summer due to poorly constructed buildings. In addition, old public office facilities have a problem of deterioration of insulation efficiency and airtightness due to deterioration of buildings. New public office facilities are often constructed in the form of curtain walls and atriums. In this case, the accumulated heat inside the building causes discomfort due to solar radiation. On the other hand, some public office facilities that do not comply with the indoor temperature standards in the summer have been reported in the news because of the discomfort caused by low indoor temperature and the excessive use of energy.

With the existing study on comfort during the study for improving the standards of public works facilities in Korea, Choi [4] demonstrated that Korean temperature standards are not optimal by simulating energy to local public institutions according to the combination of heating and cooling settings temperature. Jang [5] reported that the survey and eight points of PMV environmental factors (temperature, temperature of action, relative humidity, PMV, etc.) were measured in mid-term at public office facilities in Korea, and the current Korean standard is out of the comfort zone, which results in a decrease in work efficiency. In addition, Jang [6] obtained the results of the energy simulation according to PMV control in the summer, which showed the best comfort at 26 °C and 55% humidity, but high energy load under PMV control.

Accordingly, this study compared acts and standards related to the indoor thermal environment devised by governments and organizations of both Korea and other countries to support the need to improve the existing thermal environment regulations in Korea. Additionally, the researchers surveyed the occupants on the thermal environment comfort and measured PMV (Predicted Mean Vote), which is a thermal comfort model developed using principles of heat balance and experimental data collected in a controlled climate chamber. This study tried to obtain the objectivity by measuring various environmental elements of multiple buildings, not just a single facility. Of special note is the fact that the measurement was carried out in summer when the discomfort of the occupants is frequently reported, which the researchers believed would support the validity of the need to improve the current standards of the thermal environment in Korea.

2. The Comparison of the Thermal Environment Standards of Office Facilities in Korea and Other Countries

2.1. The Thermal Environment Standards of Office Facilities in Korea

Regulations of energy use rationalizations of public facilities is an act for efficient energy use and reduction of greenhouse gas emission implemented in Korea [3]. This current rule was enacted in accordance with Article 8 of the Energy Use Rationalization Act and Article 15 of the Enforcement Decree of the Energy Use Rationalization Act, and the South Korean Ministry of Trade, Industry and Energy will pursue initiatives [3]. Clause 14 of Regulations of energy use rationalization of public facilities, which is related to the indoor thermal environment, requires public office facilities to maintain below the average indoor temperature of 18 °C in winter and above the average indoor temperature of 28 °C in summer. Exceptionally, the aforementioned standard can be flexibly applied within plus or minus 2 °C in the following cases: (1) centrally controlled systems combined with non-electric ones accounting for over 60% of the whole cooling-heating system of a building and (2) non-electric system and individual heating and cooling system used. The following are also exempt from the indoor temperature regulations: facilities with numerous occupants such as schools, educational institutes, civil service offices, children and senior centers, accommodation facilities and buildings with aged central heating and air conditioning systems which fail to maintain a constant room temperature. In short, the room temperature is the only environmental element which the Korean law considers when it comes to regulating the indoor thermal environment.

2.2. The Thermal Environmental Standards for Office Facilities in Other Countires

In order to compare the difference between the standard of thermal environment of Korean public office facilities and those in other countries, this study investigated the thermal environmental regulations of various countries based on the existing study of Park et. al. [7]. It was found that among those investigated, except for Hong Kong, no countries have any regulations on the indoor thermal environment of public office facilities like Korea does. The temperature, the humidity, the radiation temperature and the air flow were the environmental factors investigated. The detailed content is illustrated in Table 1.

Hong Kong, Japan, China, the United States, United Kingdom and France were among the countries which encourage or require their public office facilities to comply with the thermal environment standards the governments implemented. Among those countries, France enforces the standards by law much like Korea does. The energy code in France [8], state that along with the public office facilities, residential areas, office facilities and educational institutes should comply with the regulations. According to Government of the French Republic [8], air-conditioning in summer is permitted when the room temperature is over 26 °C by the R241-30 (Provisions for the cooling of buildings; Sous-Section 5: Dispositions relatives au refroidissement des immeubles). In addition, according to the R241-26 (Provisions regarding the limitation of the heating temperature; Sous-Section 4: Dispositions relatives à la limitation de la température de chauffage), the room heating temperature during the period except vacancy is maintained at an average of 19 °C. As for Japan [9], in addition to the Cool-Warm Biz campaign implemented by Ministry of the Environment. According to Nicol et al. [10], Cool Biz Campaign is the Japanese government ordered central government officials to adjust the thermostat to 28 °C during the summer, which resulted in the introduction of a dress code called Cool Biz. Warm Biz is also a winter-time campaign in the same way. In the case of Hong Kong, the regulations on the indoor temperature in summer have been implemented under the government guideline on a trial basis [11]. Shopping malls and office facilities have been encouraged to comply with a less strict version of the regulations, too. The United States has a manual regarding the environmental elements in office facilities recommended by Occupational Safety and Health Administration, an affiliated organization of Department of Labor [12]. Additionally, ASHRAE Standard 55, which states the ranges of indoor environmental conditions for occupants of buildings, is another guideline considered acceptable in the United States [13]. In the United Kingdom, the Health and Safety Executive, an affiliated organization of the Department for Work and Pensions, recommends an appropriate room temperature range for workplaces. The guideline presented by Chartered Institution of Building Services Engineers is also recommended by the government [14].

This study also examined the guidelines presented by associations and academic societies across several countries including the Australia Standards (AS) of Australia [15], the Canadian Standards Association (CSA) of Canada [16], the European Committee for Standardization (CEN) of European Union [17], and the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) [13,18]. Australia's AS presents room temperatures of office rooms and Canadian Centre for Occupational Health and Safety recommends room temperatures of office facilities through CSA's regulations.

Most European countries, except for a few countries including France, encourage compliance with CEN's thermal regulations. Table 1 illustrates the standards of office room temperatures in the United States, the United Kingdom, and Japan. They are all suggested by labor related government bodies, which means that all the standards are designed to provide a pleasant work environment throughout the year. That is why those countries present separate room temperature standards for the heating and cooling period: CIBSE(Chartered Institution of Building Services Engineers)'s standards for United Kingdom, ASHRAE's for the United States, and the Cool Biz, Warm Biz campaign for Japan.

Table 1. Major countries and associations standard for thermal environment of office facilities.

Classification	Nation /Association	Environmental Factors (unit)	Criteria		Mandatory (M)/ Recommended (R)
			Cooling	Heating	
Country	Hong Kong	Temperature (°C)	above 25.5		R
		Relative humidity (%)	below 70		
		Region, HK Special Administrative. Guidance notes for the management of indoor air quality in offices and public places. 2003. [11]			
	Japan	Temperature (°C)	above 28	below 20	R
		Ministry of the Environment Government of Japan. Warm-Biz, Cool-Biz Campaign. [9]			
	China	Temperature (°C)	22–28	16–24	R
		Relative humidity (%)	40–80	30–60	
		Airflow (m/s)	below 0.3	below 0.2	
		China, S. C. GB/T 18883-2002 Indoor Air Quality Standard. 2002. [19,20].			
	United States	Temperature (°C)	20–24.4		R
		Relative humidity (%)	20–60		
		OSHA. OSHA Technical Manual. [12]			
	France	Temperature (°C)	Above 26	below 19	M
		Government of the French Republic. Energy Code (Code de l'énergie). 2015. [8]			
	United Kingdom	Temperature (°C)	Generally, above 16		R
			Rigorous physical effort, above 13		
		Relative humidity (%)	40–70		
		The Health and Safety Executive (HSE). Workplace Health, Safety and Welfare 1992. [21]			

Table 1. *Cont.*

Classification	Nation /Association	Environmental Factors (unit)	Criteria		Mandatory (M)/ Recommended (R)
			Cooling	Heating	
Association	AS (Australia)	Temperature (°C)	21–24	19–22	R
		Standards Australia. AS 1837-1976. [15]			
	CSA (Canada)	Temperature (°C)	23–26	20–23.5	R
		Relative humidity (%)	20–50		R
		The Canadian Standards Association. CSA Z412-17. [16]			
	CEN (EU)	Temperature (°C)	above 26	below 20	R
		CEN, EN15251. 15251, Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics. European Committee for Standardization, Brussels, Belgium, 2007. [17]			
	CIBSE (UK)	Temperature (°C)	22–24 (0.7met/0.7clo)	21–23 (1.2met/0.85clo)	R
		CIBSE. Environmental design: CIBSE guide A. Building and environment, 2006. [14]			
	ASHRAE (US)	Temperature (°C)	23.3–26.7	20.3–24.2	R
		Relative humidity (%)	50–60	20–30	
		STANDARD, ASHRAE. Standard 55-2010, Thermal environmental conditions for human occupancy. American Society of Heating, Refrigerating and Air Conditioning Engineers, 2010. [13] ASHRAE, A. ASHRAE Handbook-HVAC Applications. In: American Society of. 2011. [18]			

The heating and cooling temperature standards for public office facilities in Korea and the recommended heating and cooling temperature ranges for office buildings in major countries are shown in Figure 1. With the horizontal axis at the center, the indoor temperatures in the cooling standard are shown in the upper part and those in the heating standard are shown in the lower part. In the cooling standard in Korea is the same as that of Japan. The difference is that Japan encourages taking a measure for ventilation by letting fresh air in and using electronic fans. The other countries and organizations set the cooling standards lower than Korea. The heating standard range of Korea partly overlaps that of France, Japan, China, and the European Union. Most of the countries studied set the heating standards higher than Korea. In addition, Hong Kong, China, the United States, the United Kingdom, and Canada add the relative humidity and the air flow along with the temperature to the thermal environment elements of office facilities.

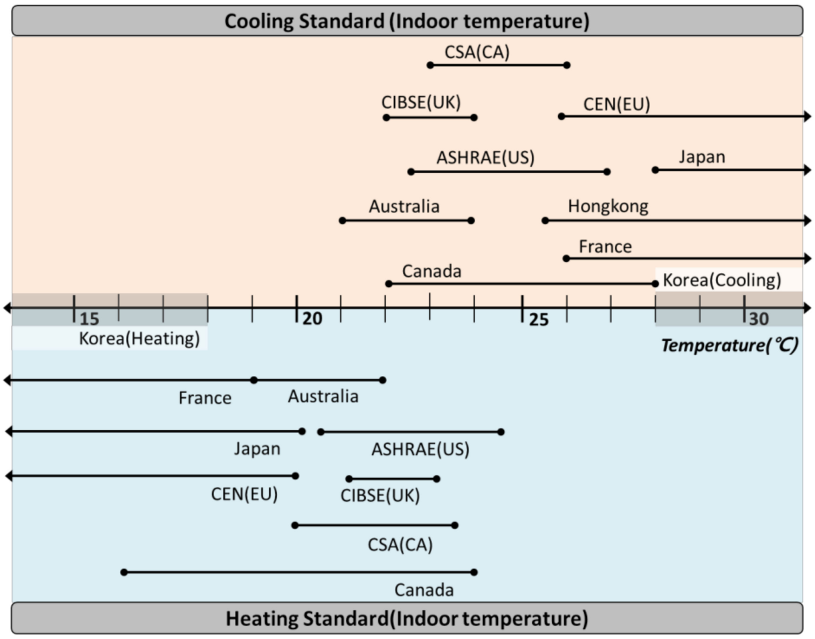


Figure 1. Standard for heating and cooling temperature of office facilities in major countries.

3. The Analysis of the Thermal Environment of Public Office Facilities in Korea

3.1. The Target Buildings

To analyze the occupant comfort of public office facilities, occupant surveys were conducted and the calculation of PMV was drawn by measuring environmental elements such as the temperature and the relative humidity. The building information is illustrated in Table 2.

Nine public office facilities were studied. Occupant surveys and measurement of the environmental elements were carried out for two days for each building from August through September of 2018, the cooling period. The buildings were built between 1979 and 1995 and it had been 25 to 41 years since their construction. The sizes varied from small size buildings with a total floor area of 400 through 1900 m^2 to mid-size ones with a total floor area of 5300 through 14,400 m^2. The external temperature at the day of the measurement ranged from 19.5 °C to 38.1 °C. During office hours the air temperature reached the highest. There was no rain except one day during the measurement, and the other days did not have high external relative humidity. The average room temperature during office hours varied from building to building. Though, the temperatures ranged from 25 to 32 °C and the relative humidity from 48% to 62%.; in order to understand the current situation over the indoor temperature regulations and compliance, the researchers checked whether each facility complied with the Korean standard.

Table 2. Building information for measurement and survey.

Bldg No.	Year of Completion (Year)	Number of Stories (Ground/ Und-erground)	Total Floor Area (m^2)	Measurement and Survey Date (Date)	Outdoor Environment (1st Day/2nd Day)				Indoor Environment (During Measurement)	
					Temperature (°C)			Precipitation (mm)	Avg. temperature (°C)	Avg. humid (%)
					Avg.	Max.	Min.			
1	1991	8/2	14,400	2018.08.06., 2018.08.07.	24.0/26.6	28.7/30.3	19.5/22.6	-/-	28.1	59.6
2	1988	8/2	7800	2018.08.08., 2018.08.09.	27.4/27.0	30.3/29.9	25.1/24.8	-/-	25.8	57.5
3	1992	3/1	5300	2018.08.13., 2018.08.14.	29.1/30.2	34.1/35.2	25.7/25.6	-/-	27.4	53.2
4	1993	5/1	6800	2018.08.15., 2018.08.16.	31.2/31.2	37.1/37.3	26.1/26.8	-/-	27.3	54.0
5	1979	5/1	8300	2018.08.20., 2018.08.21.	30.7/31.2	38.1/37.9	23.1/23.8	-/-	26.0	50.2
6	1989	2/0	700	2018.08.22., 2018.08.23.	28.9/29.2	38.1/37.9	23.1/23.8	-/-	26.0	50.2
7	1995	6/1	8600	2018.08.27., 2018.08.28	29.7/27.9	35.3/34.2	26.2/24.5	-/12.8	29.6	49.1
8	1988	5/1	1900	2018.08.30., 2018.08.31.	29.6/28.2	35.1/34.3	25.6/25.3	-/9.3	25.8	48.2
9	1989	3/1	400	2018.09.03., 2018.09.04.	24.4/25.2	26.3/29.3	23.2/22.7	-/-	26.0	62.0

3.2. The Surveys on the Thermal Environment in Public Office Facilities

The occupant surveys were conducted on eight out of the nine target buildings with Building 9 excluded. The questionnaire shown in Table 3 consisted of the degree of residential satisfaction in each season, the thermal sensation and the dissatisfactory seasonal priority, the thermal sensation in summer and in winter and the degree of satisfaction and the cause of dissatisfaction. Among the occupants, the respondents were randomly chosen regardless of which room they stayed in and the average time they stayed in the building was from 7.5 h to 10 h. The range of ages of the respondents was from 36 to 42.

Table 3. Survey question and criterion.

Survey Question	**Criterion**						
Satisfaction (all seasons/winter/summer)	Very satisfied	Satisfied	A little satisfied	Average	A little dissatisfied	Dissatisfied	Very dissatisfied
Thermal sensation (all seasons/winter/summer)	Hot	Warm	Slightly warm	Neutral	Slightly cool	Cool	Cold
Dissatisfactory seasonal priority	Spring Summer Autumn Winter						
Dissatisfactory cause of winter	Indoor air is cold. Indoor air is dry. Cold air flows in from outside. Sunlight is not enough. Heating time is insufficient. ETC (free opinion).						
Dissatisfactory cause of summer	Indoor air is hot. Indoor air is humid. Hot air flows in from outside. Too much sunlight enters. Cooling time is insufficient. ETC (free opinion).						

When asked about the overall satisfaction of the thermal environment of the building, 50% of the respondents said their satisfaction level was 'average' for all seasons. The other 50% said they were 'a little dissatisfied' for all seasons. During the winter season, 87.5% of the respondents said they were 'a little dissatisfied'. 62.5% said they were 'a little dissatisfied' during the summer period. In regards to the thermal sensation, 50% of the respondents said they felt 'slightly warm' during all seasons. The other 50% said they felt a 'neutral' level of thermal sensation. During the heating period, 75% of the respondents said they felt 'slightly cool' and the others said they felt a 'neutral' level of thermal sensation. During the cooling period, 62.5% said they felt 'slightly warm', 25% said they felt 'warm' and the others said they felt a 'neutral' level of thermal sensation. In short, more than half of the respondents said they felt slightly warm or warm during the cooling period. As for the dissatisfactory seasonal priority, summer was the most dissatisfactory season with 50.48% of the respondents and winter was the second most dissatisfactory season with 38.50%. All the occupants questioned said summer and winter were the most dissatisfactory season. They were asked about the cause of the dissatisfaction. Multiple and free opinions were allowed.

The causes of dissatisfaction in winter are illustrated in Figure 2. Although the reported causes varied from building to building, 'Indoor air is cold' and 'Indoor air is dry' accounted for the largest portion. The following are among the free opinions the respondents reported: the lack of heating equipment, being unpleasant with a window seat, the heating equipment tuned off during the extra work hours, the location of heating equipment and unpleasant air flow from the heater directed to the occupant. The causes of dissatisfaction in summer are shown in Figure 3. Most of the occupants seemed to be dissatisfied with the summer thermal environment because they thought indoor air was warm. The occupants of Buildings 1, 6, and 8 reported unwanted air infiltration, unpleasant humidity and insufficient cooling time as the causes of their dissatisfaction.

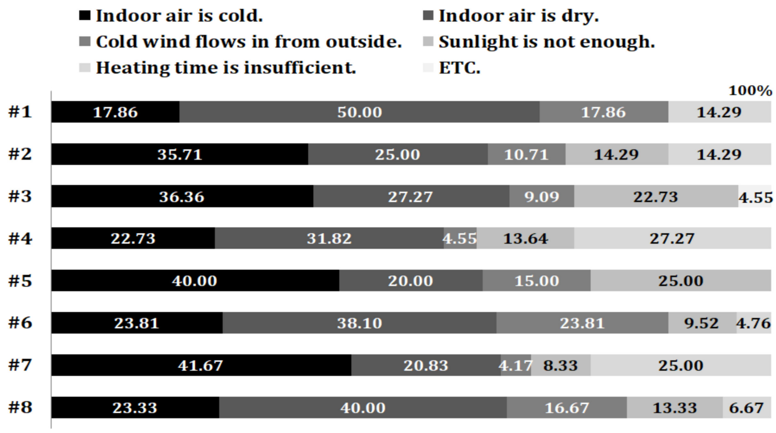


Figure 2. Dissatisfactory cause of winter.

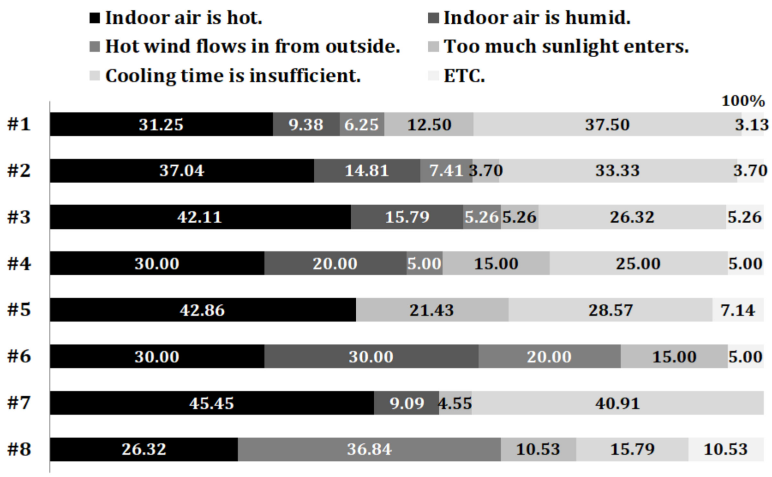


Figure 3. Dissatisfactory cause of summer.

The following were among the free opinions: being unpleasant with a window seat, the cooling equipment turned off during extra work hours, having the window opened for ventilation, the shortage of cooling equipment and the location of the air-conditioning equipment.

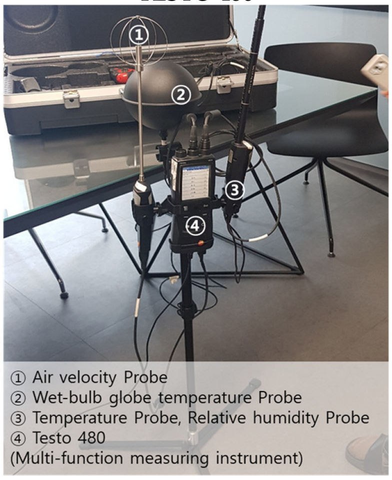
In addition to that, the respondents were required to give further opinions about the thermal environment. Some occupants said they thought it better to have the temperature of each floor controlled separately and they felt the shortage of ventilation. They declared they needed extra windows and extra ventilation systems and they wanted the uniformity of the thermal sensation of the room. The researchers believe that various causes of dissatisfaction reported by the occupants resulted from the followings: architectural features (decreased thermal transmission rate and hermeticity caused by deterioration and the orientation of the building) of each building, occupant characteristics (the ratio of men to women respondents and the amount of clothes worn) and operational features (the setting temperature and operating hours of the heater and air-conditioner) of each building.

3.3. The Measurement and Analysis of PMV of Public Office Facilities in Korea during the Cooling Period

PMV (predicted mean vote) is a measure of comfort with respect to the thermal environment proposed by P.O. Fanger [22], to predict the average value of people's expression by variables such as metabolic rate, thermal resistance, air temperature, mean radiant temperature, relative air velocity, and partial water vapor pressure. The responses −3 (Cold), −2 (Cool), −1 (Slightly cool), 0 (Neutral), +1 (Slightly warm), +2 (Warm), and +3 (Hot) are the most comfortable. The researchers calculated PMV values by measuring the indoor temperature, the relative humidity, the air flow and the radiation temperature of each building. ASHRAE 55-2010 [13] was referred to get the amount of clothes worn and the amount of activity of both male and female adults in summer. The following values were applied in calculating the PMV: 1.0 met (reading and writing while seated) and 0.5 clo (underwear, a T-shirt, a pair of socks, a pair of shoes, a half-sleeved dress shirt and a pair of pants). The locations of the measuring instruments were illustrated in Table 4, and the spots were among those the most frequently occupied. The rooms to which the energy use consumption regulations (Article 14 of Regulations of the energy use rationalization of public facilities) applied were chosen for the measurement with the exception of the following facilities and rooms: libraries, educational institutes, call centers, civil service offices and night-duty rooms. Two or three rooms were chosen from each building for the measurement, and the measuring instrument stood 1.0 m-high, a sitting height of an adult. The continuous measurement lasted at least 24 h in one-minute intervals, starting between 9 a.m. and 12 p.m. and finishing between at noon and in the afternoon the following day. The time range to be analyzed was from 9 a.m. to 6 p.m., office hours.

Table 4. Measuring location and instrument.

Bldg No.	Measuring Location	Measuring Instrument
1	4th floor, 5th floor	TESTO 480
2	1st floor, 6th floor_1, 6th floor_2	
3	1st floor, 3rd floor	
4	5th floor_1, 5th floor_2	
5	2nd floor_1, 2nd floor_2	
6	1st floor, 2nd floor	
7	3rd floor_1, 3rd floor_2	
8	1st floor, 2nd floor	
9	1st floor, 2nd floor	



The researchers considered a PMV value within the acceptable range from (−0.5 < PMV < +0.5) to be in the thermal comfort zone, ISO (International Organization for Standardization) 7730 standard [23]. PMV values were calculated for each room because each room had its own operating standard for air-conditioning. The proportion of hours not within the ISO standard and a review of compliance with the Korean regulations are shown in Table 5. Table 5 indicates that the uncomfortable time ratio of each room of the same building differed except Building 9. Though, the PMV values of the rooms of Buildings 1, 2, 4, 5, and 7 had similar changing patterns one another. Those rooms were believed to be either in the same floor or in the same zone which had the same operating pattern of air-conditioning. The PMV values of Building 1, 4, 7, and 8 sharply increased upon 12 p.m. This may be because the air-conditioners weren't operating or partly operating after some occupants left for lunch.

Building 1, 6, and 7 were complying with the temperature standards and the average uncomfortable time ratio of each building was about 52.6%, 92.1%, and 91.5%, respectively. That is, the occupants were working in a thermal environment with discomfort for more than half of their office hours. Room 2 of Building 6 was found not to have operated the air-conditioner because of the absence of the occupants. Meanwhile, the average uncomfortable time ratio of Buildings 2, 5, and 8 which weren't complying with the temperature standards was 25.0%, 44.1%, and 51.9%, respectively. Room 1 of Building 8 was found to have a relatively high uncomfortable time ratio because of the hot thermal sensation.

The other rooms of the same building had PMV values under −0.5, and that is because of the cold thermal sensation.

Table 5. Discomfort time ratio of thermal environment.

Uncomfortable Time Ratio of Thermal Environment in Office Facilities				
Bldg No.	**Measuring Location**			**Compliance With Criteria**
	#N_1 (%)	**#N_2 (%)**	**#N_3 (%)**	
1	37.71	67.49	-	O
2	0.74	57.12	17.19	X
3	4.06	31.18	-	△ *
4	13.10	21.77	-	△ **
5	3.35	85.49	-	X
6	84.13	100	-	O
7	83.03	100	-	O
8	9.59	94.28	-	X
9	75.09	77.31	-	△ **

Uncomfortable time ratio = (Time when PMV is outside ±0.5 min)/(Total Working Hours (minutes)) × 100. # = Measuring location/N = Building number. O = Complies with Korean standards/X = Not complying with Korean standards. △ * = Compliance with cooling temperature standards varies by room. △ ** = Mitigation of cooling air temperature based on deterioration of cooling system.

Building 4 was using both a non-electronic unit cooling-heating system and an electronic unit cooling-heating system. Building 9 was using a centrally controlled cooling-heating system using electricity. However, the system was more than 10 years old, hence providing non-uniform air-conditioning and heating. In the aforementioned case, the temperature standard can be flexibly applied within plus or minus 2 °C, so it is allowed to maintain the indoor temperature from 26 to 28 °C. Building 4 had a PMV value over +0.5 and the cause of the discomfort was the hot thermal sensation. Building 9 had a PMV value below −0.5 and the cause of the discomfort was the cold thermal sensation.

The rooms which had comfortable time ratios relatively high were # 2_1, #3_1, #5_1, and #8_1. The temperatures of the aforementioned rooms were mostly below 28 °C in summer, and the average temperature of each room during office hours was 25.4, 25.9, 26.3, and 26.9 °C, respectively. Those rooms weren't complying with the temperature standard for public office facilities in Korea. However, they were found to be within the thermal comfort. Additionally, those rooms remained within the comfortable range of thermal comfort except during lunch time. However, most of the rooms measured had high discomfort time ratios regardless of compliance with the standard. Hence, the researchers concluded that the current standard related to the thermal environment should be improved in order to consider the comfort of the occupants.

For Building 6 and 7, 100% of Uncomfortable time ratio means that PMV levels are out of the thermal comfort range throughout the business hours (9–18 h). In the case of room #6_2, the air conditioning was not performed due to the absence of the occupants, which made all time uncomfortable. In the case of room # 7_2, it was confirmed that the building complies with Korea's temperature standards, and it appears that there is continuous discomfort during working hours due to inflow of solar radiation and internal heat generation.

Figure 4 is a PMV graph of a building that complies with the thermal environmental standard of public office facilities in Korea. Figure 5. This is a PMV graph of a building that does not conform to the standard. Figure 6. is a PMV graph of a building whose temperature has been reduced to less than 2 °C due to the deterioration of the air conditioning system. Building 7 in Figure 4 shows that the PMV level of the building exceeds 0.5 causing discomfort due to heat. On the other hand, in Figure 5, the PMV in Building 8 was found to be mostly within the comfort range, or discomfort due to the cold. We can also see that Building 9 in Figure 6 spends more time in discomfort range than in a comfortable range during working hours.

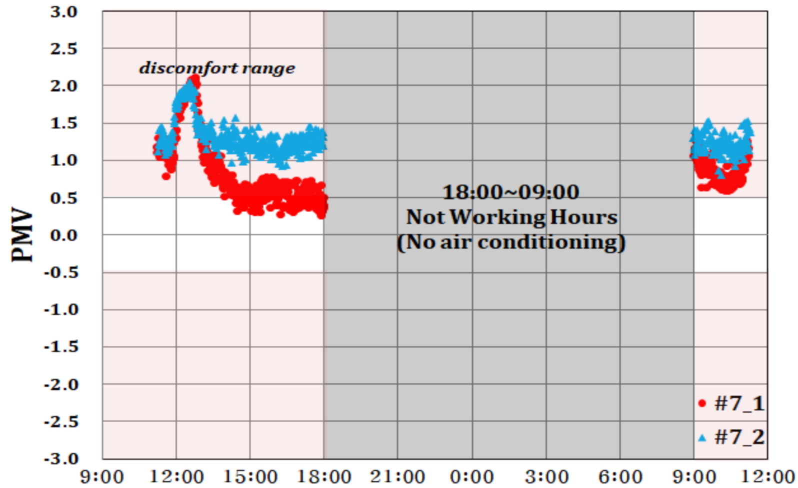


Figure 4. Example of PMV data for Building 7.

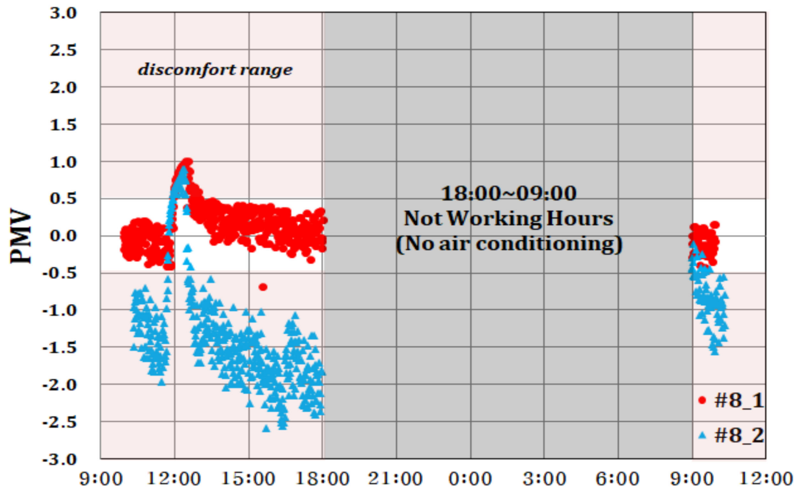


Figure 5. Example of PMV data for Building 8.

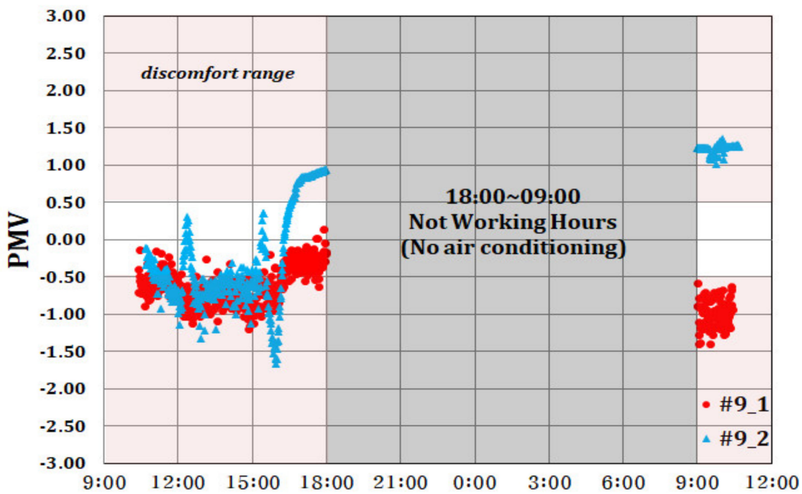


Figure 6. Example of PMV data for Building 9.

4. Conclusions

4.1. The Study Results

The room temperature standards in Korea are characterized by the followings: (1) the standards are only applied to public office facilities by law, (2) the room temperature is the only criterion, and (3) the recommended cooling and heating temperature standards are stricter (the cooling standard is lower and the heating standard is higher) than those in the other countries. Based on that, what should be improved is as follows. It is believed that the Korean standards need to be improved because they are overly strict compared to the other countries since they were designed to rationalize energy consumption. Additionally, if the humidity and the air flow are taken into account when setting the room temperature standards like in Japan and China, the thermal environment will be improved without having to ease the current temperature standards.

The survey results show that more than half of the buildings surveyed kept their occupants dissatisfied with the room temperature during both the cooling and heating period regardless of the compliance of the standards. On average, the most dissatisfying season was summer, and the cause of the dissatisfaction referred to the most was the indoor temperature, the insufficient cooling time and the high humidity. On the other hand, in winter the occupants referred to the low humidity, the cold temperature and the unwanted air infiltration as the causes of their dissatisfaction. The researchers suggested the following to improve the current thermal environment which caused dissatisfaction to the occupants. The first is to adjust the operating time of cooling and heating system. Among the regulation items to control the room temperature were the limited temperature range, the kind of facilities and the measuring method. As for the operating time, it is not regulated, though, most of the public office facilities allow the operation of cooling and heating system only during office hours for the sake of reducing greenhouse gas emission. Because of this, the operating time is needed to be extended to include non-office hours (night work or all-night work). To that end, a proper guideline should be reflected in the current standards. Second, dissatisfaction arose from the unpleasant humidity. Currently, other environmental elements are not taken into account when controlling the thermal environment. The study findings indicate that the humidity in winter is the fact that influences the comfort of the occupants the most. Therefore, criteria related to humidity during the winter needs to be additionally designed.

Lastly, regarding the buildings complying with the standards, the ratio of the office hours that were not within the comfort range was more than 50%. This means that the occupants spent more than half of the working hours in an unpleasant environment. The same was true for the occupants of the building not complying with the standards. The cause of the dissatisfaction was the heat thermal sensation for those who worked in a building which followed the regulations and the cold thermal sensation for those who worked in a building which did not follow the regulations. Hence, it is concluded that it is difficult for a building following the temperature standards to provide a pleasant thermal environment. Considering the measurement results, it is needed to mitigate the current temperature regulations. In addition, there should be measures to maintain a PMV value within the comfort range, and other environmental elements should be considered along with the room temperature.

4.2. Discussion

Considering the survey analysis and the measurement values, the temperature standards for public office facilities during the cooling period in Korea do not meet the demand for the comfort in the thermal environment. It has been revealed by many studies and news reports that working in an unpleasant environment can lead to decreased productivity. Hence, the researchers believe that the current standards for the thermal environment which take only the temperature into account need to be improved. Referring to the occupant survey results and the PMV measurement, this study suggests that the current temperature standards in Korea should be mitigated, which the researchers believe will lead to the improvement of the occupant satisfaction. Next, considering the standards in other countries which reflect the humidity and the air flow along with the temperature, this study suggests complementing the current standards by adding other environmental elements. In that way, the causes of the dissatisfaction in the indoor thermal environment such as the unpleasant temperature and humidity will be removed.

This study was conducted to support the need to improve the thermal environment of public office facilities in Korea. To that end, the researchers studied the thermal environment standards in offices of major countries and associations for a valuable comparison. Additionally, the occupant survey and the PMV measurement were carried out. This study will be a foundation for the improvement of the current temperature standards in public office facilities in Korea. The limitation of this study is that the measurement and the analysis of PMV were limited to the cooling period. Therefore, further research will be needed on the thermal environment not only during the heating period but also during extreme weather such as the rainy season in summer and winter's cold snap.

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