

## Evaluation of Indoor Environmental Factors in Office Building with Underfloor Air-Conditioning (UFAC) System

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**Key words:** Indoor environmental factors, Underfloor air-conditioning (UFAC) system, Comfort air-conditioning, Indoor air quality

### Abstract

During the last decade, an increasing interest in Underfloor Air-Conditioning (UFAC) systems has emerged. The purpose of this paper is to evaluate the indoor environmental performance of office buildings with UFAC system in order to develop the design prototype of this system. The physical measurements and the interviewing survey of occupant's sensation responses to the environment were carried out. Measurements and survey were made of the thermal environmental factors such as air temperature, relative humidity, air velocity, globe temperature, and the other several environmental factors such as the sound level and the illuminance of working plane, etc. And, the air quality was evaluated by measuring the concentration of suspended particles, carbon monoxide, and carbon dioxide in the room. Furthermore, the paper appraises the various indoor environmental factors of the room by using post-occupancy evaluation (POE) method in office building with UFAC system, and thus, it suggests the basic data for assessing the indoor comfort based on field measurements and survey.

### 1. Introduction

Since 1990, the concept of office environment was transitioned from conventional working space to living space or creative space. So, indoor environment that can secure individual comfort will be come to the front hereafter. Somewhat, indoor environment of office building become a primary factor to exert an important effect upon

the efficiency of work and the health of human. And the creativity of comfortable indoor environment has been awakened to everybody (owner, dweller, and superintendent) as an important problem. Underfloor air-conditioning (UFAC) system is one of air-conditioning systems introduced according to social demand for making comfortable indoor environment and is a pleasant air-conditioning system to make much account of dwelling that can control air volume and air velocity freely in accordance with the feeling and taste of individual.

The history that this underfloor air-condi-

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tioning system is used in office buildings actually is too short, and the example that indoor environment factor is measured in office building adopted such a system is very few.

So, the indoor environmental condition of office building having the underfloor air-conditioning system has been measured and the actual data of indoor environment through investigation have been gathered.

Therefore, the characteristics of indoor environment with POE (Post-Occupancy Evaluation) has been investigated.

## 2. The measuring and estimating method

### 2.1 The measuring target building

As a measuring target building, S office building in Youngdeungpo-Gu, Seoul has been

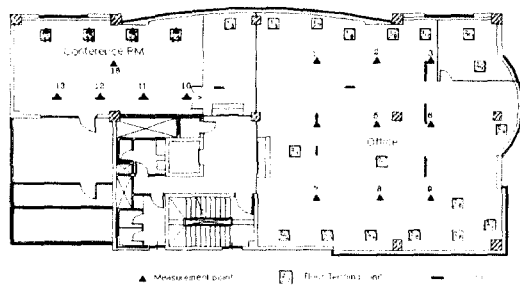


Fig. 1 Floor plan of the building (the 6th floor).

selected, and the outline of target-building is presented to Figure 1. However, although the measuring target building is eight storey building, this doesn't have all underfloor air-conditioning system on sixth floor. So, only the target of measurement office rooms and conference rooms having the underfloor air-conditioning system on sixth floor, has been investigated during the period from July 22 to July 23 in 1998 for two days in the air-conditioning period.

Table 1 shows the measuring items including instruments. Measurement has been made in five minutes interval about the thermal environmental factors (indoor temperature, outdoor temperature, globe temperature and vertical temperature), while the measurement regarding other environment factors except for above factors has been made for only four times per day from 9 AM to 5 PM.

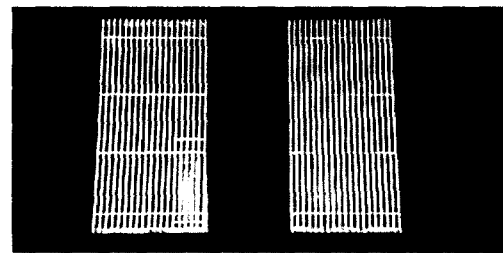


Fig. 2 Shape of floor terminal unit.

Table 1 Measuring items for environmental factors including instruments

Environmental factors	Measuring items	Instruments	Measuring position
Heat	Dry-bulb temperature	Assman psychrometer	Center of room
	Globe temperature	Globe thermometer	
	Relative humidity	Thermometer CTH-990	
	Air velocity	Anemomaster	
Air quality	Suspended particles	Digital aerosol monitor (P-5H2)	Representative points - 9 points
	Carbon dioxide	Potable CO <sub>2</sub> , CO meter (M 8550, TSI)	
Lighting	Levels of illumination	Digital lux meter Lm-2D (TOPCON)	
Sound	Noise level	Sound level meter (SL-1350)	Center of room
Occupants	No. of occupants	Counter	N/A

Figure 1 presents the location for installation of FTU (Floor Terminal Unit) and return grille and location of measurement point on the 6th floor plan of the building.

Figure 2 is a picture of the floor terminal unit used in the building which is made for the personal air-conditioning system in Hirros co., Italy.

## 2.2 Measuring items and estimating method

### 2.2.1 Measuring instrument and method

The thermal environmental factors (indoor room temperature, globe temperature, vertical temperature) which are primary measuring items for estimation of indoor environment are measured in the center of room. And the relative humidity and the air velocity are measured in the nine-representative points of office rooms and conference rooms. The air quality (suspended particles and carbon dioxide) are also measured in the nine representative points of office with due regard to area and scale of measuring rooms. The measurement and the other exami-

nation, for example, the number of occupants are carried out at the same time.

The analysis regarding the number of smoker is not performed apart because the smoking room is occupied separately in this building.

### 2.2.2 Physical measuring items and estimating standards

#### (1) Thermal environment

Table 2 shows the grade rating for physical items of thermal environment. The measuring items are room temperature, relative humidity, air velocity (the mean of air velocity during three minutes), globe temperature, vertical temperature, and PMV.

The items except PMV are measured at a height of 1.1 m. PMV is the item calculated from temperature, relative humidity, air velocity, globe temperature, clothing level and metabolism by means of "calculation of PMV" (the framing table based on ISO-7730) presented in building research institute, ministry of construction of Japan.

Table 3 presents the grade rating for survey

Table 2 Grade rating for physical items of thermal environment

Measuring items	Grade	Grade				
		1	2	3	4	5
Room temperature [°C]	Cooling period	>29≥	>28≥	>27≥	>26≥	>26≥
	Intermediate period	<21≤	<22≤	<23≤	<24≤	<24≤
		>28≥	>27≥	>26≥	>25≥	>25≥
	Heating period	<20≤	<21≤	<22≤	<23≤	<23≤
Relative humidity [%]	Heating period	>27≥	>26≥	>25≥	>24≥	>24≥
		<19≤	<20≤	<21≤	<22≤	<22≤
Air velocity [m/s]		>85≥	>75≥	>65≥	>55≥	>55≥
		<15≤	<25≤	<35≤	<45≤	<45≤
GT-Room temperature [°C]	Cooling period	>0.45≥	>0.35≥	>0.250≥	>0.15≥	>0.15≥
	Intermediate period	>4≥	>3≥	>2≥	>1≥	>1≥
		>4≥	>3≥	>2≥	>1≥	>1≥
	Heating period	<4≤	<3≤	<2≤	<1≤	<1≤
Vertical temperature difference [°C]		<4≤	<3≤	<2≤	<1≤	<1≤
		>5≥	>4≥	>3≥	>2≥	>2≥
PMV		>2.0≥	>1.5≥	>1.0≥	>0.5≥	>0.5≥
		<-2.0≤	<-1.5≤	<-1.0≤	<-0.5≤	<-0.5≤

**Table 3** Grade rating for survey items of thermal environment

Survey items \ Grade	1	2	3	4	5
Thermal sensation	Cold/Cool	-	Slightly cool	-	Neutral
	Hot/Warm	-	Slightly warm	-	Neutral
Humidity sensation	Humid	-	Slightly humid	-	Neutral
	Dry	-	Slightly dry	-	Neutral
Airflow sensation	Sensible	-	Slightly sensible	-	Not sensible
Radiation sensation	Sensible	-	Slightly sensible	-	Not sensible
Vertical temperature difference sensation	Sensible	-	Slightly sensible	-	Not sensible
Overall comfortness	Discomfortable	Slightly discomfortable	Neutral	Slightly comfortable	Comfortable

items of the thermal environment.

(2) Air quality environment

Measuring items are carbon dioxide concentration, carbon monoxide concentration, and suspended particle concentration as shown in the Table 4.

First of all, suspended particle is estimated by suspended particle concentration [mg/m<sup>3</sup>] at the height of 1.1 m on the floor. The particle below 10 μm in diameter suspended in the air is presented with weight and the estimating standard value has the standard value of allowable concentration in architecture law as the lowest link.

Second, carbon dioxide is estimated by the mean of carbon dioxide concentration [ppm] at the height of 1.1 m on the floor. The estimation standard value has the standard value of

allowable concentration in architecture law as the lowest link and concentration of the clean open air as the highest link.

Third, carbon monoxide is estimated by the mean of carbon monoxide concentration [ppm] at the height of 1.1 m on the floor. The lowest link value of estimating standard value is set to the 5 ppm as the standard value of allowable concentration because 10 ppm suggested in the building law of Korea is not realistic.

Table 5 presents the grade rating for survey items of air quality environment.

(3) Spatial environment

Various factors of spatial environment are classified into the factors related to psychological amenity and the factors related to easiness of activity.

Table 6 presents the grade rating for phy-

**Table 4** Grade rating for physical items of air quality environment

Measuring items \ Grade	1	2	3	4	5
Carbon dioxide concentration [ppm]	>1000≥	>800≥	>600≥	>400≥	
Carbon monoxide concentration [ppm]	>5≥	>4≥	>3≥	>2≥	
Suspended particle concentration [mg/m <sup>3</sup> ]	>0.15≥	>0.12≥	>0.08≥	>0.05≥	

**Table 5** Grade rating for survey items of air quality environment

Survey items \ Grade	1	2	3	4	5
Air pollution	Sensible	-	Slightly sensible	-	Not sensible
Odour	Sensible	-	Slightly sensible	-	Not sensible
Dustness	Sensible	-	Slightly sensible	-	Not sensible

**Table 6** Grade rating for physical items of spatial environment

Measuring items	Grade				
	1	2	3	4	5
Floor area per person [m <sup>2</sup> /person]	<4≤	<8≤	<10≤	<14≤	
Ceiling height [m]	<2.4≤	<2.5≤	<2.7≤	<2.8≤	
Density of plants [@/100 m <sup>2</sup> ]	<2≤	<6≤	<12≤	<20≤	
Carpet coverage	None (<70%)		-	All (≥70%)	
Width of desk [m]	<1.0≤	<1.2≤	<1.4≤	<1.6≤	
No. of additional function of chair	<2≤	<4≤	<6≤	<8≤	
Density of OA equipments [@/person]	<0.2≤	<0.4≤	<0.6≤	<0.8≤	
Density of telephone [@/person]	<0.3≤	<0.5≤	<0.7≤	<1.0≤	
Meeting area [m <sup>2</sup> /person]	<0.3≤	<0.5≤	<0.8≤	<1.0≤	
Receiving space per person [m <sup>3</sup> /person]	<0.2≤	<0.4≤	<0.6≤	<0.8≤	

**Table 7** Grade rating for survey items of spatial environment

Survey items	Grade				
	1	2	3	4	5
Room area	Not appropriate	-	Neutral	-	Appropriate
Openness to desk	Not appropriate	-	Neutral	-	Appropriate
Amount of plants	Not appropriate	-	Neutral	-	Appropriate
Interior	Bad	Slightly bad	Neutral	Slightly good	Good
Sensation of desk usage	Bad	Slightly bad	Neutral	Slightly good	Good
Sensation of chair usage	Bad	Slightly bad	Neutral	Slightly good	Good
Lack of OA equipments	Concerned	Slightly concerned	Neutral	Almost not concerned	Not concerned
Lack of meeting space	Concerned	Slightly concerned	Neutral	Almost not concerned	Not concerned
Lack of receiving space	Concerned	Slightly concerned	Neutral	Almost not concerned	Not concerned

sical items of spatial environment.

Table 7 presents the grade rating for survey items of spatial environment.

### 3. Analysis and examination of measuring result

The final estimation has two steps of estimation by factors and items and estimation synthesizing all factors. On the basis of contents from Table 2 to 7, the chart to present estimating result with estimation target-items is made out.

The chart has two kinds of physical measurement and interviewing survey by environmental factors.

Next, the radial chart is made of with esti-

rating value of some items representing each factor by factors.

The radial chart has the axis as many as the number of estimating items with equal angles radially from the center of circle.

In the case of favorable estimation, estimating value presents to enter outside and in the case of poor estimation, estimating value presents to enter inside.

The polygon is drawn by connecting entering point on the axis and adjacent points.

The polygon which is broad in area and is regular polygonal shape presents favorable environment.

In other words, if the measuring point is given as five steps for interviewing survey by environmental factors corresponding with mea-

suring and estimating target items in the figure. Number 1 presents the worst situation and the greater number presents the better situation.

Table from 9 to 15 present the results of physical and psychological estimation on environment. And, Figure from 3 to 10 present the estimating charts by factors and items on

office room and conference room.

### 3.1 Thermal environment

Table 8 and 9 present results of physical measurement and estimation and results of interviewing survey.

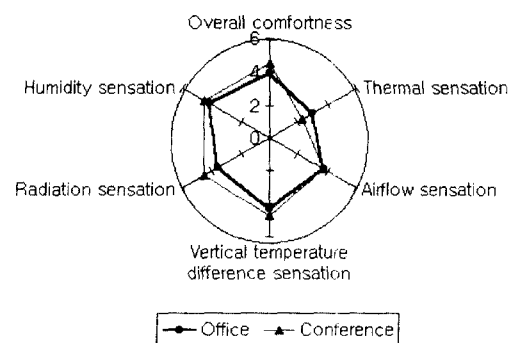
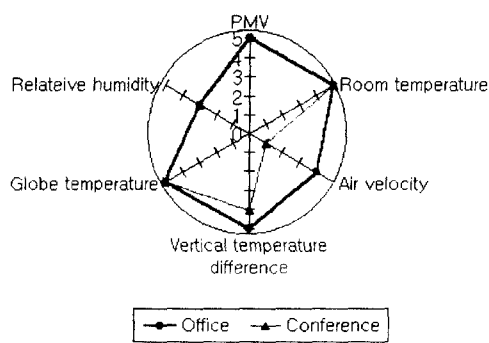
Figure 3 and 4 present these result to radial

**Table 8** Result of physical measurement on thermal environment

Measuring items	Measured value		Grade	
	Office	Conference	Office	Conference
Room temperature	25.85	25.1	5	5
Relative humidity	66.4	69.2	3	3
Air velocity	0.16	1.39	4	1
GT-DBT	-0.38	0.04	5	5
Vertical temperature difference	1.02	2.03	5	4
PMV	-1.57	-0.64	5	5
Mean value	-	-	4.50	3.83

**Table 9** Result of interviewing survey on thermal environment

Survey items	Grade	
	Office	Conference
Thermal sensation	2.95	2.25
Humidity sensation	4.13	4.50
Airflow sensation	3.72	3.75
Radiation sensation	3.56	4.50
Vertical temperature difference sensation	4.28	4.75
Overall comfortness	3.92	4.50
Mean value	3.79	4.04



**Fig. 3** Radial chart of physical measurement on thermal environment.

**Fig. 4** Radial chart of interviewing survey on thermal environment.

**Table 10** Result of physical measurement on air environment

Measuring items	Measured value		Grade	
	Office	Conference	Office	Conference
Carbon dioxide concentration	635.9	652.8	3	3
Carbon monoxide concentration	0	0	5	5
Suspended particle concentration	0.0105	0.013	5	5
Mean value	-	-	4.3	4.3

charts. In the Figure, most of items except air velocity in case of result of physical measurement and overall comfort in case of result of psychological measurement present good estimating value, and thus the thermal environment present very favorable condition relatively.

In this situation, the air velocity on conference room presented very great value, because it is measured on the underflow air-conditioning system very closely at this point of measuring time.

Especially, in the estimating items of thermal environment indoor temperature from the floor level to ceiling level presents slight vertical temperature difference of around  $0.86^{\circ}\text{C}$  regardless of the lapse of time and presents parallel moving form with slight drop with the lapse of time.

Therefore, as the vertical temperature difference is almost presented uniformly as if general radiant heating presents, the thermal environment of office room having underfloor air-conditioning system presents to be made

up very desirably.

### 3.2 Air environment

Table 10 and 11 present the result of physical measurement and the result of interviewing survey on air environment of office room and conference room.

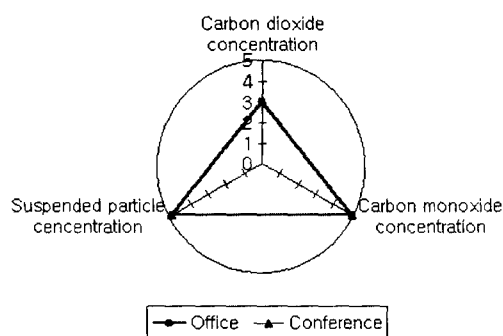
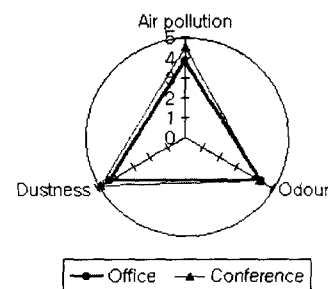
Figure 5 and 6 present the radial chart of then.

According to two Figure, the result of physical measurement and the result of interviewing survey on air environment show no problem on air environment.

So to speak, the suspended particle concentration has the range from  $0.004$  to  $0.01\text{ mg/m}^3$

**Table 11** Result of interviewing survey on air environment

Survey items	Grade	
	Office	Conference
Air pollution	3.82	4.50
Odour	4.33	4.25
Dustness	4.23	4.75
Mean value	4.13	4.50

**Fig. 5** Radial chart of physical measurement on air environment.**Fig. 6** Radial chart of interviewing survey on air environment.

**Table 12** Result of physical measurement on spatial environment

Measuring items	Measured value		Grade	
	Office	Conference	Office	Conference
Floor area per person	7.14	2.31	2	1
Ceiling height	2.45	2.45	2	2
Density of plants	0	3	1	2
Grade of desk	1.55	0.59	4	1
Grade of chair	5	5	3	3
Density of OA equipment	1.08	0.08	5	5
Meeting space	0.29	2.31	1	5
Mean value	-	-	2.57	2.71

(the mean value is less than 0.0064 mg/m<sup>3</sup>).

This is far less than 0.15 mg/m<sup>3</sup> which is the standard value suggested in the sanitary law and the building law of Korea.

So, general preconceived notion that the suspended particle drifts very much by reason of increase in air velocity is destroyed in the case

**Table 13** Result of interviewing survey on spatial environment

Survey items	Grade	
	Office	Conference
Room area	3.21	4.50
Openness to desk	3.51	4.50
Amount of plants	2.13	2.25
Sensation of desk usage	3.77	4.66
Sensation of chair usage	3.82	4.85
Lack of OA equipment	3.97	4.63
Lack of meeting space	3.85	4.38
Mean value	4.13	4.50

of introduction of underfloor air-conditioning system in office building.

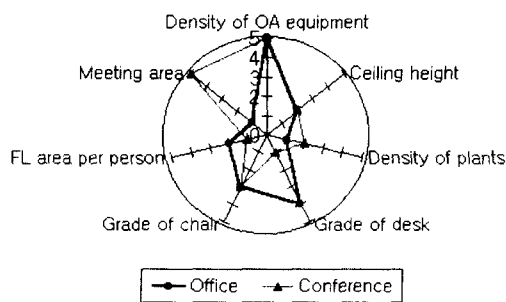
In this point, suspended particle concentration in office room and conference room show 0.0066 mg/m<sup>3</sup> and 0.0063 mg/m<sup>3</sup> on the average, respectively.

In addition, carbon dioxide concentration in office room and conference room presents average 646 ppm (maximum 707 ppm), average 650 ppm (maximum 693 ppm), and each of them are less than the standard of 1,000 ppm.

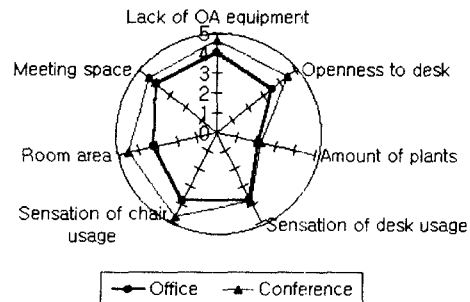
### 3.3 Spatial environment

Table 12 and 13 present the result of physical measurement and the result of interviewing survey on spatial environment of office room and conference room.

Figure 7 and 8 present the radial chart of them.



**Fig. 7** Radial chart of physical measurement on spatial environment.



**Fig. 8** Radial chart of interviewing survey on spatial environment.



Above all, according to the result of physical measurement, floor area per person, ceiling height, density of plants, and meeting space are considered to be inferior.

In this point, the meeting space of office room has no problem, because this is close by conference room.

The reason that ceiling height is low is identified as the result of attempt to make low the ceiling height from the viewpoint of characteristics of underfloor air-conditioning system.

Somewhat, as the most inferior item is the density of plants, reconsideration about this is in need.

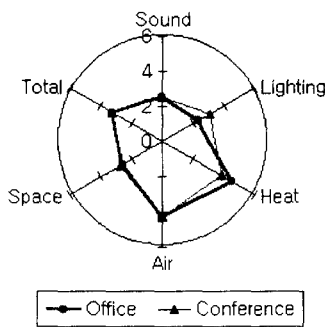
However, other items are favorable.

**3.4 Total environment**

Table 14 and 15 present the result of physical measurement and the result of interviewing survey on indoor environment in order to

**Table 14** Result of physical measurement on total environment

Measuring items	Grade	
	Office	Conference
Sound	2.5	2.5
Lighting	2.3	3.0
Heat	4.5	3.83
Air	4.3	4.3
Space	2.57	2.71
Mean value	3.23	3.27



**Fig. 9** Radial chart of physical measurement on total environment.

estimate office room and conference room synthetically.

Figure 9 and 10 present the radial chart of them.

As above mentioned, the synthetical estimating result on indoor environment is favorable as 3.0 grade or more.

Therefore, the final estimating result on measuring target rooms is relatively favorable.

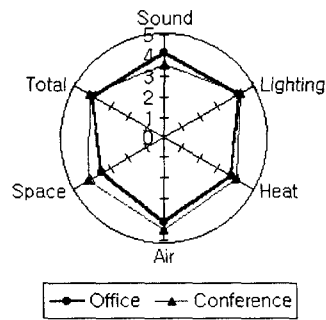
**4. Conclusions**

After the actual conditions of indoor environment with measurement and interviewing survey being examined, the characteristic of indoor environment is estimated by the use of POE method.

In other words, the result of physical measurement and the result of interviewing survey on indoor environment items of measuring target rooms are presented to table and radial

**Table 15** Result of interviewing survey on total environment

Survey items	Grade	
	Office	Conference
Sound	4.09	3.54
Lighting	4.19	4.22
Heat	3.76	4.04
Air	4.13	4.50
Space	3.41	4.17
Mean value	3.90	4.10



**Fig. 10** Radial chart of interviewing survey on total environment.

chart respectively and the method estimating the results easily and conveniently is also proposed.

To sum up these, it runs as follows.

(1) The thermal environment of office room having underfloor air-conditioning system is made very desirably.

(2) It can be seen that air environment is appraised as very desirable condition. That is, general preconceived notion that the suspended particle from the floor drifts very much by reason of increase in air velocity is destroyed.

(3) In estimation of spatial environment, as the most inferior item is the density of plants, reconsideration about this is in need. However, other items are favorable.

(4) The evaluating physical environmental factors and survey items on indoor environment introduced through the radial chart. The chart presented newly in this study are proved into that they are not only used easily and conveniently but also applied very effectively in practical use of office building.

### Acknowledgement

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