보건학석사 학위논문

Evaluation of Overall Comfort in Hospitals in Summer using Various Comforts Related Factors

예상온열쾌적도, 이산화탄소의 농도,

실내 소음도 및 조도를 통한 보건의료시설의

실내 쾌적성 평가 연구

2014 년 10 월

서울대학교 보건대학원

환경보건학과 환경보건학 전공

이 보 람

Evaluation of Overall Comfort in Hospitals in Summer using Various Comforts Related Factors

예상온열쾌적도, 이산화탄소의 농도, 실내 소음도 및 조도를 통한 보건의료시설의 실내 쾌적성 평가 연구

지도교수 이 기 영

이 논문을 보건학석사 학위논문으로 제출함

2014 년 10 월

서울대학교 보건대학원

환경보건학과 환경보건 전공

이 보 람

이보람의 보건학석사 학위논문을 인준함

2014 년 12 월

위 원 장	윤 충 식	(인)
부위원장	이 승 묵	(인)
위 원	이 기 영	(인)

Abstract

Evaluation of Overall Comfort in Hospitals in Summer using Various Comforts Related Factors

Boram Lee

Department of Environmental Health

Graduate School of Public Health

Seoul National University

A hospital is a complex building with spaces that serve many different purposes and healthy and comfortable indoor environment in a hospital has a major effect on patient well-being as well as on the work efficiency of the hospital staff. Although thermal comfort is one major factor in indoor comfort, noise, lights and air quality are also important for overall comfort. The purpose of this study was to assess the applicability of the overall indoor environmental quality (IEQ) acceptance model for evaluating indoor environmental comfort in hospitals.

Various indoor environmental conditions were measured in two general hospitals during summer 2014 (June–September). Each hospital was measured for 1 month, after which the monitoring instruments

were moved to the other hospital also for 1 month. The indoor air temperature, relative humidity (RH), mean radiant temperature and air velocity were measured to calculate the predicted mean vote (PMV), which estimates patient comfort. Carbon dioxide concentration, noise level and illuminance level were measured at the same time. The overall IEQ acceptance model for an office environment was applied to evaluate the overall indoor comfort in hospitals.

The PMV values varied among places within the hospital buildings. The most comfortable place in hospital A was the emergency room and the least comfortable was the health-screening center. In hospital B, the injection room was the most comfortable thermally and the waiting room was the least comfortable. The lobby and waiting room showed the greatest fluctuation in daily PMV, whereas PMV values in the emergency room and nurse station were relatively consistent compared to other places. The overall IEQ acceptance evaluation showed that indoor air quality and acoustic environment were highly satisfactory, whereas the visual environment was not. A new proposed IEQ acceptance model with adjusted illuminance guidelines was proposed for hospital environments.

The indoor thermal comfort was combined with indoor air, noise and illuminance to evaluate the overall comfort level in the hospitals.

The two hospitals studied were comfortable in terms of temperature, noise and indoor air, but not in terms of illuminance. Adjusting the standard for illuminance in the IEQ acceptance model may be necessary when applied to hospital environments.

Keywords: overall comfort, thermal comfort, hospital, noise, illuminance, carbon dioxide, PMV, IEQ acceptance

Student Number: 2013-21825

Contents

List of Figures

List of Tables

Ⅰ. Introduction

General hospitals are complex indoor buildings housing numerous spaces that serve many different purposes (Balaras et al., 2007). Hospital occupants include healthy individuals, such as hospital staff and visitors and patients with diverse health problems. In hospitals, occupants are exposed to various potentially hazardous substances, which that can be classified as biological factors, chemical factors and physical agents (Yassi, 2001).

The physical factors include temperature, humidity, air velocity, radiant heat, lighting, ventilation and noise. A healthy indoor environment is important in hospitals because of patient susceptibility. Furthermore, a comfortable indoor environment has important effects on the well-being of patient and on the work efficiency of the hospital staff (Melikov et al., 2002).

Comfort is defined as a sense of physical or psychological ease, often characterized as a lack of hardship. Providing comfort to sick and injured people is one of the major goals of hospitals and indoor comfort has numerous aspects such as indoor air quality, along with thermal, acoustic and visual comfort (Kolcaba, 2003). Previous research has primarily considered the effects of a single environmental condition on individuals. For example, some studies have focused singly on thermal, air quality, acoustic, or visual conditions that facilitate or hinder satisfaction with the environment (Frontczak and Wargocki, 2011).

To fully explain the conditions associated with human comfort, a comprehensive evaluation of these factors is needed (Wong et al., 2008; Cao et al., 2012). The indoor environmental quality (IEQ) in offices was examined in terms of thermal comfort, indoor air quality, noise level and illuminance level. Based on an evaluation of the IEQ by 293 occupants of offices in Hong Kong, empirical expressions have been proposed to approximate an index of overall IEQ acceptability of an office environment in terms of temperature, carbon dioxide (CO_2) level, noise level and illuminance level (Wong et al., 2008). Another predictive model for evaluating overall satisfaction with the indoor environment was developed based on an analysis of the relationship between occupants' satisfaction and environmental parameters in public school buildings in China (Cao et al., 2012).

Thermal comfort is the state of satisfaction with the thermal condition of the environment (ISO, 2005). Standard ISO 7730 offers indices of the predicted mean vote (PMV) and predicted percentage dissatisfied (PPD), which predict people's mean thermal sensation and satisfaction, respectively, regarding the thermal condition. The PMV is an index of thermal comfort based on the heat exchange between a human body and the surrounding environment (Fanger, 1973). The evaluation of thermal comfort is based on four physical variables and two personal variables. The physical parameters are air temperature, humidity, mean radiant temperature and air velocity and the personal factors are activity level and the thermal resistance of clothing.

The PMV predicts the mean thermal sensation of individuals on the seven-point scale shown in Table 1 and was calculated using the following heat balance equation:

Table 1. Seven-point scale thermal sensation of PMV

+3	Hot
+2	Warm
+1	Slightly warm
0	Neutral
-1	Slightly cool
-2	Cool
-3	Cold

$$PMV = (0.303 e^{-0.036M} + 0.028) \{ (M - W) - 3.05 * 10^{-3}$$
$$* [5733 - 6.99 (M - W) - p_a] - 0.42$$
$$* [(M - W) - 58.15] - 1.7 * 10^{-5} M (5867 - p_a)$$
$$- 0.0014 M (34 - t_a) - 3.96 * 10^{-8} f_{cl}$$
$$* [(t_{cl} + 273)^4 - (t_r + 273)^4] - f_{cl} h_c (t_{cl} - t_a) \}$$

where,

$$t_{cl} = 35.7 - 0.028 (M - W) - I_{cl} \{ 3.96 * 10^{-8} f_{cl} * [(t_{cl} + 273)^4 - (t_r + 273)^4] + f_{cl} h_c (t_{cl} - t_a) \}$$

$h_c = 2.38 (t_{cl} - t_a)^{0.25}$ for $2.38 (t_{cl} - t_a)^{0.25} > 12.1 \text{ root } (v_{ar})$

$h_c = 12.1 \text{ root } (v_{ar})$ for $2.38 (t_{cl} - t_a)^{0.25} < 12.1 \text{ root } (v_{ar})$

$f_{cl} = 1.00 + 1.290 I_{cl}$ for $I_{cl} < 0.078$ m^2'C / W

$f_{cl} = 1.05 + 0.645 I_{cl}$ for $I_{cl} > 0.078$ m^2'C / W

M : metabolic rate, unit : Surface area of W/m^2, 1 metabolic unit = 1 met = 58 W/m^2

W : external work, unit : W/m^2, at most activity = 0

I_{cl} : thermal resistance of clothing, unit: m^2'C/W, 1 unit of thermal resistance of clothing = 1 clo = 0.155 m^2'C/W

f_{cl} : surface area to the human body with clothing

t_a : air temperature , unit: °C

t_r : mean radiant temperature, unit : °C

v_{ar} : relative air velocity, unit : m/s

P_a : partial water vapour pressure, unit: pascals

h_c : convective heat transfer coefficient, unit : W/m^2 °C

t_{cl} : surface temperature of clothing, unit: °C

Numerous thermal comfort studies have been conducted to develop guidelines for designing and maintaining thermally comfortable indoor environments (Dear, 2004). The thermal comfort zone was defined by a combination of physical and personal factors reflected in the PMV. Acceptable general comfort is reflected by a PMV value in the range of –0.5 to +0.5 (ASHRAE, 2010) and thermal comfort should be a major consideration when solutions for indoor environmental management are developed.

The indoor CO_2 level is sometimes regarded as an indicator of indoor air quality (Persily, 1996). Without adequate ventilation, the CO_2 level in an indoor environment increases in the presence of people. The physiological limit for CO_2 is around 4% (40,000 ppm) by volume; above this level, people in the building may experience breathing problems. (Mundt, 2001; Cermak and Melikov, 2006). The indoor air guideline for CO_2 is 1,000 ppm and the recommended level of ventilation for maximum indoor comfort (Indoor Air Quality Control in Public Use Facilities Act, 2003). The purpose of monitoring CO_2 levels in indoor environments is to control the supply of fresh air for the comfort of the occupants.

Acoustic comfort is defined as “a state of contentment with the acoustic conditions.” Although the concept of acoustic comfort is not often used, a poor acoustic environment is associated with annoyance and discomfort. Exposure to sudden and unexpected noise has been shown to raise patients’ heart rates and to have negative effects on recovery time (Maschke, 2000). Chronic exposure to high levels of noise tends to increase blood pressure levels and a study of 4,115 patients in a Berlin hospital found that exposure to chronic noise increased the risk of heart attack by 50% for male and 75% for female patients (Stefan, 2006). In a hospital environment, patients are already weak because of their illness and noise may exacerbate their condition. For hospital staff, noise can interrupt their concentration and may contribute to medication errors, which can cause costly and dangerous problems. Typical effects of noise in hospitals are sleep disturbance, annoyance and difficulty hearing and understanding speech. The guideline for acceptable noise is 65 dB A-weighted equivalent sound level (LAeq) during the daytime and 60 dB LAeq at night.

Visual comfort is defined as “a subjective condition of visual well-being induced by the visual environment (Skoog, 2004). Visual stimuli are described in terms of the illuminance distribution, the uniformity of illumination, glare, color of light, flicker rate and sunlight (Stoops, 2001).

The definition and evaluation of visual comfort are less standardized than the evaluation of thermal comfort. However, a fundamental rule exists for artificial lightning in indoor work places related to glare issues. The Illuminating Engineering Society of North America (IESNA) recommends an average illuminance of 300 Lux for general hospital lighting.

Several studies in hospitals have shown that increased levels of natural light created a comfortable working environment and improved the comfort of the hospital staff (Verderber, 1987). Additional research has shown that natural lighting or bright artificial lighting reduces depression. Indeed, light therapy appears to have an effect similar to that of antidepressant drugs (Golden et al., 2005). Other studies have found that patients with depression show greater improvement in rooms with more daylight (Benedettin et al., 2001).

Most research on the indoor environment has addressed these comfort conditions separately, although the relative importance of discomfort due to the different physical properties has been considered (Wong et al., 2008). Wong et al. (2008) examined the IEQ in office buildings in Hong Kong. Their IEQ acceptance model evaluated the indoor environment using four environmental variables: thermal comfort, CO_2 level as an index of indoor air quality, noise level and illuminance level. The evaluation was based on 293 occupants of offices in Hong Kong. The personal experiences of building occupants were assessed to approximate the overall IEQ acceptance of the office environment. Overall IEQ acceptance was calculated using a multivariate logistic regression model.

The purpose of the present study was to assess the applicability of a comprehensive IEQ acceptance model to hospital indoor environmental comfort.

Ⅱ. Materials and Methods

1. Environmental measurements

This study was conducted in two hospitals. Hospital A is a 623-bed facility located in Seoul, Korea. The hospital is approximately 99,909 m^2 (1,075,411 ft^2) in area and comprises 18 floors (B4 to 14). Hospital B is a 500-bed facility located in Go-yang, Gyounggi-Do, Korea. Its total area is approximately 22,155 m^2 (238,474 ft^2), covering 22 floors (B1 to 10). Both hospital buildings have heating, ventilation and air-conditioning (HVAC) systems. The measurements were carried out at five places in each hospital where patients and hospital staff spent most of their time. The five measurement places are shown in Figure 1 and their places within the hospitals are given in Table 1. The monitoring equipment was placed near the patients, visitors and hospital staff at about 1 m above the floor, the level of the upper body of a seated individual.

(a) Lobby

(b) Injection room

(c) Health-screening center

(d) Nurse station

(e) Waiting room

(f) Emergency room

Figure 1. View of measurement places in two hospitals

Table 2. Floor information of measurement places in two hospitals

Hospital	Place	Floor
Hospital A B4~13th floor	Lobby reception	1st
	Health-screening center	2nd
	Injection room	2nd
	Emergency room	B1
	Nurse station	9th
Hospital B B3~10th floor	Lobby reception	1st
	Health-screening center	2nd
	Injection room	2nd
	Waiting room	2nd
	Nurse station	8th

Measurements were taken at the two hospitals during the period from the end of May through September 20, 2014. Each hospital was measured for 1 month and the monitoring equipment was then moved to the other hospital for the next month’s monitoring; over the course of 4 months, each hospital was measured for a total of 2 months. During the monitoring period, the mean outdoor temperatures were 19.9–25.2℃ and the mean outdoor relative humidity (RH) was 72.8–77.2% (Table 3).

Table 3. Outdoor temperature and RH during measurement period

Measurement period	Hospital	Outdoor temperature (℃)	Outdoor RH (%)
May 30- June 30	A	23.1±1.4	72.8±8.4
July 1- July 28	B	24.7±1.3	76.1±6.1
July 29- August 30	A	25.2±1.9	77.2±11.5
August 30- September 20	B	19.9±1.7	75.0±6.9

The measurement instruments included a PMV monitor, sound meter, illuminance meter and CO_2 sensor. The PMV monitor measured the temperature, humidity, air velocity and mean radiant temperature. The CO_2 concentration, illuminance and noise level were measured simultaneously at 1-minute intervals.

The PT100 sensor measured surface radiation in the range of –40 to 80°C with an accuracy of ±0.5°C. The range of the air temperature sensor was –10 to 60°C (±0.3°C) and the measurement range for humidity was 0.5–95 (±1.8%). The measurement range of the air velocity sensor was 0.15–5.0 m/s (±0.05 m/s) and the detection range of the noise sensor was 30–130 dB (±1.5 dB). The CO_2 sensor had a detection range of 0–10,000 ppm (±5%) (Table. 4).

Table 4. Specification of measuring instruments

	Probe	Apparatus model	Operating range	Accuracy
PMV	Mean radiant temperature	PT100	-40 ~ 80 ℃	± 0.5
	Temperature	SHT-75	-10 ~ 60 ℃	± 0.1
	Humidity	SHT-75	0.5 ~ 95%	± 1.8%
	Black-Ball Temperature	PT100	-40 ~ 80 ℃	± 0.5
	Air-Flow	F900	0.15 ~ 5.0 m/s	± 5%
Other	CO_2	Telaire 7001	0 ~10,000ppm	± 5%
	Sound	TM-103	30 ~130 dB	± 1.5dB
	Illuminance	TEL2560	NA	NA

Clothing and activity values for PMV calculation were estimated according to the American Society of Heating, Refrigeration and Air-Conditioning Engineers (ASHRAE) standard 55. The clothing (Clo) and activity values (Met) were applied to the subjects' general clothing condition directly in the field (Table 5). Subjects' clothing was observed once per week. The thermal comfort evaluation of the lobby, injection room, health-screening center, waiting room and emergency room was based on visitors' thermal condition and the evaluation of the nurse station was targeted to hospital staff.

Table 5. Clothing and activity values used for calculating PMV

	Hospital	Month	Lobby	Injection room	Health-screening center	Nurse station	Waiting room	Emergency room
Clothing Insulation Values (Clo)	A	June	0.5	0.5	0.5	0.7		0.5
	B	July	0.3	0.3	0.3	0.5	0.3	
	A	August	0.7	0.7	0.7	0.7		0.7
	B	September	0.7	0.7	0.7	0.5	0.7	
Activity Levels (Met)	A	June	1.2	1.0	1.2	1.6		1.2
	B	July	1.2	1.0	1.2	1.6	1.2	
	A	August	1.2	1.0	1.2	1.6		1.2
	B	September	1.2	1.0	1.2	1.6	1.2	

2.2 Calculation of overall comfort

The overall IEQ acceptance θ was dependent on four environmental parameters, the operate temperature ξ_1 (℃), the CO_2 level ξ_2 (ppm), the equivalent noise level ξ_3 (dB(A)) and the illuminance level ξ_4 (Lux).

$$\theta = f(\emptyset_i); \quad i = 1, \ldots, 4, \tag{1}$$

$$\emptyset_i = \emptyset_i(\xi_i); \quad i = 1, \ldots, 4, \tag{2}$$

where $\emptyset_i$ is the level of acceptance of the four environmental factors. The overall comfort model was based on 293 occupants of office building in Hong Kong (Wong et al., 2008).

The level of acceptance of a thermal comfort ξ_1 at certain operative temperature $\emptyset_1$ was related to the predicted percentage dissatisfaction (PPD) of thermal comfort:

$$\emptyset_1 = 1 - \frac{PPD}{100}. \tag{3}$$

$$\emptyset_2 = 1 - \frac{1}{2}\left(\frac{1}{1+\exp(3.118-0.00215\xi_2} - \frac{1}{1+\exp(3.230-0.00117\xi_2}\right);$$

$$500 \ll \xi_2 \ll 1800, \tag{4}$$

$$\emptyset_3 = 1 - \frac{1}{1+\exp(9.540-0.134\xi_3)}; \quad 45 \ll \xi_3 \ll 72, \tag{5}$$

$$\emptyset_4 = 1 - \frac{1}{1+\exp(-1.017+0.00558\xi_4)}; \quad 200 \ll \xi_4 \ll 1600. \tag{6}$$

The overall IEQ acceptance $\emptyset$ for an office indoor environment perceived by an occupant expressed by a multivariate logistic regression model was proposed, as follows.

$$\emptyset = 1 - \frac{1}{1+\exp(k_0+\sum_{i=1}^{4} k_i\emptyset_{i})} \tag{7}$$

Based on the result of IEQ acceptance model, indoor environment can be evaluated as followings:

1) Good IEQ ($\emptyset \geq 0.9$): It represented a Grade A office which had an indoor environmental performance better than average.

2) Average IEQ ($0.8 \leq \emptyset < 0.9$): It represented an average grade office.

3) Bad IEQ ($\emptyset \leq 0.4$): It represented a below average grade office.

2.3 Data analysis

The data collected at 1-minute intervals were divided into two categories based on the operating hours of the HVAC system: time during HVAC operation (08:00–18:00 h) and nonoperational hours. The emergency room and nurse station were analyzed using 24-hour data. All data were summarized using 1-hour averages prior to analysis. The values are shown as the arithmetic mean ± standard deviation.

The average values for the environmental factors were compared among measurement places using analysis of variance (ANOVA) and Tukey's method. Comparisons of average environmental factors during HVAC operation with those during nonoperational hours were analyzed using Student's *t*-tests. All analyses were performed using the SAS 9.3 statistical package (SAS Institute, Inc., Chicago, IL, USA). The daily average PMV values for each 4-month period were analyzed using SigmaPlot 12.5 (Systat Software, Inc., San Jose, CA, USA) to observe daily changes.

A 2 × 2 analysis was conducted to evaluate concordance between criteria for indoor environmental factors and the acceptance level using the overall IEQ acceptance model. ASHRAE standard 55 for PMV, the

Indoor Air Quality Control in Public Use Facilities Act for CO_2 levels, the Noise and Vibration Control Act for noise level and IESNA for illuminance were applied.

Ⅲ. Results

In hospital A, the emergency room had the lowest temperature and the nurse station had the highest. The lowest average temperature in hospital A during June was 25.9±1.0°C in the emergency room and the highest was 27.5±0.8°C in the health screening center. The nurse station had an average temperature of 27.5±0.7°C. The average temperatures in the health screening center and the nurse station were significantly higher than other places during June ($p<0.05$). The lowest average temperature in hospital A during August was 25.1±0.5°C in the emergency room and the highest was 27.0±0.6°C at the nurse station. The average temperature at the nurse station was significantly higher than other places during August ($p<0.05$).

In hospital B, the injection room had the lowest temperature and the highest temperatures were recorded in the waiting room during July and the nurse station during September. The lowest average temperature in hospital B during July was 24.8±0.7°C in the injection room and the highest was 27.1±0.9°C in the waiting room. During July, the average temperatures in the lobby and the injection room were significantly lower than other places ($p<0.05$). During September, the lowest average temperature in hospital B was 25.2±1.0°C in the lobby and the highest was 27.0±0.5°C at the nurse station. The average temperature of nurse station was significantly higher than other places ($p<0.05$).

In hospital A, the nurse station had the lowest RH. The highest RH was recorded in the emergency room during June and in the lobby during August. The lowest average RH recorded in hospital A during June was 59.0±6.6% at the nurse station and the highest was 67.5±9.0% at the emergency room. The average RH was higher in the emergency room and the lobby than other places during June ($p<0.05$). During August, the lowest average RH in hospital A was 67.2±5.8% at the nurse station and the highest was 85.2±5.8% at the emergency room. The average RH at the nurse station during August was significantly lower than other places ($p<0.05$).

In hospital B, the waiting room during July and nurse station during September had the lowest average RH. The injection room and the emergency room had the highest RH during July and August, respectively. During July, the lowest average RH in hospital B was 72.9±6.8% at the waiting room and the highest was 83.7±6.4% at the injection room. The average RH was significantly lower at the nurse station and the waiting room compared to other places during July (p<0.05). During September, the lowest average RH in hospital B was 54.7±9.2% at the nurse station and the highest was 67.7±11.9% at the injection room. The average RH at the nurse station was significantly lower than other places during September (p<0.05).

In hospital A, the lowest air velocity was recorded in the emergency room during July and in the lobby during August, whereas the emergency room had the highest air velocity during June and the lobby had the highest during August. The lowest average air velocity in hospital A during June was 0.02±0.02 m/s at the injection room and the highest was 0.08±0.06 m/s at the emergency room. The average air velocities in the lobby and emergency room were significantly higher compared to other places during June (p<0.05). The lowest average air velocity during August in hospital A was 0.05±0.03 m/s recorded at the nurse station and the highest was 0.16±0.17 m/s measured in the injection room. During August, the average air velocity at the nurse station and the injection room was significantly lower compared to other places (p<0.05).

In hospital B, the health-screening center during July and the waiting room during August had the lowest air velocity, while the lobby had the highest air velocity during June and August. The lowest average air velocity in hospital B during July was 0.02±0.03 m/s in the health-screening center and the highest was 0.1±0.07 m/s in the emergency room. The average air velocity in the lobby was significantly higher than other places during July ($p<0.05$). During August, the lowest average air velocity was 0.02±0.02 m/s in the waiting room and the highest was 0.1±0.08 m/s in the lobby. The average air velocity of the lobby during September was significantly higher than other places ($p<0.05$).

In hospital A, during June and August, the injection room had the lowest mean radiant temperature and the emergency room had the highest. The lowest average mean radiant temperature in hospital A during June was 25.6±1.2°C at the emergency room and the highest was 28.8±1.2°C at the lobby. During June, the average mean radiant temperature was significantly higher in the lobby and the injection room than in other places ($p<0.05$). The lowest average mean radiant temperatures during August in hospital A was 24.9±0.6°C at the emergency room and the highest was 28.6±1.1°C at the lobby. The average mean radiant temperature of the lobby was significantly higher than other places during August ($p<0.05$).

In hospital B, the lobby and the injection room had the lowest mean radiant temperature during August and July, respectively. The highest mean radiant temperature during July was recorded in the health-screening center and that during August was in the waiting room. During July, the lowest average mean radiant temperature in hospital B was 25.1±1.1°C at the lobby and the highest average was 27.4±0.9°C at the health screening center. The average mean radiant temperature of the lobby was significantly lower than other places during July ($p<0.05$). The lowest average mean radiant temperature in hospital B during September was 25.3±0.6°C at the injection room and the highest was 28.2±0.3°C at the waiting room. The average mean radiant temperature of the waiting room during September was significantly higher than other places ($p<0.05$).

Table 6. Monthly average of temperature, RH, air velocity and mean radiant temperature in measurement places of hospitals A and B

	Hospital	Month	Lobby	Injection room	Health screening center	Nurse station	Emergency room	Waiting room
Temperature (℃)	A	June	26.3±1.1	26.5±1.1	27.5±0.8	27.5±0.7	25.9±1.0	NA
	B	July	25.4±1.0	24.8(±0.7)	26.7±0.8	26.7±0.7	NA	27.1±0.9
	A	August	26.1±1.0	26.1±1.0	25.4±1.0	27.0±0.6	25.1±0.5	NA
	B	September	25.2±1.0	25.3±0.6	25.5±0.9	27.0±0.5	NA	25.9±0.9
RH (%)	A	June	66.6±10.5	62.3±7.5	59.4±7.7	59±6.6	67.5±9.0	NA
	B	July	80.3±4.3	83.7±6.4	78.3±7.7	75.8±6.1	NA	72.9±6.8
	A	August	83.8±8.9	79.7±5.2	80.3±4.3	67.2±5.8	85.2±5.8	NA
	B	September	66.9±11.0	67.7±11.9	63.6±11.5	54.7±9.2	NA	64.7±10.7

	Hospital	Month	Lobby	Injection room	Health screening center	Nurse station	Emergency room	Waiting room
Airflow (m/s)	A	June	0.06±0.05	0.02±0.02	0.05±0.03	0.04±0.04	0.08±0.06	NA
	B	July	0.1±0.07	0.04±0.03	0.02±0.03	0.03±0.03	NA	0.04±0.03
	A	August	0.16±0.17	0.06±0.09	0.1±0.07	0.05±0.03	0.09±0.09	NA
	B	September	0.1±0.08	0.04±0.04	0.02±0.02	0.04±0.02	NA	0.02±0.02
Mean radiant temperature (℃)	A	June	28.8±1.2	26.9±1.2	26.9±1.0	28.4±3.7	25.6±1.2	NA
	B	July	25.1±1.1	27.1±0.9	27.4±0.9	27.0±0.7	NA	26.1±1.0
	A	August	28.6±1.1	26.9±1.0	25.1±1.1	26.3±0.7	24.9±0.6	NA
	B	September	25.7±0.9	25.3±0.6	25.4±1.0	26.3±0.6	NA	28.2±0.3

Table 6. continued.

The average temperature, RH, air velocity and mean radiant temperature during the hours of HVAC operation and non-operation were analyzed (Table 7). During the hours of operation, the lowest temperature in hospital A was 25.5±0.9°C at the emergency room and the highest was 27.6±0.7°C at the health-screening center. The average temperatures of the health-screening center and the nurse stations in hospital A during the hours of HVAC operation were significantly higher than other places ($p<0.05$). The lowest mean temperature in hospital B during the hours of operation was 24.7±0.6°C at the injection room and the highest was 27.1±1.0°C at the waiting room. The average temperatures of the nurse station and the waiting room in hospital B were significantly higher than other places ($p<0.05$). The average temperature of all monitoring places exceeded the ASHRAE standard for indoor temperature, which recommends maintaining the temperature at 21–24°C.

The lowest mean RH in hospital A was 60.3±9.7% at the nurse station and the highest was 74.0±15.9% at the lobby. The average RH was significantly greater in the lobby and emergency room than at other places in hospital A ($p<0.05$). In hospital B, the lowest mean RH was 68.7±9.9% at the waiting room and the highest was 77.3±6.4% at the lobby. The average RH in the waiting room was significantly lower than that in other places in hospital B (*p*<0.05). However, at hospitals A and B, the mean RH exceeded the ASHRAE standard of <60%.

The lowest mean air velocity in hospital A was 0.04±0.02 m/s at the health screening center and the highest was 0.14±0.1 m/s at the lobby. The average air velocity was significantly higher in the lobby and the emergency room than other places in hospital A (*p*<0.05). In hospital B, the lowest mean air velocity was 0.01±0.01 m/s at the health screening center and the highest was the 0.1±0.03 m/s at the lobby. The average air velocity in the lobby was significantly higher than other places (*p*<0.05). The ASHRAE 55 standard for indoor air velocity is <0.25 m/s; no place exceeded this standard.

The lowest mean radiant temperature in hospital A was 25.3±1.0°C at the emergency room and the highest was 28.7±1.3°C at the lobby. The mean radiant temperatures in the injection room and the emergency room were significantly lower than other places (*p*<0.05). The lowest mean radiant temperature in hospital B was 25.4±1.1°C at the lobby and the highest was 27.2±1.4°C at the waiting room. The mean radiant temperature in hospital B did not differ significantly among monitoring places (*p*>0.05; Table 7).

Table 7. Average temperature, RH, air velocity and mean radiant temperature during the operation hours

		Lobby	Injection room	Health screen center	Nurse station	Emergency room*+	Waiting room*+
Temperature (℃)	A	26.2±1.2	26.2±1.0	27.6±0.8	27.3±0.7	25.5±0.9	NA
	B	24.7±1.0	24.7±0.6	25.8±0.9	27.0±0.6	NA	27.1±1.0
RH (%)	A	74.0±15.9	68.8±13.0	64.3±13.2	60.3±9.7	73.1±13.7	NA
	B	77.3±6.4	75.8±12.2	75.0±9.1	75.7±6.0	NA	68.7±9.9
Air velocity (m/s)	A	0.14±0.13	0.04±0.05	0.04±0.02	0.04±0.0.2	0.08±0.02	NA
	B	0.1±0.03	0.04±0.01	0.01±0.01	0.03±0.01	NA	0.03±0.01
Mean radiant temperature (℃)	A	28.7±1.3	26.8±1.1	28.4±1.0	27.6±1.3	25.3±1.0	NA
	B	25.4±1.1	26.1±1.1	26.5±1.2	27.0±0.6	NA	27.2±1.4

Average PMV and standard deviation of hospitals A and B were showed in Table 8. In hospital A, the emergency room was the most thermally comfortable and the nurse station was the least thermally comfortable place during June and August. In hospital A during June, PMV levels were 0.6±0.3 at the lobby, 0.5±0.3 at the injection room, 1.0±0.2 at the health-screening center, 1.1±0.2 at the nurse station and 0.2±0.2 at the emergency room. During August, the PMV levels were 0.9±0.4 at the lobby, 0.8±0.3 at the injection room, 1.1±0.2 at the health screening center, 0.8±0.2 at the nurse station and 0.2±0.2 at the emergency room.

In hospital B, the injection room was the most thermally comfortable place during July and September. The nurse station during July and the waiting room during September were the least thermally comfortable places in hospital B. During July in hospital B, the PMV levels were –0.2±0.3 at the lobby, 0.02±0.2 at the injection room, 0.3±0.2 at the health screening center, 0.6±0.2 at the nurse station and 0.2±0.2 at waiting room. During September, the values were 0.5±0.3 at the lobby, 0.5±0.2 at the injection room, 0.5±0.2 at the health-screening center, 0.5±0.1 at the nurse station and 0.9±0.2 at the waiting room

(Table 8).

Table 8. Monthly average PMV of measurement places in two hospitals

	Hospital	Lobby	Injection room	Health Screening center	Nurse station	Emergency room	Waiting room
June	A	0.6±0.3	0.5±0.3	1.0±0.2	1.1±0.2	0.2±0.2	NA
July	B	-0.2±0.3	0.02±0.2	0.3±0.2	0.6±0.2	NA	0.2±0.2
August	A	0.9±0.4	0.8±0.3	1.1±0.2	0.8±0.2	0.5±0.2	NA
September	B	0.5±0.3	0.5±0.2	0.5±0.2	0.5±0.1	NA	0.9±0.2

In hospital A, lower ASHRAE compliance rates were observed at the nurse station during June and at the emergency room during August. In hospital B, lower compliance rates were observed at the nurse station during July and the waiting room during September. During June, the lowest compliance with ASHRAE comfort standards in hospital A was 1.1% at the nurse station and the highest was 87.7% at the emergency room. The lowest rate of compliance with ASHRAE comfort standards in hospital B during July was 45.7% at the nurse station and the highest was 99.94% at the health screening center. All of the substandard PMV values calculated in this study were found in hospital B during July. During August, the lowest rate of compliance with the ASHRAE comfort standards in hospital A was 5.0% at the health screening center and the highest was 65.6% at the emergency room. The lowest compliance with the ASHRAE 55 standards during September in hospital B was 12.3% at the waiting room and the highest was 70.2% at the nurse station (Table 8).

Table 9. The compliance rate of ASHRAE standard of comfort in hospitals A and B

	Hospital	PMV	Lobby	Injection room	Health-screening center	Nurse station	Emergency room	Waiting room
June	A	>0.5	62.7%	54.4%	58.6%	98.9%	12.3%	NA
		-0.5~0.5	37.3%	45.6%	41.4%	1.1%	87.7%	
		<-0.5	0%	0%	0%	0%	0%	
July	B	>0.5	1.4%	1.4%	0%	54.3%	NA	5.5%
		-0.5~0.5	93.6%	98.4%	99.94%	45.7%		86.4%
		<-0.5	5.0%	0%	0.06%	0%		8.1%
August	A	>0.5	84.5%	81.1%	95.0%	93.1%	34.4%	NA
		-0.5~0.5	15.5%	18.9%	5.0%	6.9%	65.6%	
		<-0.5	0%	0%	0.0%	0%	0%	
September	B	>0.5	39.5%	38.4%	51.1%	29.8%	NA	87.7%
		-0.5~0.5	60.5%	61.6%	48.9%	70.2%		12.3%
		<-0.5	0%	0%	0%	0%		0%

-0.5~0.5: ASHRAE Standard of thermal comfort zone

Daily PMV levels were relatively consistent for monitoring places during each 1-month monitoring period. The average PMV was higher on weekends except at the nurse station and emergency room. During June in hospital A, only the emergency room maintained comfort thermal conditions; the average PMV level was 0.2±0.2 and it was always <0.5. The nurse station had a PMV level >0.5 daily. Daily PMV levels at the injection room were <0.5 on weekdays, but >0.5 on weekends. The weekdays and weekends PMV levels at the injection room were not significantly different (p>0.05).

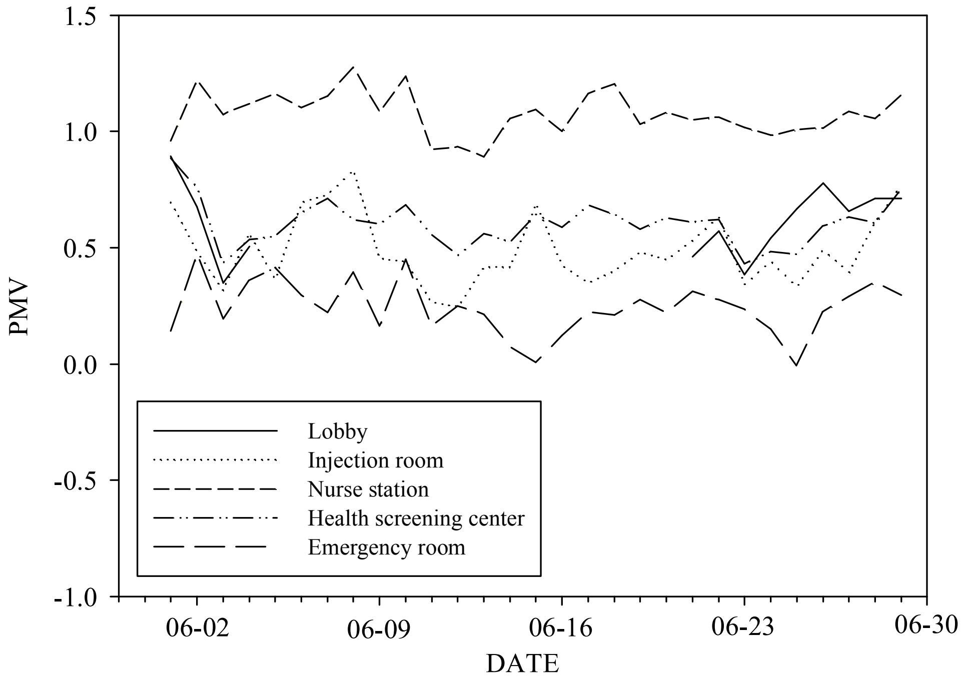

Figure 2. Daily thermal comfort in June (hospital A) (data for 15 days of lobby was missing due to mechanical failure of measuring instrument)

During July, the average PMV at the nurse station in hospital B was 0.6±0.2; other places in hospital B recorded values had –0.5 to 0.5. A large increase in daily PMV was observed in the waiting room every weekend (Figure 4) and the resultant values were significantly different from those for weekdays ($p<0.05$). Differences between weekdays and weekends PMV values at the remaining places were not significant ($p>0.05$).

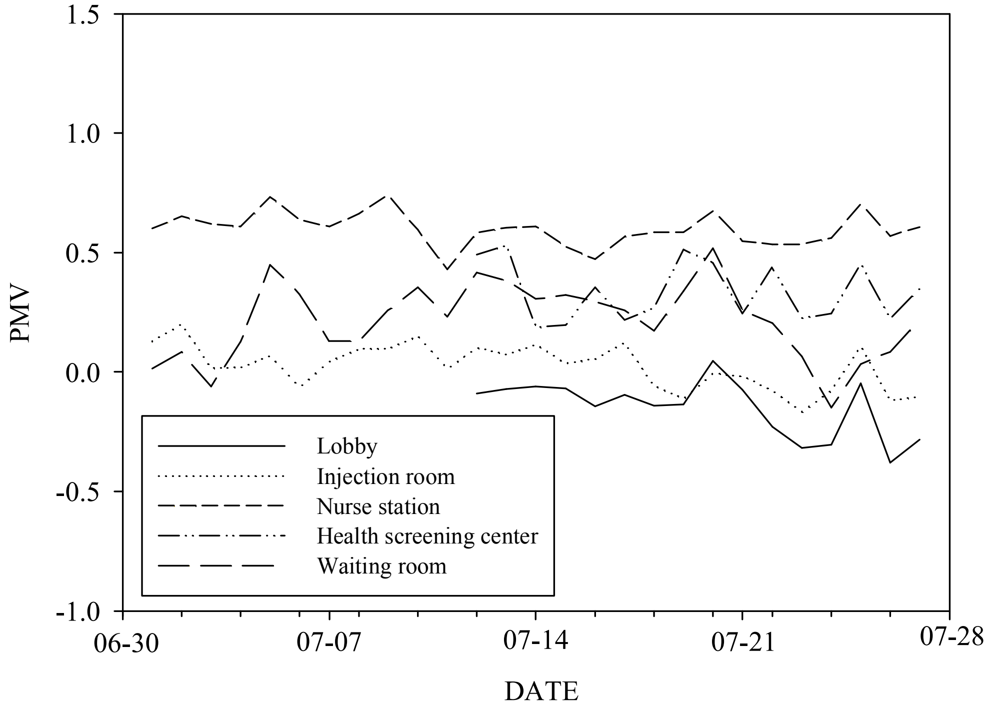

Figure 3. Daily thermal comfort in July (hospital B) (data for 15 days of lobby and health-screening center were missing due to mechanical failure of measuring instrument)

During August, the average PMV values at all monitoring places in hospital A except the emergency room were >0.5 throughout the month. The daily average PMV at the health screening center was 1.1±0.2. The daily PMV values at the lobby, injection room and health screening center tended to increase on weekends (Figure 5), reaching levels significantly higher than those for weekdays (p<0.05).

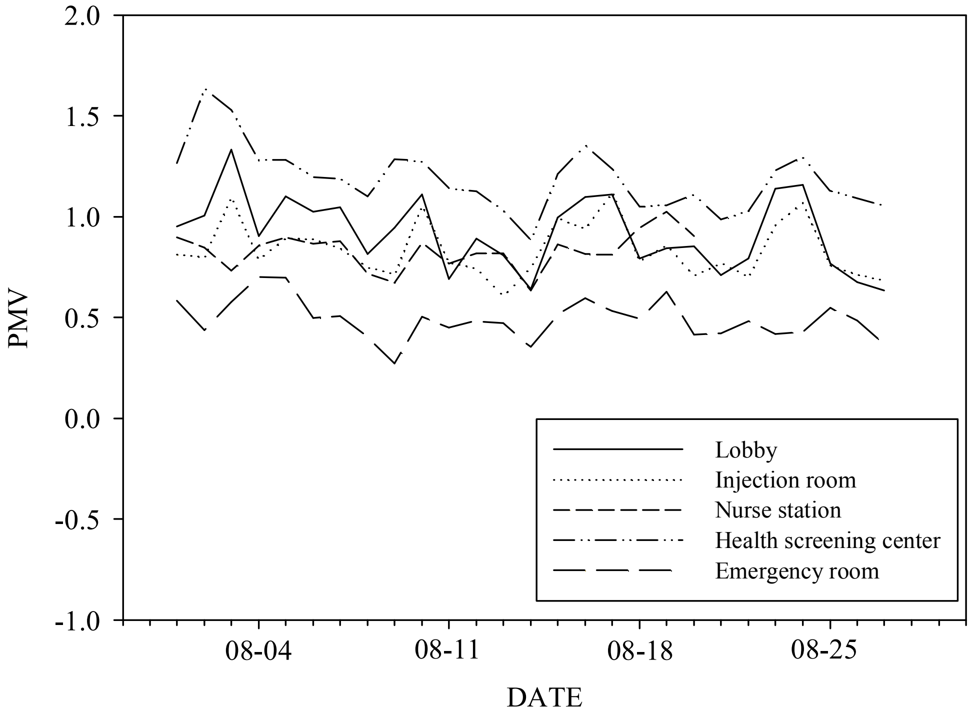

Figure 4. **Daily thermal comfort in August (hospital A) (data for 15 days of nurse station was missing due to mechanical failure of measuring instrument.**

During September, the waiting room in hospital B maintained the highest daily PMV, with one weekend peak measuring >1.0. The daily PMV values in the health screening center and waiting room tended to rise over the weekend, whereas the daily averages at the lobby, injection room and the nurse station were stable at about 0.5 (Figure 6). The average PMV values at the waiting room and the health screening center were significantly higher on weekends than on weekdays in September ($p<0.05$).

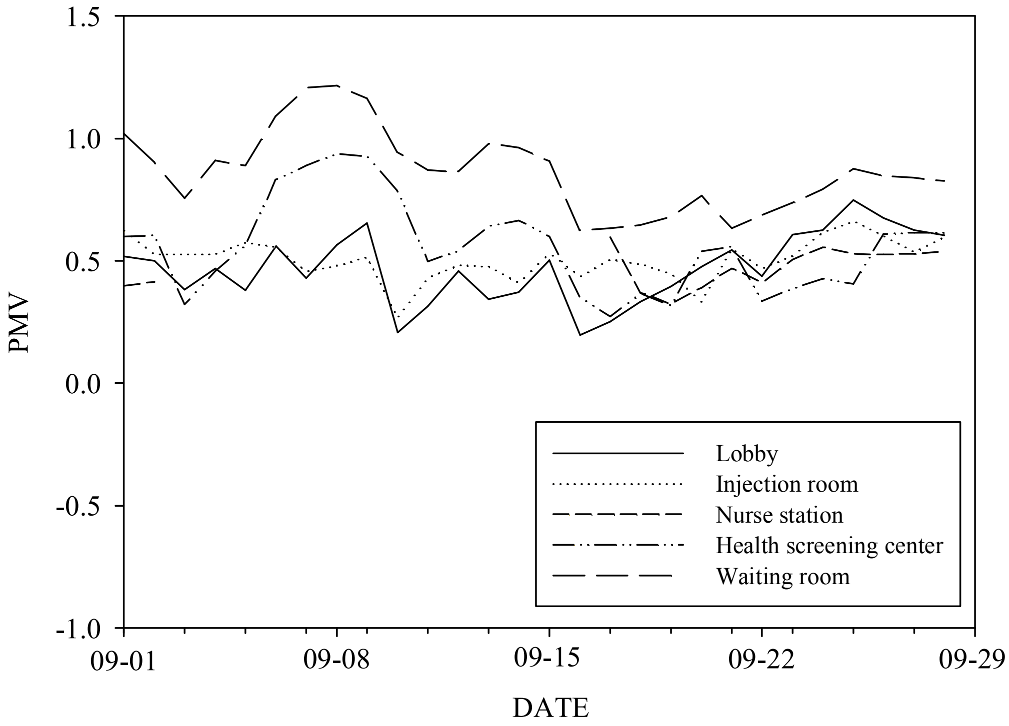

Figure 5. Daily thermal comfort in September (hospital B) (data for 15 days of nurse station was missing due to mechanical failure of measuring instrument)

During the hours of HVAC operation in hospital A, the emergency room had the lowest CO_2 level and the nurse station had the highest. The highest air velocity during HVAC operation was observed at the emergency room during June and at the lobby during August. The lowest average CO_2 level was 400±63 ppm at the emergency room and the highest was 743±139 ppm at the nurse station. The average CO_2 concentrations during the hours of HVAC operation were significantly higher at the nurse station than other places in hospital A ($p<0.05$).

During HVAC operation hours in hospital B, the injection room had the lowest CO_2 level and the waiting room had the highest. The highest average CO_2 level was 623±176 ppm at the waiting room and the lowest was 558±127 ppm at the injection room. The average CO_2 concentrations during the hours of HVAC operation in hospital B were significantly higher in the waiting room than other places ($p<0.05$). In both hospitals, the average CO_2 levels remained below the 1,000ppm limit during both operational and nonoperational hours.

During the hours of HVAC operation in hospital A, the injection room had the lowest noise level during the daytime and the lobby had the highest. The lowest average noise level was 47.8±6.9 dB at the injection room and the highest was 57.8±4.9 dB at the lobby. During

HVAC operation, the average noise levels were significantly higher in the lobby and the emergency room compared to other places in hospital A ($p<0.05$).

During HVAC operation in hospital B, the injection room had the lowest daytime noise level and the lobby had the highest. The lowest average noise level was 44.0±9.3 dB at the injection room and the highest was 59.5±2.9 dB at the lobby. The average noise levels during HVAC operation were significantly higher at the lobby than other monitoring places in hospital B ($p<0.05$). No place in either hospital exceeded the reference noise levels of 65 dB for daytime and 60 dB for nighttime.

During the hours of HVAC operation in hospital A, the health-screening center had the lowest illuminance level and the emergency room had the highest. The lowest average illuminance was 99±66 Lux at the health-screening center and the highest was 180±23 Lux at the emergency room.

During HVAC operation in hospital B, the health-screening center had the lowest illuminance level and the nurse station had the highest. The lowest average illuminance was 92±70 Lux at the health-screening center and the highest average was 390±249 Lux at the injection room.

Only the nurse station and the injection room in hospital B complied with the IESNA standard of 300 Lux (Table 10). The average illuminance in the health-screening centers was significantly lower than other places in both hospitals ($p<0.05$). The average CO_2, noise and illuminance levels were significantly lower during HVAC nonoperational hours than during operational hours at two hospitals ($p<0.05$).

Table 10. Comparison of CO_2 level, noise and illuminance by operation and non-operation hours

		Time*	Lobby	Injection room	Health screen center	Nurse station	Emergency room*+	Waiting room*+
CO_2 (ppm)	A	operation	535±127	558±127	567±100	743±139	400±63	NA
		non-operation	458±30	474±39	481±37			
	B	operation	559±104	558±127	574±138	597.8±37.0	NA	623±176
		non-operation	525±104	474±39	421±65		NA	479±52
Noise (dB LAeq)	A	Day	57.8±4.9	47.8±6.9	53.8±3.7	49.5±3.4	56.0±2.1	NA
		Night	47.2±5.6	39.3±4.1	47.7±4.3			NA
	B	Day	59.5±2.9	44.0±9.3	45.5±8.2	49.6±2.9	NA	52.4±6.6
		night	54.1±5.6	40.3±8.1	38.4±5.4		NA	42.5±6.2
Illuminance (Lux)	A	operation	113±69	139±118	99±66	155±8	180±23	NA
		non-operation	14±19	15±52	88±73			
	B	operation	292±70	390±249	92±70	359±37	NA	181±111
		non-operation	139±37	119±214	30±55		NA	71±100

*Time: operation (08:00-18:00), non-operation (18:00-07:00), day (07:00-18:00), night (18:00-07:00)
*+: operate 24hours

The overall IEQ acceptance evaluation showed that the values for visual comfort in both hospitals were much lower than thermal comfort, air quality and acoustic comfort. The emergency room in hospital A and the injection room in hospital B provided the most comfortable thermal environments. The comfort level provided by indoor air quality, as measured by CO_2 concentrations, was >0.9 at two hospitals. In terms of noise, two hospitals had "Good" noise environments, with values >9.0, with the exceptions of the emergency room in hospital A and the lobby in hospital B. No place had an illuminance value >0.8. The hospital A showed "Bad" visual comfort values, with values <0.5. The emergency room in hospital A (0.50±0.03) and the nurse station in hospital B (0.73±0.05) had the highest visual comfort values (Table 11).

Table 11. Overall IEQ acceptance of hospitals A and B

	Hospital	Lobby	Injection room	Health screen center	Nurse station	Emergency room	Waiting room
Thermal comfort (PMV)	A	0.80±0.13	0.84±0.09	0.68±0.10	0.73±0.08	0.91±0.05	NA
	B	0.93±0.04	0.98±0.04	0.88±0.07	0.87±0.06	NA	0.85±0.10
Air quality (CO_2)	A	0.98±0.03	0.98±0.03	0.99±0.03	0.94±0.01	0.99±0.03	NA
	B	0.97±0.04	0.98±0.03	0.97±0.04	0.97±0.04	NA	0.97±0.03
Acoustic comfort (Noise)	A	0.90±0.09	0.96±0.05	0.96±0.06	0.93±0.02	0.89±0.04	NA
	B	0.82±0.09	0.98±0.04	0.98±0.04	0.94±0.04	NA	0.94±0.06
Visual comfort (Illuminance)	A	0.35±0.10	0.36±0.14	0.38±0.09	0.46±0.01	0.50±0.03	NA
	B	0.61±0.17	0.54±0.30	0.34±0.09	0.73±0.05	NA	0.42±0.16

Overall IEQ acceptance: Good IEQ (Ø ≥0.9), Average IEQ (0.8≤ Ø <0.9), Bad IEQ (Ø ≤0.4)

The results of the 2 × 2 analysis are shown in Figure 8 and Table 12. The accuracy and specificity of the thermal comfort and air quality models were very high, whereas the sensitivity of the acoustic and the visual comfort models was low. The thermal comfort model had 49% true-positive and 1.5% false-negative results. The sensitivity of the thermal comfort model was 97%, with true-negative and false-negative values of 49% and 0.2%, respectively. The specificity of the thermal comfort model was 99%. The indoor air quality comfort model had a true-positive result of 95% and a false-negative result of 4.3%. The sensitivity of the indoor air quality comfort model was 97%, with 0.2% true negatives and 0% false negatives. The specificity of the indoor air quality comfort model was 100%. The acoustic comfort model had 63% true positives and 37% false negatives. The sensitivity of the acoustic comfort model was 63%, with 0.8% true negatives and 0% false negatives. The visual comfort model had true-positive results of 0% and false-negative results of 32%. The sensitivity of the visual comfort model was 0.001%, with 68% true-negative and 0% false-negative results. The specificity of the visual comfort model was 100%, but its sensitivity was extremely low (Table 12).

The level of acceptance (Good)	Standard: yes	Standard: No
yes	3100	15
no	92	3117

(a) Thermal comfort

The level of acceptance (Good)	Standard: yes	Standard: No
yes	6039	0
no	274	11

(b) Carbon dioxide

The level of acceptance (Good)	Standard: yes	Standard: No
yes	3957	0
no	2311	56

(c) Noise level

The level of acceptance (Good)	Standard: yes	Standard: No
yes	1	0
no	970	2090

(d) Illuminance

Figure 6. Agreement of the standard and the level of acceptance criteria

Table 12. Sensitivity and specificity of comfort models

Test	Sensitivity (%)	Specificity (%)
Thermal comfort (PMV)	97	99
Indoor air quality (CO_2)	100	100
Acoustic comfort (noise level)	63	100
Visual comfort (illuminance)	0.001	100

The proposed model for an illuminance guideline for office buildings developed by Wong et al. (2008) designated visual comfort as “Good” (>0.9) when the illuminance was approximately 600 Lux. However, the general standard for hospital illuminance according to the IESNA is 300 Lux. Therefore, the earlier Wong et al. (2008) model was adjusted to employ an illuminance standard of 300 Lux as indicating “Good” illuminance for hospitals (Figure 9). Formula of the illuminance of new proposed model is as follows:

$$\emptyset_{4'} = 1 - \frac{1}{1+\exp(-1.017+0.010719\xi_4)}; \quad 200 \ll \xi_4 \ll 1600. \qquad (8)$$

ξ_4 = illuminance level (Lux)

$\emptyset_4$ = the level of acceptance of the illuminance

where $\emptyset_{4'}$ is the level of acceptance of the illuminace in general hospital.

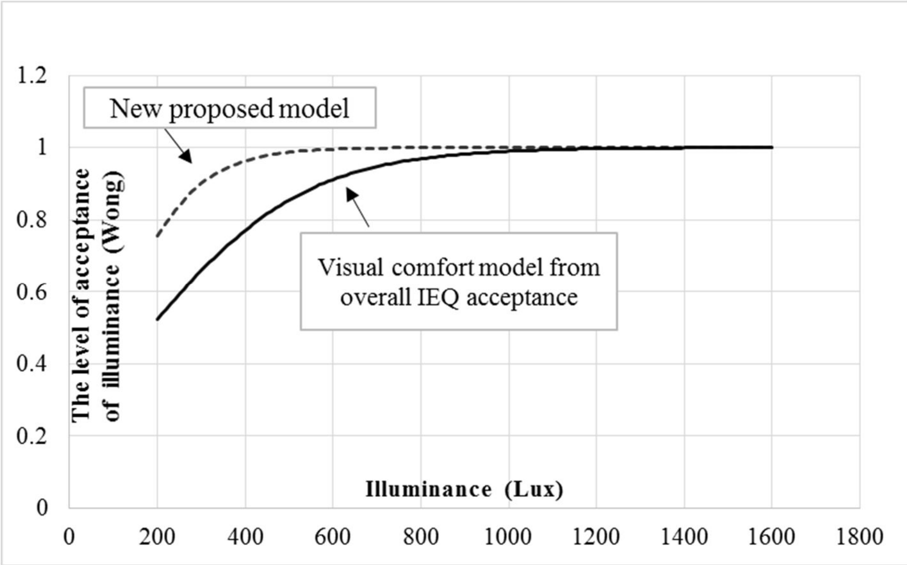

Figure 7. Relationship between illuminance and acceptance level with 600 Lux and 300 Lux criteria

The results of the overall evaluation based on IEQ acceptance and using the new model are shown in Table 12. This evaluation showed that the indoor air quality and acoustic environment reflected relatively high levels of satisfaction, but the evaluation of the visual environment was significantly poorer.

In no place was the overall IEQ acceptance level above 0.9, the value representing a grade of “Good” for overall IEQ acceptance. The emergency room in hospital A had the highest value at 0.8, which represents an “Average” for overall IEQ acceptance. The values for the lobby, injection room and the nurse station in hospital B were between 0.8 and 0.9. The overall IEQ acceptance levels for the lobby, injection room, health-screening center and the nurse station in hospital B were higher than other places in hospital A. The most comfortable indoor environment was the nurse station in hospital B and the worst was the health-screening center in hospital A.

The overall IEQ acceptance using the new proposed model with the IESNA illuminance guideline revealed values >0.9 for the injection room and the emergency room in hospital A. The lobby, health-screening center and the nurse station in hospital A were between 0.4 and 0.8, which represented lower than “Average” grade. In hospital B, however, the values for the lobby and nurse station were >0.9 and the injection room and health-screening center showed values between 0.8 and 0.9. The waiting room was the only place in hospital B where overall IEQ acceptance values were <0.8 (Table 13).

Table 13. Comparison of the overall IEQ acceptance with adjustment with illuminance criteria

	Hospital	Lobby	Injection room	Health screen center	Nurse station	Emergency room	Waiting room
Overall IEQ acceptance	A	0.54	0.67	0.47	0.62	0.80	NA
	B	0.81	0.86	0.72	0.89	NA	0.69
Overall IEQ acceptance using new proposed model	A	0.63	0.90	0.52	0.77	0.90	NA
	B	0.91	0.87	0.89	0.95	NA	0.78

Overall IEQ acceptance: Good IEQ ($\emptyset \geq 0.9$), Average IEQ ($0.8 \leq \emptyset < 0.9$), Bad IEQ ($\emptyset \leq 0.4$)

VI. Discussion

Indoor thermal conditions in two hospitals were measured during summer 2014. In this study, the mean temperature exceeded the ASHRAE 55 recommended temperature of 21–24°C in both hospitals. However, the Korean government enacted a new law stating that buildings over a certain size must keep the indoor temperature above 26°C in summer. Although both hospitals complied with this directive, keeping the indoor temperature above 26°C during the monitoring period, this temperature was not suitable for maintaining comfort.

The average RH exceeded the ASHRAE standard of 60% (ASHRAE/ASHE standard 170-2008) in two hospitals. Summer is humid in Korea and the outdoor RH was >70% during the monitoring period. The indoor RH levels were similar to and sometimes higher than the outdoor levels, indicating that the air-conditioning units in the hospitals may not have had a humidity control system. Given that very high indoor humidity is associated with an increased microorganisms such as mold and bacteria (IOM, 2004), dehumidification of indoor air in hospitals during summer may be necessary.

The average air velocities at two hospitals were below the maximum air velocity of 0.25 m/s recommended by ASHRAE 55. Although air velocity in the lobby did not exceed this limit, the average was significantly higher than other places due to airflow into the building via the entrance. The indoor air velocity can affect the convective heat exchange between a person and the environment. Increased airflow can reduce the heat caused by a rise in temperature (ISO, 2005). It can also cause thermal discomfort due to the drying effect on the environment. In a hospital, increased air velocity should be limited due to the potential spread of airborne infections (Li et al., 2007).

The thermal comfort of the two hospitals in this study was compared with the study in Taiwan during summer. In the present study, 43.8% of the total PMV data fell within the comfort range specified by ASHRAE 55 standards, and the 0.3% of the data that showed PMV values <–0.5 derived from measurements made in hospital B during July. In a study in Taiwan, 83% of PMV data satisfied ASHRAE 55 standards, and 6% reflected temperatures slightly cooler than the standard during summer (Hwang et al., 2007). The rate of compliance with the ASHRAE 55 standards for comfort was only about one-half that of the study in Taiwan. In Taiwan, the indoor temperature was maintained at 24°C during summer. PMV of the complex building had different results depending on the operate temperature (De dear and Brager, 1998).

The daily PMV results for the two hospitals showed similar temporal profile, despite the differences in the buildings. The average daily PMV increased every weekend, except at the nurse station and the emergency room. The indoor temperature naturally rose in summer because the HVAC systems were not operated in all places on weekends except for the nurse station and the emergency room. Changes in the daily profile in the emergency room and the nurse station were relatively small because their HVAC systems were operational 24 hours every day. The daily PMV was consistently highest in August.

The average noise levels did not exceed the national noise standard, which requires that noise be maintained below 65 dB (A) in daytime and 60 dB (A) at night. In a hospital, the critical effects of noise are often sleep disturbance, annoyance and interference with communication (Konkani and Oakley, 2012). Hospital wards where patients stay should be managed more strictly.

In hospital environment, the role of the illuminance level is important for its health effect on patients and the efficiency of hospital staff. The average illuminance in hospital B except for nurse station was <300 Lux during the operation hours. In hospital A, the average illuminance was <300 Lux. The average illuminance in hospitals is recommended to be maintained at around 300 Lux. Hospitals are required to keep the average illuminance within the range of 300–2,000 Lux, depending on the features of the place (IESNA). Several studies have shown that light, including daylight and bright artificial light, may reduce depression (Golden et al., 2005; Beauchemin and Hays, 1996). The adequate illuminance for working is important for all hospital staff. One hospital study showed that errors in medication formulation were 37% more likely to occur at levels of 450–1,000 Lux on the working surface compared to a light level of 1500 Lux (Buchanan et al., 1991). Maintaining higher illuminance in certain places such as the injection room and nurse station is necessary.

The sensitivity and specificity of the visual comfort were remarkably low. This represented the possibility of underestimation of illuminance. The illuminance acceptance model proposed by Wong was designed to evaluate the visual comfort as "Good" when the illuminance was around 600 Lux or greater than 600 Lux. IESNA recommended illuminance levels in office building from 300-750 Lux according to type of the task. The proper illuminance levels of office and the hospital were very different because of the occupant's purpose. The office is where the occupants conducted precision work such as paperwork. The surveyed results from 293 occupants in office building showed that the subjects found it 'more comfortable' at an illuminance level higher than 500 Lux (Mui and Wong, 2005). Therefore, calibration for the illuminance of the general hospital was conducted for re-evaluation of overall IEQ acceptance.

The overall IEQ acceptance of hospitals A and B were lower than "Good" grade. Hospital B was more comfortable than hospital A. Hospital A used more natural light than artificial light compared to hospital B. Health-screening center had relatively small visitors and they did not visit regularly. Because of the few visitors, health-screening center usually did not have bright visual environment. The waiting room which in hospital B had the highest population density per certain space compared to the other places. Discomfort of the health-screening center in hospital A and the waiting room in hospital B were derived from the lower visual comfort and thermal comfort compare to other places.

The overall IEQ acceptance with new proposed model were lower than average grade at the health-screening center, lobby and the nurse station in hospital A and the waiting room in hospital B. After evaluation with new proposed model, the results were poor in visual comfort. The discomfort associated with visual comfort should be investigated by field research and surveys in the future study.

This study had several limitations. Because of the limited number of measuring devices available, the two hospitals were not measured at the same time. Measuring two hospitals simultaneously would have enabled comparisons of monthly variations between hospitals A and B. However, the main purpose of this study was not simply to compare indoor comfort. The data obtained were suitable for assessing overall IEQ acceptance as a means of evaluating hospital's indoor comfort. This study presented results obtained only in summer. The mean temperature and RH are significantly different between summer and winter. Indoor thermal environments are known to vary seasonally (Kim et al., 2011). Evaluations of indoor comfort for year including winter were needed. Since the monitoring will be continued for a year, the overall IEQ acceptance levels for these two hospitals for a year will be evaluated in a future study.

The evaluation of indoor comfort in hospital wards is very important, as this is where inpatients are housed. However, this study did not include assessments of the IEQ in hospital wards due to the risk of disturbing the patients. Different patients are likely to respond differently to thermal comfort and other comfort-related factors depending on their health condition and people with different activity levels are situated in the same part of a hospital (Skoog et al., 2005). The results of research on differences in the impact of thermal comfort on patients compared with healthy people were unclear. If differences in thermal adaptation between patients and healthy people were clarified, this would provide further information about how the IEQ acceptance model could be developed.

The overall IEQ acceptance model has been largely developed for use in improving the indoor environment for office building occupants. Developing a model based on illuminance that specifically addresses the needs of hospital occupants is necessary. Further studies will be needed to confirm the new proposed model with its modified illuminance guideline.

V. Conclusions

The average temperature and RH measured in two hospitals exceeded the ASHRAE 55 standards. The cause of the temperature excess might be due to the government's energy-saving policy. Hospital B was more thermally comfortable than hospital A. The indoor air quality and noise level were comfortable at two hospitals. The average illuminance in 8 of 10 places in the two hospitals was below the IESNA standard. No place in either hospital met the requirements for “Good” overall IEQ acceptance based on the model for office environments. The failure to meet this standard was due to different needs of illuminance level between office and hospital. Even with the adjusted illuminance criteria, the lobby, health-screening center and nurse station in hospital A and waiting room in hospital B provided lower than “Average” comfort. A follow-up study should be conducted to confirm the suitability of the new proposed IEQ acceptance model specifically designed for hospital occupants.

References

Abdou OA, Lorsch HG. The impact of the building indoor environment on occupant productivity-Part 3: effects of indoor air quality. ASHRAE Transactions-American Society of Heating Refrigerating Air Conditioning Engineering. 1994; 100(2):902-913.

ANSI/IESNA RP-20-60. 1995. Lighting for Hospitals and Health Care Facilities. Illuminating Engineering Society of North America

Balaras CA, Dascalaki E, Gaglia A. HVAC and indoor thermal conditions in hospital operating rooms. Energy and Buildings. 2007; 39(4):454-470.

Beauchemin KM, Hays P. Sunny hospital rooms expedite recovery from severe and refractory depressions. Journal of Affective Disorders. 1996; 40(1):49-51.

Benedetti F, Colombo C, Barbini B, Campori E, Smeraldi E. Morning sunlight reduces length of hospitalization in bipolar depression. Journal of Affective Disorders. 2001; 62(3):221-223.

Berglund B, Lindvall T, Schwela DH. Guidelines for community noise. In: Guidelines for Community Noise: OMS. 1999.

Cao B, Ouyang Q, Zhu Y, Huang L, Hu H, Deng G. Development of a multivariate regression model for overall satisfaction in public buildings based on field studies in Beijing and Shanghai. Building and Environment. 2012; 47(0):394-399.

De Dear, Richard and Gail Schiller Brager. The adaptive model of thermal comfort and energy conservation in the built environment. International Journal of Biometeorology. 2001; 45(2): 100-108.

De Dear R. Thermal comfort in practice. Indoor Air. 2004; 14(7):32-39.

Fanger PO. Assessment of man's thermal comfort in practice. British Journal of Industrial Medicine. 1973; 30(4):313-324.

Golden RN, Gaynes BN, Ekstrom RD, Hamer RM, Jacobsen FM, Suppes T, Wisner KL, Nemeroff CB. The efficacy of light therapy in the treatment of mood disorders: a review and meta-analysis of the evidence. American Journal of Psychiatry. 2005; 162(4):656-662.

Hwang RL, Lin TP, Cheng MJ, Chien JH. Patient thermal comfort requirement for hospital environments in Taiwan. Building and Environment. 2007; 42(8):2980-2987.

ISO 7730. 2005. Ergonomics of the thermal environment–analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria.

ISO/DIS 28802. 2009. Ergonomics of the physical environment e assessment by means of an environmental survey involving physical measurement of the environment and subjective responses of people. Geneva: International Organization for Standardization.

Institute of Medicine (IOM). 2004. Damp Indoor Spaces and Health, Institute of Medicine, Washington, DC, National Academy Press.

Kim H, Chun C, Kwok A, Ota A, Tamura A. Cross-city comparison of indoor air temperatures in air-conditioned spaces. Indoor Air. 2011; 21(4):311-318.

Kolcaba K. Comfort theory and practice: a vision for holistic health care and research: Springer Publishing Company; 2003. p. 2-17.

Konkani A, Oakley B: Noise in hospital intensive care units—a critical review of a critical topic. Journal of Critical Care 2012, 27(5):521-529.

Li Y, Leung G, Tang J, Yang X, Chao C, Lin J, Lu J, Nielsen PV, Niu J, Qian H. Role of ventilation in airborne transmission of infectious agents in the built environment–a multidisciplinary systematic review. Indoor Air. 2007; 17(1):2-18.

Lorsch HG, Abdou OA. The impact of the building indoor environment on occupant productivity--part 1: recent studies, measures and costs. Transactions-American Society of Heating Refrigerating and Air Conditioning Engineers. 1994; 100:741-741.

Maschke C, Rupp T, Hecht K, Maschke C. The influence of stressors on biochemical reactions-a review of present scientific findings with noise. International Journal of Hygiene and Environmental Health. 2000; 203(1):45-53.

Melikov AK, Cermak R, Majer M. Personalized ventilation: evaluation of different air terminal devices. Energy and Buildings. 2002; 34(8):829-836.

Mui K, Wong L. Acceptable illumination levels for office occupants. Architectural Science Review 2006, 49(2):116-119.

Persily AK. Evaluating building IAQ and ventilation with indoor carbon dioxide. Transactions-American Society of Heating Refrigerating and Air Conditioning Engineers. 1997; 103:193-204.

Skoog J, Fransson N, Jagemar L. Thermal environment in Swedish hospitals: Summer and winter measurements. Energy and Buildings. 2005; 37(8):872-877.

Stoops JL. The Physical Environment and Occupant Thermal Perceptions in Office Buildings An Evaluation of Sampled Data from Five European Countries: Chalmers University of Technology; 2001.

Verderber S, Reuman D. Windows, views and health status in hospital therapeutic environments. Journal of Architectural and Planning Research. 1987; 4(2): 120-133.

Willich SN, Wegscheider K, Stallmann M, Keil T. Noise burden and the risk of myocardial infarction: false interpretation of results due to inadequate treatment of data: reply. European Heart Journal. 2006; 27(5):624-624.

Wong LT, Mui KW, Hui PS. A multivariate-logistic model for acceptance of indoor environmental quality (IEQ) in offices. Building and Environment. 2008; 43(1):1-6.

Yassi A, Kjellstrom T, Kok TD, Guidotti TL. Basic environmental health, vol. 1. Oxford University Press; 2001. p. 52-104.

국문초록

Evaluation of Overall Comfort in Hospitals in Summer using Various Comforts Related Factors

예상온열쾌적도, 이산화탄소의 농도, 실내 소음도 및 조도를 통한 보건의료시설의 실내 쾌적성 평가 연구

이 보 람
서울대학교 보건대학원
환경보건학과 환경보건 전공

지도교수 이 기 영

다양한 실내 환경 중 보건 의료 시설의 경우, 환자와 보호자, 의사, 간호사, 편의시설의 직원 등 다양한 사람들이 활동하는 곳이다. 병원환경에서 노출 될 수 있는 위해 요소는 병원균, 바이러스, 바이오 에어로졸, 미생물등과 같은 생물학적 요인과 무기 혹은 유기 화학물질과 같은 화학적 요인, 온도, 습도, 조도, 소음과 같은 물리적

요인, 그리고 스트레스와 같은 심리적 요인 등이다. 그 중에서 실내 쾌적성에 영향을 미치는 대표적인 요인은 물리적 요인이다. 실내 쾌적도를 평가하는 요소 중 가장 대표적인 것은 PMV (예상온열쾌적도)로 온도, 습도, 기류, 복사열, 활동량, 의복 값을 이용하여 예상온열쾌적도를 구하는 것이다. 그 밖에 실내쾌적에 영향을 주는 요인은 실내 공기 질을 대표하는 지표인 이산화탄소, 음향환경인 소음, 시각적 환경인 조도가 있다.

이 연구는 기존에 개발된 사무실의 통합쾌적도 평가 모델이 병원 실내환경에 적용가능한지 평가하고, 이를 적용시킨 병원의 실내 통합쾌적도를 알아보는 것이다. 측정은 2014년도 5월에서 9월말에 걸쳐 서울의 종합병원 1곳과 경기도의 종합병원 1곳 총 2곳의 종합병원 실내의 각각 5장소에서 쾌적도 측정을 실시하였다. PMV를 평가하기 위한 온도, 습도, 기류, 복사열과 통합실내쾌적도를 평가하기 위하여 소음, 조도, 이산화탄소농도를 1분 간격으로 연속 측정하였다.

Fanger의 PMV 를 이용한 예상온열쾌적도 평가와 Wong의 통합 실내 쾌적도 평가 모델을 이용하여 종합병원의 실내쾌적도를 평가 비교하였다. 예상온열쾌적도가 가장 높았던 곳은 A병원의 응급실이었으며, B병원은 주사실이었다. A병원 보다는 B병원의 예상온열쾌

적도가 더 높았다. 일일 실시간 예상온열쾌적도 양상은 24시간 운영하는 간호사 스테이션과 응급실의 경우는 변화 폭이 비교적 크지 않았으며, 공간 대비 인구가 밀집되는 진료대기실 및 건강검진센터의 변화폭이 비교적 크게 나타났다. 또한 대부분의 장소에서 PMV가 매주 주말마다 상승하는 패턴을 보였다. 모든 측정장소의 평균온도는ASHRAE의 실내온도기준인 21℃-24℃ 범위를 모두 벗어났으며, 이는 정부에서 실시하는 에너지 효율정책으로, 두 종합병원 모두 실내온도를 26℃로 유지하는 것에서 비롯된 결과라 사료된다. 모든 장소의 실내 이산화탄소 농도와, 소음도는 국내 기준을 초과하지 않았다. Wong의 통합실내쾌적도 모델을 이용한 평가 결과통합쾌적도가 0.9이상인 “Good” comfort로 평가된 장소는 없었으며, A병원의 응급실이 0.8, B병원의 간호사 스테이션이 0.89로 가장 높은 쾌적도를 나타냈으며, A병원의 건강검진센터가 0.47 그리고 B병원의 진료대기실이 0.69로 가장 낮은 overall IEQ acceptance를 나타냈다. Wong의 overall IEQ acceptance 모델은 일반 사무실 빌딩의 재실자를 대상으로 개발된 모델로서, 쾌적한 조도의 수준이 600 Lux로 개발된 모델이다. 일반 사무실의 재실자들은 서류, 문서작업등 하며 일반적인 사무실의 조도 기준은 공간의 용도와 작업종류에 따라 100 Lux에서 500 Lux이다. 따라서 병원 방문자들에 대한 평가를 위

해 병원 기준인 300 Lux를 적용하여 조도로 인한 과소평가의 영향을 조절하여 재 평가 하였다. IESNA의 일반 병원의 조도 권고치인 300 Lux를 쾌적한 상태로 보정하여 재 평가를 실시하였다. 그 결과, A병원의 로비, 건강검진센터, 간호사스테이션 그리고 B병원의 진료대기실에서 overall IEQ acceptance는 “Average” 수준 이하였다. 이 결과는 낮은 조도 수준에서 비롯되었는데, 이후 연구에서는 병원 방문자들의 설문조사들을 통한 적정 조도 보정모델의 실효성을 평가하고, 확인하는 연구가 추가 되어야 할 것이다.

주요어: 실내쾌적도, 온열환경, PMV, 통합실내쾌적도, 병원실내환경, 예상온열쾌적도.

학번: 2013-21825