CLIMA 2016 - proceedings of the 12th REHVA World Congress

volume 7

Heiselberg, Per Kvols

Publication date:
2016

Document Version
Publisher's PDF, also known as Version of record

Citation for published version (APA):
Heiselberg, P. K. (Ed.) (2016). *CLIMA 2016 - proceedings of the 12th REHVA World Congress: volume 7*. Department of Civil Engineering, Aalborg University.

Study on Housing Indoor Thermal Comfort Evaluation Using Measurement Around the Winter

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Abstract

In this study, amenity evaluation technique for indoor air quality in the underground space was developed and evaluated real-time amenity by utilizing real-time sensor monitoring system equipped with the technique. The factors used for amenity evaluation were PMV value. The purpose of this paper is to provide a thermal comfort index to Zero Energy Residential Building. For making a thermal performance index of the Zero Energy , Residential Building was a questionnaire and monitoring to the occupant of existing residential building. Questionnaire results showed that the amount of clothing a woman is higher than men, this amount of clothing range was 0.45 ~ 0.92 clo. Main activity in the indoor is sleeping, seating, cooking, house cleaning, it confirmed by the hourly activity. Indoor thermal performance results, the thermal comfort was high as on the canopy household > the top floor household > the lowermost story household > the middle floor household. Research results will be used by comparison and evaluation of thermal comfort data between the Zero-Energy Make Up House and exsiting residential building.

Keywords – Indoor Thermal Comfort; Measurement; PMV Evaluation;

1. Introduction

South Korea has adopted low carbon green growth as national long-term strategy. Initially, it set the greenhouse gas reduction goal to reduce its emissions by 30% below Business As Usual (BAU) emissions by 2020 but the goal was re-adjusted to 37% reduction by 2030 due to the opposition from the civil society and business community. To achieve this goal, many efforts have been made from a variety of industry sectors to reduce emission of greenhouse gases.

In particular, building sector is the most energy consumed industry around the world and its energy consumption is on the rise. As at 2010, the building sector represents 32% of total final energy consumption and 19% of energy base greenhouse gas emission. These data mean that if the energy efficiency in the building sector is not improved, energy consumption in buildings will rise two to three times than the current level by 2050 due to the improvement in civilization and living standards of population in developing countries and increase in energy use facilities.

Accordingly, South Korea divided a building type into residential and non-residential types to reduce energy consumption thereby planning the road map for building energy sector by 2025. For residential buildings, a goal of energy reduction was set to 60% or more energy reduction of the current level, which is a passive house level, by 2017, and a mandatory reduction was planned to ensure a zero energy performance by 2025. To achieve the greenhouse gas reduction goal and energy reduction, a zero energy building pilot project is now underway.

According to the energy saving design standards, a heating setting temperature of apartments in winter shall be in a range of 20–22℃ but the actual indoor temperature in winter was found 24℃ or higher on average. Therefore, it would be difficult to satisfy indoor thermal comfort for residents during the zero energy apartment design according to the energy saving design standards.

Thus, this study investigated environmental changes in air environment by household location by comparing and analyzing thermal comfort in winter according to household locations (rightmost and leftmost households or in-between households living in bottom floor, upper canopy, middle floor, and top floor) as well as measuring indoor air environment factors additionally. The results of this study will be used as foundational data to develop zero energy use apartments while maintaining thermal comfort environments suitable for residents when zero energy apartments are applied in Korea.

2. Evaluation model of thermal comfort in apartments

Existing studies on comfort of thermal environment have been focused on office buildings and evaluations on them have been done through mock-up tests and numerical analysis as well as dynamic simulation. Studies on indoor thermal environments of apartments have been focused on high-rise apartments mainly.

To evaluate the thermal comfort in high-rise apartments, measurements and survey study were conducted to analyze thermal comfort in summer and numerical analysis on air current distribution was conducted to evaluate thermal comfort during air supply in residential spaces. Furthermore, a control method in indoor residential space has been proposed utilizing resident comfort index by analyzing thermal comfort and energy consumption during winter.

The most typical evaluation index that represents thermal comfort of residents is predicted mean vote (PMV), which can establish a thermal equilibrium model at the steady state for human body theoretically and predict person's sensation of warmth or cold as an evaluation index developed by P. O. Fanger in 1967. The PMV and predicted percentage of dissatisfied (PPD) are based on subject experiments conducted within a climate chamber, which is precisely controlled based on thermal equilibrium equation between human and surrounding environment. In early 2000s, 20,693 sets of data were analyzed based on thermal comfort experiments in 160 buildings around the world to verify the PMV model and the result found that prediction based on the PMV was not accurate.

2.1 PMV Model

Based on the PMV evaluation index developed by P. O. Fanger, a number of studies on physical and personal variables in the PMV model have been conducted since 1970s through climate chambers and site measurements. The results of those studies have become international standards such as ASHRAE Standard 5515) and ISO 773016), which have been widely used as indices to evaluate indoor thermal environments. The PMV equation is determined by physical indexes such as temperature, humidity, air current, a mean radiation temperature (MRT), and amounts of wearing clothes and activities. The PMV model is a 7-point scale from -3 (extremely cold) to +3 (extremely hot) to score warmth and cold using the ASHRAE scale in which comfort indoor thermal environment conditions are in a range of -1 (slightly cold) and 0 (neutral) to +1 (slightly warm).

The PMV model was developed based on the steady-state. The model is regarded as a static model and widely used in a variety of areas. However, it is difficult to score physical environment and personal variables accurately in studies on various field measurements. In particular, natural ventilation buildings had a problem of wider comfort range than actual residents were felt17)18). That is, it is difficult for the PMV model to reflect changes in various daily environments experienced by residents and the model revealed its limitation which is difficult to apply for general circumstances except for steady-state spaces where physical variables are relatively changed slowly.

2.2 Adaptive PMV

The adaptive PMV theory was proposed as a reaction to oil price surge in 1970s for the first time. The theory was based on studies on field measurements that comfort zone of residents was increased through a process of adaptive action and thermal adaptation by residents in order to solve the limitation and problems in the PMV model, which was used as a thermal environment evaluation index before then. The differences between PMV and adaptive PMV models are listed in Table 1.

Table 1. The differences between PMV and Adaptive PMV models

Item	PMV model	Adaptation comfort model
Experiment condition	· Climate chamber room isolated from the outdoor	· Daily environment where human lives
Definition of thermal comfort	· State that most people do not complain about thermal condition	· State that is matched between indoor thermal environment condition and thermal expectation of resident
Role of residents	· Passive reactor that receives given environment (thermal stimulation) as it is	· Active being that shows cognitive reaction such as human thought, memory (experience), and expectations

The important premise in the adaptive PMV model theory is that subjects are not passive to thermal stimulation in contrast to them under the test room condition so that subjects take various adaptation behaviors to adjust thermal environments to suit their thermal preference and expectation and attempt to change environmental and personal variables actively to make uncomfortable environment comfortable. The adaptation behavior of the adaptive PMV model theory is divided into three: behavioral, physiological, and psychological adjustments, which are shown in Table 2 Classification of the adaptation behavior.

Table 2. Classification of the adaptation behavior

Category	Behavioral adjustment	Physiological adjustment	Psychological adjustment
Description	- Individual adjustment - Technical adjustment - Indoor environment adjustment - Cultural adaptation	- Genetic adaptation - Climate adaptation	- Personal experience - Personal expectation

3. Overview of evaluation on thermal environment comfort and measurements on the indoor air environments in apartments

3.1 Overview of thermal comfort and indoor air environment monitoring in apartments

In order to determine thermal comfort performance and status of indoor air environment in apartments, thermal environment monitoring was conducted with 30 rental housing households in S District located in Seoul from Nov. 30 to Dec. 25 in 2015. The monitoring location of plan, thermal environment, and indoor air environment was installed at the center of the living room.

The measured households were rightmost and leftmost houses and in-between houses in the bottom floor, upper canopy, the middle floor, and the top floor. Monitoring was done for three days for each household. The measurement equipment to measure thermal environments is shown Table 3.

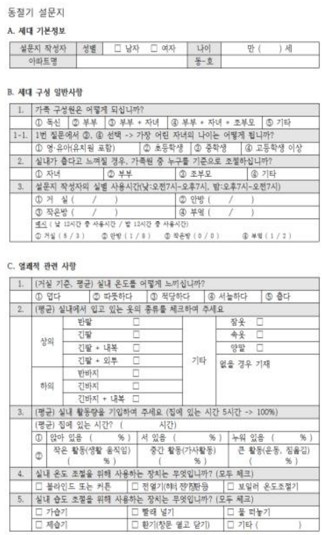
Table 3. Monitoring measurement items and equipment

<table>
<tr><th colspan="2">Measurement item</th><th>Used equipment</th><th>Measurement interval</th></tr>
<tr><td rowspan="3">Outdoor</td><td>Temperature (℃)</td><td rowspan="3">Utilizing KMA data of Seoul at Jan and Feb 2015</td><td rowspan="3">1 hour</td></tr>
<tr><td>Wind speed (m/s)</td></tr>
<tr><td>Solar radiation (W/m2)</td></tr>
<tr><td rowspan="9">Indoor</td><td>Bulb globe temperature (℃) (mean radiant temperature)</td><td rowspan="5">Temperature/humid data logger(Testo 480)</td><td rowspan="5">5 min</td></tr>
<tr><td>Indoor temperature (℃)</td></tr>
<tr><td>Air current (m/s)</td></tr>
<tr><td>Humidity (RH %)</td></tr>
<tr><td>Pressure (hPa)</td></tr>
<tr><td>Surface temperature (℃)</td><td>Infrared rays thermometer</td><td>-</td></tr>
<tr><td>VOCs</td><td>HAL-HVX501</td><td>instantaneous measurement</td></tr>
<tr><td>CO2</td><td>Wohler KM 410</td><td>instantaneous measurement</td></tr>
<tr><td>PM10</td><td>CW-HAT200S</td><td>instantaneous measurement</td></tr>
</table>

3.2 Overview of the survey on residential behavior of residents

In order to determine thermal In order to determine thermal environment performance, a survey was conducted as an interview format to know gender, schedule, and wearing clothes during winter during the monitoring for each household. The survey items are summarized in Table 4,

Table 4. Survey items and questionnaire

Measurement item		**Questionnaire**
Basic Information	Gender	
	Age	
	Residential address	
Household type	Family member	
	Residential type	
	Resident schedule	
Thermal comfort-related item	Wearing clothes	
	Thermal comfort by hour	
	Behavior by indoor activity time	
	Temperature and humidity adjustment device other than boiler	

동절기 설문지

A. 세대 기본정보

설문지 작성자	성별	☐ 남자 ☐ 여자	나이	만 ( ) 세
아파트명			동-호	

B. 세대 구성 일반사항

1. 가족 구성원은 어떻게 되십니까?
① 독신 ② 부부 ③ 부부 + 자녀 ④ 부부 + 자녀 + 조부모 ⑤ 기타

1-1. 1번 질문에서 ③, ④ 선택 -> 가장 어린 자녀의 나이는 어떻게 됩니까?
① 영·유아(유치원 포함) ② 초등학생 ③ 중학생 ④ 고등학생 이상

2. 실내가 춥다고 느껴질 경우, 가족원 중 누구를 기준으로 조절하십니까?
① 자녀 ② 부부 ③ 조부모 ④ 기타

3. 설문지 작성자의 실별 사용시간(낮:오전7시-오후7시, 밤:오후7시-오전7시)
① 거 실 (/) ② 안방 (/)
③ 작은방 (/) ④ 부엌 (/)
예시 (낮 12시간 중 사용시간 / 밤 12시간 중 사용시간)
① 거실 (5 / 3) ② 안방 (1 / 8) ③ 작은방 (0 / 0) ④ 부엌 (1 / 2)

C. 열쾌적 관련 사항

1. (거실 기준, 평균) 실내 온도를 어떻게 느끼십니까?
① 덥다 ② 따뜻하다 ③ 적당하다 ④ 서늘하다 ⑤ 춥다

2. (평균) 실내에서 입고 있는 옷의 종류를 체크하여 주세요

상의	반팔 ☐	기타	잠옷 ☐
	긴팔 ☐		속옷 ☐
	긴팔 + 내복 ☐		양말 ☐
	긴팔 + 외투 ☐		없을 경우 기재
하의	반바지 ☐		
	긴바지 ☐		
	긴바지 + 내복 ☐		

3. (평균) 실내 활동량을 기입하여 주세요 (집에 있는 시간 5시간 -> 100%)
(평균) 집에 있는 시간? (시간)
① 앉아 있음 (%) 서 있음 (%) 누워 있음 (%)
② 작은 활동(생활 움직임) (%) 중간 활동(가사활동) (%) 큰 활동(운동, 짐옮김) (%)

4. 실내 온도 조절을 위해 사용하는 장치는 무엇입니까? (모두 체크)
☐ 블라인드 또는 커튼 ☐ 전열기(히터 전기장판 등) ☐ 보일러 온도조절기

5. 실내 습도 조절을 위해 사용하는 장치는 무엇입니까? (모두 체크)
☐ 가습기 ☐ 빨래 널기 ☐ 물 떠놓기
☐ 제습기 ☐ 환기(창문 열고 닫기) ☐ 기타 ( )

4. Evaluation model of thermal comfort in apartments

4.1 Survey results of residents

The heading of the The survey result to evaluate the wearing clothes and activities done by residents showed that main indoor activities were sleep, sitting and resting (watching TV), cooking, and house cleaning. Accordingly, an amount of each activity (a mean value was applied for cooking and house cleaning) identified via ASHRAE Standard 55 is shown in Figure 2 (activity amount of residents by hour).

For wearing clothes, a difference was found according to gender. That is, women wore thicker clothes than men did. Men wore thin T-shirts and pants or sweat pants during winter while women wore thick T-shirts and skirt or pants. As a result, a wearing amount of residents was 0.45–0.92 and a mean amount was 0.67.

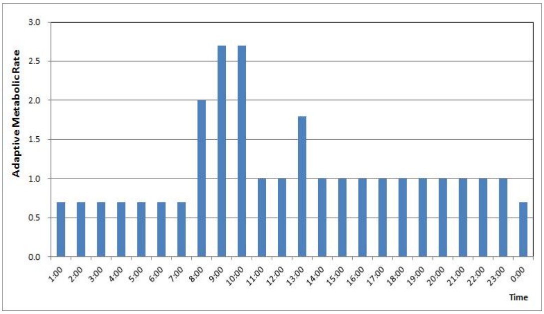


Fig. 1 Activity amount of residents by hour

4.2 Evaluation result on thermal environment comfort

The heading of the In order to evaluate thermal comfort in apartments during winter, thermal environment monitoring on each household was done and outdoor temperature and solar radiation were checked through Seoul meteorological data, which are shown in Figure 2 and a mean outside wind velocity was approximately 2.8 m/s. And the red line is the average outside temperature, the yellow line is the average insolation.

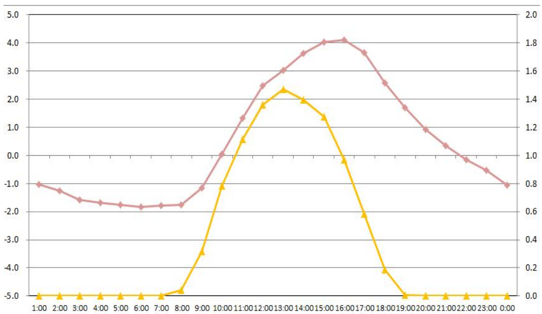


Fig. 2 Distribution of outdoor temperature

The indoor temperature distribution of monitoring household showed that the maximum temperature, minimum temperature, and mean temperature were 26.3℃, 19.0℃, and 22.1℃, which met the heating setting temperature of 20–22℃ during winter according to the Korean Energy Saving Design Standards. Figure 3 shows the frequency of the mean temperature by hour in measured households, in which approximately 46% of the households were over 22℃ of their indoor temperature.

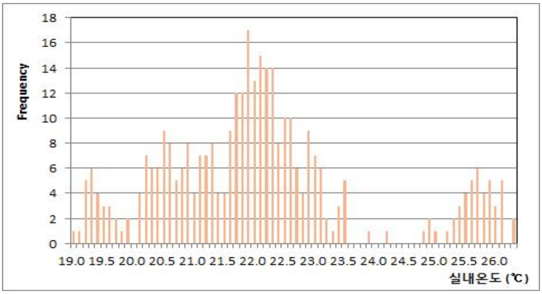


Fig. 3 Distribution of indoor temperature in households

Among the monitoring indoor temperatures, lowest temperature 19.0℃ was obtained from one of the rightmost and leftmost households at the upper canopy where heat was lost through the bottom surface and side walls to the outside compared to other households.

In previous studies on evaluations on thermal environment comfort by households, outdoor and operative temperatures, humidity, activity amounts, and wearing clothes were compensated to derive PMVnew. However, this study analyzed PMV values based on the survey results about activity amounts (living pattern) and wearing clothes, which was why the PMV result values were applied without compensation.

Based on the monitoring results on thermal environment and survey results of residents living in upper canopy, thermal environment comfort performance for each household was evaluated, which is shown in Figure 4.

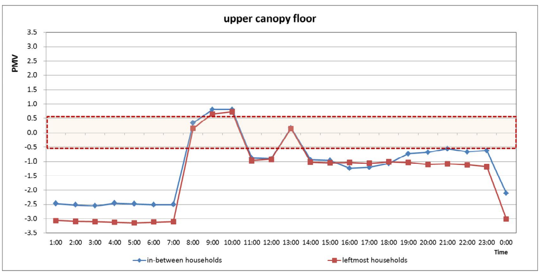


Fig. 4 Thermal comfort performance in households at the upper canopy floor

For residents living in the upper canopy, the PMV comfort range, which was within ±0.5, was achieved when residents increased activity amounts such as house cleaning or cooking. When they were sitting and resting (watching TV), PMV comfort was -1, which was felt as slightly cool. This was also due to the lost heat through external walls compared to other households as the same as the indoor temperature monitoring results. As another factor for this result, monitoring was not done at the sleep space of residents because monitoring location was the center of the living room from 0 to 8 am. A difference in rightmost and leftmost households and in-between households was approximately 0.5 occurred at times (resting and watching TV) when residents had few activities.

The monitoring result of thermal environment at the bottom household showed that thermal comfort performance was indicated as shown in Figure 5. Similar to the households in the upper canopy, the bottom floor household had the comfort range at times when activities of the residents were active. The in-between household at the bottom floor had the comfort range during the most activity times in the living room except for sleeping time while the rightmost and leftmost households felt slightly cool as PMV value was -1, which was similar to the canopy households at the resting time even in the living room.

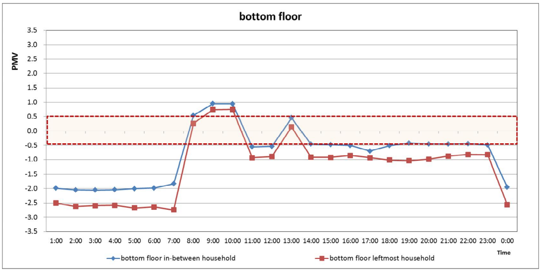


Fig. 5 Thermal comfort performance at the bottom floor household

The monitoring result of thermal environment at the middle household showed that thermal comfort performance was indicated as shown in Fig.7.

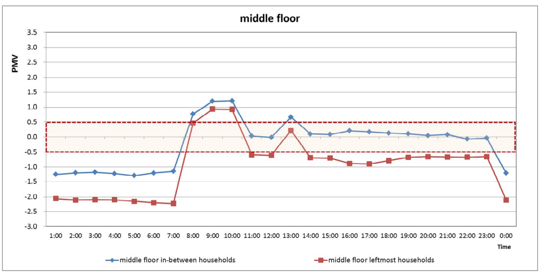


Fig. 6 Thermal comfort performance at the middle floor household

The middle floor in-between households had the comfort range at all activity times in the living room except for morning cooking and cleaning time (PMV value +1.2) and the in-between households had -0.6, which was close to the comfort range even at resting (watching TV, 19:00–23:00). The survey result showed that the in-between households turned their boiler off to save energy during day time (15:00–17:00), which was why those times had lower thermal comfort performance than other times.

The monitoring result of thermal environment at the top household showed that thermal comfort performance was indicated as shown in Figure 8 (Thermal comfort performance at the top floor household). The top floor also showed that in-between households had better thermal comfort performance than rightmost and leftmost households similar to other floor households. The thermal comfort performance during the activity times in the living room showed that the in-between households met the comfort range almost at all times whereas the rightmost and leftmost households felt slightly cool as their PMV value was approximately -0.8 at night time (18:00–23:00).

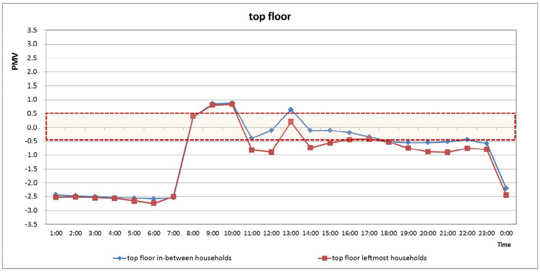


Fig. 7 Thermal comfort performance at top floor household

5. Evaluation model of thermal comfort in apartments

This study verified thermal comfort performance in apartments during winter and conducted monitoring and survey on thermal performance and indoor air environment to determine the status of indoor air environments thereby evaluating thermal comfort performance and measuring indoor air environments in rental houses.

(a) Result of thermal environment monitoring for each household

The mean outdoor temperature was in a range of –2.4℃–4.4℃ during the measurement period. The indoor temperature was ranged between 19.0℃ – 26.3℃ and its mean temperature was 22.1℃. The bulb globe temperature was ranged between 18.0℃ –26.6℃, and its mean temperature was 21.6℃. The indoor mean temperature was revealed as similar to the energy saving design standard, which was 20–22℃ but a frequency that exceeded 22℃ accounted for 46% approximately, which suggested that the standard shall be revised considering thermal comfort felt by the residents.

(b) Result of the survey

The survey results on activity amounts such as wearing clothes by residents for each household to analyze thermal comfort performance showed that main indoor activities were sleeping, sitting and resting (watching TV), cooking, and cleaning (Figure 2). For wearing clothes, a difference was found according to gender. That is, women wore thicker clothes than men did. As a result, a wearing amount of residents was 0.45–0.92 and a mean amount was 0.67.

(c) Result of thermal comfort performance

Thermal environments in apartments were monitored and thermal comfort performance of residents were examined through activities and wearing clothes and the best result was the upper canopy household followed by the top floor household, the bottom floor household, and the middle floor household. The top floor households showed that thermal comfort performance at the night time was similar to that of the upper canopy household but during the day time, thermal performance was better than the bottom floor household due to solar radiation via the top roof surface. The comparison result between rightmost and leftmost households and in-between households showed that rightmost and leftmost households whose walls were faced outdoor air more than in-between households had higher thermal discomfort. In the future, the study results will be utilized as comparison and evaluation data for thermal comfort performance in zero energy demonstration complex and thermal comfort felt by residents will be compared and analyzed according to energy usage measured at the zero energy complex.

Acknowledgment

This study is supported by the research grant (13AUDP-B067603-01) provided by the Urban Construction Research and Development Project in the Ministry of Land, Infrastructure, and Transport.

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[2] IPCC(2014)Intergovermental panels on Climate Change AR5(WG3) Chapter9 Buidings