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A field study on thermal comfort in the shopping malls in a temperate humid climate

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Abstract

Shopping Malls where the number of occupants changes according to the days use the HVAC systems in order to provide thermal comfort. This study evaluated the relation between efficiency of the HVAC systems and thermal comfort conditions in the heating and cooling seasons. The aim of this study is to compare the indoor thermal comfort conditions according to standards. In order to analyze the thermal comfort conditions of two enclosed above-ground shopping malls that have a different HVAC systems, measurements (PMV-PPD) and surveys (AMV-APD) were conducted simultaneously. Occupant density and energy consumption data were taken from the shopping malls. The results show that the cooling season was more comfortable than the heating season in both shopping malls and one of the Shopping Malls has a better thermal comfort and a less energy consumption although it has a higher occupant density. According to the results, suggestions were developed for improving the thermal comfort conditions and reducing the energy consumption.

Keywords
AMV-APD, Energy efficiency, PMV-PPD, Shopping malls, Thermal comfort.

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1. Introduction

Nowadays, shopping malls not only meet the shopping needs but also meet the social needs of the people. The number of shopping malls has increased in the past few years (Turkish Federation of Shopping Centers and Retailers, TFSCR, 2016). The increase in the number of the occupants in the shopping malls also increases the importance of maintaining the thermal comfort conditions and energy consumptions. A thermally comfortable indoor environment has significant impact not only on shoppers' well-being, but also the attractiveness of shopping malls (Shang et al., 2016). In this regard, providing and maintaining the thermal comfort condition are important in terms of physical and mental health, especially in enclosed shopping malls.

There are lots of detailed and superficial researches on thermal comfort. When the thermal comfort studies are investigated, it is seen that the functions of the buildings are generally the residential buildings (Chen et al., 2017; Liu et al., 2017; Yu et al., 2017; Yao et al., 2018; Hansen et al., 2019) and office buildings (Karyono, 2000; Liu et al., 2013; Indraganti et al. 2015; Kumar et al., 2016; Andargie & Azar, 2019; Che et al., 2019; Thapa, 2020) and some of these studies are aimed to reduce energy consumption (Karyono, 2000; Chen et al., 2017; Yao et al., 2018; Che et al., 2019; Hansen et al., 2019). However, a few studies have been conducted on the thermal comfort conditions in the enclosed above-ground shopping malls, and these mainly concentrated on temperate humid climate regions and especially carried out during cooling season.

Chun and Tamura conducted a research in order to analyze two underground shopping malls and department stores in Japan in terms of thermal environment and the occupant sensations. As a result, the measurement results of this study showed that the underground shopping malls have unstable thermal conditions compared to the department store (Chun & Tamura, 1998). Kwok et al. not only explained the energy management decisions for the commitment to the voluntary energy conservation agreement but also conducted a survey study in order to understand the occupant satisfaction at a specified temperature during the summer season regarding thermal conditions in the shopping malls in Hong Kong. As a result, suggestions were made related to the thermal comfort and energy consumption (Kwok et al., 2017). Shang et al. conducted a study on thermal parameters, CO2, TVOC and formaldehyde concentrations in the shopping malls in China during the summer season. It is aimed to contribute to the perception of people, the pollutants and the air-conditioning systems (Shang et al., 2016). Li et al. carried out a field study (measurements and survey) on thermal environment in six underground shopping malls in China during summer. Thermal Sensation Votes (TSV) of the occupants and Predicted Mean Vote (PMV) were compared. The sensations of the occupants in the thermal environment were evaluated according to the temperature, relative humidity, air velocity variables and customer's duration (Li et al., 2018).

In the indoor environments that have a HVAC (Heating, ventilation, and air conditioning) systems, vast amount of energy is consumed in order to provide and maintain the thermal comfort conditions. When the number and the gross areas of the shopping malls are considered, it is well understood that attention must be paid to the amount of energy consumed while providing and maintaining the thermal comfort conditions. There are a limited number of researches, in the current literature, that take into account the energy consumption in the field of the shopping malls and thermal comfort. Chow and Lam conducted a field study on the thermal comfort and energy consumption of the commercial buildings in Hong Kong. In the study that includes the shopping malls, the buildings having different functions such as restaurants, hotels and offices are also presented. As a result of the study, it was observed that most of the spaces are cooled 3-4 0C more than the required temperature during the summer season. Also, with the help of the building energy simulation programs it was seen that for a typical office, raising indoor air comfort temperature set-point from 21.5 to 25 achieved an energy saving of 29% during summer (Chow & Lam, 1992). Lam et al. measured the thermal and visual conditions of ten shopping malls with an HVAC systems in Hong Kong and compared them according to the international standards. The effects of the thermal and visual conditions on energy consumption were generally calculated and evaluated (Lam et al., 2001).

In the current literature, the limited number of studies examining both thermal comfort and energy consumption in shopping malls have been conducted in cooling and heating seasons of temperate humid climate. Most of these studies were conducted in underground shopping malls. The underground shopping malls are different from above-ground shopping malls in terms of environmental effects (solar radiation, air velocity, etc) and indoor thermal environments. Thus, the scope of the study is determined considering the need for defining the thermal comfort condition in enclosed above-ground shopping malls in temperate humid climates regarding energy consumption.

This study is based on the hypothesis that the efficiency of the HVAC systems is different in terms of providing and maintaining thermal comfort conditions of the shopping malls in the heating and cooling seasons. This study aims to investigate whether the shopping malls having a high percentage in energy consumption are in compliance with the thermal comfort conditions. In addition this study propose suggestions for reducing the energy consumption while at the same time maintaining the thermal comfort.

This study, unlike other studies carried out for the temperate humid climate regions, determined that cooling season was more comfortable than heating season. In both seasons the amount of energy consumption was higher than the amount needed to maintain good thermal comfort.

2. Methodology

Two enclosed above-ground shopping malls were selected as thermal comfort study fields. Measurement and survey conditions (seasons, days, hours and points) were determined according to the weather data, occupant density, plans (interior design) and functions.

Thermal comfort data (measurements and surveys) of the shopping malls were collected and also occupant density and energy consumption data were obtained from technical offices of shopping malls. Measurements and surveys were conducted simultaneously between 15.00-19.00 at the same

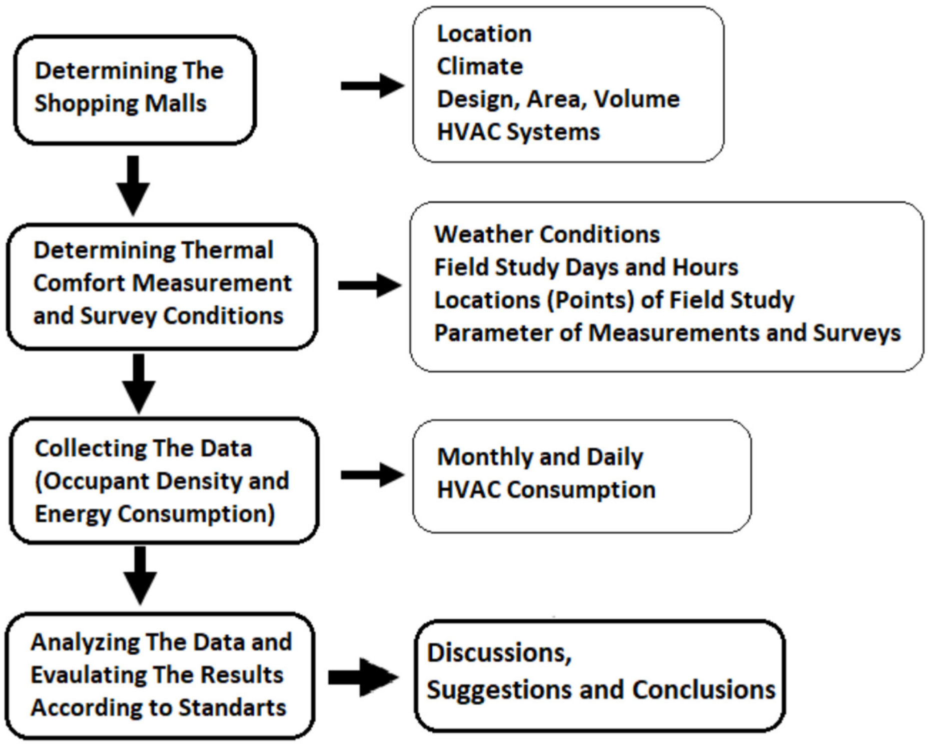


Figure 1. *Method of the study.*

points. The measurement results were compared with international standards. In addition, survey results and measurement results were evaluated and compared with each other. Thermal comfort values were associated with energy consumption and occupant density. According to the results, suggestions were proposed for improving the thermal comfort conditions and reducing the energy consumption at the same time. The method of this study is shown in Fig. 1.

2.1. Determining the shopping malls and the field study conditions

The outdoor conditions are important factors that affect the indoor thermal comfort conditions. This study was conducted in two enclosed above-ground shopping malls on the same transportation axis close to each other for similar weather conditions in Istanbul, Turkey.

The importance of green building rating systems increases day by day, within the concept of sustainable architecture. One of the shopping malls was specifically selected because it has a green energy certificate. Since the HVAC system type is one of the important parameters in thermal comfort and energy consumption, the shopping malls were selected such that they have different types of HVAC systems (heat pumps and air conditioning units).

Shopping Mall 1 (S. Mall 1) is located in a mixed-use project that is composed of shopping malls, residences and offices. The area of the S. Mall 1 is 152,997 m2. The architectural roof system consists of skylights covering the gallery spaces. The skylight to roof ratio (SRR) of S. Mall 1 is 11%. The window to wall ratio (WWR) of S. Mall 1 is 54.8% for the South fa-

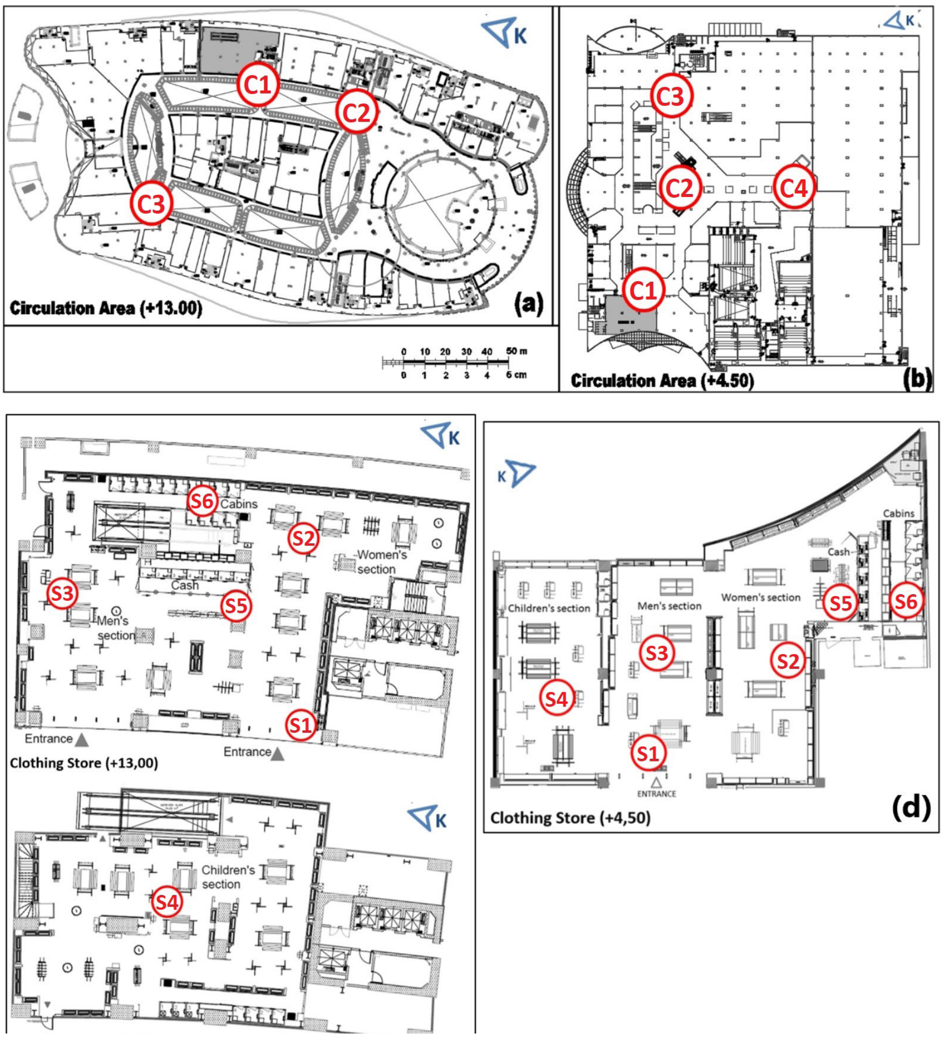


Figure 2. *Measurement points in the circulation areas of S. Mall 1 (a) and S. Mall 2 (b) and inside the clothing stores of S. Mall 1 (c) and S. Mall 2 (d).*

cade, 32.2% for the North facade and there is not or <5% for other facades. In 2013, it certificated as "good" from BREEAM Certification System. The air-conditioning of the shopping mall is accomplished using heat pumps. An automatic system is used to set the required temperature and the fresh air volume in S. Mall 1.

Shopping mall 2 (S. Mall 2) is only consist of shopping mall. The area of the S. Mall 2 is 154,587 m2. The architectural roof system consists of skylights covering the gallery spaces. The SRR of S. Mall 2 is 2.5%. The WWR of S. Mall 2 is 13.9% for the Northeast, 7.4% for the Southeast and there is not or <5% for other facades. The air-conditioning of the shopping mall is accomplished via ACU (Air Conditioning Units).

The stores (clothing stores of the same brand) and circulation areas were determined as measurement areas because they are widely used units. Clothing stores have different sections such as women's and men's. The number of occupants of these sections is different. Measurement points were selected on plans (Fig. 2) according to the functions of the sections and the number of occupants. The measurement points are S1 (Entrance), S2 (Women's section), S3 (Men's section), S4 (Children's section), S5 (Cash), S6 (Cabins). The points in the circulation area were determined in areas not affected by direct solar radiation and natural ventilation.

When the weather condition of Istanbul is analyzed, it is seen that from 1929 to the year 2017 annual mean temperature is 14,4 °C, sunshine duration is 79,7 hours and monthly precipitation is 817,4 mm (Turkish Republic Ministry of Forestry And Water Affairs, 2018). This study was carried out during heating (March, April) and cooling (July) season for the comparison. Occupant thermal sensation in the shopping malls can vary based on the occupant density of the shopping mall. Thus, the field study days and hours were determined as Thursday, Friday, Saturday and Sunday and between 15.00-19.00, respectively. Field study days and weather conditions data for these days are given in Table 1.

2.2. Determining the thermal comfort parameters

According to the steady-state model, Fanger developed a scale consist of seven different senses that define the thermal sensation of the people for the conditioned spaces (Fanger, 1970).

AMV (Actual Mean Vote) is used to measure the thermal condition satisfaction of the occupants. APD (Actual Percentage Dissatisfied) is used to measure the thermal condition dissatisfaction of the occupants. They are used to determine the thermal comfort level of the environment via ASHRAE 55 (American Society of Heating, Refrigerating and Air-Conditioning Engineers) seven-point thermal sensation scale. PMV (Predicted Mean Vote) is calculated according to this scale by taking into account six variables such as clothing insulation, activity level, indoor air temperature, mean radiant temperature, air velocity and relative humidity. Since the thermal sensation changes according to the physiological and psychological variables of a person, PPD (Predicted Percentage of Dissatisfied) index is used together with PMV for determining the thermal condition. In this model, PMV and PPD are developed to evaluate and predict the mean thermal comfort and the percentage of dissatisfaction with the thermal environment of a group of people rather than each individual.

Calculation the PMV and PPD using equations and classification regarding the PMV and PPD values that describe the satisfaction state is given in ASHRAE 55 and ISO 7730 (International Standardization Organization) Standards (BS EN ISO 7730, 2005; ANSI/ASHRAE Standard 55, 2017).

2.3. Determining the thermal comfort measurement conditions

The measurements were carried out with Testo 480 - Digital Temperature and Humidity Meter (Testo 480- Product Details, 2019). This device has an air velocity probe, a black globe probe and a temperature and humidity probe. Testo 480 gives the thermal comfort as PMV and PPD according to the input data and the instantaneous values of the objective parameters.

The input data were entered to the thermal comfort meter based on ISO

Table 1. Weather conditions of the field study days.

Heating Season								
	S. Mall 1				**S. Mall 2**			
Date (2017)	**30.03**	**31.03**	**01.04**	**02.04**	**23.03**	**24.03**	**25.03**	**26.03**
Mean Temperature (°C)	11,8	9,3	7,9	7,8	9	8,7	8,6	9
Mean Relative Humidity (%)	57,6	86	69,4	76,6	78	84,2	83,8	85,7
Mean air velocity (m/sn)	3,8	5,9	4,3	4,5	2,2	1,4	1,5	1,2
Cooling Season								
	S. Mall 1				**S. Mall 2**			
Date (2017)	**13.07**	**14.07**	**15.07**	**16.07**	**06.07**	**07.07**	**08.07**	**09.07**
Mean Temperature (°C)	25,4	23,6	25,0	21,9	23,2	22,7	23,3	23,9
Mean Relative Humidity (%)	87,3	78,1	76,0	57,3	59,0	71,0	56,5	57,2
Mean air velocity (m/sn)	2,2	4,5	5,0	5,4	2,2	2,3	1,9	1,1

Note: Prevailing wind direction is between North East and North West in Istanbul.

7730 and ASHRAE 55 Standards (BS EN ISO 7730, 2005; ANSI/ASHRAE Standard 55, 2017). The input data were determined as clothing insulation value: 1 clo during heating season, 0.5 clo during cooling season, Activity Level: 1.6 met.

Taking into account the customers' duration time in store, measurements were carried out for 10 minutes at 30 second intervals at each point.

ASHRAE 55 stated that air temperature and average air speed shall be measured at the 0.1, 1.1, and 1.7 m height levels and operative temperature (to) or PMV shall be measured or calculated at the 1.1 m level for standing occupants (ANSI/ASHRAE Standard 55, 2017). In addition, it is assumed that people use their hands for shopping at an average height of 1.1 m and this value is determined as the measurement height.

2.4. Determining the thermal comfort survey conditions

Since the differences in thermal comfort can be due to physiological reasons (Fountaın et al., 1999), surveys should be conducted for the correct evaluation. The aim of the surveys is to determine the thermal comfort conditions of the customers in the stores and to compare survey results with measurement results. For a proper comparison, surveys were conducted at the same time and at the same points with the measurements. In order to determine the quality and convenience of the surveys, a pilot study is conducted on a group of people prior to the field study. Correct understanding and answering of the survey questions affect the reliability of the results. Therefore, the surveys were asked to the participants verbally and the possible mistakes were minimized.

Gender, age, and other factors might lead to individual difference in thermal comfort (Wang et al., 2018). Demographic questions in the survey include age, gender, weight, education level, employment status.

The comfort temperature changes according to adjustment behaviour which are mainly due to changes of clothing (Takasu et al., 2017). Since another important parameter affecting thermal comfort is clothing insulation value, questions were asked to assess the clothes on the participants in the survey. In order to compare the thermal sensations of the participants, clothing insulation values were calculated separately for the two seasons. It is considered that the sensations of the people to the thermal conditions change over time. In this regard, questions were directed to the participants for the purpose of determining the variation of the thermal condition based on the duration they were in the store. The other question was asked to determine the relation between the locations (measurement points) of the customers and thermal comfort condition. The questions were asked to rate thermal sensations on the ASHRAE 55 seven-point thermal sensation scale. Answers were used to find AMV and APD.

Figure 3. The occupant density (total number of people) according to measurement dates (a) and the relationship between Indoor Environmental Conditions of S2 (women) point (b).

3. Results

PMV and PPD are based on measurements and AMV and APD are based on surveys. Statistical analyses were performed using SPSS 22 (Statistical Package for the Social Sciences). Occupant density and energy consumption data of the HVAC systems were taken from the shopping malls' management and technical departments.

3.1. Occupant density in the shopping malls

Human body produces heat at the end of the metabolic activity. Since the metabolic heat production will be high in spaces where the number of people is high, it can cause thermal discomfort especially in indoor environments. The number of occupants, of course, changes according to days in the shopping malls.

Occupant density of the S. Mall 1 and S. Mall 2 during the heating and cooling seasons related to study days are given in figure 3 (a). The total number of occupants in the heating season, in March is 1.411,399 (million) people for S. Mall 1 and 831,959 (thousand) people for S. Mall 2; in the cooling season in July total number of occupants is 892,360 (thousand) people for S. Mall 1. Occupant density increases on Saturdays and Sundays in both seasons (Fig. 3 (a)). It is seen that the occupant density of the S. Mall 1 is higher than the S. Mall 2 when daily and monthly data are analyzed.

3.2. Thermal comfort measurement results in the shopping malls

In the evaluation of the measurements, -0,5<PMV<+0,5 range is considered as comfortable according to ISO 7730 and ASHRAE 55 standards. The closer the PMV is to 0, the more comfortable the environment. PMV obtained from measurements were evaluated according to this range (BS EN ISO 7730, 2005; ANSI/ASHRAE Standard 55, 2017). In the evaluation, results on the hot side mean greater than neutral and on the cold side means less than neutral. The measurement results are shown in the Fig. 4.

According to the measurement results, PMV is on the hot side (above neutral) at all the measurement points in both S. Malls and during both season (except S6 (cabin) in the S. Mall 1 during the cooling season). S. Mall 1 and S. Mall 2 have exceeded the comfort range by 62% and 76% on the hot side during the heating season, respectively. PMV is within the comfort range in cooling season. PMV value of S. Mall 1 is within the comfort range in cooling season and is close to neutral by 2% and

69% on the hot side according to comfort range (Fig. 4 and Table 3). PMV value of S. Mall 2 has exceeded the comfort range by 4% on the hot side during the cooling season. Measurement results show that the cooling season is more comfortable than the heating season for both of the shopping malls (Fig. 4). According to the measurement results Saturdays and Sundays are generally the most uncomfortable days (Fig. 4). The relation between PMV and occupant density is statistically significant because of p<0,05 according to analysis of variance (ANOVA) and is positive because r is positive according to analysis of correlations. Therefore, the increase in the occupant density caused the PMV to increase on the hot side. The occupant density has affected the indoor air temperature and relative humidity of the S2 point especially in S. Mall 2 (Fig. 3 and 4). Inside the store, generally S2 (women) point is the most uncomfortable point among the measurement points. There is a decrease in PMV value from Point 1 to Point 6 because r is negative according to analysis of correlations.

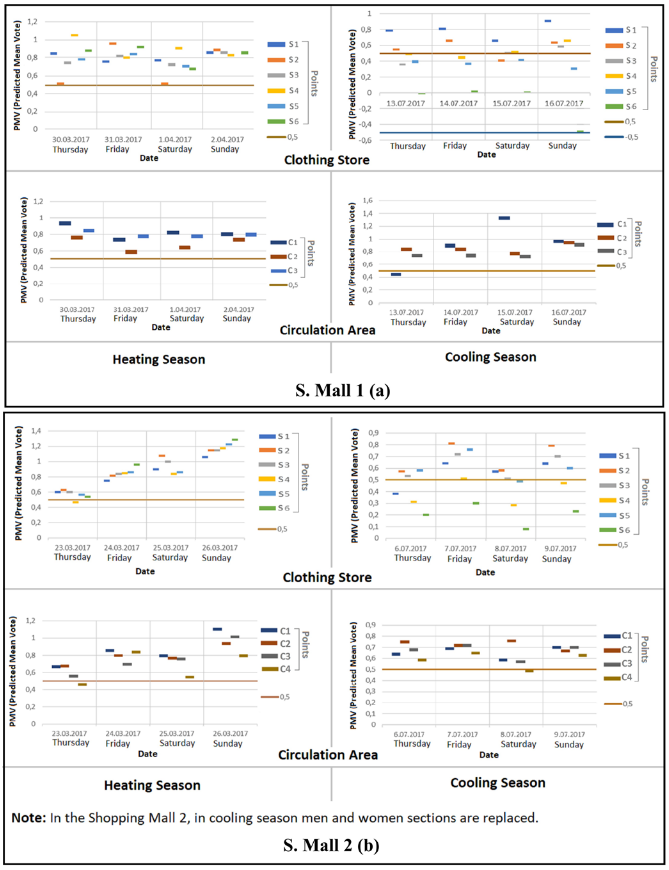


Figure 4. *Thermal comfort measurement results of the S. Mall 1 (a) and S. Mall 2 (b).*

3.3. Thermal comfort survey results in the shopping malls

Results obtained upon processing and analyzing the surveys are presented in Table 2.

The relationship between gender, age, clothing insulation values, location, day and duration data and thermal comfort were examined. According to Cross Tabulation analysis, it is seen that men feel hotter than women during heating season (60.9% of males and 54.1% of females felt hotter) while there is no significant difference during the cooling season. It is determined that as the age gets older thermal sensation approaches normal during both cooling and heating seasons. The average clothing insulation value of the participants during the cooling season is 0.45 clo while during the heating season 0.80 clo. The identified clothing insulation values according to the survey results are closer to the measurement input data determined according to the standards in the cooling season than in the heating season.

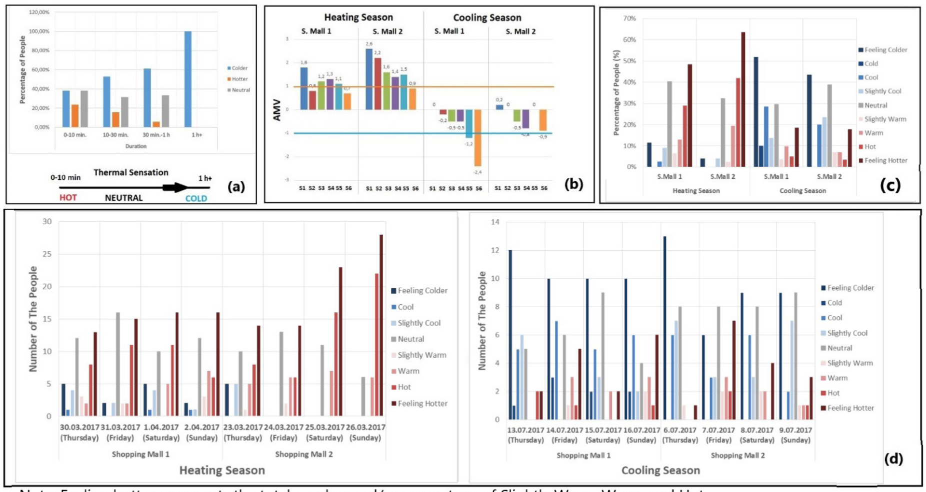
According to analysis of variance (ANOVA), in the cooling season, in both shopping malls as the duration increases, they feel colder in the same environment because they have difficulty in achieving their body heat balance over time. In cooling season, after a certain time people feel colder in a conditioned environment (Fig. 5(a)).

At the end of the analysis, it is identified that especially in S. Mall 1 S6 (Cabin) point was to be uncomfortable

Table 2. *Questions and results of the customer (occupants) surveys.*

Questions		Heating Season		Cooling Season	
		S. Mall 1	S. Mall 2	S. Mall 1	S. Mall 2
Number of Surveys		124	124	81	85
Gender	**Female**	**%73,4**	**%70,2**	**%75,3**	**%67,1**
	Male	%26,6	%29,8	%24,7	%32,9
Age	**12-18**	%10,5	%10,5	%1,2	%5,9
	18-24	%23,4	%24,2	**%35,8**	%15,3
	24-35	**%35,5**	%24,2	%27,2	**%36,5**
	35-50	%20,2	**%28,2**	%29,6	%29,4
	50+	%10,5	%12,9	%6,2	%12,9
Weight (Mean)		67,1	67,57	66,66	70,15
Clo (Mean)		0,75	0,84	0,43	0,48
Location	**S1**	%9,8	%5,6	%2,5	%12,9
	S2	**%32,8**	**%21,8**	**%44,4**	%23,5
	S3	%20,5	%19,4	%14,8	**%24,7**
	S4	%16,4	%21	%18,5	%11,8
	S5	%7,4	%19,4	%11,1	%14,1
	S6	%13,1	%12,9	%8,6	%12,9
Thermal Sensation Values	**Hot (+3)**	%29	**%41,9**	%4,9	%3,5
	Warm (+2)	%12,9	%19,4	%9,9	%7,1
	Slightly Warm (+1)	%6,5	%2,4	%3,7	%7,1
	Neutral (0)	**%40,3**	%32,3	**%29,6**	**%38,8**
	Slightly Cool (-1)	%8,9	%4	%13,6	%23,5
	Cool (-2)	%2,4	%0	%28,4	%20
	Cold (-3)	%0	%0	%9,9	%0

Note: The bold numbers represent high percentages.



Note: Feeling hotter represents the total number and/or percentage of Slightly Warm, Warm, and Hot.
Feeling colder represents the total number and/or percentage of Slightly Cool, Cool, and Cold.

Figure 5. *Thermal sensation according to the duration time in the store in cooling season (a) and to the locations (points) (b). Seasonal thermal sensation (c) and thermal sensation according to study days (d).*

Table 3. *Thermal comfort scales.*

	Heating Season		Cooling Season		ISO 7730 and ASHRAE 55 Standards Comfort Range
	S. Mall 1	S. Mall 2	S. Mall 1	S. Mall 2	
Number of people	124	124	81	85	
AMV (Actual Mean Vote)	1,05	1,58	-0,62	-0,31	-1, 0, +1
Std. Dev. (AMV)	0,16	0,58	0,12	0,44	
APD (Actual Percentage Dissatisfied)	44,3	61,3	53,1	30,6	
PMV (Predicted Mean Vote)	0,81	0,88	0,49	0,52	-0,5 < PMV < 0,5
PPD (Predicted Percentage Dissatisfied)	19,22	22,48	11,56	11,83	<10%

towards the cold side during the cooling season. Also, it is seen that participants feel hotter during heating season and normal during cooling season at S1 (entrance). It has been concluded that S2 (women) point in S. Mall 2 is found to be uncomfortable towards the hot side during heating season and comfortable in both shopping malls during cooling season (Fig. 5(b)).

According to Cross Tabulation analysis, during heating season, there has been an increase in the number of the people who felt hotter than neutral on Saturdays and Sundays (weekends) when compared to Thursday and Friday (weekdays) (Fig. 5(d)). On the other hand, during cooling season there has been generally decrease in the number of the people who felt colder on Saturdays and Sundays (weekends) when compared to Thursday and Friday (weekdays) (Fig. 5(d)).

The acceptable comfort range AMV is classified as +1, 0, -1 (BS EN ISO 7730, 2005; ANSI/ASHRAE Standard 55, 2017). Shopping malls are out of comfort range in heating season. S. Mall 1 and S. Mall 2 have exceeded the comfort range by 5% and 58%, respectively. AMV is within the comfort range in cooling season (Table 3). AMV value of S. Mall 1 and S. Mall 2 are close to neutral by 38% and 69% according to comfort range, respectively. During heating season, the total number of people feeling hotter (Slightly Warm + Warm + Hot) is higher than neutral. During cooling season, the total number of the people feeling colder (Slightly Cool + Cool + Cold) is higher than neutral (Table 2, Fig. 5 (c and d). However, this fact is more apparent in the heating season. Cooling season is more comfortable than heating season (Fig. 5(b and c),

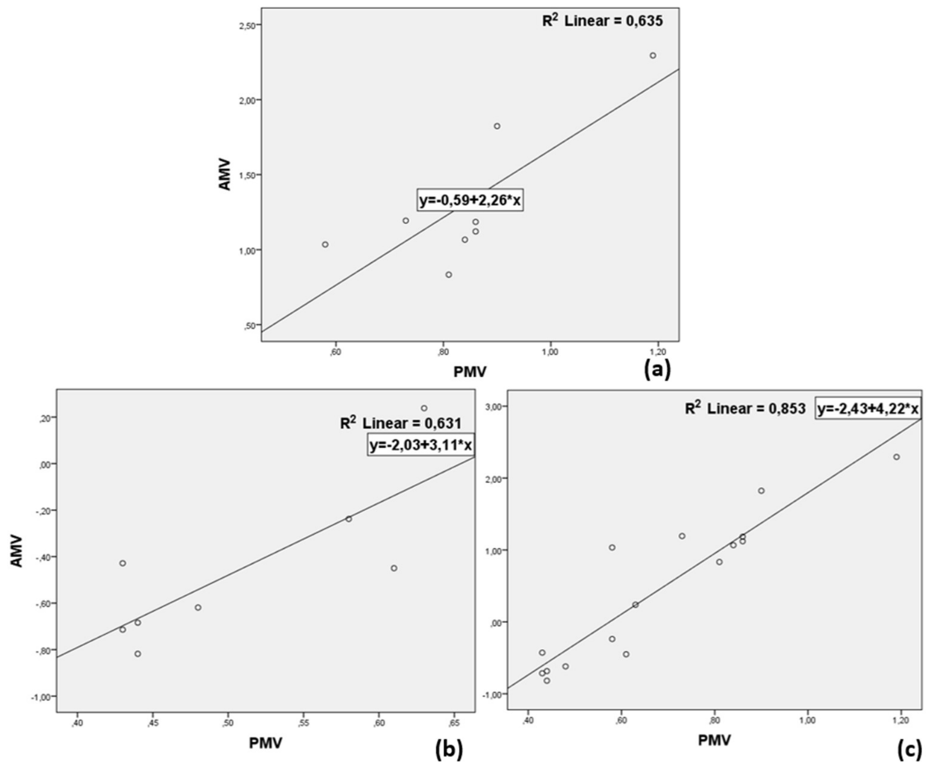


Figure 6. *Linear Regression of AMV-PMV for heating season (a), cooling season (b) and two season (c).*

Table 3). S. Mall 1 is more comfortable than S. Mall 2 during heating season but S. Mall 2 is more comfortable than S. Mall 1 during cooling season according to AMV and APD (Table 3).

Most of the occupants felt colder than neutral although measurement results were positive (hotter) during cooling season (Fig. 4 and Fig. 5 (c and d), Table 2 and 3). Linear regression was used for the comparisons of PMV and AMV. The regression equations control relationship between the variables (dependent and independent). The relation between the variables (dependent and independent) is a statistically significant association when the correlation coefficient (R value) is close to 1. The relationship between PMV and AMV is high (Fig. 6). Linear regression equations are 1 for heating season, 2 for cooling season and 3 for two seasons.

AMV=-0,59+2,26PMV (1) in heating season,

AMV=-2,03+3,11PMV (2) in cooling season and

AMV=-2,43+4,22PMV (3) in two seasons.

3.4. Energy consumption in the shopping malls

Thermal comfort has a direct effect on the comfort, health and productivity of the occupants (Wargocki et al., 2002; De Giuli et al., 2012; Al-Horr et al., 2016) and has a direct impact on energy consumption of any building (Corgnati et al., 2009; Catalina & Iordache, 2012).

Nearly half of the energy consumption in commercial buildings is used to operate heating, ventilation and air conditioning (HVAC) systems (Bisset, 2007; Laustsen, 2008) and varies depending on the location (Enteria & Mizutani 2011). By using the HVAC systems in an increased temperature range reduces energy use by lessening the cooling and heating loads (Hoyt et al., 2009). Energy consumption will reduce significantly with the optimal selection of the set values of air conditioning systems (Arslanoğlu & Yiğit, 2011). Shopping malls that are growing day by day, should use the energy in an effective and efficient way.

HVAC systems are used in the enclosed shopping malls where the study was conducted. Heat pumps are used

Table 4. *Energy consumption data of the HVAC Systems at field study days.*

Months and Days	Heating Season Energy Consumption (kwh)		Cooling Season Energy Consumption (kwh)	
	S. Mall 1	S. Mall 2	S. Mall 1	S. Mall 2
Monthly	323.344,34	376.950	245.263	666.915
Thursday	-	11,590	-	23,232
Friday	-	11,490	-	23,210
Saturday	-	15,530	-	21,440
Sunday	-	11,650	-	21,040

for the air-conditioning system in S. Mall 1. In the air-conditioning system of the S. Mall 1, seasonal temperature adjustment and fresh air amount are changed and fixed with the help of the automation system. The air-conditioning system of the S. Mall 1 is set to 22 °C during heating season while in cooling season it is set to 26 °C. The air-conditioning of S. Mall 2 is provided with air conditioning units (ACU). Heating systems are provided with hot water pipes with a 3-way valve system. Refrigeration compressors are used in the cooling of S. Mall 2 (Shopping mall management, 2017).

Energy consumption data was taken from the energy analyzers in shopping malls and the amount consumed for conditioning was taken consulting the people working at the management and technical departments. Energy consumption data of the S. Mall 1 are saved monthly, thus daily energy consumption data could not be obtained. The energy consumption of the Shopping Malls, during cooling and heating seasons, are presented in Table 4.

The usage area sizes (m2) of the shopping malls that the study is conducted are nearly the same (S. Mall 1: 152,997 m2; S. Mall 2: 154,587 m2). When the energy consumption data are analyzed, in the cooling season, the monthly energy consumption of S. Mall 2 is 172 % more than S. Mall 1. Although heat pump and automation system are used in S. Mall 1, in the heating season, the monthly energy consumption of S. Mall 2 is only 16.5 % more than S. Mall 1. In the S. Mall 1, the monthly energy consumption of heating season is 31.8 % more than cooling season. As given at the end of the study, cooling season was more comfortable than heating season (Fig. 4, Fig. 5(b and c), Table 3). The comfort temperature set-point during the heating period is more than the amount needed in S. Mall 1.

In the S. Mall 2, the monthly energy consumption of cooling season is 76.9 % more than heating season. In cooling season, greenhouse effects occur due to the Shopping Mall's architectural roof system and internal heat gains increase. The greenhouse effect and the lack of an automation system increases the cooling load in the S. Mall 2 in cooling season. The use of the automation system and the heat pumps for the conditioning of the S. Mall 1 lead to an important difference by ensuring an efficient use of energy and lower energy consumption especially in cooling season.

4. The main findings and discussion

As a result of the data obtained, in both seasons the amount of energy consumption was higher than the amount needed to maintain the thermal comfort and this situation causes discomfort. Cooling season was more comfortable than the heating season in both Shopping Malls (Fig. 4, Fig. 5(b and c), Table 3). The S. Mall 1 is generally more comfortable and consumes less energy in cooling and heating seasons than the S. Mall 2 although it has a higher occupant density. The findings obtained while reaching the result are as follows. Suggestions for improving the thermal comfort conditions while simultaneously reducing the energy consumption were developed.

- S. Mall 1: Studies, related to thermal comfort and energy consumption in shopping malls suggested that the temperature set-point should be lower than 25.5 °C during summer (Lam et al., 2001; Shang et al., 2016; Kwok, Xu & Wong, 2017). However, raising indoor air comfort temperature set-point achieved an energy saving during summer (Chow & Lam, 1992; Lam et al., 2001). One of the results of this study is that energy consumption during heating season is higher than during cooling season, but cooling season is more comfortable than the heating season. The reason for this is the HVAC system of the S. Mall 1 is set to 22 °C during heating season. This causes an uncomfortable environment on the warm side and unnecessary energy consumption. This study, determined that the temperature set point was kept high during the heating season. AMV is on the cold side and occupants felt colder than they should feel according to measurement results although set-point was 26 °C during cooling season. The comfort temperature set-points of the HVAC systems should be determined correctly for two seasons.

- S. Mall 2: The amount of energy consumption during cooling season in the S. Mall 2 is higher than the amount of consumed during heating season while the cooling season is more comfortable than the heating season. However, although the monthly energy consumption of cooling season is 76.9 % more than heating season, there is no significant difference in thermal comfort.
- The total number of people feeling hotter (Slightly Warm + Warm + Hot) is higher than neutral and AMV is on the hot side during heating season. Although the S. Mall 1 energy consumption is 16.5% lower than S. Mall 2 in heating season, S. Mall 1 is more comfortable than S. Mall 2 because heat pump and automation system is used in S. Mall 1.
- Thermal comfort changes depending on the occupant density in the shopping malls. The increase in the occupant density caused comfort level to increase on the warm side according to measurement and survey results. Although the occupant density is high, the use of an automation system in S. Mall 1 balances the increase in heat load caused by the occupant density. Fanger suggested obeying five principals in which one of them is that individual control of thermal control of the environment should be provided (Fanger, 2001). The use of automation system especially in the spaces that have high number of occupants such as shopping malls both provides and maintains thermal comfort and contributes to reducing the energy consumption.
- Depending on the function and occupant density, there are large differences in PMV between points in shopping malls. HVAC systems should be planned in design phase according to the function and temperature set values should be different according to the units (points).
- Dear and Nakano stated that the clothing insulation value might have impacted the results is effective in their studies (de Dear & Brager, 1998; Nakano et al., 2002). It was found that the clothing insulation value in shopping malls in the heating and cooling season differs from that given in the standard (ANSI/ASHRAE Standard 55, 2017; BS EN ISO 7730, 2005). In future studies, conducting the measurement study and determining the clothing insulation value of the occupants should be done simultaneously. Entering the data input to thermal comfort meter according to these results will increase sensitivity of the measurements.
- According to the survey results men feel hotter than women during heating season while there is no significant difference during cooling season. In addition, it was determined in the studies that women prefer a warmer environment than men (Karjalainen, 2007; Nico et al., 2015). When the relation between age and thermal sensation is considered, it is seen that as the age increases people begin to feel more comfortable. Since the shopping malls serve everyone, user profile cannot be limited. For this reason, it is not possible to make the design according to each user in terms of thermal comfort. However, designing to minimize thermal discom-

fort will ensure thermal parameters remains between the values defined in the standards.

- Thermal sensation of the people changes based on the duration. According to Li et al., among customers, those who had spent less than an hour in the underground mall perceived the thermal environment to be cooler during summer (Li et al., 2018). However, this study does not provide detailed information for situations within 1 hour. Considering the 1 hour period (0-10 min, 10-30 min, 30 min-1h), the number of those who felt cold increased as the time of duration approached 1 hour. As a result of this study, it was determined that after a certain time people feel colder in cooling season in a conditioned environment.
- The thermal condition of the circulation areas in shopping malls varies according to the air flows in galleries, the indoor conditions created by the shopping mall's architectural covering systems and the occupant density. In the future design of shopping malls, covering systems should be designed according to sun path and the automation system should be used according to occupant density.

5. Conclusions

Due to the fact that the shopping malls are the places with high volumes of people, large amounts of energy are consumed for providing and maintaining the thermal comfort conditions. This study was aimed to investigate the compliance of shopping malls having different HVAC systems to thermal comfort conditions and to compare their energy consumption in relation to the thermal comfort.

The conclusions of this study are summarized as follows:

- Cooling season was more comfortable than the heating season in both Shopping Malls.
- S. Mall 1 having heat pump and automation systems and rated via green building rating systems has a better thermal comfort condition although it has a higher occupant density and lower energy consumption compared to S. Mall 2.
- Energy consumption during heating season higher than during cooling season, but cooling season is more comfortable than the heating season in S. Mall 1 because temperature set point (22 °C) was kept high during the heating season.
- Although the monthly energy consumption of cooling season is 76.9 % more than heating season, there is no significant difference in thermal comfort of S. Mall 2.
- Thermal comfort changes depending on the occupant density and thermal sensation of the people changes based on the duration in the shopping malls.
- According to the survey results men feel hotter than women during heating season while there is no significant difference during cooling season.
- This study suggested that conducting the measurement study and determining the clothing insulation value of the occupants should be done simultaneously in the future studies.

Although the amount of consumed energy increased, thermal comfort did not change as expected. Efficient usage of energy will make it possible to provide and maintain thermal comfort. It is important that the HVAC systems should be designed according to the season, occupant density and functions in order to provide and maintain thermal comfort conditions in indoor environment. While providing and maintaining the thermal comfort conditions in these buildings where occupant density is continuously variable, passive design systems should also be used and solutions related to the change of the efficiency of mechanical systems should be developed.

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