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Thermal Comfort and Perception Inside Air-Conditioned Areas

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ABSTRACT

This study describes and compares the results of two field surveys about thermal comfort inside air conditioned buildings in two different classrooms. Both field studies were conducted in classrooms at The University of South Florida, Tampa, USA during the summer of 2014 and the fall of 2015. The purpose of this study is to investigate the temperature perception of humans in closed areas based on the American Society of Heating, Refrigeration and Air-Conditioning Engineers (ASHRAE) Standard 55 and to understand whether or not these areas are within the acceptable level of thermal comfort. The study also investigates the influence of gender on temperature perception and thermal comfort. The field studies consisted of 14 multiple-choice questions that were distributed to students in the classrooms. The results of the two studies showed significant differences in temperature perception and prediction between genders. The results also showed that participants reported an average of "neutral" thermal sensation even though the the temperature inside the classrooms was raised significantly.

INTRODUCTION

The thermal comfort level inside closed areas has been studied for decades in various places in the world. According to the American Society of Heating, Refrigeration and Air-Conditioning Engineers, thermal comfort can be defined as "the condition of mind that expresses satisfaction with the thermal environment" (ASHRAE 2005). Based on the definition, thermal comfort is a subjective sensation and it can differ from one person to another even if they are in the same environment. Thermal comfort is influenced by different factors that can be categorized as physical and psychological. The physical factors can be categorized by: air temperature, mean radiant temperature, relative humidity, air speed, clothing level, and metabolic rate (Berglund 1978). The psychological factors are related to cultural differences, personal temperature expectations, and mood differences. Thermal comfort can be reached physically by maintaining a thermal equilibrium between the heat generated by the human body (represented in the metabolic rate) and the surroundings (Gagge 1972). ASHRAE Standard 55 specified the comfort zone inside closed spaces where at least 80% of occupants feel thermally comfortable (ASHRAE 2013). This specification is based on generalized theoretical and mathematical models that were developed from experiments and studies conducted by Fanger and others (Djongyang 2010).

The purpose of this study is to investigate the temperature perception of humans inside air conditioned areas based on ASHRAE Standard 55 and to study whether or not these areas are within the acceptable level of thermal comfort. The study also investigates the influence of climate on temperature perception and thermal comfort.

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BACKGROUND

Most of the studies that were conducted on thermal comfort follow two different approaches. The first approach is conventional laboratory studies. Perhaps the most famous of them is Fanger's experiments in 1970 (Fanger 1970; Djongyang 2010). This approach is based on conducting thermal experiments inside a well-controlled environment like chambers and cabins. Another approach is the field study approach where the experiments are conducted in real-life environments. This approach proved its effectiveness in studying the thermal comfort inside closed spaces like classrooms in schools and universities. Most of these studies were conducted using ASHRAE's seven point thermal scale (Djongyang 2010). Fanger developed a comfort equation and related it to ASHRAE's thermal scale to form a predicted mean vote (PMV) index. The predicted percentage of dissatisfaction (PPD) was also added to form Fanger's thermal model for indoor environments (Fanger 1970).

It was found that the outdoor climate is related to the indoor comfort temperature (Humphrys 1978). This relation is different between air conditioned and naturally ventilated buildings. It was also suggested that occupants of air conditioned buildings do not tolerate a wide range of temperatures (De Dear 1998). Yamtraipat found that the recommended thermally acceptable indoor temperature is around 78.8°F (26°C) inside air conditioned buildings in Thailand (Yamtraipat 2005). However, the range of thermally comfortable conditions inside buildings depends on the physical factors of occupants and can be as narrow as 3.5°F (2°C) deviation above or below the comfort temperature (Nicol 2002).

Many studies have been conducted to test ASHRAE Standard 55 in different climates inside naturally ventilated and air conditioned buildings. It was shown that, in naturally ventilated buildings, the indoor temperature at which occupants feel comfortable increases during hot climate and decreases during cold climate (De Dear 2004). Another study found that occupants' thermal preferences change gradually between the heating and the mid seasons in naturally ventilated classrooms in Italy (Corgnati 2009). However, de Dear showed that Fanger's PMV/PPD model is only applicable for air conditioned areas (de Dear 1998). Huizenga studied air quality and thermal comfort inside air conditioned buildings and found that only 11% of the buildings had 80% or higher occupant satisfaction. The results showed the importance of field surveys in measuring the thermal performance of buildings (Huizenga 2006).

Additionally, field surveys provide more reliable information about the thermal environments compared to laboratory studies (De Dear 1991). By analyzing this information, researchers were able to study how occupants interact with their environment based on their thermal comfort level. Wong investigated the thermal comfort inside mechanically ventilated classrooms in Singapore and found that the classrooms did not fall within ASHRAE's comfort zone Standard. However, subjects felt thermally comfortable (Wong 2003). Humphreys conducted a study of thermal comfort and clothing in primary schools in England. The results showed that discomfort was related to the temperature variation in the classroom but not the temperature itself (Humphreys 1977). Another study in a Japanese school showed that most of the naturally ventilated classrooms did not fall within the Standard 55 comfort zone whereas the air conditioned classrooms complied with it. However, the mean thermal comfort vote reported by occupants of the air conditioned classrooms was "slightly cool" sensation on ASHRAE scale. Adaptive behaviors regarding clothing in the air-conditioned rooms where students brought sweaters and sweatshirts in the classrooms was also observed (Kowk 2003).

METHOD

Two field studies took place in Tampa, USA during the summer of 2014 and fall of 2015. Both studies were conducted inside air conditioned buildings. The locations were inside classrooms at the university. Florida's climate is considered humid and subtropical where it is typically wet in the summer season, with average temperatures above 80°F (~27°C) and dry from fall through spring with average daytime temperatures above 77°F (25°C) (Duever 1994).

A survey was carried out in an air conditioned classroom at the University in June 2014. The summer classroom has 11 inlet/outlet ducts and windows on its southern side. Due to the low representation of female subjects in the summer class and to test occupants' thermal comfort and temperature perception during a relatively colder weather, another survey was conducted in November 2015 in a different air conditioned classroom at the university. The fall classroom has 9 inlet/outlet ducts and no windows. Both surveys were conducted in a one-hour class session for four days in the summer classroom and three days in the fall classroom.

Survey Procedure

We studied the thermal perception of subjects in three different scenarios: A constant temperature, a gradually increasing temperature, and a gradually decreasing temperature. In the summer classroom, the room's thermostat was set to its original set point temperature of 68°F (20°C) in day 1 and day 2. On day 3, the temperature was increased from 68°F (20°C) at the beginning of the class session to 73°F (~23°C) at the end of the class. On day 4, the temperature was decreased from 73°F (~23°C) to 70°F (~21°C) at the end of the class. A similar scenario was applied in the fall classroom where the temperature remaind constant at 71.5°F (22°C) on day 1. On day 2, the room temperature was increased from 71.5°F (22°C) at the beginning of the class session to 75°F (24°C) at the end of the class. On day 3, the room temperature was decreased from 71.5°F (22°C) to 68°F (20°C). The temperature was also measured using a portable thermocouple in both of the classrooms during the surveys. The outside temperature was recorded in all survey days and it ranged between 87°F (30.5°C) and 89°F (31.6°C) during the summer class sessions and between 71°F (21.6°C) and 83°F (28.3°C) during the fall class sessions.

The temperature was monitored during the class periods to insure it was not fluctuating during the sessions where the temperature remaind constant, and it was changing gradually during the sessions where the temperature was increasing or decreasing. The surveys were handed to subjects at the end of the class. The subjects were informed that the surveys were anonymous and participation was voluntary. The survey consisted of 14 multiple choice questions, which are shown in Figure 1.

1- How did you feel in the classroom?
Hot | Warm | Slightly warm | Comfortable | Slightly cool | Cool | Cold

2- How would you describe the weather today?
Sunny | Partly cloudy | Cloudy | Rainy

3- What do you think the outside temperature is?
70~75°F (21~24°C) | 75~80 (24~26.5°C) | 80~85 (26.5~29.5°C) | 85~90 (29.5~32°C) | 90~95 (32~35°C)

4- What did you think the room temperature was?
68 ~ 70 (20~21°C) | 70 ~ 72 (21~22°C) | 72 ~ 74 (22~23°C) | 74 ~ 76 (23~24.5°C) | 76 ~ 78 (24.5~25.5°C)

5- Five minutes prior from entering the class, were you...
Outside the building? | Inside the building?

6- Would you like the room temperature to be:
Warmer? | No change | Cooler?

7- Is the room temperature:
Increasing with time | Does not change | Decreasing with time

8- Are you within 3 ft range of an air duct?
Yes | No

9- Are you within 3 ft of a window?
Yes | No

10- Would you like...
More air movement? | No change | Less air movement?

11- Are you...
Male | Female

12- Please place a check sign by the pieces of clothing that you are wearing:

Top	Bottom	Footwear
Short sleeve shirt/ T-shirt	Trousers /Jeans	Socks and shoes
Long sleeve shirt/ Jacket	Shorts	Sandals
Sweater/ Sweatshirt	Ankle-length skirt/ skirt	Slippers

13- Are your clothes mainly...
Light colored? | Natural? | Dark colored?

14- Do you have a...
Cold drink? | Hot drink? | None

Figure 1 The survey used in the classrooms.

Survey Subjects

A total of 98 surveys were collected in the summer class in four days. In the fall class, a total of 131 surveys were collected in three days. All subjects were healthy and between 18 and 55 year old. The subjects' numbers varied between the class sessions. Table 1 shows their distribution along the survey days. All the surveys were anonymous and no personal data were collected. The surveys followed a protocol approved by the University's Institutional Review Board.

Table 1. Subjects Distribution in Summer and Fall Classroom

Class	Day	Number of Subjects	Male/Female
Summer Class	1	29	26/3
	2	24	20/4
	3	26	23/3
	4	19	17/2
Fall Class	1	44	7/37
	2	42	6/36
	3	45	9/36

RESULTS AND DISCUSSION

Summer Class

An ANOVA with a dependent variable of the thermal scale (question 1) was conducted in the analysis of this study. In the summer class, the results showed statistically significant differences between genders $F(1; 97) = 7.81$, $p < 0.01$) and between survey days $F(3; 97) = 6.99$, $p < 0.005$). The analysis also showed a statistically significant difference between the answers of question 5. Subjects who were inside the building prior to class had a significantly "cooler" thermal perception (with an average thermal sensation of -0.6) than subjects who came from outside the building (with an average thermal sensation of 0) which suggests that the subjects who were inside the building prior to class may have had lower skin temperatures. Strigo showed that cool ambient temperatures can decrease the mean skin temperature significantly (Strigo 2000). Also, there was a clear shift on the thermal sensation scale in day 3. However, the average thermal sensation for all four days was -0.18. Figure 2 shows the average thermal sensation between genders, and between the four days. The mean insulation value was also analyzed and was found to be 0.48 clo which is considered typical summer clothes (Charles 2003).

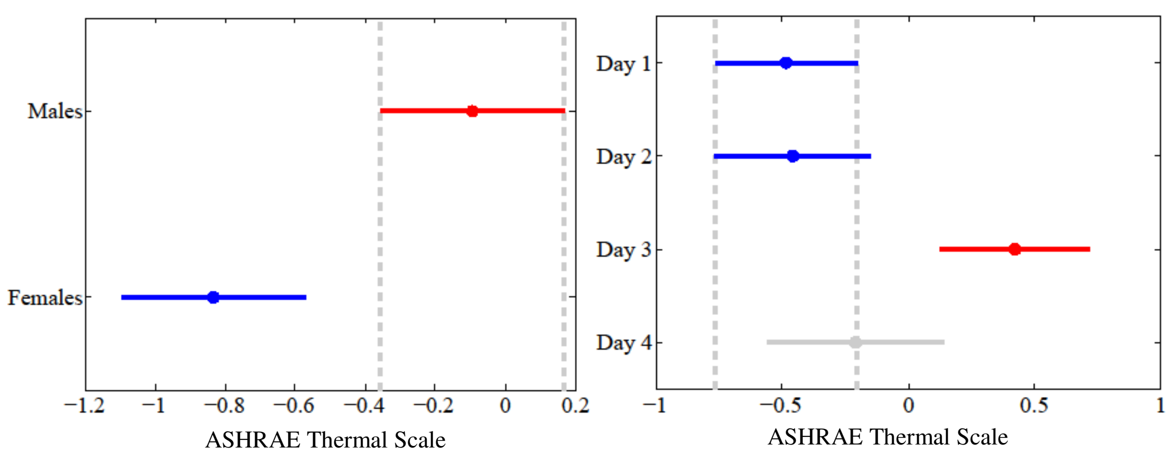

Figure 2 The summer classroom survey results. The thermal perception of females is statistically significantly different than males. The thermal perception in day 3 is statistically significantly different than the other days.

According to the results of the summer class, the average thermal sensation for female subjects was -0.84 while for male subjects was -0.08. Previous studies found that females can feel uncomfortably cold more often than males (Karjalainen 2007). However, the survey showed that more than 80% of subjects felt thermally comfortable during the four days of survey considering the range from -1 to 1 being thermally acceptable. Question 6 also showed similar results where 75.5% of subjects voted for "no change" when answering whether they prefer the room temperature to be cooler or warmer. Figure 3 (b) shows the average thermal sensation of subjects in the four days.

Additionally, the majority of the subjects voted for "no change" in the air movement in day 3. Other studies indicated that higher air speeds may improve the occupants' comfort level (Jones 1986; Cândido 2010). We also did not find a significant difference between the air ducts and window locations and the thermal perception of subjects (questions 8 and 9).

In addition to these results, the survey showed that the temperature prediction of the subjects improved in day 3 when the room temperature was gradually increasing, as shown in Figure 3 (a). In day 1 and 2, subjects predicted the room temperature to be around 72°F (~22°C) which is four degrees higher than the actual temperature. In day 3, their average prediction was 73.8°F (~23°C) which was only 0.3°F (0.16°C) above the actual temperature. Moreover, only 7 out of 26 subjects were able to detect that the room temperature was increasing in day 3. This finding suggests that the indoor temperature can be raised to a higher temperature in order to reduce energy consumption without sacrificing the level of comfort or causing significant physiological changes to occupants (Chen 2011). A previous study showed that a 1.8°F (1°C) increase in a room temperature can significantly reduce energy consumption (Lovins 1992). Other researchers have shown that occupants preferred indoor temperatures between 75.5°F (24.2°C) and 80°F (26.7°C) inside air conditioned areas in several hot-humid locations in the world (Busch 1992; De Dear 1991; Kwok 1998).

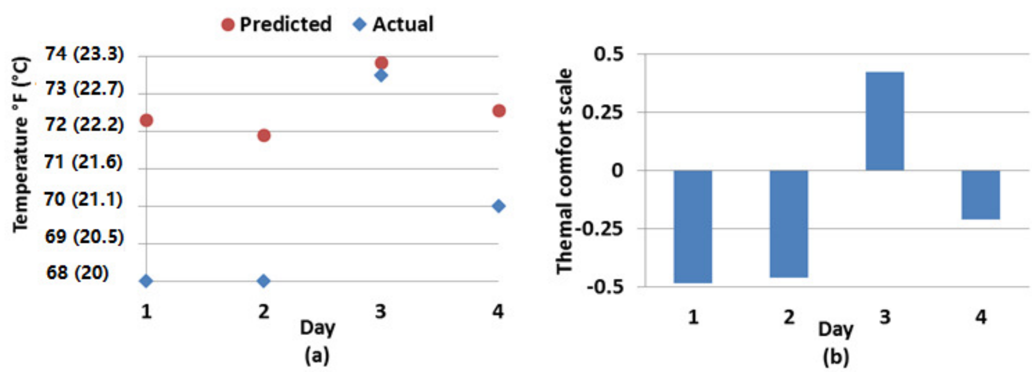

Figure 3 The summer classroom temperatures. (a) The actual temperature of the summer class versus the average predicted temperature from subjects. (b) The average thermal comfort level of subjects for four days during summer class.

Fall Class

In the fall class, the results showed statistically significant differences between the survey days F (2; 118) = 14.29, p < 0.005). The results also showed that females were statistically significantly more accurate in predicting the room temperature F (1; 118) = 4.46, p < 0. 05). The average temperature prediction for female subjects was 73.5°F (23°C) while for male subjects was 74.6°F (32.7°C). This agrees with previous studies which suggest that female subjects are more sensitive to temperature deviation (Fanger, 1970). Figure 4 shows the average thermal sensation between the three days, and the temperature prediction between male and female subjects. The survey also showed that 87% of subjects felt thermally comfortable during the three days of survey considering the range from -1 to 1 being thermally acceptable. Figure 5 (b) shows the average thermal sensation of subjects in the three days. Also, the mean insulation value of the fall class survey was 0.64 clo.

The results of the fall class surveys showed that the temperature prediction of the subjects improved when the room temperature increased as shown in Figure 5 (a). In day 1, subjects predicted the room temperature to be 74.2°F (23.4°C) which was close to three degrees above the actual temperature. In day 2, subjects' prediction was 74°F (23.3°C) which was only one degree below the actual room temperature.

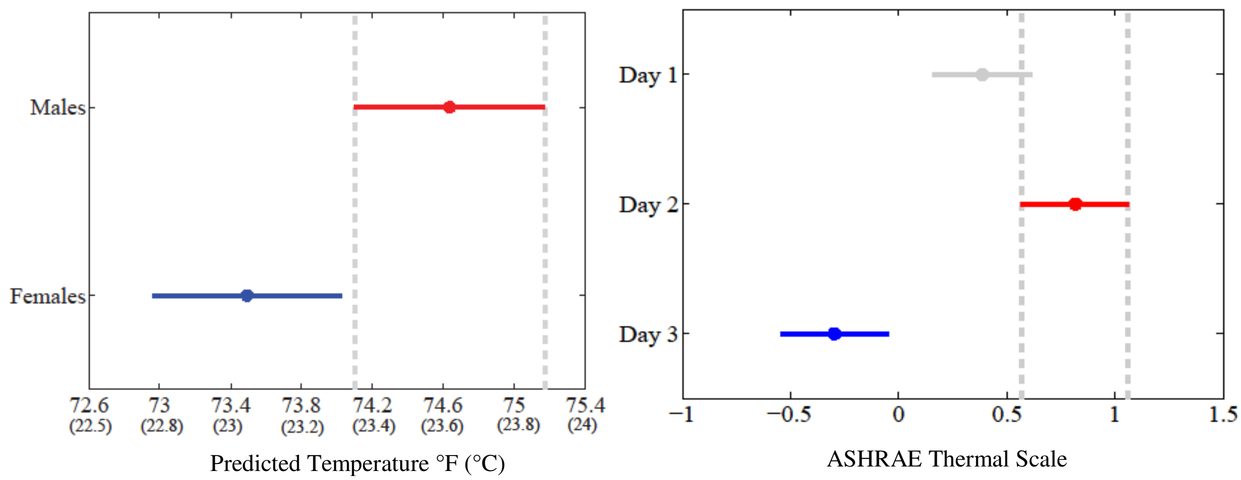

Figure 4 The fall classroom survey results. The thermal prediction of females is statistically significantly different than males. The thermal perception in day 3 is statistically significantly different than the other days.

Both surveys investigated the thermal perception and the comfort level inside air conditioned buildings. The results of both surveys showed that subjects were sensitive to temperature change in the classrooms. In the summer class, subjects were more senstivtive to the increasing temperature while in the fall class subjects were more sensitive to the decreasing temperature. This contrast between the results may be related to the difference in the outside temperatures between the summer and fall classes. It can also be related to the percentage of female subjects in both of the classes. In the summer class, only 12% of the subjects were females, whilest in the fall class 83% of the subjects were females. Previous studies showed that females prefer higher room temperatures than males (Karjalainen 2007).

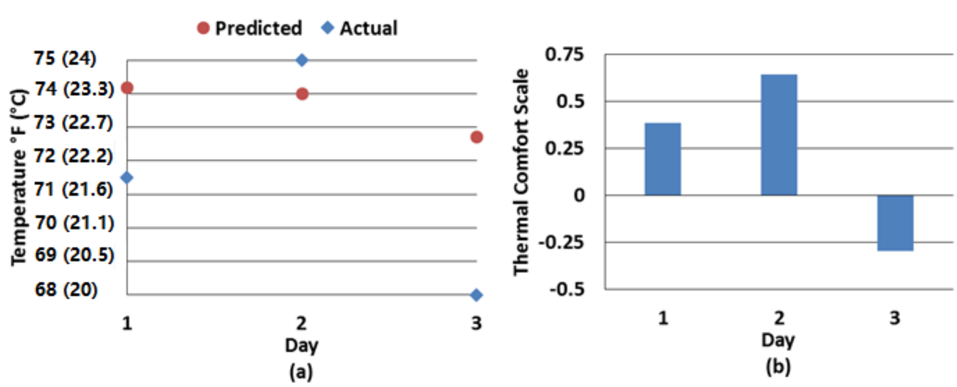

Figure 5 The fall classroom temperatures. (a) The actual temperature of the fall class versus the average predicted temperature from subjects. (b) The average thermal comfort level of subjects for three days during fall class.

The results of the temperature prediction were similar between the two classes. In the summer class, subjects expected the temperature to be 4°F (~2°C) higher in a 68°F (20°C) room temperature. Their prediction became more accurate with a higher room temperature. We did not, however, find significant differences between male and female subjects. In the fall class, we noticed a significant difference between male and female subjects. The average prediction for male subjects was around 3°F (~1.7°C) higher in a 71.5°F (22°C) room temperature whilst female subjects were significantly more accurate as was shown in Figure 4.

Additionally, subjects from both classrooms reported an average "neutral" level of comfort despite the difference in the room temperatures in both of the classes. The summer class subjects had a thermally "neutral" comfort level even when the room temperature was raised to 73.5°F (23°C) while the fall class subjects reported the same comfort level in a slightly higher temperature range even though they had the same metabolism rate. This difference may be linked to the clothing insulation level in the fall class which was noticeably higher than it is in the summer class. However, it did not affect the thermal comfort level or temperature prediction of subjects.

CONCLUSION

We presented two field surveys that studied thermal comfort and perception inside air conditioned areas. Both surveys were conducted inside two classrooms in Tampa, USA. In the summer class, a total of 98 surveys were conducted for four days. The results showed that subjects had a significantly more accurate temperature prediction at a slightly elevated room temperature. Also, there was a significant difference in thermal votes between male and female subjects. In the fall class, a total of 131 surveys were conducted for three days. The results showed that female subjects had a significantly more accurate temperature prediction than male subjects. In both surveys, subjects were thermally comfortable despite the difference in the operating temperature inside the two classrooms.

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