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Investigation on the impacts of different genders and ages on satisfaction with thermal environments in office buildings

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ABSTRACT

This paper investigates the effects of occupant gender and age on thermal satisfaction in office environments. The data used for the analyses was collected from 40-sampled occupants and their workstations on 38 floors in 20 office buildings in the U.S. with support from the U.S. General Services Administration. The field measurements include data collection for air temperature, radiant temperature, temperature stratification, relative humidity and air velocity of the sampled workstations. Occupant satisfaction surveys were distributed to each occupant in the workstations measured, and the thermal attributes of building systems were recorded. The objective and subjective data sets support statistical correlation analysis between environmental qualities and user satisfactions.

The statistical analysis of air temperatures, occupant thermal satisfaction, age and gender revealed that females are more dissatisfied with their thermal environments than males especially in the summer season with high significance, and occupants over 40 years old are more satisfied than under 40 in the cooling season with marginal significance.

1. Introduction

Individual thermal comfort is typically affected by room thermal parameters of air temperature, radiant temperature, air speed and relative humidity, and by human physiological conditions including metabolism rate and clothing insulation [1]. However, the current thermal comfort formula does not consider the impacts of variables related to gender and age. These variables could significantly impact thermal comfort and may need more codification.

Cena [2] states that females reported higher thermal dissatisfaction than males in a large field study despite no variations in thermal conditions. Karjalainen's study also identified that females are less satisfied with indoor temperatures than males in both cold and hot conditions [3]. Modera [4] asserts that statistically significant differences were found between the physiological responses of men and women, which showed women are much more sensitive to temperature excursion. A Parsons' laboratory study result shows there are only small differences between the genders in neutral and slightly warm conditions, but females feel cooler than males in cool conditions with identical levels of clothing and activity [5].

Relative to age, Young's study states that aging males may require different thermal comfort conditions due to changed physiology. At the same time, he identified that aging females do not show significant variations in thermal satisfaction compared to all ages of females [6]. This result is well supported by Meier's study which reports that elderly people prefer higher temperature due to lower activity levels in the daily life [7].

However, earlier studies in 1970s by Fanger's [8] and Collin's [9] studies do not find any significant difference in comfort conditions by gender and age. As such, these two gender and age issues are not clearly established with contradictory results from various research studies.

A team of researchers at Center for Building Performance and Diagnostics at Carnegie Mellon University have performed post-occupancy evaluation studies in 20 office buildings across the U.S. These measured objective and subject data reveal differences in indoor environmental satisfaction depending on gender and age in identical activity and clothing insulations.

2. Methods

User satisfaction questionnaires and spot measurements were performed. The satisfaction questionnaires are based on National Research Council Canada (NRC) Cost-effective Open-Plan Environment (COPE) [10] survey which asks building users' satisfactions with indoor environmental qualities. The spot measurements include indoor environmental quality parameters: thermal, lighting, air, spatial and acoustical qualities. For this paper, thermal qualities on the satisfaction survey are considered.

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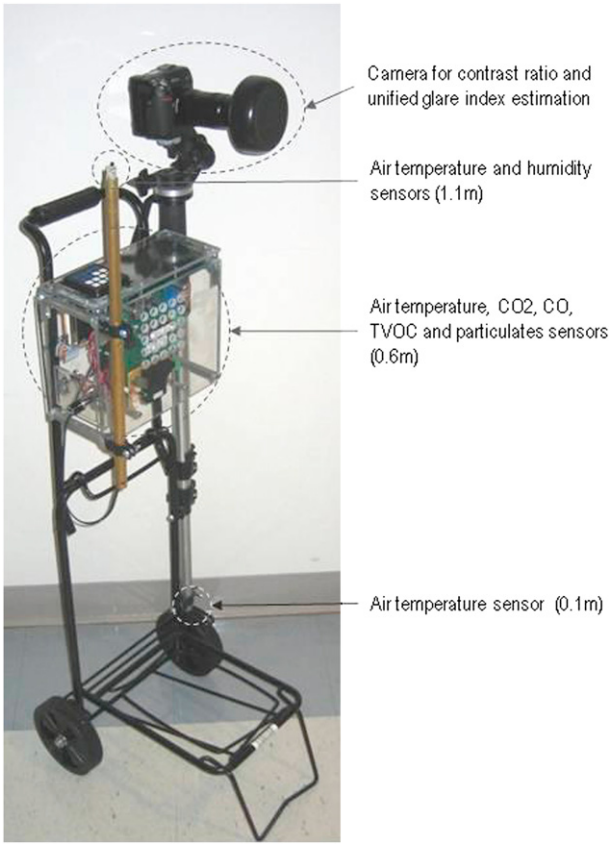

Fig. 1. Environmental quality instrument cart.

2.1. Workstation sampling strategy and spot measurements

The studies were conducted in 38 floors of 20 commercial office buildings in the U.S. from 2005 through 2008 across the year including cooling, heating and swing seasons. The sample size is between 10 and 15 percent of the total building workstations. 402 workstations were sampled and the users were recruited for user satisfaction questionnaire. In the samples, 212 are female and 190 are male, and 170 are between 19 and 39 years old and 230 are between 40 and 69 years old. Those two sample age groups are defined as "under 40's" and "over 40's" respectively.

For the spot measurements, an environmental quality instrument cart developed by the Center for Building Performance and Diagnostics (Fig. 1), is used to measure temperatures at 1.1 m, 0.6 m and 0.1 m from the floors. The instrument cart is placed in the position of the occupant's chair for approximately 15 min for each sampled workstation. For the first few minutes, the sensors are allowed to acclimatize to the environment in the workspace. Then, automated sensor readings of temperature at three heights, relative humidity and air velocity are taken over the next 4 min, at 15 s intervals, and averaged to obtain the final measurements in that workstation. The radiant temperature on wall surfaces of a workstation was also measured with a hand-held sensor.

2.2. User satisfaction surveys

While the spot measurements are recorded in a workstation, the occupant is asked to complete a 25 question 'User satisfaction Survey' based on his/her indoor environmental quality perception at that moment. The modified survey was initially developed by the National Research Council Canada to support the Cost-effective Open-Plan Environment (COPE) Project. The survey consists of 25 questions on satisfaction with indoor environmental qualities including air quality, thermal comfort, acoustic, and lighting. In addition, questions on spatial qualities and job satisfaction were also asked. Each answer uses a 7-point scale: 1-very dissatisfied, 2-dissatisfeid, 3-slightly dissatisfied, 4-neutral, 5-slightly satisfied, 6-satisfied, and 7-very satisfied.

The survey also contains demographic questions including gender and age. The answer for age is categorized with 10 year interval from 18 to 69. For this paper, only demographic information and thermal satisfaction answers data are assessed relative to simultaneous temperature measurements.

Table 1
Recommended comfort zone by ASHRAE Standard 55/62 -2004 in 30–60% relative humidity.

Air temperature	Cooling season	23.3–27.8 °C
	Heating season	20–25.5 °C
	Swing season	20–27.8 °C
Relative humidity		Lower than 65%
Radiant asymmetry	Horizontal	Lower than 10 °C difference
	Vertical	Lower than 5 °C difference
Air speed		Lower than 0.2 m/s

2.3. Data analysis

The collected data was grouped by season depending on when the site measurements were performed, divided into heating, cooling and swing seasons. The seasons were defined based on the modes of the building HVAC systems (Heating, Ventilating, and Air Conditioning) during the on-site measurement time. Based on the demographic information, all the data were grouped again by gender and by age. To ensure statistical significance in the dataset, the occupants were divided into two groups, under 40 and over 40 years old.

To analyze the user satisfactions by gender and age groups, two sample *T*-test, one-way and ANOVA statistics were completed. The significance of the data analysis was set at 95% ($p \leq 0.05$) and 90% ($p \leq 0.10$), which describe significance and marginal significance respectively. When a sample size of a group is less than 10, the group was not considered in the statistical analysis.

2.4. Thermal comfort guidelines

ASHRAE-55 and -62.1 [1,11] is used to define thermal comfort conditions based on a range of relative humidity and temperature by season. For more detailed analysis on thermal condition in each workstation, radiant temperature on all wall surfaces, floor and ceiling, and air speed were measured and verified with ASHRAE recommendations. Table 1 summarizes the thermal comfort ranges used in the analyses.

2.5. Human factors for thermal comfort

All the sampled workstations were from governmental office buildings in the U.S. Most activities of occupants during the measurement and survey are sedentary (1.2 MET) over gender and age groups. Most occupants wore typical formal suits for office work. The observed clothing insulations are 0.5 clo and 1.0 clo in the cooling and heating seasons respectively. The clo values might not be identical between the gender groups, but the difference was estimated as no-significance. Thus, this paper assumes there is no significant difference in activities and clothing among the age and