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Comparison between qualitative and quantitative measurement in assessing thermal comfort in an elementary school

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ABSTRACT

We compare qualitative and quantitative measurements to assess an elementary school building's thermal comfort. Quantitative measurements of the physical environment are useful but not sufficient, since different people respond differently in the same indoor environment. A qualitative survey of the school employees shows the thermal comfort level has a 3.73 out of 7 score and 40% of subjects rated it unsatisfactory, even though the temperature and humidity level are measured within the comfort range recommended by ASHERA 90.1 – 2004. This gap occurs because human metabolism is not taken into account in current design guidelines, even though there is a clear correlation between human metabolic level and perceived thermal comfort. The gap between design guidelines and occupants' thermal comfort presents an opportunity to improve indoor environmental quality. School buildings are especially challenging because they have a mix of adult and child occupants with widely varying metabolic rates. Therefore, an elementary school was used as a case study to compare differences between quantitative and qualitative measurement. We conducted a series of simulations to compare the thermal comfort in relation to adult and children's metabolism and their thermal responses. We demonstrate that the negligence of occupants' metabolism can lead to inaccurate design guidelines for the physical environment's thermal comfort. Our results could potentially improve design manuals to accommodate buildings with mixed occupants to maximize comfort levels.

KEYWORDS

Thermal comfort, metabolic rate, qualitative and quantitative, elementary school, adaptive model

INTRODUCTION

Most elementary schools in United States were built during the 1950s to 1970s and are in need of renovation, modernization and repairs (Sheryl, et. Al, 2017). One of the most critical issues among those public schools that were built prior to active mechanical systems is the lack of control of thermal comfort of the interior environment (U.S.ED, 2012). As the design standard evolves, new buildings optimize indoor environment comfort, especially thermal comfort via active mechanical systems. However old facilities are designed with passive strategies which try to create a steady singular environment. Maintaining a comfortable indoor environment while simultaneously preserving energy will be a major challenge for both designers and school administrations.

Clients are usually given three options for old school buildings: demolishing, renovating, and retrofitting. To get a better understanding of existing school buildings and to understand the targeted area of improvement through retrofitting, we took a case study that focuses on an elementary school built prior to active mechanical systems. We measured an elementary school facility in Maryland, USA, which is in climate zone 4 according to IEC (International

Energy Code). The building is a 44,200 square foot educational facility approaching the end of its expected life cycle. Constructed in 1968, the building envelope consists primarily of CMU block with a single layer of brick veneer, gypsum roof assembly, and a hollow core concrete slab finished with terrazzo over a plenum space for gas furnace duct system. The primary massing of the building is one story with partial double height at the gymnasium. School classrooms are installed with a water-based heating system, which are non-adjustable, and with window-mount air conditioners.

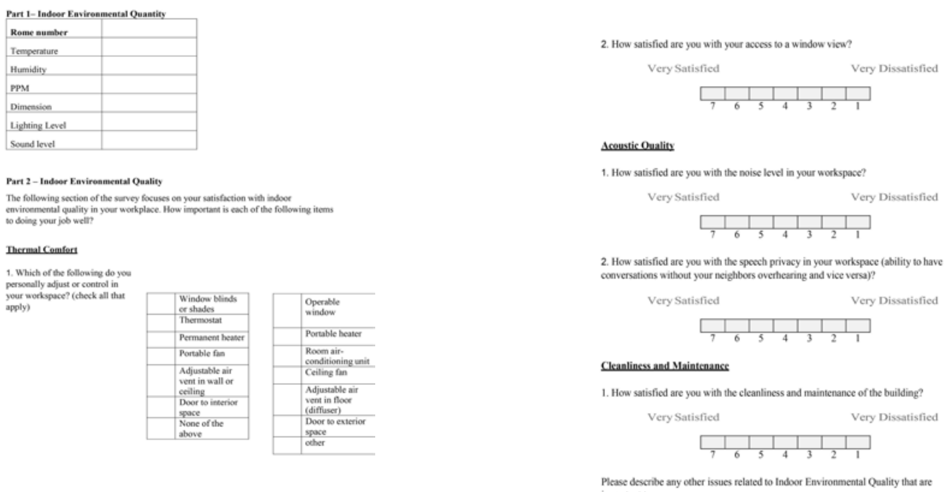
The assessment of thermal comfort in elementary school is challenging because both adults and children use the space relatively equally. Many people have conducted research focusing on regional climate and indoor environment and its impact to students' health and learning process (Sheryl. et.Al. 2017). Research shows that thermal comfort may have a direct impact on working efficiency and learning ability in an enclosed environment. Even though the current ASHRAE considers an adaptive model when measuring thermal comfort, assessing thermal comfort in buildings that are built with passive strategies requires an additional evaluation to gain the users' responses.

METHODS

Qualitative

The first step of evaluating the building performance was to take qualitative data, which helps to understand which part of the building needs to be improved. We distributed an occupancy survey among 19 faculty and staff. The survey had 11 questions, covering comfort and satisfaction ratings on lighting, daylighting, thermal, acoustic and air quality. Survey respondents were provided the opportunity to respond on a scale of 1-7 for each question; responses measured as 3 or under were regarded as "dissatisfied." Survey results were anonymous and unbiased regardless of staff occupation and working locations.

In the thermal comfort portion, we asked the participants two questions. The first was to identify whether they could adjust the thermal comfort level of the rooms, and the second was to evaluate the overall thermal comfort of their work environment.



Part 1– Indoor Environmental Quantity

Rome number	
Temperature	
Humidity	
PPM	
Dimension	
Lighting Level	
Sound level	

Part 2 – Indoor Environmental Quality

The following section of the survey focuses on your satisfaction with indoor environmental quality in your workplace. How important is each of the following items to doing your job well?

Thermal Comfort

1. Which of the following do you personally adjust or control in your workspace? (check all that apply)

	Window blinds or shades		Operable window
	Thermostat		Portable heater
	Permanent heater		Room air-conditioning unit
	Portable fan		Ceiling fan
	Adjustable air vent in wall or ceiling		Adjustable air vent in floor (diffuser)
	Door to interior space		Door to exterior space
	None of the above		other

2. How satisfied are you with your access to a window view?

Very Satisfied 7 6 5 4 3 2 1 Very Dissatisfied

Acoustic Quality

1. How satisfied are you with the noise level in your workspace?

Very Satisfied 7 6 5 4 3 2 1 Very Dissatisfied

2. How satisfied are you with the speech privacy in your workspace (ability to have conversations without your neighbors overhearing and vice versa)?

Very Satisfied 7 6 5 4 3 2 1 Very Dissatisfied

Cleanliness and Maintenance

1. How satisfied are you with the cleanliness and maintenance of the building?

Very Satisfied 7 6 5 4 3 2 1 Very Dissatisfied

Please describe any other issues related to Indoor Environmental Quality that are important to you.

a) b)

Figure 1. Survey questions regarding thermal comfort. a) thermal comfort questions 1: Which of the following do you personally adjust or control on your work space. b) question 2: how satisfied are you with your access to a window view.

Quantitative

In this survey, measurements included CO_2 levels in parts per million, decibel levels, lux levels, humidity percentages, and air temperature. Instruments used included portable digital CO_2 meters, digital sound level meters, digital light meters, and digital psychrometers. We split into three groups, and measurements were acquired from all locations of the school at approximately 1:30 pm on February 7th, 2017.

Psychrometers graph is one of the best way to represent temperature and humidity as the parameter of thermal comfort. To further expand our data analysis we utilized the CBE thermal comfort tool developed by Center for the Built Environment in UC Berkeley. The model is based off Gail and Brager's original research ASHRAE RP-884, now the new ASHRAE 2004 standard hypothesized a thermal conform model called 5h3 adaptive model. This model accounts for behavioral adjustment, physiological and psychological adaptation within a built environment. (Richard and Gail, 1998) The fundamental principal of adaptive model for thermal comfort is to acknowledge human behavioral adjustment, physiological and psychological adaptation within a built environment. (Richard and Gail, 1998)

Thermal comfort in buildings built before active mechanical control is achieved by passive strategies and natural ventilation. Constructing active control in these buildings would be expensive and require significant maintenance, therefore retrofitting is one of the best options for minimal energy consumption.

RESULTS

Existing Conditions

We found an average thermal comfort satisfaction level of 3.9 out of 7. Of 19 responses, 40% ranked 3 or lower. (*fig 1*) Surveyed occupants had access to operable blinds/shades, permanent heaters, doors to interior space, operable windows, and room air conditioning units. Occupants did not, however, have access to customizable thermostats, portable fans, adjustable vents in wall or ceiling, portable heaters, or ceiling fans. (*fig 1b*). In other words, humidity of 33.5%. Recorded temperatures ranged from 22 °C to 26 °C and humidity ranged from 27.7% to 38%. (*fig 2*). We used this data to generate a psychrometric chart, applying the metabolic rate of a seated adult with average summer clothing (given the outdoor conditions on February 7th were quite temperate). The result was outside the noted range of accepted thermal comfort. (*fig 3*)

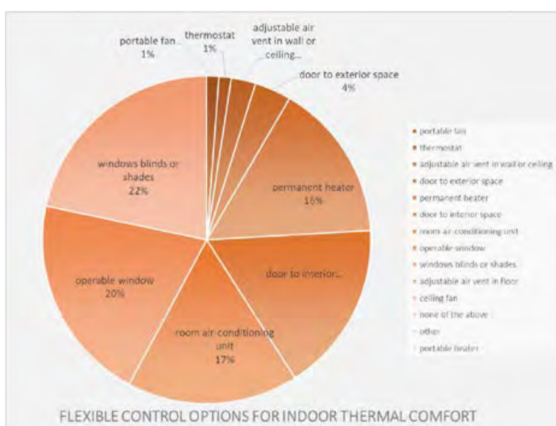


Figure - 1.a) Thermal comfort satisfaction. b) Thermal comfort control flexibility

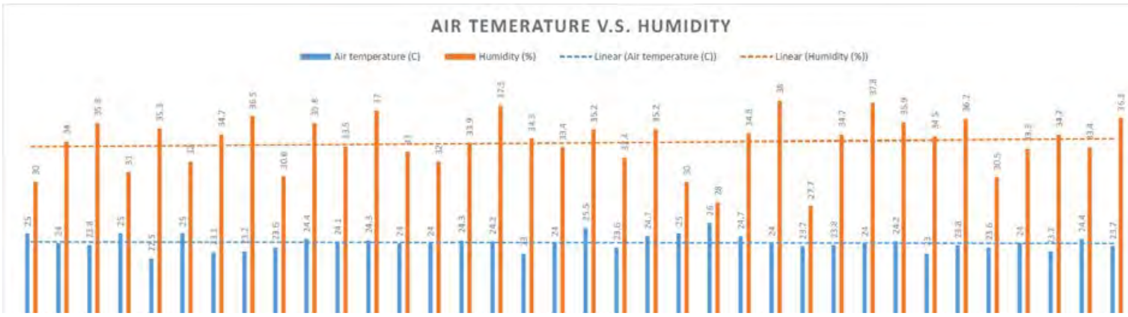


Figure - 2. - Air temperature vs humidity

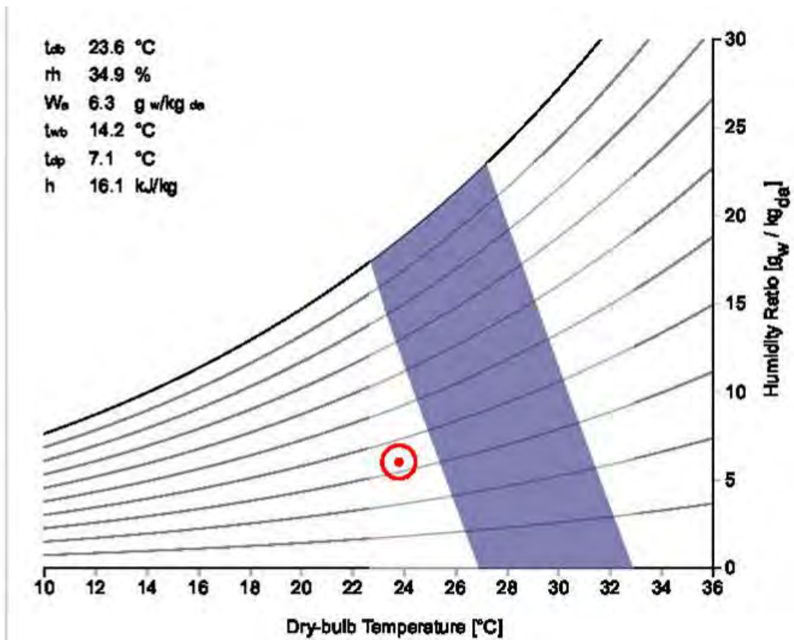


Figure - 3. Psychrometric chart based on a seated adult

We concluded from the qualitative and quantitative data that the thermal comfort in the building under study was unsatisfactory for adults. We next simulated the children's thermal comfort using the same physical environment. The two most prevalent methods for determining the thermal comfort of individuals are the adaptive method, and the rational method. The adaptive method involves surveying the occupants to determine the most comfortable conditions for users. Problems with this method include environmental variability and inaccuracy of survey reports in terms of reproduction. A key stipulation of the adaptive approach is "*if a change occurs such as to produce discomfort, people react in ways which tend to restore comfort.*"(Nicol *and* Humphreys, 2002) According to De Dear's research on adaptive model, the adaptive process also predicts that persons in warmer climates will prefer warmer temperatures indoors, whereas persons in colder climates will prefer cooler temperatures indoors (1998).
The rational method, according to Nicol and Humphreys (2002), involves an index which develops a model for thermal comfort based on variables listed above such as metabolic rate and clothing insulation. We used both the rational and the adaptive method when analyzing our case study school in Maryland.

Simulation comparison of thermal comforts

Interestingly, the resting metabolic rate is reduced from infancy to adulthood by 1.5-2 times according to Son'kin and Tambovtseva (2012). Taking this fact into account, we produced a series of psychometric charts using CBE comfort simulation analyzing isolated variables between persons with a metabolic rate of 1 (adults) 2 (children), assuming an indoor temperature of 23.8 °C and a relative humidity level of 50%. The variables included high air speed, low air speed, and varying clothing. We found each variable tested made either the adult control or child control uncomfortable. However, we produced a chart overlaying child comfort over adult comfort, where airspeed was adjusted for children and clothing insulation was adjusted for adults.

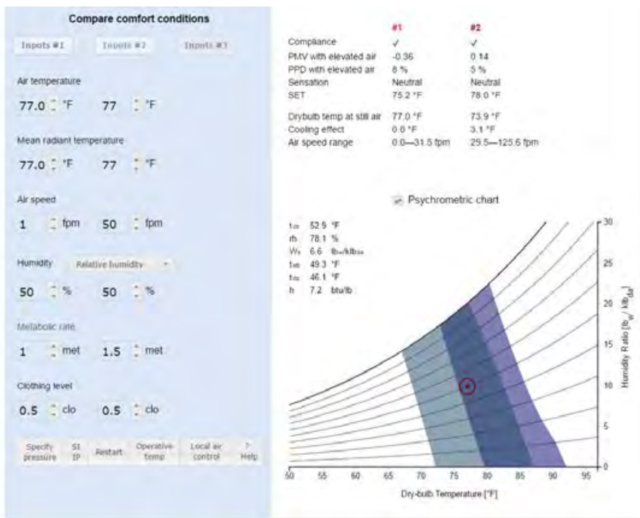


Figure.4 - Simulated thermal comfort comparison of pupils and adults in the same environment due to different metabolic rate.

DISCUSSIONS

This research produces thermal comfort for both adults and children via the rational index. The overlaying result shows that using the adaptive model could produce a comfortable condition for everyone, which would require either one of the occupancy group adjust clothing level or activity level (direct relative to MET rate).
To adjust air speed, a building could either upgrade the HVAC system to be active or zoned to cater to either students or faculty. Another option which reflects the survey is to increase the use of portable devices that allows the faculty to control the ventilation rate. Elementary school usually tend to have a student-teacher ratio between 15:1 and 20:1. Priority of improving thermal comfort would be given to students. Faculty and staff in classrooms would adjust their clothing levels to adapt to the higher air speed conditions.

Taking both qualitative and quantitative data into account mitigates some of the limitations of both data sets. However, neither rational nor adaptive methods provide accurate thermal comfort for students (Zahra, et al 2017). One of the concerns for conducting pupil-focused qualitative surveys is that students have not yet developed a complete and comprehensive perception of thermal comfort. To minimize the potential impact on the qualitative data, we decided to adopt the simulation result to generalize the possible thermal comfort responses from pupils. Surveys for children, especially 5^{th}-grade and below, may require a different writing style to be properly understood than surveys for adults. The school administration may consider providing thermal comfort education to allow the students to express their feelings accurately and respond to indoor environments properly.

CONCLUSIONS

As many school facilities approach the end of their life cycle, it is critical to reconsider the design of the school facilities. Because implementing an active HVAC system for a whole building might be too economically challenging to be feasible, it is useful to learn and assess occupants' thermal comfort from multiple perspectives. Having a comprehensive assessment for a school facility that in need of future repair and renovation will help the school administrators identify potential problems, minimizing the discrepancy between design and end product of the architect. More importantly, better assessments of school facilities will enable more accurate responses to occupants' sick-building syndrome and eventually create better and healthier environments for both young and adult occupants.

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