Thermal Acceptability in Tropical Schools

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Abstract

This paper examines the comfort criteria of *ANSI/ASHRAE Standard 55-1992, Thermal Environmental Conditions for Human Occupancy* (1) for their applicability in tropical classrooms. A field study conducted in Hawaii used survey questionnaires, physical measurements, interviews, and behavioral observations to collect the data. A total of 3,544 students and teachers completed questionnaires in 29 naturally-ventilated and air-conditioned classrooms in six schools during two seasons. The majority of classrooms failed to meet the physical specifications of the Standard 55 comfort zone. Acceptability votes by occupants of both naturally-ventilated and air-conditioned classrooms exceeded the Standard 55 criteria, regardless of whether physical conditions were in or out of the comfort zone. Responses from these two school populations suggest not only a basis for separate comfort standards, but energy conservation opportunities through raising thermostat set points.

Key Words: comfort, thermal environment, thermal sensation, acceptability, standards

Introduction

One major significance of examining the comfort standards in the tropics lies in the potential for conserving energy through modifying building design and careful temperature control. Nicol (2) suggested that one-quarter of all energy used in developed economies is used for indoor temperature control, a circumstance that could be achieved by reducing the indoor-outdoor temperature difference. After finding satisfaction with temperatures and humidities outside the ASHRAE comfort zone by Thai office occupants, Busch (3) concluded that higher set point adjustments can potentially yield significant energy savings, particularly in the developing regions of the hot and humid tropics. Aggregate building systems (HVAC and lighting) add up to approximately 38% of the United States' annual energy use (4). This statistic becomes important because of the influence that U.S. buildings have as models for the Pacific Rim cities now witnessing unprecedented economic development and construction of modern, air-

conditioned buildings. Rarely mentioned in this quest toward modernization are discussions of occupant well-being (comfort), or the architectural loss of vernacular designs – often passive strategies in naturally-ventilated buildings that allow the occupant a wide range of personal control and connections to the physical and temporal conditions of the outdoor climate.

Schools in the tropics offer a setting to study the application of Standard 55. Hawaii is a compelling location for such a study because it is the only U.S. state truly located in the tropics and, because of its dependence on imported fuel, commercial energy costs rank among the most expensive in the country (5). The majority of schools in Hawaii are more than 30 years old. With a rising school-age population, the trend toward year-round schooling, and an aging building stock, school districts will require a program of renovation, expansion, or construction of new schools. We

are at a “fork in the road,” where decisions made in the early design stages of school expansion could chart distinctly different energy courses as well as the architectural design of buildings.

The objectives of this research were to determine the applicability of the thermal comfort (Standard 55) to school settings in a tropical climate. To determine the standard’s applicability, the following specific questions directed this study:

1. What ranges of thermal environmental conditions are found in typical tropical classrooms and do these physical conditions comply with the Standard?
2. What is the relationship between measured indoor climate and the subjective comfort responses and do classroom occupants find their conditions in accordance with the Standard 55 80% acceptability criterion? .
3. How well do the prediction models of comfort match the observed subjective responses? .
4. Can the naturally-ventilated and air-conditioned data from Hawaii classrooms inform future revisions of the comfort standards?

Methods

Physical Measurements and Equipment.

Physical measurements of the classroom environment were taken with equipment that fit compactly on a laboratory tray or cart. Sensors measured air temperature, humidity, globe temperature, air movement, carbon dioxide, and particles, located at a height of 1.1 meters (43 inches) above the floor, one of the three heights specified in Standard 55 and selected as most appropriate to reflect the thermal experience of the seated occupant.

Comfort Survey.

A six-page standardized questionnaire consisted of four sections of inquiry and required approximately 15 minutes to com-

plete. It was administered approximately 25 minutes after the start of the last period to allow students to reach a stable metabolic rate. The first section incorporated classic thermal comfort questions, asking subjects to assess their comfort on a variety of subjective scales – thermal sensation, thermal preference, and thermal acceptability. Questions on other variables such as humidity, air movement, air quality and acoustics, subsequently used the formats of both the preference and acceptability scales.

Statistics.

A total of 3,544 classroom occupants were polled at six schools during the hot (1,755) and cool (1,789) season. Approximately two-thirds of the respondents (2,181) were from 19 naturally ventilated classrooms and the other third (1,363) were from 9 air-conditioned classrooms. Clothing insulation values were first tabulated from the clothing checklists marked on the questionnaire and then increased by 0.10 clo, estimated as the incremental insulating value of the typical classroom chair (6, 7). Clothing and metabolic rate were then combined with averaged physical measurements as inputs to a thermal comfort simulation program (8) used to calculate climate and comfort indices.

Results

Averaged temperature and humidity data for each class visit are plotted on a psychrometric chart and compared to the criteria specified by the Standard 55 for summer conditions in Figure 1. More than 75% of the total number of classroom visits (139 of 182) fell outside the standard’s comfort zone requirements. In naturally-ventilated classrooms, 92% (94 of 102 visits) had warm and humid conditions well outside of the Standard 55 prescriptions, exceeding the standard’s upper humidity limit (20°C wet bulb). Less than half (44%) of the air-conditioned class visits had conditions within the boundaries of the comfort zone, most falling beyond the cool

boundary ($<23^{\circ}\text{C ET}^*$), reflecting over-cooled conditions by the air-conditioning systems. Both a temperature and humidity shift is clearly evident between naturally-ventilated and air-conditioned classrooms. Although seasonal differences are graphically less distinct, more than a 2.5°C temperature difference existed between the hot and cool seasons in the naturally-ventilated classrooms.

Standard 55 defines an acceptable thermal environment as one that satisfies at

least 80% of the occupants. Figure 2 compares several methods of determining acceptability (9) to determine compliance to the 80% thermal acceptability criterion of Standard 55. The traditional and most commonly used method is an indirect measure that equates satisfaction (or acceptability) with the central three categories of the seven-point thermal sensation scale. Seventy-four percent of naturally-ventilated occupants and 65% of air-conditioned occupants are assumed to be satisfied with their thermal conditions, perhaps in part

Figure 1. Indoor climate conditions on Standard 55 revised summer comfort chart (each symbol represents averaged climate values measured for a class visit during the hot and cool seasons).

because the naturally-ventilated responses were centrally distributed around the neutral thermal sensation category, encompassing more of the population. The *second* method asks a direct question using a present-time condition: "Are the conditions in this classroom acceptable to you, right now?" Both naturally-ventilated and air-conditioned occupants found conditions acceptable, exceeding the 80% acceptability criterion specified by Standard 55. The *third* method assumes that those within the comfort zone prescriptions of Standard 55 will find conditions acceptable. A low proportion of the total sample had conditions within the comfort zone - 7% of the naturally-ventilated and 45% of the air-conditioned occupants, less than a quarter of the

entire sample (820 of 3544 subjects), had environments complying with Standard 55 specifications. In the *fourth* method, votes of "no change" on the preference scale represents an assumption of acceptability and are far below the standard's 80% satisfaction criterion. This question forces the response into a particular category and demonstrates the difference between a more stringent measure of ideal (preferred) conditions vs. wider acceptable range. For example, the majority of naturally-ventilated occupants preferred to feel cooler but still found surrounding warm conditions acceptable.

Central 3 categories of thermal sensation scale

Direct acceptability

Physical conditions within comfort zone

Thermal preference vote of "no change"

Figure 2. Various methods of acceptability.

Discussion

Indirect, Direct and Preference.

These methods of measuring acceptability showed differing results. The direct method yielded high acceptability levels from both naturally-ventilated (86%) and air-conditioned subjects (92%), exceeding the standard's 80% criterion shown in Figure 1. In fact, when dividing the sample across the coordinates of the comfort zone, those within the comfort zone (representing a small portion of the sample) and those outside of the comfort zone, both found conditions acceptable above the standard's criteria. In contrast to the traditional indirect measure of acceptability (three central categories of the thermal sensation scale), votes of both naturally-ventilated occupants (74%) and the air-conditioned occupants (65%) acceptability did not meet the 80% acceptability criterion of Standard 55. This method does not take into account the fact that people experiencing non-neutral thermal sensations might consider conditions acceptable, which the Hawaii sample expressed through the direct acceptability question. Direct thermal acceptability data of the Hawaii air-conditioned occupants corroborated the results of the data in Townsville (10), which also met the standard's 80% acceptability goal. The assumptions associated with the indirect method become more apparent when examining thermal preferences. A significant number of people (62% during the hot season and 43% during the cool season) in naturally-ventilated classrooms preferred to feel cooler while experiencing neutral thermal sensations. This matches the results of Busch's Bangkok study where 64% of naturally-ventilated office workers preferred cooler conditions while experiencing neutral sensations (11). These findings strongly suggest that "neutral" thermal sensations do not correlate to people's ideal or preferred thermal state. The contrasting results between the indirect and direct methods has shown that the validity of the assumptions that associate neutral sensations with acceptability are questionable for two reasons: (1) a significant number of people

experiencing non-neutral thermal sensations voted the conditions as acceptable, and (2) thermal neutralities calculated by thermal sensation did not match those calculated using preference (12). Results also suggest that neutrality is not necessarily ideal and that measures of direct acceptability and thermal preference are perhaps better tools for determining ideal conditions (single, optimum temperatures) instead of neutral temperatures. One approach might ask subjects to mark on the thermal sensation scale their preferred thermal condition (rather than the three choices, "want warmer," "no change," or "want cooler"). In turn, the results might be easier to compare to the thermal sensation scale itself.

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