THE CROWN RE–VIEWED: REFLECTIONS ON STUDENT THERMAL SATISFACTION IN IIT CROWN HALL

Abstract

Historic buildings are confronted by two key challenges: the increased concern for energy reduction and the need for providing occupant thermal comfort. Yet, the challenge is often to find a balance between improving energy efficiency and meeting thermal comfort standards while maintaining the building's architectural values. A significant percentage of energy consumption in buildings is used to meet thermal comfort needs through heating and cooling systems. In an attempt to address this topic on our own campus, we conducted a field survey in IIT's iconic Crown Hall to measure indoor thermal environmental parameters and collect responses to user thermal comfort questionnaires. The building design has inspired innovation and technologies for building materials since its construction; however, anecdotal evidence has suggested that more can be done to ensure that this inspiring space can meet the thermal comfort needs of occupants. To expand on this, physical measurements and user subjective surveys were collected simultaneously on November 7, 2018. The specific time period was selected representing a typical winter day in Chicago with cloudy sky and outdoor temperature ranging between -3°C and 3°C. The subjective survey investigated students' thermal sensation, thermal satisfaction, and perceived level of productivity using the 7-point scale developed by Fanger (1970). The findings of the survey were compared with the results of the field measurements, including outdoor temperature, indoor temperature, and indoor relative humidity, and assessed based on the compliance with ASHRAE thermal comfort standards. Results showed that the students, who are also the main users of the space, expressed dissatisfaction with their thermal environment. Results can be used to inform further innovative solutions in the space to improve comfort.

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Keywords

Crown Hall, thermal comfort, thermal sensation, user survey

Introduction

Historic buildings offer great potential for energy saving measures given their established structure, already embodied energy, yet typically high energy usage. The major challenge in implementing an energy efficient retrofit in historic buildings is often to find a balance between the historic/architectural values to be preserved and the energy and comfort requirements to be met. Moreover, failure to achieve contemporary comfort standards poses a threat to preserving the built heritage for future generations. The means through which the building is retrofitted can significantly impact the architecture, even though the field of thermal comfort in historic buildings remains understudied (Martínez-Molina et al., 2016). Thus, this paper aims at contributing to this field of knowledge by studying the thermal performance and comfort conditions of IIT Crown Hall. This research proposes a systematic methodology based on qualitative and quantitative methods to assess the performance of the building by means of user survey and physical measurements. The main question this study addresses is: What are the current comfort levels in the IIT Crown Hall? The main objectives are:

— To understand students' perception of thermal comfort in Crown Hall, and
— To apply the ASHRAE adaptive comfort model or deciding whether or not the building is in the comfort zone.

THERMAL COMFORT

For decades, advanced technologies have contributed to improvements of the indoor thermal environment by means of heating and cooling mechanical systems. This established a mutually dependent relationship between technologies and the user's thermal satisfaction. Thus, user comfort in buildings is highly associated with the indoor environmental quality. Among all parameters associated with comfort in a building (i.e., thermal, visual and acoustic environment, and air quality and building characteristics [Zagreus et al., 2004]), thermal comfort is ranked to be of higher influence in the overall indoor satisfaction compared to the impact of others parameters (Frontczak & Wargocki, 2011). The American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) defines thermal comfort as "*the condition of the mind on which satisfaction is expressed with the thermal environment*" (ASHRAE Standard 55, 2013). Another common definition of thermal comfort is defined by Hensen (1990) as *"a state in which there are no driving impulses to correct the environment by the behavior."* This poses an immediate recognition that thermal comfort is influenced by both environmental and psychological factors (Singh et al., 2011).

Due to this complexity, researchers have mainly resorted to measuring mainly physical variables (i.e., air temperature, mean radiant temperature, and relative humidity; mean air velocity; metabolic rate; clothing insulation), and assess the comfort level by determining the average Predicted Mean Vote (PMV) and percentage of people dissatisfied (PPD). Optimally, the building needs to achieve a standard of 80%–90% of users having thermal satisfaction (ASHRAE Standard 55, 2013). Two commonly used models for determining indoor temperature are 1) heat balance model — measured in closed Climate Chamber — and 2) the adaptive model accounting for human adaptive behaviours — measured by means of user's surveys and field studies (Yang et al., 2014).

Studies on thermal comfort developed by Fanger (1970) are based on the understanding of human thermoregulatory models and accordingly estimate the design values for operative temperature through thermal comfort equations. For decades, an increased attention in thermal comfort studies in buildings is evident due to its direct implication on energy saving if wider comfort limits are provided. Moreover, the importance of an adequate thermal environment inside the building is not only crucial for the health of the occupants but also has a major influence on the progress and productivity of the users (Leaman & Bordass, 1999; Wagner et al., 2007; Nicol et al., 2012).

Research Methods

CASE STUDY

Since its opening in 1956, Mies van der Rohe's Crown Hall has been home to the College of Architecture at the Illinois Institute of Technology. It was designated a national landmark in 2005, a very rare recognition for a building fewer than 50 years old (Sexton, 2017). The building embodies the architect's "less is more" philosophy and mirrors the historic one room schoolhouse. While the open universal space evokes qualities of nature for student's creativity, the building materials create a challenging environment for architects and engineers to ensure thermal satisfaction for students using the space. The building has undergone several modifications throughout its history, yet thermal performance has anecdotally remained a weak point.

The building must now host 400 students compared to 120 students at its inception (Figure 1). Accordingly, the building must now account for new comfort requirements that were not present in the initial process of the design. A $15 million renovation aimed primarily to restore the building to its original condition included: 1) the removal of existing glazing and steel stops; 2) removal of all lead-based paint from interior and exterior steel; 3) repairs to corroding steel; 4) refurbishment and reactivation of louvers; 5) refurbishment of select steel stops with new replacement stops as required; and 6) recoating (painting) of steel, stops, and louvers (Sexton, M. 2017). However, thermal comfort and energy reduction were not properly addressed during the renovation process (Pottgiesser & Ayón, 2019).

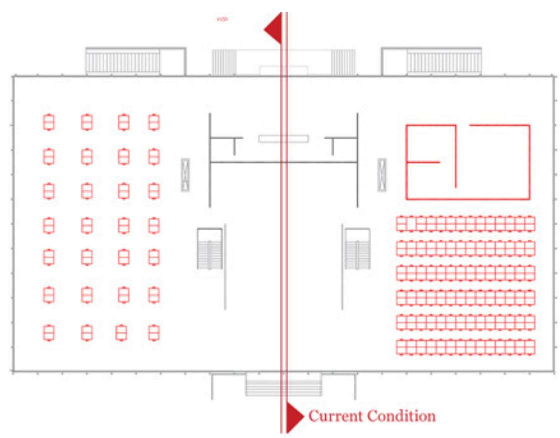

Figure 1: Comparison between interior space originally hosting 120 students (left) and the current condition hosting 400 students (right). (Source: Authors.)

THERMAL COMFORT ASSESSMENT

The study is based on both objective and subjective evaluations of the thermal comfort of students in the space and includes analysis of student perceptions regarding thermal sensation, level of satisfaction, and perceived level of productivity. Field measurements and questionnaires were conducted simultaneously on November 7, 2018, between 16:30 and 17:30 pm during the maximum student capacity (design studio time). Methods are explained in more detail below.

USER SURVEY

Survey data was collected through a printed survey targeting 90% of students, which was divided into subjective and objective variables. The objective variables assessed included the students' demographic information (e.g., background, gender, etc.) and the location of their workspace in the building. The subjective variables assessed included: students' subjective thermal sensation vote, level of satisfaction, and self-reported productivity perceptions. The survey also assessed students' adaptive responses to discomfort in addition to general comments concerning thermal environment comfort related to their workspace. A 7-point scale was used to assess all three subjective variables, from -3 (with endpoints including Very Cold, Very Dissatisfied, Interfere with Productivity) to 3 (with endpoints of Very Hot, Very Satisfied, Enhance Productivity) for Thermal Sensation, Thermal Satisfaction, and Perceived Level of Productivity, respectively, with 0 as the neutral midpoint for each. Out of 130 students in attendance on the sampling day, 118 students (63 male, 55 female) completed surveys, with a 90% response rate (Figure 2).

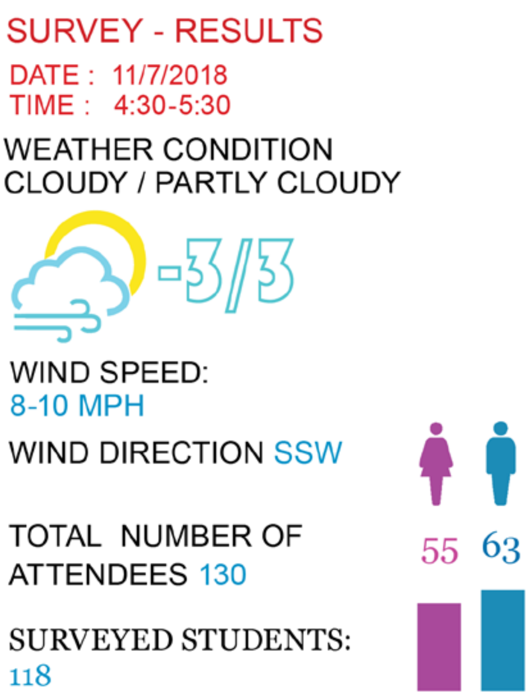

Figure 2: Survey Summary. (Source: Authors.)

PHYSICAL MEASUREMENTS

The manually distributed questionnaires were distributed in conjunction with the collection of physical measurements to analyze how environmental factors affect the student's comfort in the space. The sensor placement plan is shown in Figure 3. The sensors were placed at a height of approximately 80 cm from the ground, located on the student's desks.

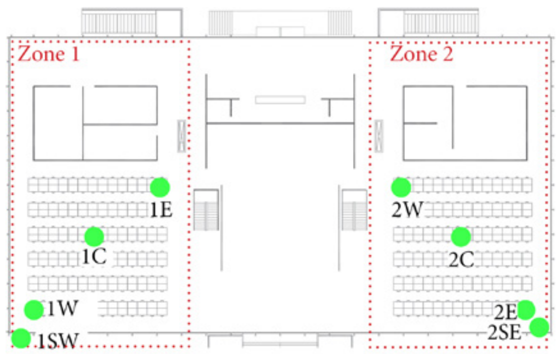

Figure 3: Sensor Placement Plan. (Source: Authors.)

Results and Key Findings

The results revealed that the students expressed dissatisfaction with their thermal comfort (Figure 4). Figure 5 shows the distribution of thermal comfort sensation votes for all of the student respondents. A majority (53%) reported cold thermal sensations, while 21% reported warm thermal sensations, and 23% reported neutral sensations. Overall, more students were dissatisfied (63%) than satisfied (23%), with only 13% of the students reporting neutral satisfaction levels (Figure 6), with a high percentage of responses in the -1 and -2 categories. For reference, the distribution of responses for overall workspace satisfaction is presented in Figure 6.

The survey results also show that the thermal conditions are noticeably affecting the students' perceived productivity level. The survey results showed that 55.8% reported that the thermal conditions interfere with their overall productivity, while only 30.5% reported neutral perceptions on productivity impacts. A minority (14%) responded that thermal conditions enhance their productivity.

By plotting the students' subjective responses in conjunction with their designated workspace location, it is apparent that cold sensation votes are mostly located along the perimeter of the building (Figure 5). However, thermal satisfaction and perceived self-reported productivity votes were more randomly distributed among the space (Figures 6 and 7).

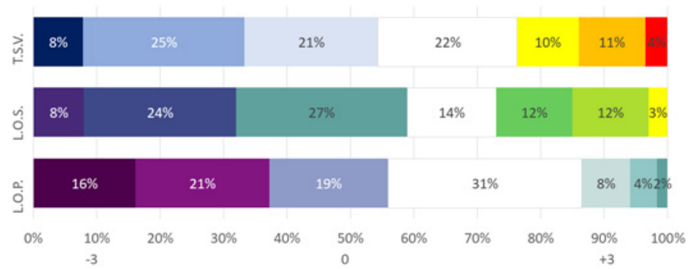

Figure 4: Survey Results – Summary Diagram for Percentage of Thermal Sensation Votes, Percentage of People Dissatisfied, and Perceived Level of Productivity. (Source: Authors.)

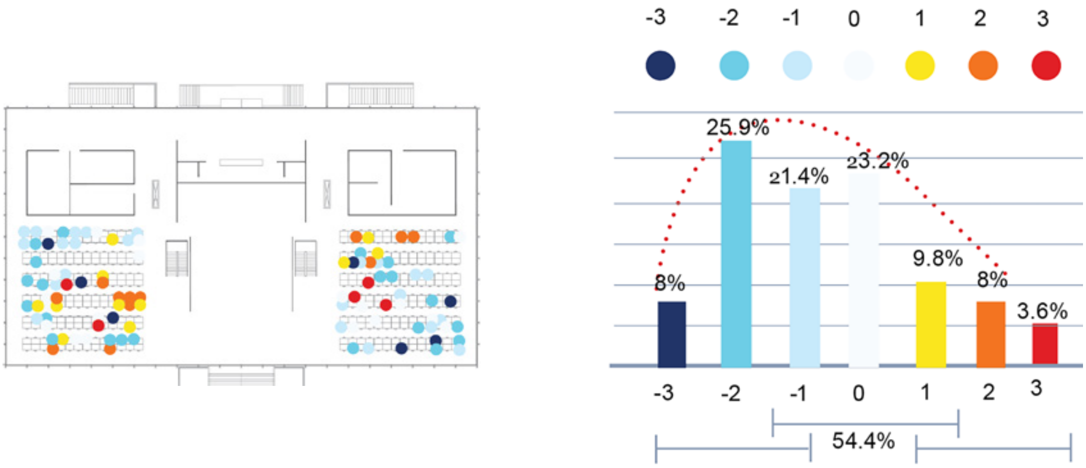

Figure 5: Spatial distribution of thermal sensation votes. (Source: Authors.)

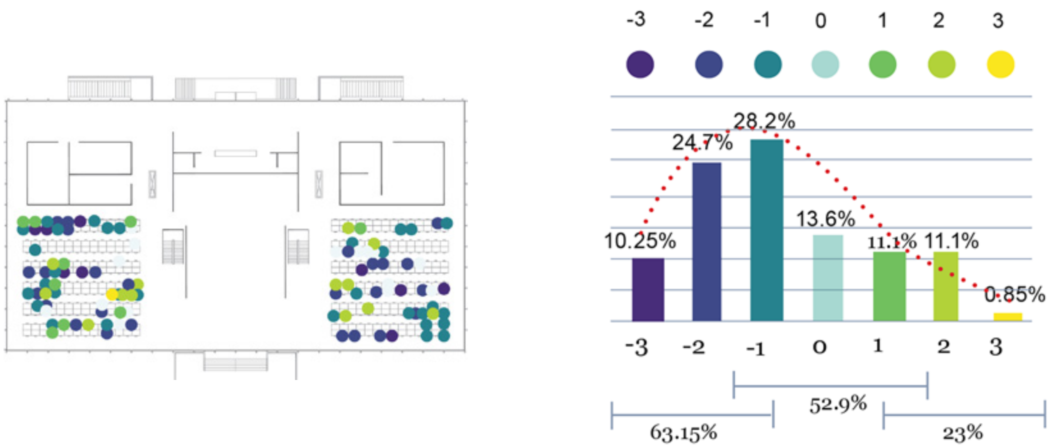

Figure 6: Spatial distribution of students' level of satisfaction. (Source: Authors.)

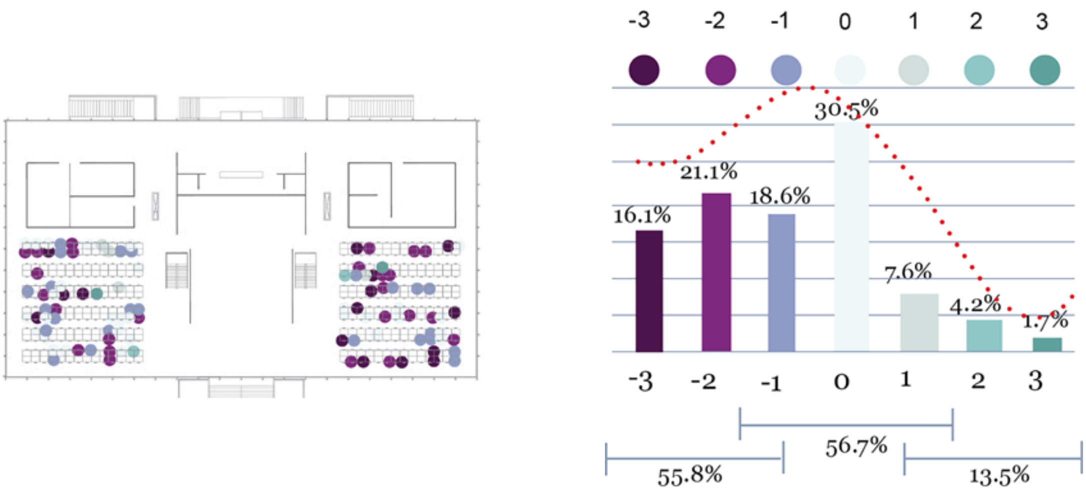

Figure 7: Spatial distribution of students' perceived level of productivity. (Source: Authors.)

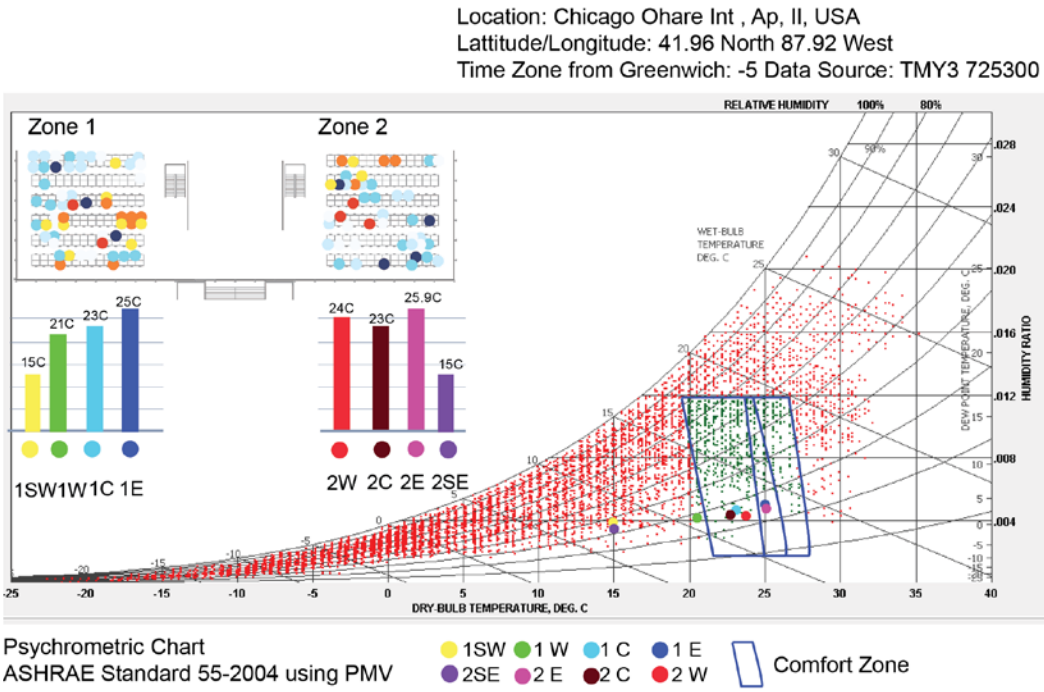

Figure 8: Psychrometric chart presenting physical measurement. (Source: Authors.)

Zone 1								
	1 SW		1W		1C		1E	
	T_a(°C)	RH(%)	T_a(°C)	RH(%)	T_a(°C)	RH(%)	T_a(°C)	RH(%)
Min	14.75	37.36	20.93	28.15	23.24	26.70	23.30	25.84
Max	15.2	39.6	21.2	29.2	23.6	27.3	23.5	26.8
Mean	15.08	38.82	21.06	28.89	23.48	27.01	25.35	26.47
	» Direction to Center Core							

Table 1: Comparison of the recorded environmental parameter data for Zone 1 between 16:30 and 17:30 pm. (Source: Authors.)

Zone 2								
	2SE		2E		2C		2W	
	T_a(°C)	RH(%)	T_a(°C)	RH(%)	T_a(°C)	RH(%)	T_a(°C)	RH(%)
Min	14.92	36.24	24.82	23.43	23.34	26.52	23.93	25.75
Max	15.7	38.7	25.3	24.39	23.8	27.3	24.7	26.5
Mean	15.39	37.91	25.3	24.39	23.62	27.00	24.23	26.04
	» Direction to Center Core							

Table 2: Comparison of the recorded environmental parameter data for Zone 2 between 16:30 and 17:30 pm. (Source: Authors.)

Physical measurements were analyzed by comparing measured temperature and relative humidity with respect to ASHRAE Standards using an online thermal comfort tool offered by the Center of Built Environment (CBE), UC Berkeley (Tartarini et al., 2020). Typical winter conditions were considered including 1.1 met for metabolic rate and clothing level 1 clo. The results showed uneven distribution of temperature along the space. Tables 1 and 2 show temperature distributions throughout the spaces. The measurement showed non-uniform readings. The lowest temperature recorded was 15.08ºC at sensor location (1 SW and 2 SE). As the sensor location is set away from the glazed facade, the temperature gradually increases to approximately 23.5ºC (sensor 1 C, 1 E, 2 C and 2 W). These measurements all comply with standards set by ASHRAE 55, with exception of sensor locations 1 SW, 1 W and 2 SE which are located in close proximity to the glazed facade (Figure 8).

Reflections and Concluding Remarks

The Crown Hall thermal condition directly relates to the building architecture and construction characteristics, and results reveal that more can be done to ensure that this inspiring space has more ideal thermal conditions for students to support their productivity. To provide better understanding of thermal comfort in the building and related issues, building users are a rich source of information about indoor environmental quality and its impact on comfort and productivity. One step toward an energy efficient retrofit of historical buildings is to understand and assess thermal comfort of the users of the space.

Based on this empirical field study at IIT Crown Hall, it is clear that thermal comfort and its associated implications for energy savings require a considerable amount of attention. The recommendations set out by the standards suggests that 80%–90% of the building users need to be satisfied with the building thermal conditions; however occupants in Crown Hall on the sampling day perceive satisfaction with comfort well below this standard, even if the required physical parameters were met. The layout of Crown Hall resulted in non-uniform thermal zones due to the combination of solar radiation, different radiant heat transfer modes caused by the glazed surfaces (facades), drafts (openings), etc. It is suggested to apply the same methodology and re-collect the survey among the students of Crown Hall in different indoor and outdoor climatic conditions to provide a more holistic view of comfort conditions in this space.

Presumably the percentage of the people dissatisfied indicates a deficiency in the building's thermal systems (e.g., enclosure, HVAC, or both). A wide disparity in thermal sensation based on location was observed, which emphasizes the need for micro-level thermal comfort solutions. Focusing on satisfaction of the user means that the indoor climate is a key for a holistic design approach. Results of this survey should allow the building operators to move forward in investigating how to enhance the thermal comfort condition and should help to promote a better understanding of the HVAC system in the building and improve its efficiency. Doing so will not only make the building more inhabitable for its users but also preserve the building for future generations.

Acknowledgments

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