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THERMAL COMFORT ASSESSMENT THROUGH MEASUREMENTS IN A NATURALLY VENTILATED LEED GOLD BUILDING

Amy Kim, Ph.D.[1,4], Shuoqi Wang[2], and Dorothy Reed, Ph.D., P.E.[3]
[1] Assistant Professor, Civil and Environmental Engineering, University of Washington, Box 352700, Seattle, WA 98195-2700, United States
[2] Graduate Student, Industrial & Systems Engineering, University of Washington, Box 352650, Seattle, WA 98195-2650, United States
[3] Professor, Civil and Environmental Engineering, University of Washington, Box 352700, Seattle, WA 98195-2700, United States
[4] amyakim@uw.edu

Abstract: Reductions in electric power consumption at the University of Washington are an established sustainability performance target. In order to meet this target, Leadership in Energy & Environmental Design (LEED) certification of buildings on campus is part of a long term plan for the University. It has been assumed that LEED certification will result in less power usage by occupants while improving indoor environmental quality. However, the related indoor environmental quality for these certified buildings has not been evaluated in situ. The primary objective of our study was to investigate the indoor quality assessment, more specifically in this paper, we discuss the thermal comfort of a LEED Gold building through both in-situ measurements of temperature, humidity, and occupant comfort surveys. Three measurement stations have been implemented in a low-rise retrofitted Student Union Building starting April of 2014: two in a food court or commercial kitchen environment and the other in a small office. Surveys to assess the comfort levels of both populations have been undertaken. The resulting data set is rich in terms of providing technical and nontechnical feedback on the thermal comfort of a LEED certified building. Preliminary findings indicate that thermal comfort parameters employed for heating, ventilation and air-conditioning systems control were not optimum in practice.

1 INTRODUCTION AND BACKGROUND

In 2009, University of Washington (UW) President Mark A. Emmert stated his intent to establish a climate-neutral campus having no net greenhouse gas emissions (University of Washington Climate Action Plan Oversight Team 2009). As part of a plan to accomplish this goal, over 216 smart meters have been placed on buildings on the Seattle campus to monitor energy consumption through the related Pacific Northwest Smart Grid demonstration project. Another major strategy adopted by the university is to require high-performance building standards (University of Washington Climate Action Plan Oversight Team 2009). As a founding signatory of the American College and University Presidents' Climate Commitment, UW uses the United States Green Building Council's (USGBC's) Leadership in Energy & Environmental Design (LEED) rating system for all buildings on the UW campus. According to UW's Environmental Stewardship and Sustainability Office, the number of LEED-certified buildings has increased from 15 in 2011 to 27 in 2013.

The newly renovated UW Husky Union Building (HUB) (i.e., the Student Union Building) received a LEED Gold rating. To achieve these goals, dramatic changes were made to the building. New mechanical, electrical, lighting, and audiovisual systems were brought into the building to replace antiquated systems, although half of the building's more than 60-year-old superstructure was preserved (Bussard & Chan 2012,

“The University of Washington opens newly renovated husky union building” 2012). In addition, a series of sustainable elements were incorporated into the new HUB. For example, the newly designed atrium, the large expanses of glass, and supporting mechanical systems created a naturally illuminated and ventilated building. As a result, in principal, the indoor environment can be improved while energy usage is reduced. This led to the research question of this study: does the LEED-certified Gold HUB perform according to protocols established by agencies such as the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), the Charted Institute of Building Services Engineers, and USGBC in terms of thermal comfort?

Studies about occupant and indoor environmental quality (IEQ) in green buildings have focused mostly on occupant surveys without investigating the on-site physical measurements of the indoor environment (Abbaszadeh et al. 2006, Altomonte and Schiavon 2013, Asmar et al. 2014) and mostly for office buildings (Radwan et al. 2013). This study takes into consideration both the subjective (occupant surveys) and objective (physical measurements) aspects of indoor environment in a LEED-Gold certified building. In addition, IEQ measurements for commercial kitchen environment were undertaken.

2 RESEARCH OBJECTIVE

The predicted energy performance of a building is based upon several assumptions about the indoor environment quality such as the indoor temperature, relative humidity, CO_2 levels, lighting and acoustics. In this paper, we present one segment of preliminary findings of a long-term investigation focused on the development of a comprehensive framework to evaluate the effectiveness of sustainable practices used in new and existing green buildings. Specifically, we characterize the in situ IEQ for a naturally ventilated LEED Certified Gold building through physical measurements and occupant surveys. This paper presents the collected data on temperature, humidity, and occupant comfort surveys in both a small office and a commercial kitchen environment of a naturally ventilated LEED Gold building on UW campus in the year of 2014.

3 METHODOLOGY

3.1 Equipment Selection and Set-Up

After investigating the required measurement equipment, the research team mounted all the handheld devices on a moveable I.V. pole and delivered the three measurement stations to the office and the kitchen. The research team consulted multiple references (ASHRAE, USGBC, & CIBSE 2010, ASHRAE 2009, Haruyama et al. 2010, Simone et al. 2013, Stoops et al.2012) to evaluate the necessary equipment for accessing the IEQ of the office area and commercial kitchen. Table 1 lists all the purchased equipment related to measurement of air temperature (Ta), globe temperature (TG), and relative humidity (RH) for the study to physically measure the thermal comfort parameters. Mounting heights were also extracted from existing sources (ASHRAE 2013a) and are summarized in Table 2.

Table 1: Partial specifications of instruments used in this study

Parameter (Abbreviation)	Unit	Model Name	Sensor Type	Accuracy	Range
Air Temperature (Ta)	°C	REED SD-4214 Thermo-anemometer/Data Logger	Telescoping Hot Wire Slim Probe (12-mm Diameter)	±0.4°C	0°C~50°C
		Fluke 975 Airmeter	Built-In	±0.9°C from 40°C to 60°C ±0.5°C from 5°C to 40°C ±1.1°C from -20°C to 5°C	-20°C~60°C
		HOBO U12 Temp/RH/Light/External Data Logger	Built-In	±0.35°C from 0°C to 50°C	-20°C~70°C
Globe Temperature (TG)	°F	Extech HT30	Black Ball: 1.57 Diameter, 1.37 Height	TG Indoor: ±4°F TG Outdoor: ±5.5°F Ta: ±1.8°F RH: ±3%	WBGT: 32°F to 122°F TG: 32°F to 176°F Ta: 32°F to 122°F RH: 0 to 100%
Relative Humidity (RH)	%	Fluke 975 Airmeter	Built-in	±2% RH (10% RH to 90% RH)	10% to 90 % RH, Non-condensing
		HOBO U12 Temp/RH/Light/External Data Logger	Built-in	±2.5% RH (10% RH to 90% RH), to a Maximum of ±3.5%	5% to 95 % RH

Table 2 Vertical placement information for the instruments

Parameters	Height (above Floor)		References
	Standing Occupants	Seated Occupants	
Air temperature	0.1, 1.1, and 1.7 m	0.1, 0.6, and 1.1 m	ASHRAE Standard 55
Air velocity	0.1, 1.1, and 1.7 m	0.1, 0.6, and 1.1 m	
Relative Humidity	1.1 m	1.1 m	

3.2 Testing Location Selection

Three locations were used for data gathering. The selection of each location was based on how well it represented the surrounding area. Through consulting the kitchen and office staff, the research team decided that these locations were ideal in terms of keeping the impact of the data measurements on normal business operations to a minimum level. Within the kitchen environment there were two data-gathering

locations. The first location was near the restaurant's cooking equipment. The second location was identified near the dishwashing machine. In the office, the unit was located in the general occupant seating/desk area.

3.3 Survey preparation

The International Organization for Standardization and ASHRAE have established indoor thermal environment standards. The Center for the Built Environment (CBE) of the University of California, Berkeley provided an occupant IEQ survey for researching building performance (Center for the Built Environment n.d.). The survey covers thermal comfort, indoor air quality, lighting/daylighting, and acoustics and served the purpose of this study. The CBE also has large databases of accumulated survey results. Therefore, the research team chose to use the CBE survey for occupants in the office inside the HUB.

The kitchen area is a different indoor environment from the office areas. The main activity in the HUB kitchen is cooking, which generates heat and effluents that must be captured and exhausted in order to control and guarantee thermal comfort and good air quality for the employees (ASHRAE 2009). Relatively little research has been conducted regarding thermal comfort in commercial kitchens. Therefore, a standardized survey for commercial kitchen employees could not be found. Haruyama (Haruyama et al. 2010) used questionnaire surveys to evaluate subjective thermal strain in different kitchen working environments in Japan. In the United States, ASHRAE-supported research (Simone et al. 2013, Stoops et al. 2012) investigated the thermal comfort in commercial kitchens of different types and locations in different climatic zones. A modified version of Stoops et al's "Thermal Comfort in Commercial Kitchens Survey" was used in this research to collect subjective measurements. The modified survey contained 36 questions covering background information, personal comfort, personal control, work conditions, environmental sensitivity, and clothing.

Both the office and kitchen surveys were pre-tested with the HUB associate director. Based on the feedback, kitchen survey questions about building features including window blinds, roller shades, exterior shades, and security systems were deleted since they were not available or accessible to most kitchen staff. Questions in the office survey about exterior shades and the security system were also deleted given their limited installation.

4 PRELIMINARY RESULTS AND DISCUSSION

The preliminary results are provided for the thermal comfort measurement in the office and the kitchen. The results of the thermal comfort measurements include the indoor operative temperature, measured data as plotted in the graphic comfort zone, and the vertical temperature difference measured at 0.1, 1.1, and 1.7 m. The results for the office area were assessed separately for occupied hours for both summer months and autumn months. Summer months were from June through August. Autumn months were from October through November. Survey results were used to assess whether these objective data aligned with the occupants' subjective assessment of the thermal comfort.

4.1 Measured Thermal Comfort Data

4.1.1 Office Area

Figures 1 and 2 contain representative time series plots comparing the daily average five-minute mean indoor operative temperature readings for the working hours for the summer and autumn, respectively. The indoor operative temperature (ASHRAE 2009) represents the temperature of a uniform environment that includes the effects of relative humidity. The globe temperature measurement is used as equivalent to the indoor operative temperature. Excursions of peak values above and below the 80 percent ASHRAE acceptability limits as defined in ASHRAE 55-2013 Section 5.4 occur occasionally, especially early in the morning during the summer months due to the free-cooling strategy, night ventilation. The 80 percent limits are a function of the outdoor temperature and vary as the weather changes. The statistical variance in the record is much smaller for the autumn readings.

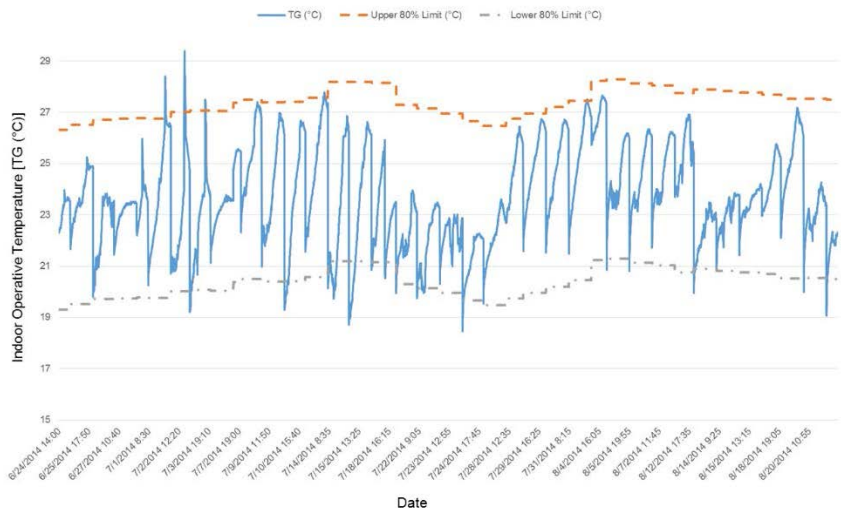

Figure 1: Representative time series data for globe temperature TG (°C) in the office during working hours in the summer.

Figure 2: Representative time series data for globe temperature TG (°C) in the office during working hours in the autumn.

Figures 3 and 4 contain the measured data as plotted in the graphic comfort zone method for identifying the acceptable range of dry-bulb temperature and humidity as defined in Section 5.3 of ASHRAE Standard 55-2013 (ASHRAE 2013). For summer, the 0.5 clothing insulation zone is shown in Figure 3. Both the 0.5 clothing zone and the 1.0 clothing zone are shown in Figure 4 for autumn to reflect the clothing choices made by the office workers. The data often extended beyond the suggested comfort zones during the summer months. The plots illustrate the variability in the ranges of thermal comfort in the summer, with a wider, more acceptable range in the autumn.

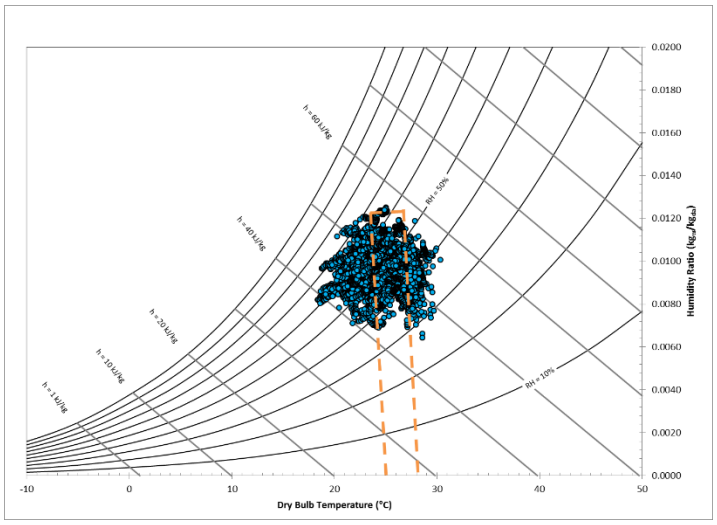

Figure 3: Graphic Comfort Zone for working hours (8 am to 8 pm) in the office during the summer. The "boxed" area with dash line shows the 0.5 clothing zone.

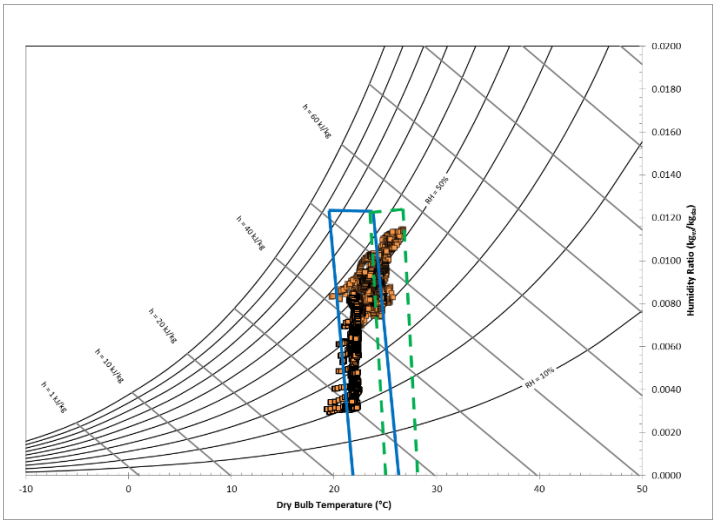

Figure 4: Graphic Comfort Zone for working hours (8 am to 8 pm) in the office during the autumn. The two "boxed" areas represent the 0.5 (dash line) and1.0 (solid line) clothing zone.

The vertical temperature difference in the office was also investigated but did not exceed the recommended ASHRAE limit of 3°C during the study. The ASHRAE limit of 3°C was occasionally violated during summer (1.81 percent of the time during summer months and 0.36 percent of the time during summer and autumn months). Most of the violations happened between 5 p.m. and 6 p.m.

4.1.2 Kitchen Area

Indoor temperatures at various vertical locations in the kitchen cooking area were notably different. ASHRAE Standard 55 recommends that the vertical air temperature difference between 0.1 and 1.7 m should not exceed 3°C. Figure 5 shows the five-minute average air temperature on a weekday at three heights as well as the spatial average. During the peak service hours, which are from 11:00 am to 1:30 pm, the spatial average ranged between 26 and 28 °C while the temperature at 1.7 m was above 27°C. The vertical air temperature difference was above the ASHRAE recommended limit 17 percent of the time for a particular day.

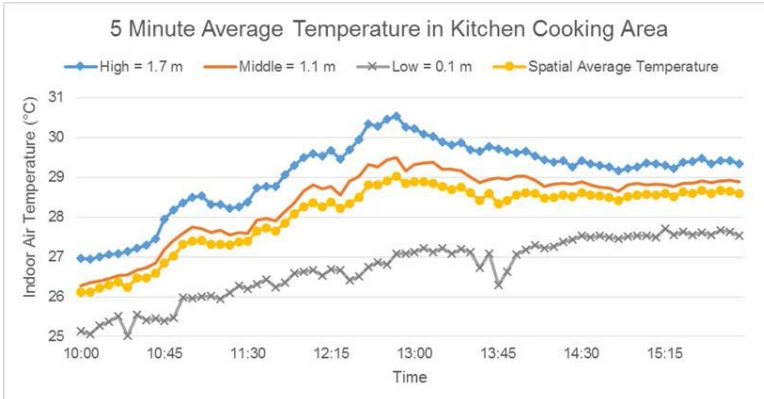

Figure 5: Five-minute average indoor air temperature in the cooking area on Wednesday July 2, 2014.

Figure 6 shows the five-minute average air temperature near the dish-washing machine on a weekday. Similar to the cooking area, the spatial average temperature ranged between 26 and 28°F during peak service hours. The vertical air temperature difference was also above the suggested standard limits 38 percent of time for that particular day.

In the cooking area, the difference in the vertical temperature gradually increased from 10 a.m. and peaked around 12:30, followed by a gradual decrease. The dishwashing area showed recurrent peaks and valleys, most likely due to the fact that heat was generated when the dishwashing equipment was in operation intermittently to clean the cooking utensils, dishes, cutlery, and other items. In the dishwashing area, the vertical temperature difference peaked around 14:30. This lag of about two hours was observed as the kitchen cooking activities peaked and started to decrease at about 12:30.

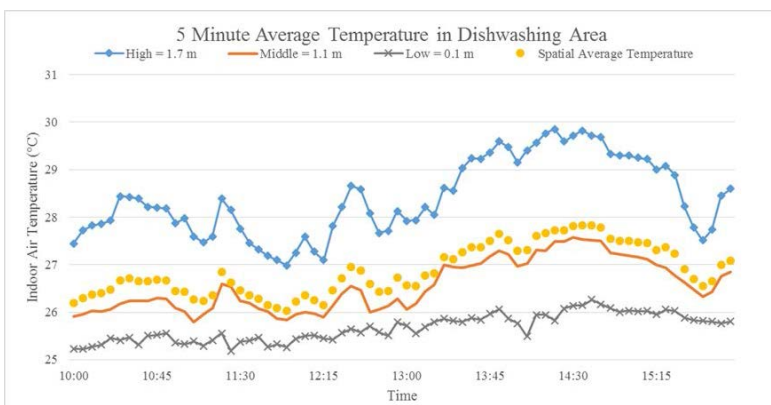

Figure 6: Representative five-minute average indoor air temperature near the dishwashing area on Thursday July 24th, 2014.

Figures 7 and 8 contain the measured data as plotted in the graphic comfort zone method for identifying the acceptable range of dry-bulb temperature and humidity as defined in Section 5.3 of ASHRAE Standard 55-2013 (ASHRAE 2013). For both the cooking and dish washing area, the “0.5 and 1.0 clothing insulation zone” is shown in Figures 7 and 8. The data repeatedly extended beyond the suggested comfort zones in both kitchen areas.

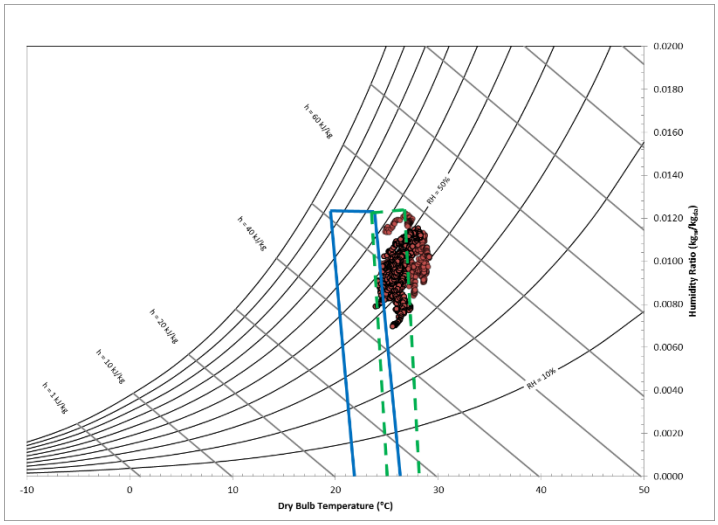

Figure 7: Graphic Comfort Zone for cooking area (6 am to 9 pm) in both summer and autumn. The solid "boxed" area shows the 1.0 clothing zone. The dashed "boxed" area shows the 0.5 clothing zone.

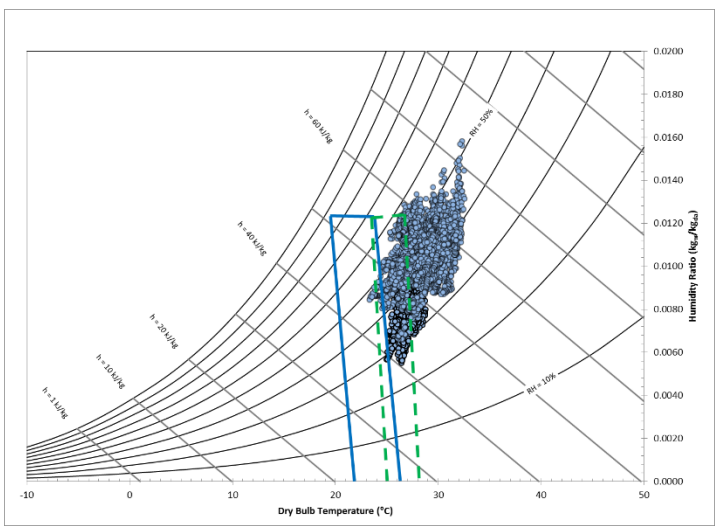

Figure 8: Graphic Comfort Zone for dishwashing area in both summer and autumn. The solid "boxed" area shows the 1.0 clothing zone. The dashed "boxed" area shows the 0.5 clothing zone.

4.2 Survey Results Regarding Occupants' Thermal Comfort

4.2.1 Office Area

The survey used seven-point ordered scale questions to evaluate the occupants' satisfaction with the thermal comfort parameters. These seven-point order scales ranged from very dissatisfied (0) to very satisfied (7), with neutral being the midpoint (3). The initial invitation to participate in the survey was emailed to only those six office employees that were stationed in the space where the continuous measurements of the IEQ were being collected. However, recognizing that the building (HUB) serves 54 other permanent employees throughout the various office spaces, an identical survey was made available online to capture the responses from a greater number of occupants of the building. A total of 41 responses were collected out of 60 employees, which resulted in a 68.3 percent response rate. This also exceeded the ASHRAE Standard 55 (ASHRAE 2013) requirement for having at least 35 percent of occupants respond to the post-occupancy survey for evaluating the IEQ in a subjective manner.

Determining thermal comfort included asking questions about the indoor temperature in the workspace. On average, the respondents indicated feeling slightly above the neutral level at 3.5. However, about 40 percent of respondents were slightly to very dissatisfied (range from 0 to 2) with the indoor temperature. Of those people that were dissatisfied, 75 percent of them actually had a portable fan in their workspace, and 37 percent had access to window blinds or shades and/or operable windows. In conclusion, 94 percent of the occupants that expressed discomfort had means to individually control their environment with personally adjustable or controllable systems in place. None of the occupants indicated discomfort from the cooler morning temperatures.

4.2.2 Kitchen Area

The kitchen survey asked employees questions about air movement and discomfort. The employees of the kitchen area consist of regular staff and temporary student employees. Fifteen regular staff members worked in the kitchen at the time of assessment. The manager distributed 15 paper copies of surveys to the regular staff, and all 15 copies were answered and returned.

Over half of the employees (60 percent) did not feel adequate air movement normally during work. Those employees complained about excessive heat from ovens or woks, and suggested increasing air flow and installing air conditioning or fans. Seventy-three percent of the employees stated that they did not feel comfortable most of the time. Most of them felt warm at the front and back of their bodies. Regarding different environmental conditions in the kitchen that could cause discomfort, “too high temperature” and “sweating” bothered most of the employees. Complaints of other conditions such as “draft” or “smoky kitchen” were relatively low.

5 CONCLUSION

Occupants of the offices were mainly satisfied with the thermal comfort of the building. Nevertheless, slightly lower and higher room temperatures were observed during early mornings and late afternoons in the summer. The free-cooling strategy, night ventilation, was successful in reducing the indoor operable temperature to a comfortable level in the morning. Without a mechanical air-conditioning system in the office spaces, the rise in outdoor temperature during the summer afternoons, in combination with the higher occupancy rate, increased the temperature to exceed the 80 percent ASHRAE acceptability limits as defined in ASHRAE 55-2013 Section 5.4. The survey showed that occupants were not bothered by the lower temperature in the morning but were disturbed by the higher temperature in the afternoons. Interestingly, 94 percent of those that were dissatisfied with the temperature had means to control their environment with personally adjustable or controllable systems such as windows and fans.

Objective measurement of the two kitchen areas, cooking and dishwashing, showed frequent exceedance of 80 percent ASHRAE acceptability limits as defined in ASHRAE 55-2013 Section 5.4. Complaints did exist among most of the kitchen employees about the indoor operable temperature. Specifically, these included low air movement causing discomfort with high temperature and sweating. An overwhelming number of respondents, almost three-fourths, indicated that most of the time they felt uncomfortable working in the kitchen. They suggested adding additional mechanical cooling systems.

The results presented here are preliminary and data collection continues through 2015.

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