TherMOOstat: Occupant Feedback to Improve Comfort and Efficiency on a University Campus

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ABSTRACT

Despite the significant amount of energy spent on Heating, Ventilation, and Air Conditioning (HVAC) at universities, thermal comfort conditions in campus buildings are frequently poor. Conventional HVAC management systems at universities are typically out of the hands of building occupants and facilities management departments have limited resources to involve them. These factors can lead to over-heating or over-cooling and undiagnosed mechanical issues. Previous research has shown that thermal comfort feedback, or participatory thermal sensing, can simultaneously improve energy efficiency and occupant comfort in university buildings. However, these studies have been limited to single campus buildings and restricted populations of occupants. The success, scalability, and sustainability of any participatory thermal sensing program is dependent upon ongoing participation that is meaningful to occupants and useful to facilities management. Therefore, research is warranted to explore patterns of voluntary participation, thermal comfort, and occupant satisfaction in extended, campus-wide deployments of participatory thermal sensing programs. The present research begins to address these gaps in the context of an 18-month, campus-wide deployment of TherMOOstat, a participatory thermal sensing app and HVAC management system at University of California, Davis.

Introduction

Heating, Ventilation, and Air Conditioning (HVAC) typically accounts for more than 40% of energy use in institutional buildings (DOE 2010). There are many solutions available to optimize efficiency in new construction (e.g., building envelope, mechanical equipment, and temperature controls) that are more difficult to implement in existing buildings, e.g., on university campuses. Innovative HVAC control strategies are a solution to HVAC efficiency more easily implemented in existing buildings (Wang et al. 2011; Leach et al. 2010; Katipamula et al. 2012).

Conventional HVAC control strategies in large institutional buildings typically involve centralized control of temperature setpoints, which are standardized based on building use. Occupants have restricted access to controls, which are often exclusively available to facilities management personnel. University campuses frequently use “work order” systems to manage temperature issues, but this process is slow and not widely used by students, i.e., the majority of building occupants. When occupants are out of the loop, HVAC control systems are necessarily reactive and based on assumptions regarding thermal comfort, thus often providing inadequate comfort and using more energy than needed (Brager et al. 2015). Furthermore, lack of perceived control of thermal conditions is associated with lower occupant satisfaction (Paciuk 1990).

A number of recent studies have discussed an innovative strategy to incorporate thermal comfort feedback from occupants, or participatory thermal sensing (Erickson and Cerpa 2012), into HVAC management and control in institutional buildings. The general strategy is to solicit thermal comfort “votes” (e.g., hot, cold) from building occupants via a web or mobile app. Most of these studies focus on university buildings (Balajiy et al. 2013; Erickson and Cerpa 2012; Ghahramani, Jazizadeh, and Becerik-Gerber 2014; Jazizadeh et al. 2011; Hang-yat and Wang 2013; Hang-yat et al. 2014; Purdon 2013) and imply or demonstrate improved energy efficiency as a result.

Past studies of participatory thermal sensing at universities have been conducted from an engineering perspective rather than a behavioral perspective. For example, most emphasize the development and evaluation of algorithms that incorporate occupant feedback into HVAC control. Most evaluations are based on simulations, not actual occupant behavior. Two field experiments are the exception (Balajiy et al. 2013; Erickson and Cerpa 2012), but they were relatively limited in terms of the testbed, participation, and/or duration of the experiment. Balajiy et al. tested their system in one university building with 65 participants for ten days. Erickson and Cerpa tested their system, Thermovote, for five months with 39 participants in a graduate student lab and administrative office space, together comprising seven HVAC zones within a single building.

The success, scalability, and sustainability of any participatory thermal sensing program is dependent upon ongoing participation that is meaningful to occupants and useful to facilities management. To date, no research has reported patterns of voluntary participation, thermal comfort, or occupant satisfaction in a participatory thermal sensing program implemented across an entire university campus for an extended period of time. Furthermore, no studies have teased out the effects of participation in participatory thermal sensing programs versus the effects of changes in thermal conditions. More specifically, the opportunity to provide feedback in itself, regardless of the integration of that feedback into HVAC control systems, could promote greater perceived control and thus greater comfort and satisfaction (Paciuk 1990).

Finally, no studies have investigated the opportunity to leverage participatory thermal sensing programs to promote engagement in energy efficiency and willingness to adapt to more conservative thermostat settings. Two studies have suggested that occupants can vote exaggeratedly in hopes of encouraging a stronger response from facilities (Erickson and Cerpa, 2012; Zhang, Lam, and Wang 2014), thus improved comfort. It may, therefore, be equally important to engage occupants in energy efficiency in addition to thermal comfort.

The present research begins to address these gaps in the context of TherMOOstat, a participatory thermal sensing program at University of California, Davis. Sixteen months of data collection from a campus-wide deployment of TherMOOstat presents the first opportunity to investigate user response to a university participatory thermal sensing program at a large scale, with a diverse population of student, staff, and faculty users. We describe usage of the system in terms of participation and comfort feedback, and report results of an experiment to investigate the impact of this participatory system on occupant satisfaction and willingness to conserve.

Methodology

Prior to TherMOOstat, UC Davis exclusively used a "work order" system to manage comfort complaints, but this process was slow and not widely used by students. The Energy Conservation Office of the Facilities Management Department and Consumer Energy Interfaces, a UC Davis research lab, developed TherMOOstat to access more granular and instantaneous data about occupant comfort. Facilities Management uses the data to identify common issues and prioritize campus initiatives aimed at improving comfort and energy efficiency. The Facilities team is also testing how to integrate comfort votes into the building automation system, automatically changing setpoints based on occupant feedback (Pritoni et al. 2016).

TherMOOstat

TherMOOstat includes two user-facing platforms: a widget on the university web portal and a mobile web application. The widget was launched September, 2014; the app was launched October, 2015. Data for the present research were collected from launch of each, widget and app, through March 4, 2016. The widget is accessible to all UC Davis students, faculty, and staff; it was featured on the main page for the first few months, then moved onto a subsequent page as more new widgets replaced it on the main page (this is the process for all widgets on the portal). Reasons for adding the mobile web app were to enable easier access for students, staff, and faculty who do not frequent the university portal, and create a platform amenable to experimentation. The web app works on all operating systems and was developed to work with all browsers; it has been promoted at university events and around campus via giveaways (t-shirts, stickers, and coffee sleeves), as well as flyers and chalk drawings on classroom blackboards.

The widget. User interaction with the widget consists of a simple user interface (UI; Figure 1b) to prompt the user to enter their location (Figure 2a) and submit thermal feedback (Figure 2b). Thermal feedback is solicited by asking, “How does the room feel?” Response options are Hot, Warm, Perfect, Chilly, or Cold, an abridged version of the ASHRAE scale with more colloquial wording intending to appeal to student users (i.e., ‘Perfect’ instead of ‘Neutral’). Users are also given the opportunity to leave comments in an open-response format (Figure 2e).

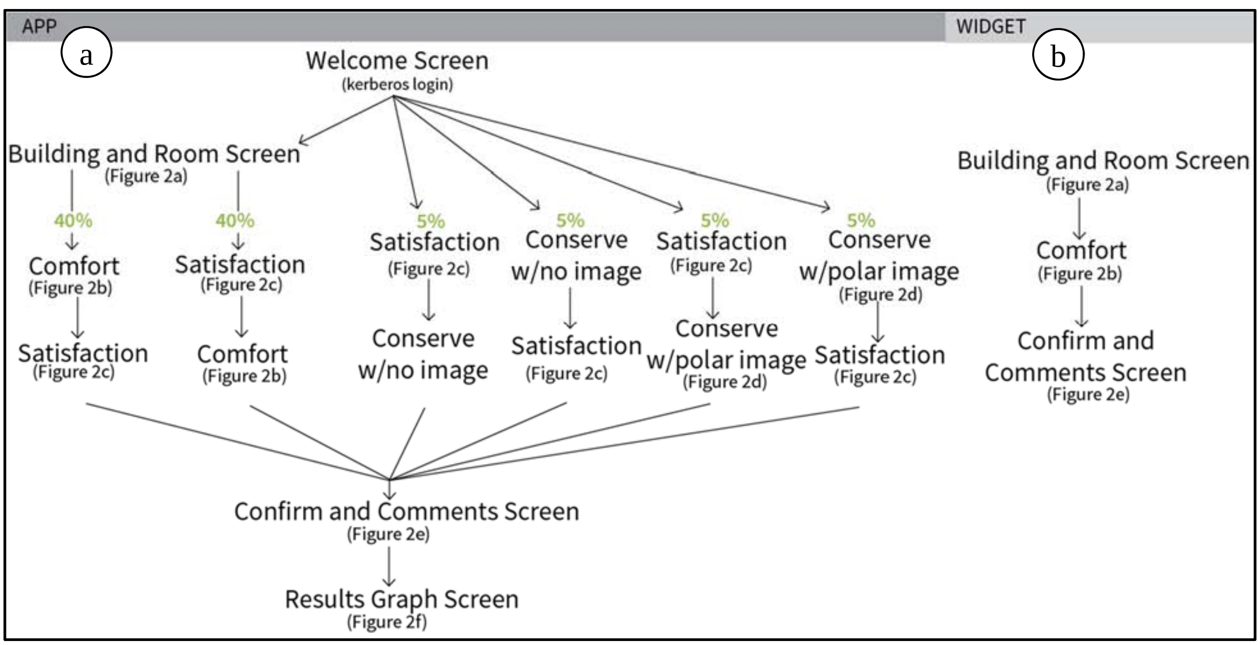

Figure 1. TherMOOstat user interface pathways.

The app. User interaction with the app is divided into six UI pathways to accommodate two experiments (Figure 1a). All pathways begin with a welcome screen where users log in with their UC Davis (kerberos) account (Figure 2a); login is required every visit. Users are then randomly assigned to either thermal comfort feedback (80% of visits), or are instead asked if they are willing to vote for a change in thermostat settings on campus to conserve energy (not specific to their voting location; 20% of visits). The conserve vote screen (Figure 2d) first solicits a yes or no response. If the user votes no, they continue to the next screen; if they vote yes, they are asked to select a change of +/- 1, 2, or 3 degrees (they are not able to specify the direction). All users are asked about their overall satisfaction with room temperatures on campus (not specific to their voting location; Figure 2c). After willingness to conserve feedback is submitted, a summary of all willingness to conserve votes is provided to the user (similar to Figure 2f).

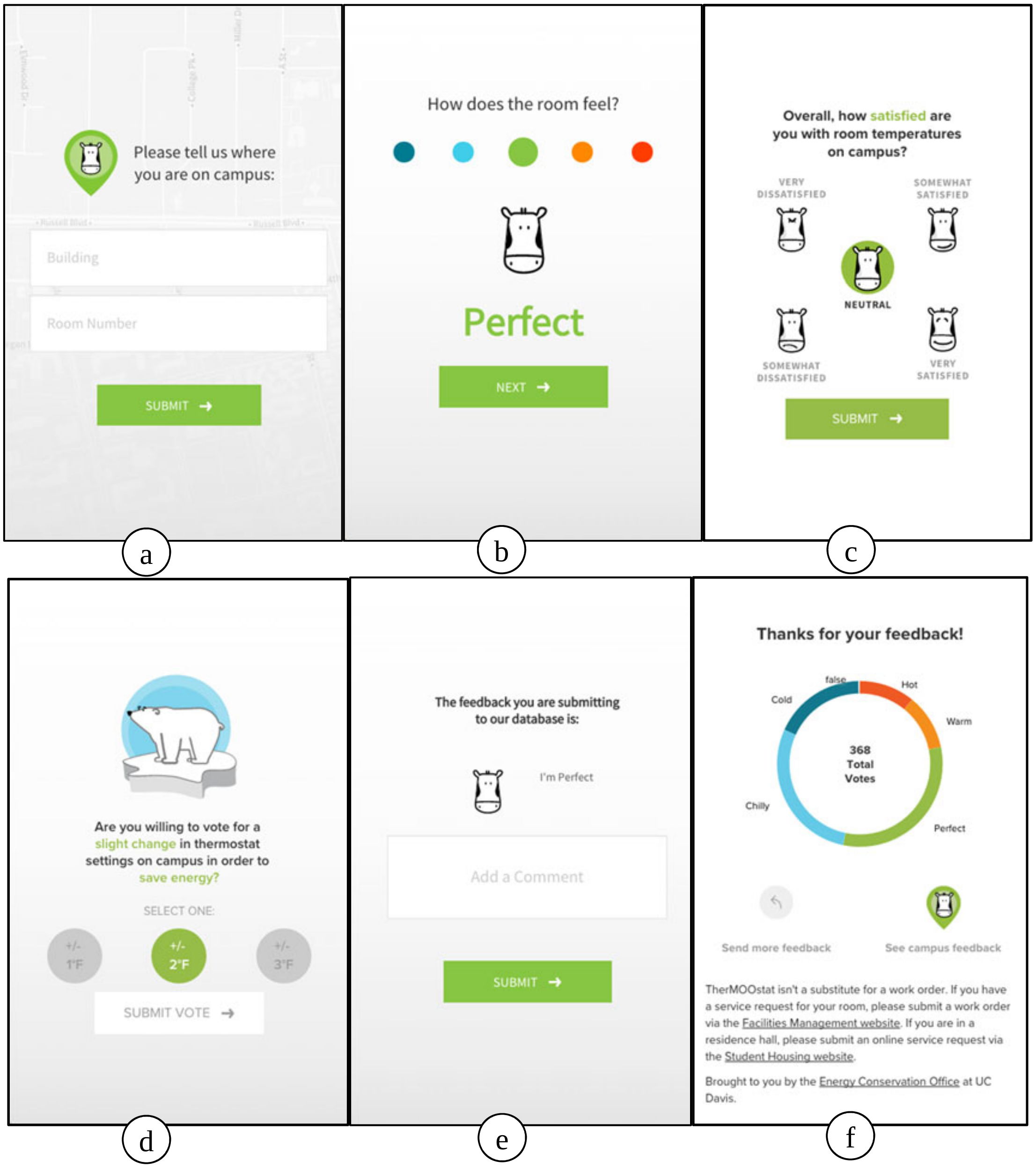

Figure 2. TherMOOstat user interface screens.

The experiments. Our first experiment (results reported in this paper) with the app UI aimed to test the hypothesis that the opportunity to give thermal feedback has an immediate effect on overall satisfaction with indoor temperatures on campus, independent of any actual changes in thermal conditioning. To this end, one UI pathway solicited thermal comfort prior to satisfaction rating, and the other solicited satisfaction rating first. The second experiment (results not reported in this paper), explored whether use of an empathetic gauge (Petersen, Frantz and Shammin 2014) would increase users' willingness to conserve. Specifically, when a willingness to conserve vote was solicited there was either no image on the screen or an image of a polar bear on an icecap, the size of which corresponded to the user's vote (+/- 1, 2, or 3 degrees).

Data Analysis

We performed descriptive analyses of patterns of participation, thermal comfort, satisfaction, and willingness to conserve, and inferential tests (alpha level of .05, two-tailed) of relationships between these variables, as well as differences between widget and app and between user groups. We used Mann Whitney U tests for difference in average scores of ordinal dependent variables (comfort votes and satisfaction ratings), and Chi-squared tests for difference in proportions of willingness to conserve as a two-level dependent variable (yes v. no).

We excluded votes from the TherMOOstat research and development team, as well as submissions without data (visitors browsing without voting), from all analyses. Analyses of votes (e.g., distributions of votes across platform, location, and season; Table 1, Figures 3, 5, and 7) included all submissions. Analyses of individual users (e.g., user characteristics and voting rates; Table 2, Figure 4) excluded data from 342 unidentified users (widget users who did not log in to the system). Analysis of user groups excluded unidentified users and unclassified users (identified users who could not be classified as student, staff, or faculty). Analyses of satisfaction with indoor temperatures and willingness to conserve used only data from the first visit of each app user in order to meet criteria of independence of data for inferential tests, and to capture some users' satisfaction levels prior to the opportunity to give feedback per our experiment.

Results

Participation

TherMOOstat accumulated 10,315 votes since deployment (Table 1), averaging 573 votes per month. Votes were submitted for 2,684 rooms in 183 buildings. Buildings with the highest number of votes have a higher student population and more fluctuations in occupancy; most are predominately composed of classrooms, including large lecture halls that seat 100-400 people. Comments were included with 8% of votes overall, but significantly more with the app (37%). The widget was used more frequently than the app. There was a drop in participation during summer months, including May when school was still in session (Figure 3).

Table 1. Characteristics of the Votes

	Widget	App	Total
Votes	9,515 (528 per month)	800 (160 per month)	10,315 (573 per month)
Comments	508 (5% of votes)	298 (37% of votes)	806 (8% of votes)
Buildings	174	74	183
Rooms	2,512	565	2,684

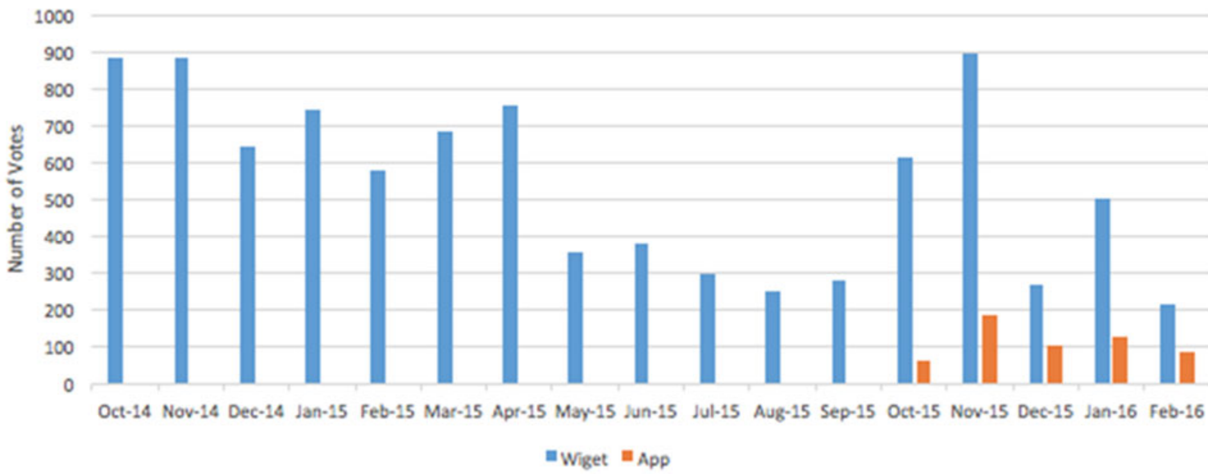

Figure 3. Votes per month on widget and app.

TherMOOstat users totaled 4,471 (Table 2), including approximately 9% of the student population and 1% of all staff. Students were the predominant users of the widget, while the majority of app users were staff. Users vote 2.23 times on average; most voted only once (Figure 4). Ten percent of all users submitted a comment: 7% of widget users and 41% of app users.

Table 2. Characteristics of the Users

	Widget	App	Total
Users	4518	412	4219
% Student	81%	42%	91%
% Staff	2%	51%	7%
% Faculty	1%	7%	2%
% Unclassified	0%	0%	0%
Mean Votes per User	2.19	2.09	2.23
% Users that Comment	7%	41%	10%

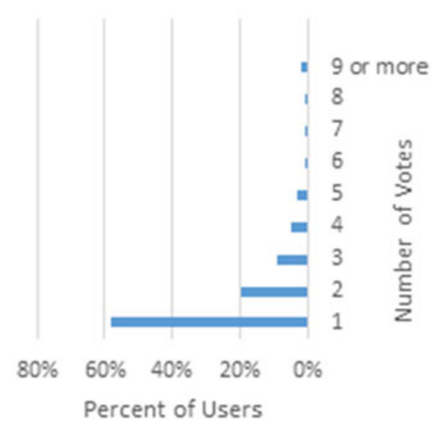

Figure 4. Frequency of votes per user.

Comfort

'Chilly' and 'Cold' votes (55%) outnumbered 'Warm' and 'Hot' votes (27%); 16% of votes were 'Perfect'. Votes on the widget were warmer on average than votes on the app (Mann Whitney $U = 2522962$, $p < .001$; Figure 5), and student votes were warmer on average than staff votes (Mann Whitney $U = 2380562$, $p = .02$; Figure 6). The distribution of votes also varied by season (marked by academic quarters; Figure 7). Winter was the only season during which 'Cold' was not the most frequent vote.

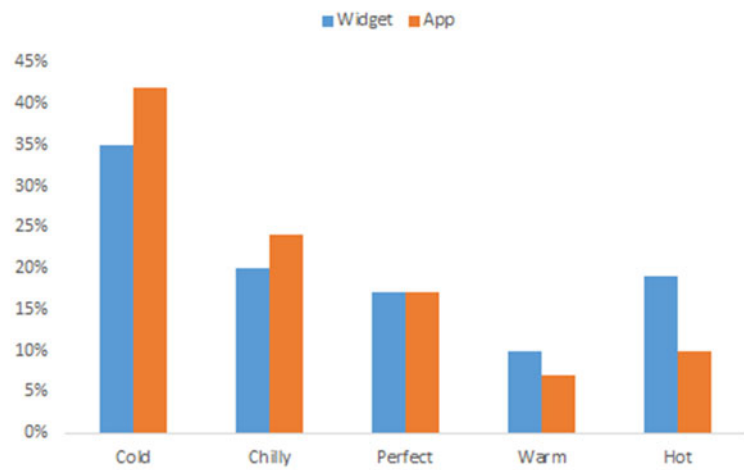

Figure 5. Comfort votes: Widget and app.

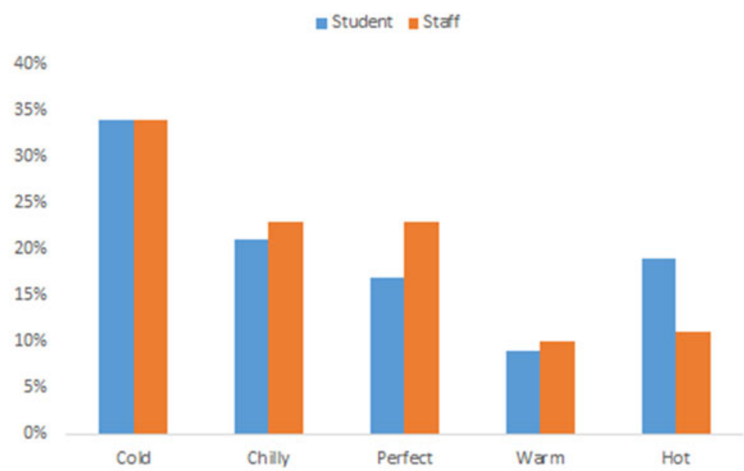

Figure 6. Comfort votes: Students and staff.

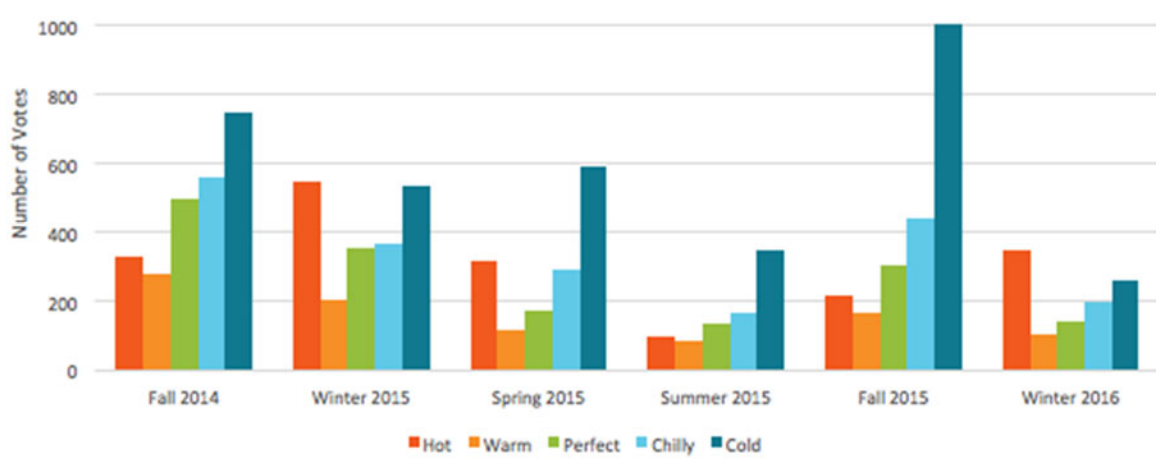

Figure 7. Comfort votes: Seasonal distributions.

It is difficult to gauge how comfort may have changed over time for TherMOOstat participants because each user voted only twice, on average. However, looking into cases of repeat users sheds some light on potential effects of participation on comfort. For example, one student submitted frequent feedback about how hot a classroom felt (Figure 8). We responded to his feedback via email, and his subsequent feedback was more positive. As the room temperature was stable throughout his series of comments and no changes were made based on his feedback, we hypothesize the positive turn in his feedback was due to effects of participating in the thermal feedback program, such as perceived control, and/or the contrast with outdoor temperature.

As previously mentioned, the thermal comfort data have been analyzed to identify a variety of mechanical HVAC and comfort issues on campus (See Pritoni et al. 2016). These have included adjusting ceiling vents to address low airflow, finding temperature set points that were changed in a previous season and were no longer appropriate, and identifying opportunities to optimize building automation system scheduling sequences.

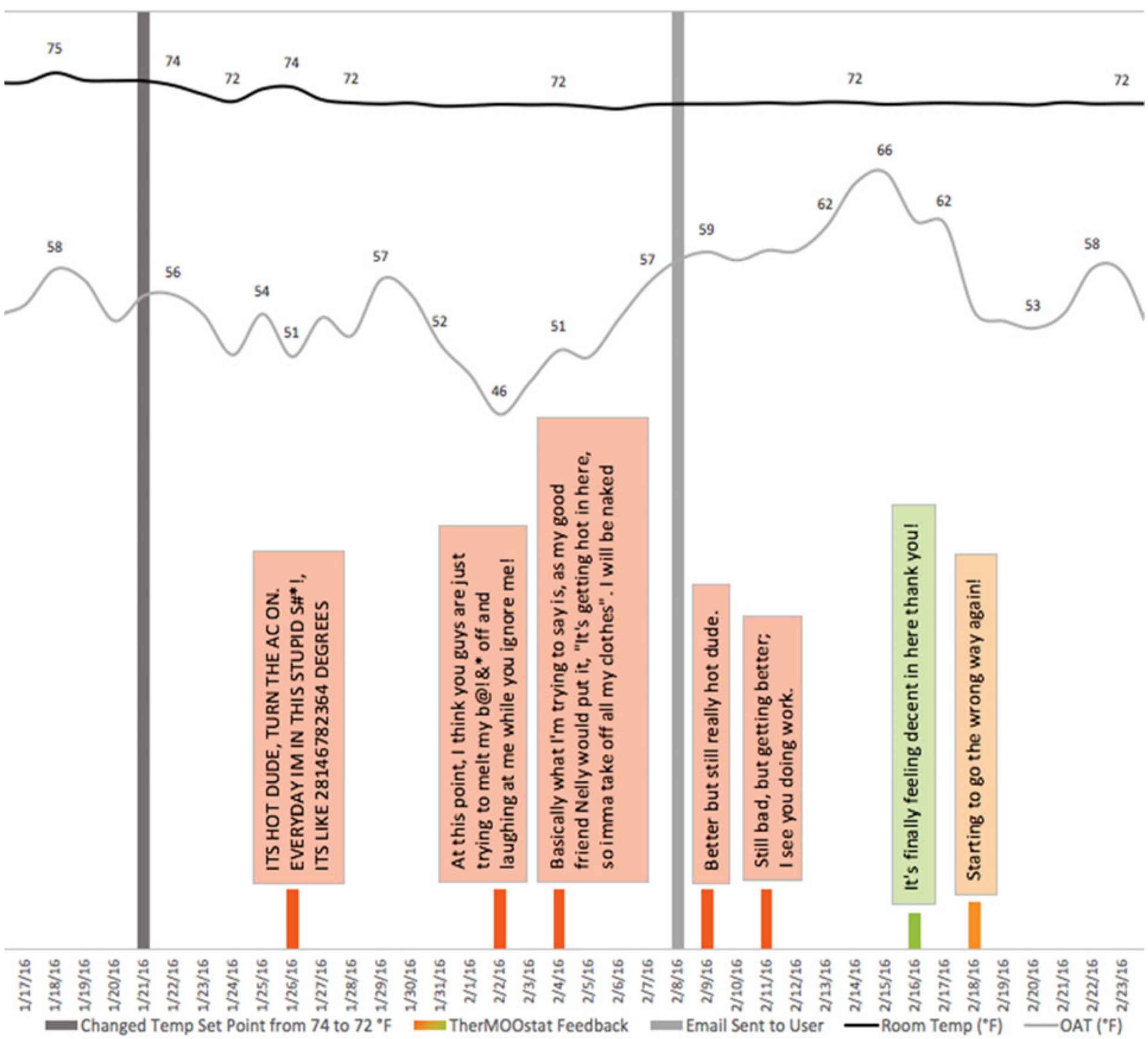

Figure 8. One users' votes in the same classroom over time.

Satisfaction

Users most frequently reported being ‘somewhat dissatisfied’ (34%) or ‘very dissatisfied’ (33%) with overall indoor temperatures on campus (34%); 19% were ‘neutral’, 11% were ‘somewhat satisfied’, and only 2% were ‘very satisfied’. We explored relationships between satisfaction rating and comfort vote (Figure 9), as well as user group (Figure 10). Students were more satisfied than staff (Mann-Whitney U = 22799.5, p < .001).

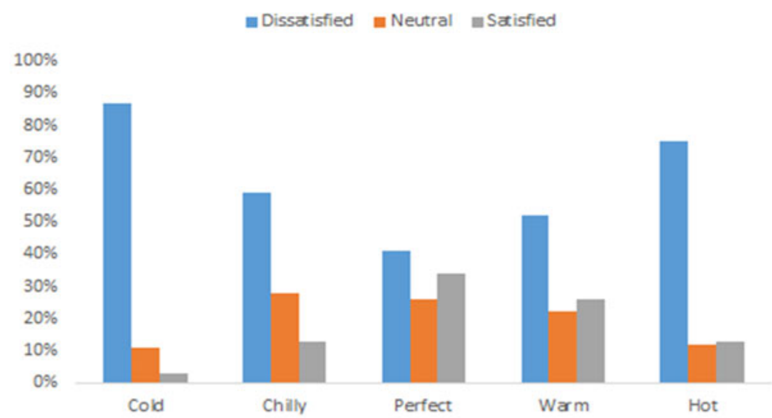

Figure 9. Comfort vote and overall satisfaction.

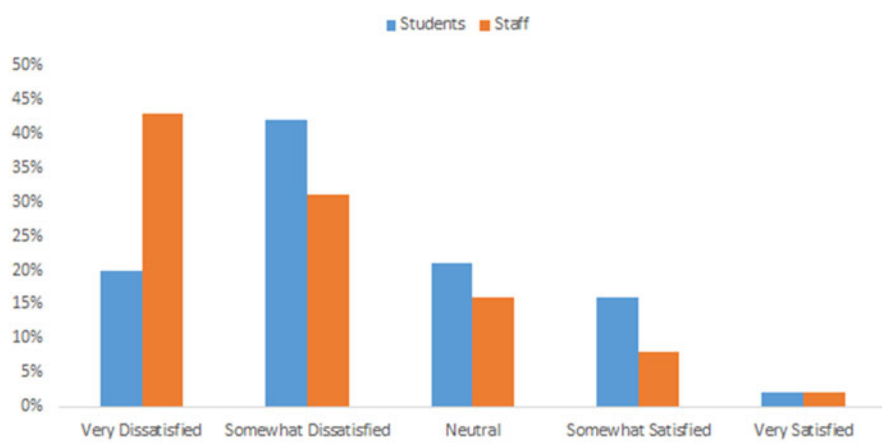

Figure 10. Satisfaction by user group.

Experiment. The results from our experiment supported our hypothesis that users who had the opportunity to provide thermal comfort feedback *before* reporting overall satisfaction with indoor temperatures reported greater satisfaction than those who reported satisfaction before submitting thermal comfort feedback (Mann-Whitney U = 41663, p = .047; Figure 11).

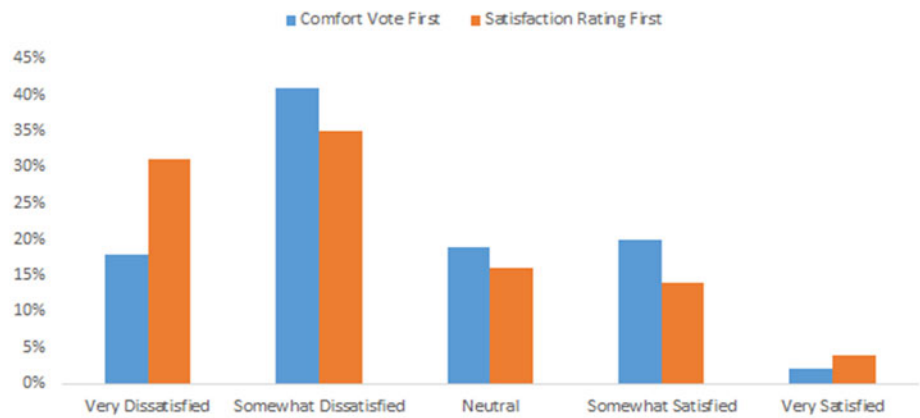

Figure 11. Relationship between voting order and satisfaction.

Willingness to Conserve

When asked, most users (65%) voted for an energy-conserving change in thermostat settings on campus (Figure 12). This was true regardless of reported satisfaction level (Dissatisfied: 62%; Neutral: 73%; Satisfied: 87%), although a higher proportion of 'satisfied' users were willing to conserve [$\chi^2(2) = 6.21$, $p = .045$]. Willingness to conserve also varied by user group; 87% of students voted to conserve compared to 58% of staff [$\chi^2(1) = 8.10$, $p = .004$].

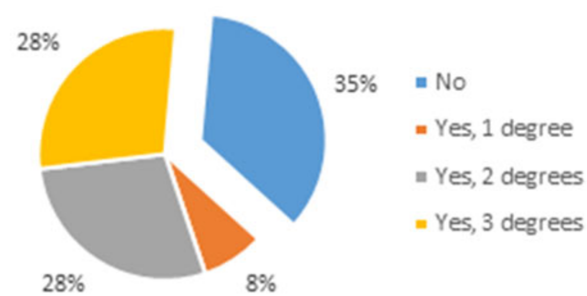

Figure 12. Willingness to conserve.

Discussion

Participation in TherMOOstat has been encouraging; however, there does seem to be a novelty effect whereby participation decreases over time. Lower rates of participation with the app suggests that a great deal of promotion is required to engage occupants with this method. Future research should investigate whether higher rates of voting can be achieved and maintained in a closed loop system where votes affect direct change in thermostat settings. We plan to investigate this in a large pilot study of an automated closed loop system (See Pritoni et al. 2016 for description of initial pilot).

Buildings with the highest number of votes are those with relatively large fluctuations in occupancy and a dense student population; most are predominately composed of classrooms, including large lecture halls that seat 100-400 people. Comfort is difficult to address in large lecture halls because of the fluctuating occupancy. A hall can go from unoccupied to over 300 occupants in a matter of minutes. The HVAC system will either pre-cool the space in anticipation or be catching up to the sudden increase in occupancy.

We discovered that thermal discomfort on campus most frequently means occupants are cold, though ironically not in winter. Cold votes, more so than hot votes, are associated with overall dissatisfaction with indoor temperatures on campus. Staff, who primarily vote with the app, submit more cold votes, are less satisfied, and are less willing to vote for energy-conserving changes in thermostat settings. Together, these findings suggests over-cooling is common and implies opportunities to improve efficiency, comfort, and satisfaction simultaneously.

Participation in TherMOOstat promotes higher satisfaction with indoor temperatures on campus. Our user story suggests perceived control may contribute to this effect. In turn, higher satisfaction predicts greater willingness to conserve. Combined, these findings confirm potential for leveraging participatory thermal sensing programs to encourage occupants to accept and adapt to energy-conserving thermostat settings. Future plans for TherMOOstat include integrating advice on how to adapt to indoor temperatures.

Acknowledgements

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