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Adaptive Comfort in Mixed-Mode Buildings: Research Support Facility, National Renewable Energy Lab

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Internal Report April 2013

Adaptive Comfort in Mixed-Mode Buildings: Research Support Facility, National Renewable Energy Lab

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1. OBJECTIVES

This project builds on the recent development of new methods for studying Mixed-Mode (MM) buildings, as well as contexts with other means of Personal Comfort Systems (PCS), towards the goal of establishing an adaptive comfort standard with broader applications beyond purely naturally ventilated buildings. Some of the intended field studies have been delayed until we get warmer weather. This report describes one phase of the project, summarizing the findings from the CBE survey implemented in the Research Support Facility of the National Renewable Energy Lab in Golden, CO.

2. BACKGROUND

The Research Support Facility (RSF) is NREL's newest sustainable green building. This 360,000 ft² LEED Platinum office building is a showcase for energy efficiency and renewable energy technologies. The relatively narrow floor plate (60ft wide) and low profile, modular workstations provide daylight, views and natural ventilation for all occupants. Workstations are located within 30 ft. of the nearest window, and employees are able to open windows to bring in fresh air and cool the building naturally. Window shading is designed to address different orientations and positions of glazed openings. Building orientation and geometry minimize east and west glazing. North and south glazing is optimally sized and shaded to provide daylighting while minimizing unwanted heat losses and gains. Approximately 42 miles of radiant piping runs through all floors of the building, using water as the cooling and heating medium in the majority of workspace. A demand-controlled dedicated outside air system provides fresh air from a raised floor when building windows are closed on the hottest and coolest days. Ventilation is distributed through an underfloor air distribution system. Evaporative cooling and energy recovery systems further reduce outdoor air heating and cooling loads.

The building is being studied in collaboration with researchers at the University of Colorado Boulder (Prof. Gregor Henze and PhD student Ryan Tanner). The goal of this larger project is to use stochastic modeling to develop near-optimal control strategies that will improve a building's energy performance without any sacrifices to occupant comfort. CBE's occupant satisfaction survey will be implemented before and after the controls intervention to verify the continued comfort of the occupants and to test our new methods for evaluating mixed mode buildings.

3. ABSTRACT

The RSF is performing well for the occupants in terms of indoor environmental quality (IEQ), particularly with respect to air quality. The building scores in the 90th percentile of the buildings in the CBE database for thermal comfort and air quality satisfaction. Nevertheless, less than 80% of the building's occupants are satisfied with temperature, air movement, and air quality, so there is room for improvement to meet the code standard.

The new survey methods allowed us to explore how occupants use and view their windows. The windows were rated extremely highly in terms of accessibility, usability, and responsiveness; however, they are not used as often as expected. Only 6% of window users adjust their windows on a daily basis, compared to 38% weekly and 41% monthly. The most frequently cited reason for opening windows is fresh air, followed by wanting to feel cooler, and then the desire to increase air movement. Other reasons for opening and closing windows include the desire to save energy or increase the connection with the outdoors. From this it is clear that people operate windows for more than just thermal comfort.

4. METHODS

The standard CBE web-based general indoor environmental quality (IEQ) survey includes extensive questions about satisfaction with various IEQ characteristics. For this project, we reduced the standard survey to focus primarily on thermal comfort aspects of IEQ, and then developed new questions that asked about:

- building manager responsiveness to thermal discomfort issues
- available and utilized personalized controls (general)
- satisfaction with ability to control temperature, air movement and air quality
- more detailed questions about preference for air movement
- accessibility, usability, responsiveness, and effectiveness of operable windows and thermostats
- frequency of use of operable windows and local thermostats
- sole vs. shared access to operable windows
- duration of discomfort problems
- implicit or explicit dress codes (which relate to adaptive opportunity)

The survey was administered to 104 occupants in selected areas of NREL's RSF during a 2-week period, from August 6 – 17, 2012, and 62 people completed the survey. It is intended that the survey will be repeated after the controls interventions have been implemented. Since this was the first time the new survey was administered, our objectives were both to use the results as a baseline prior to the controls intervention, but also to pilot test the new methods and propose changes, where needed, for the second survey following the new controls strategies.

5. RESULTS

Demographics

- 66% of the users are between 31 and 50 years old
- 60% of the users are males

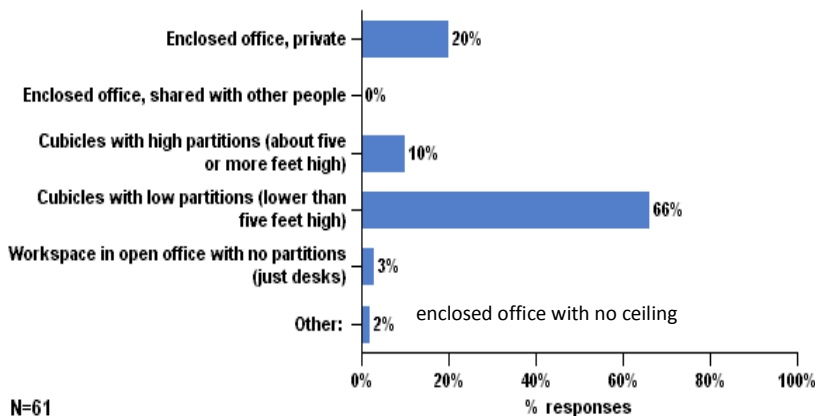
Workspace Usage and Distribution

- 77% of the respondents have been working in their present workspace for more than a year, and the same percentage spend more than 30 hours/week in their workspace.
- 20% of the respondents are in enclosed, private offices, 66% are in cubicles with low partitions (lower than 5 ft. high), 10% in cubicles with high partitions (about 5 or more ft. higher), and the remaining 5% sitting at desks with no partitions or in an enclosed office with no ceiling.
- 62% of the occupants are within 15 ft. of an exterior window
- The distribution of the respondents' workspace location is as follows. Note that the option "More than 15 ft. to an exterior wall" is independent of the orientation. A desk can be located on the southern side but more than 15 ft. to an exterior wall.

| | TOTAL | SOUTH | NORTH | EAST | No orientation noted | More than 15 ft. from an ext. wall |
|-----------------------|-------|-------|-------|------|----------------------|------------------------------------|
| TOTAL | 62 | 33 | 23 | 3 | 3 | 36 |
| 2 nd floor | 23 | 15 | 7 | 0 | 1 | 14 |
| 3 rd floor | 15 | 7 | 7 | 1 | 0 | 7 |
| 4 th floor | 22 | 11 | 8 | 2 | 1 | 15 |
| No floor noted | 2 | 0 | 1 | 0 | 1 | 0 |

Table 1. Workspace Distribution.

Which of the following best describes your personal workspace?



Workspace Adjustability

- An operable window is the most common form of personal control, and 56% say they have access to personally adjusting a window. 23% say they have access to an adjustable floor diffuser. Only 8% say they can adjust a thermostat, and 34% say they do not have access to any personal controls.

Workplace Culture - Dress Code

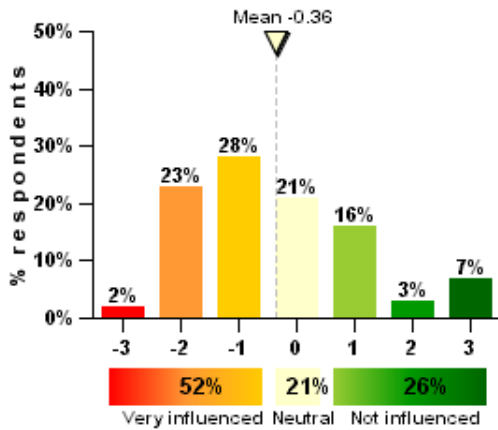
- 53% felt that what they wear to work is influenced by an implied or explicit dress code (which may limit adaptive opportunity).
- Based on the comments, there is no explicit dress code, but people have very different opinions about an implicit dress code: “Business casual is expected.” “I do not feel restricted in what I can wear to work.”
- People seem to feel that they should dress up when they are going to interact with management.
- The dress code question was new, and we think it was confusing and didn’t necessarily get at what we were trying to investigate. This question may be revised in future survey implementations.

Workplace Culture - Windows

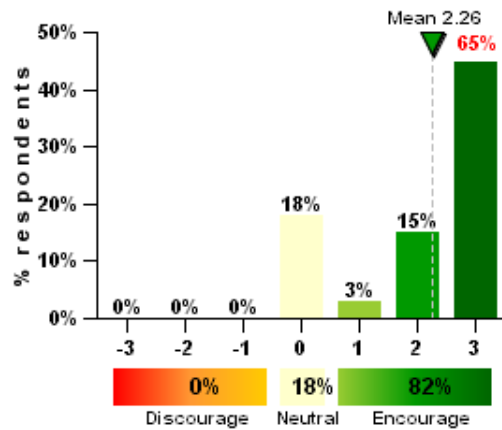
- 82% feel that management encourage the use of the operable windows, and no one believed that there was any discouragement. This was a very positive result.

To what extent do you feel that what you wear to work is influenced by an implied or explicit dress code (as in, social norms or policy)?

To what degree does the building management encourage or discourage the use of operable windows?



N=61



N=34

Window Use and Ownership

- 38 people have a workspace within 15 ft. of a window, and 35 say that they adjust or control a window. Surprisingly, these groups do not completely overlap: only 25 people are both within 15 ft. of and adjust or control a window.
- 10 people adjust or control a window despite having a workspace that is more than 15 ft. from a window.
- 13 people have a workspace within 15 ft. of a window but do not adjust or control that window.
- Although management encourages the use of windows, and satisfaction with the windows' different features was very high (see next section), the windows are not actively used.
- Only 6% adjust their windows on a daily basis, compared to 38% weekly and 41% monthly.
- While this was surprising, the current survey does not allow us to fully assess this. We may add another branching question to the survey, probing low-activity users. Note that this may not necessarily be a bad thing. Perhaps because the building is operating well thermally, people simply do not have a need to use their windows frequently, although it's clear from the next set of questions that they are greatly valued.
- Approximately 1/3 of the respondents have a window just to themselves, and the remaining 2/3 shares it between at least 3 people.
- According to the comments, negotiating control of the window isn't a big problem.

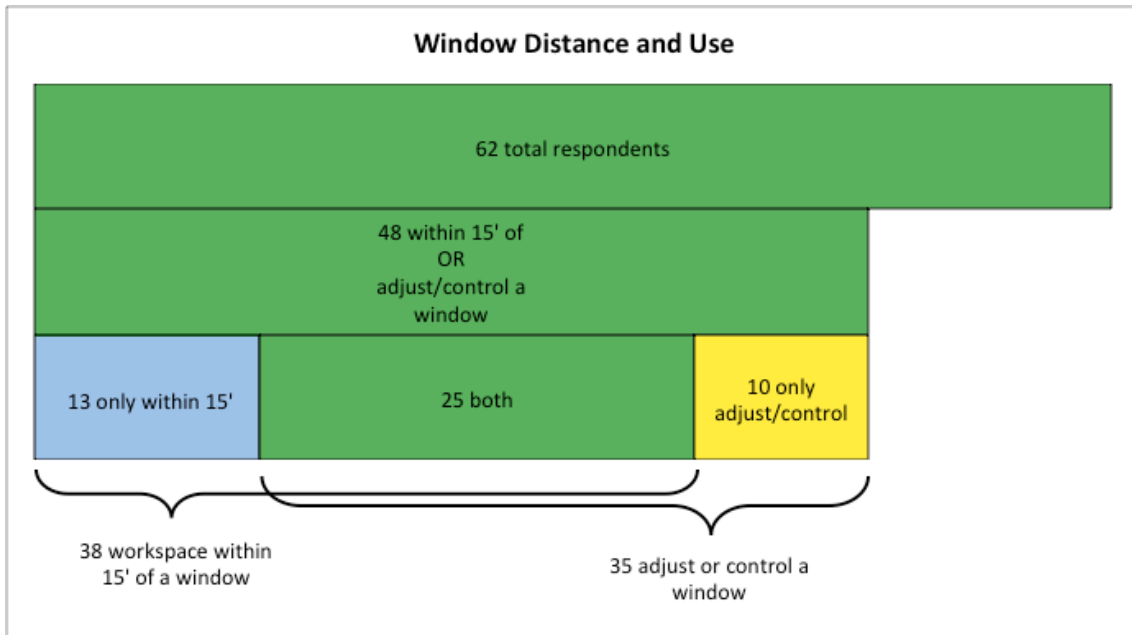
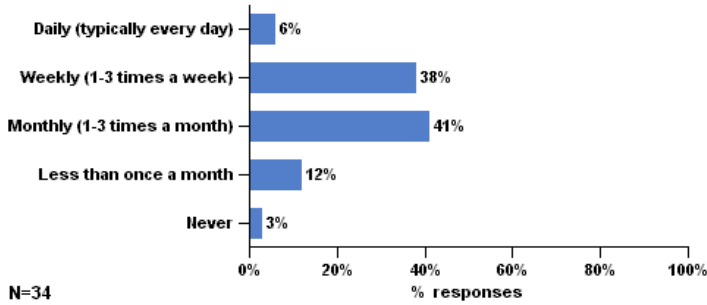
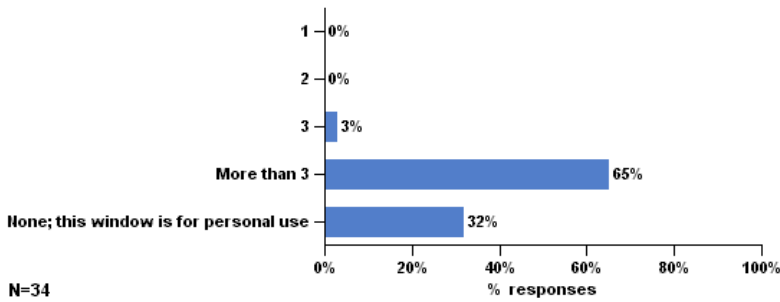


Figure 1. Distance from and control of windows.

Considering just the last month, how often do you typically adjust your window?



How many people other than yourself share access to the same window?

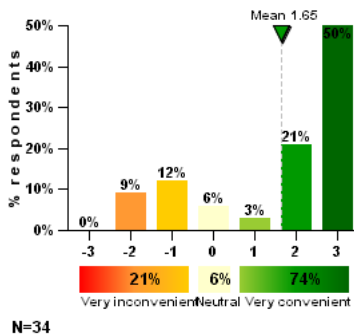


Window Impressions

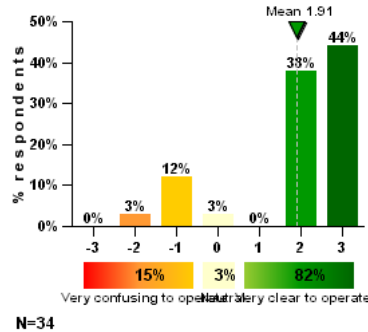
- Windows were rated extremely highly in terms of accessibility, usability, responsiveness, and as seen earlier, management encouragement to use the windows.
- Several people complained that the windows with sliding screens are inconvenient/hard to get to.
- There were a couple of complaints about the automatic controls. One person wants some indication about how long it will be favorable to open the windows. Another is frustrated that the algorithm doesn't include air quality (e.g., construction dust) or noise.

Rate your impression of the window's....

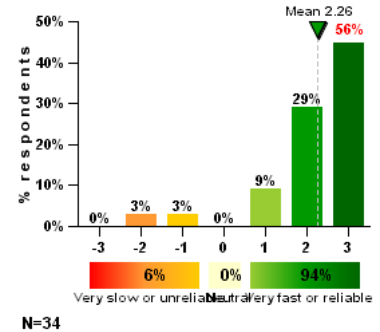
accessibility.



usability



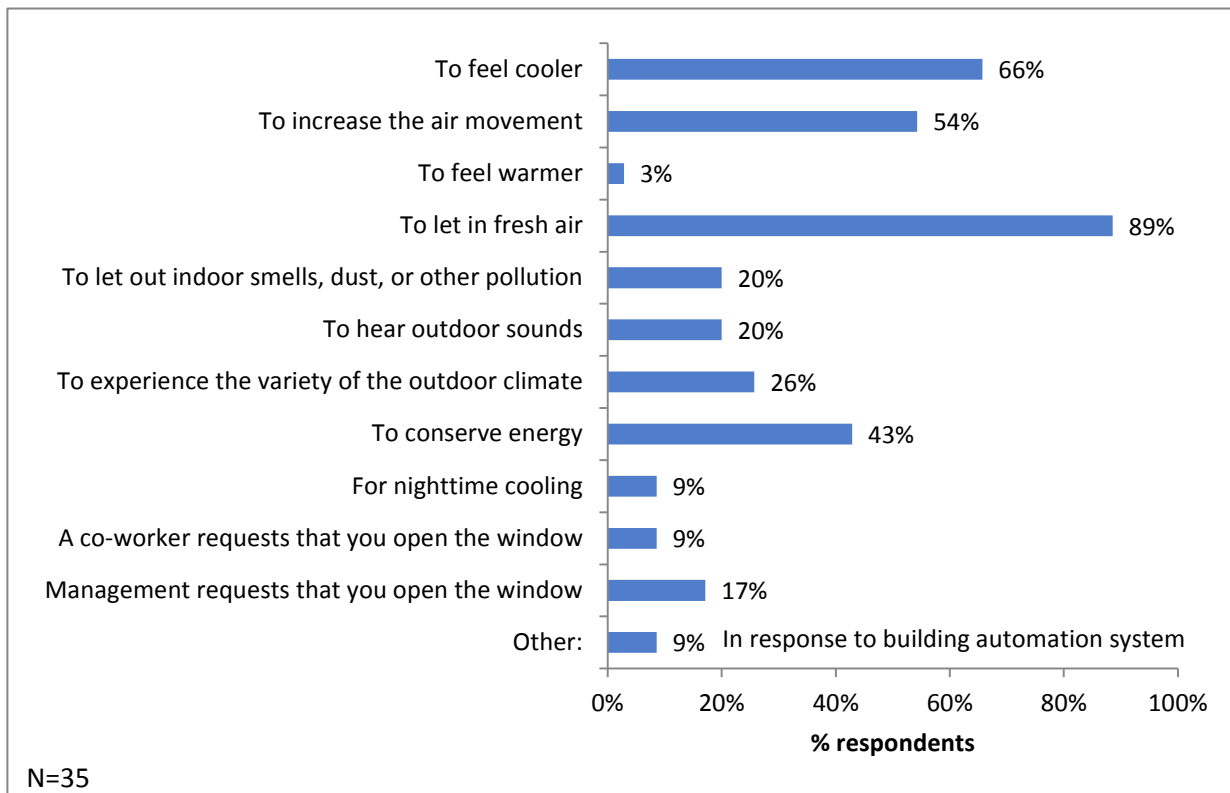
responsiveness



Reasons for Opening a Window

- The 35 occupants who personally adjust or control a window were asked about their reasons for opening that window. The percentages reported below are based on those 35 people.
- Windows are not used just for thermal comfort. The most frequently cited reason for opening windows (89%) is for fresh air.
- The 2nd most important reason for opening windows is to feel cooler (66%), followed by the desire to increase air movement (54%). It is not apparent just from this question whether the desire for increased air movement is always associated with the desire to feel cooler, or just for the sake of air movement alone.
- 43% of the people open their windows to conserve energy, which is particularly interesting given that a nearly comparable number (54%) close their windows for the same reason.
- 26% of the people open the windows simply to have a connection with the outdoors, which may be entirely unrelated to thermal comfort.

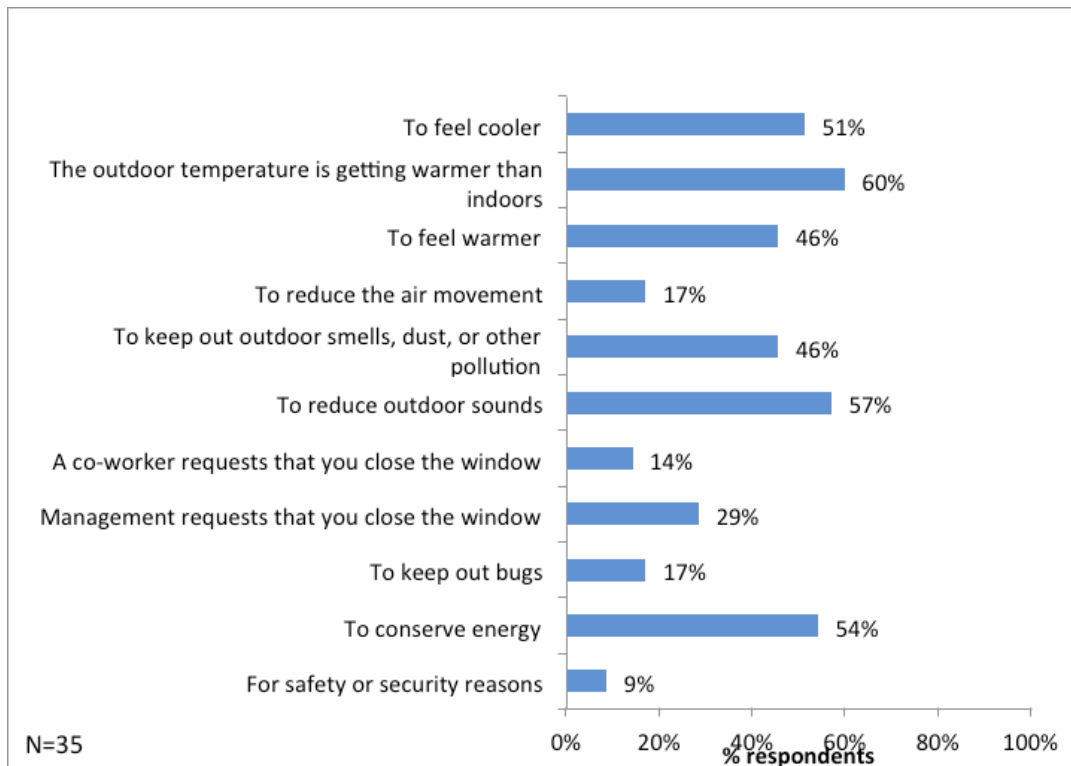
Below is a list of reasons why someone might open a window. Please identify all the reasons why you open the window(s) in your workspace, considering just the last month.



Reasons for Closing a Window

- The 35 occupants who personally adjust or control a window were asked about their reasons for closing that window. The percentages reported below are based on those 35 people.
- Thermal-related reasons for closing the window are not always consistent, as would be expected because it would depend entirely on whether the outside temperature is hot or cold.
- 51% close their windows when they are too warm and want to feel cooler (i.e., presumably because it's hot outside and they want mechanical cooling).
- 46% close their windows when they are too cold and want to feel warmer (i.e., presumably because it's cold outside).
- 60% close their windows because the outdoors is warmer than indoors. While this is suggestive that they are themselves too warm, it may also reflect an understanding of maintaining comfortable temperatures in the building overall.
- Approximately half of the people close their windows for non-thermal reasons, such as to reduce outdoor sounds (57%) or to keep out outdoor smells, dust or pollution (46%). It should be noted that this survey was administered sometime after there were large nearby fires in Colorado, so it's unclear whether this affected these results.
- It was surprising to see that 29% said they closed the window because management requested it, when 0% said that management discouraged the use of windows. This may speak to the difference between general discouragement vs. guidance in a particular moment that windows should be closed. The request might also come from the building management software that controls the automatically operated windows.

Below is a list of reasons why someone might close a window. Please identify all the reasons why you close the window(s) in your workspace, considering just the last month.



Energy-Conscious Window Users

- 57% of window users adjust their windows to conserve energy.
- Of these energy-conscious window users, 70% both open and close their windows to conserve energy.
- It is encouraging that a slight majority of people is basing their actions on a desire to conserve energy, but 43% of window users are not, so there is still a ways to go. Perhaps education could help.
- It is particularly interesting that of the energy-conscious window users who only open or only close their windows with energy in mind, more close the windows. Perhaps they are afraid that letting out indoor air when a mechanical system is operating is wasteful. However, with such a small sample size (6), it is hard to tell if this is significant.
- Energy conservation is only one of the reasons that these occupants operate their windows.

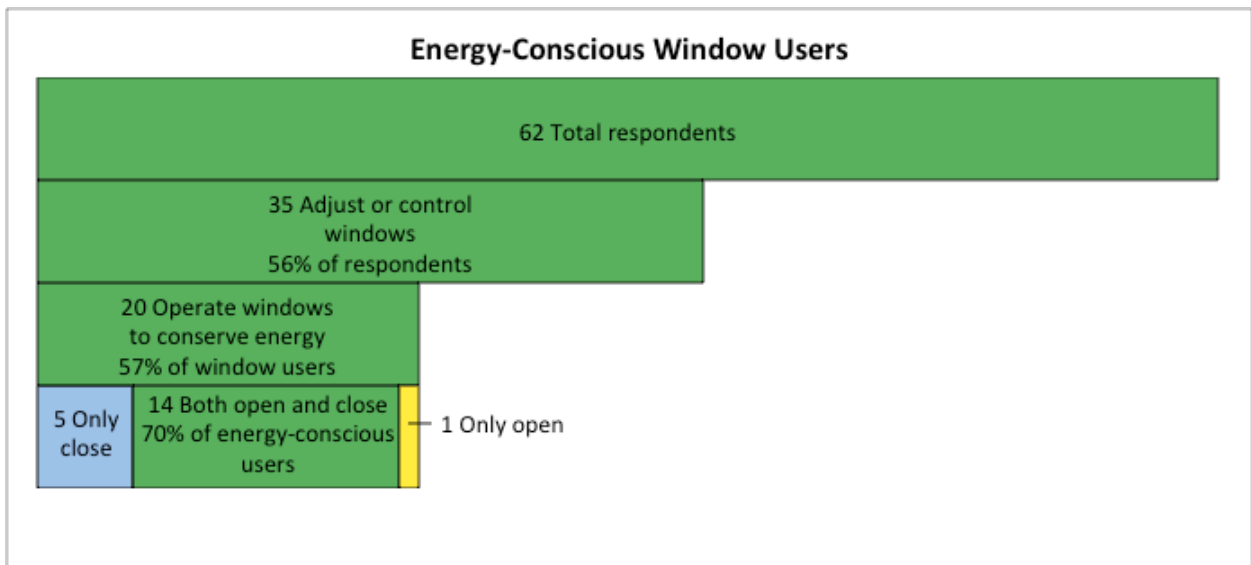


Figure 2. Window adjustments for energy savings.

Satisfaction with Indoor Environmental Quality

The specific results are shown below, but a summary is:

- IEQ satisfaction was highest for air quality (75% satisfied), followed by air movement (67%) and temperature (66%).
- But the ability to control each of these variables garnered lower satisfaction ratings (air quality-56%, air movement-47%, temperature-44%).
- Most of the compliments are about daylighting.
- Most of the complaints are about acoustics.

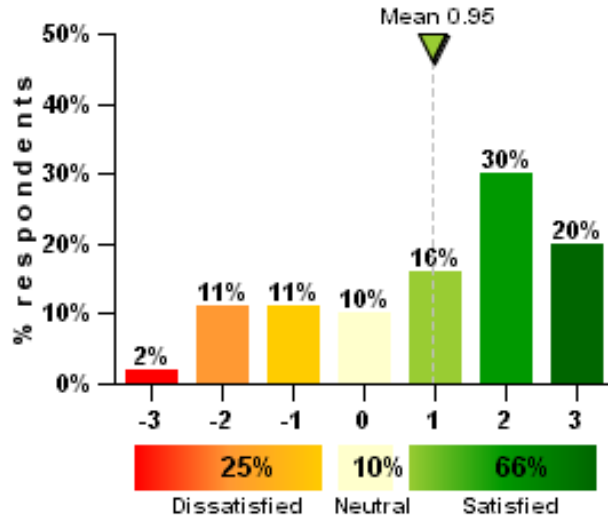
Satisfaction - Temperature

This data will be explored in detail in the following pages, starting first with the overall results of the survey, then looking at the spatial distribution of responses, a comparison to the physical measurements (where available), and a comparison to the CBE survey benchmark database.

- Overall, 66% were satisfied, 25% were dissatisfaction, and 10% felt neutral.

- One person mentioned that the building is more comfortable in other months.
- We will see in the next graph where in the building dissatisfaction was most commonly expressed.

How satisfied are you with the temperature in your workspace?

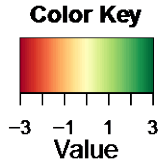


N=61

Satisfaction - Temperature - spatial distribution

Note that the color key refers to the 7-point satisfaction scale, with positive numbers (green) being satisfied, and negative numbers (orange-red) being dissatisfied.

- As shown by the colors in the chart below, we found considerable variation in satisfaction between spatial zones.
- In 6 out of the 12 zones, more than 80% of the people are satisfied with the temperature.
- The people on the third floor are the most satisfied overall.
- The people on the fourth floor, particularly in the interior, away from the window, are the least satisfied.
- As noted later, we were not able to get physical data for the 4th floor, so we do not know the reason for this. But it is something we will investigate further, during and after the controls intervention planned for Summer '13.



Satisfaction with Temperature

| | | | | | | |
|---------------------|--------------|--------------|--------------|--------------|------------|-----|
| % satisfied | 57% | 25% | 50% | 67% | 50% | 4th |
| | 7 | 4 | 2 | 6 | 22 | |
| number of responses | 100% | 100% | 100% | 75% | 87% | 3rd |
| | 3 | 4 | 3 | 4 | 15 | |
| | 50% | 71% | 100% | 83% | 70% | 2nd |
| | 8 | 7 | 1 | 6 | 23 | |
| | 61% | 67% | 71% | 75% | 65% | All |
| | 18 | 15 | 7 | 16 | 62 | |
| | South | South | North | North | All | |
| | window | no window | no window | window | | |

Figure 3. Temperature satisfaction by floor and orientation.

Satisfaction – Temperature – comparison to measured data

We were able to obtain temperature data from ongoing records in the RSF BACnet system (see graphs on following page). All of the temperature data we had was associated with HRVs (Heat Recovery Ventilators) physically located in the stairwells at the east and west ends of the different wings of the building, and our understanding is that the temperature sensors for that data are in the return air ducting that goes to the HRVs from the different floors (1-3) of the building. As such, this data could be considered average indoor dry-bulb temperature for these office areas, but are not necessarily representative of what occupants are directly experiencing. This is because 1) occupants' near thermal environment may vary across the floor and the data is only an average, and 2) occupants actually "feel" an operative temperature, which is a combination of dry-bulb (air) temperature and mean radiant temperature (which is a combination of cool radiant slabs, but perhaps also warm windows for individuals sitting near the exterior wall).

- Outdoor daily maximum air temperature was typically in 80-90°F during the survey period, and sometimes rose slightly above 90°F during the preceding month.
- Indoor air temperature data are the average of multiple sensors within each area.

- Indoor air temperature was almost constant during the monitoring period shown in the graphs below; it varied only 5° from 71 to 76°F with an average of 73.5° and a standard deviation of less than 1°. These small temperature variations are common to heavy mass buildings with radiant cooling systems.
- The third floor, where thermal satisfaction was highest, was about 1°F cooler than the other areas.
- Unfortunately, we do not have temperature data for the fourth floor. However, on the second and third floors, 3 people reported being too hot and only one person reported being too cold. This is particularly interesting because the dry bulb temperature is about 3°F cooler than the temperatures recommended by the PMV and adaptive comfort models. In addition, the actual operative temperature that people are experiencing (combination of dry-bulb and mean radiant temperature) is even lower because the building uses radiant cooling.
- We compared the indoor temperatures to two different comfort zones from ASHRAE Standard 55, shown as horizontal bars - the PMV-based (red) and adaptive-based (blue) comfort zones. The PMV zone was calculated with $met=1.2$ and $clo=0.6$. Note that this is not a precise comparison because the comfort zones refer to operative temperature, and the measured data was only dry-bulb temperature. The measured average indoor air temperature is towards the bottom of, and occasionally crossing over, the lower limit of the 80% satisfied comfort zone as calculated with the PMV and adaptive models. If the radiant slabs were cool, then the experienced indoor operative temperatures would be even lower. This is surprising, because although both comfort zones were recommending warmer conditions than seemed to exist, the most common source of thermal dissatisfaction was people feeling too warm. This suggests that much more detailed investigations of the physical environment would be helpful in the next phase of data collection.

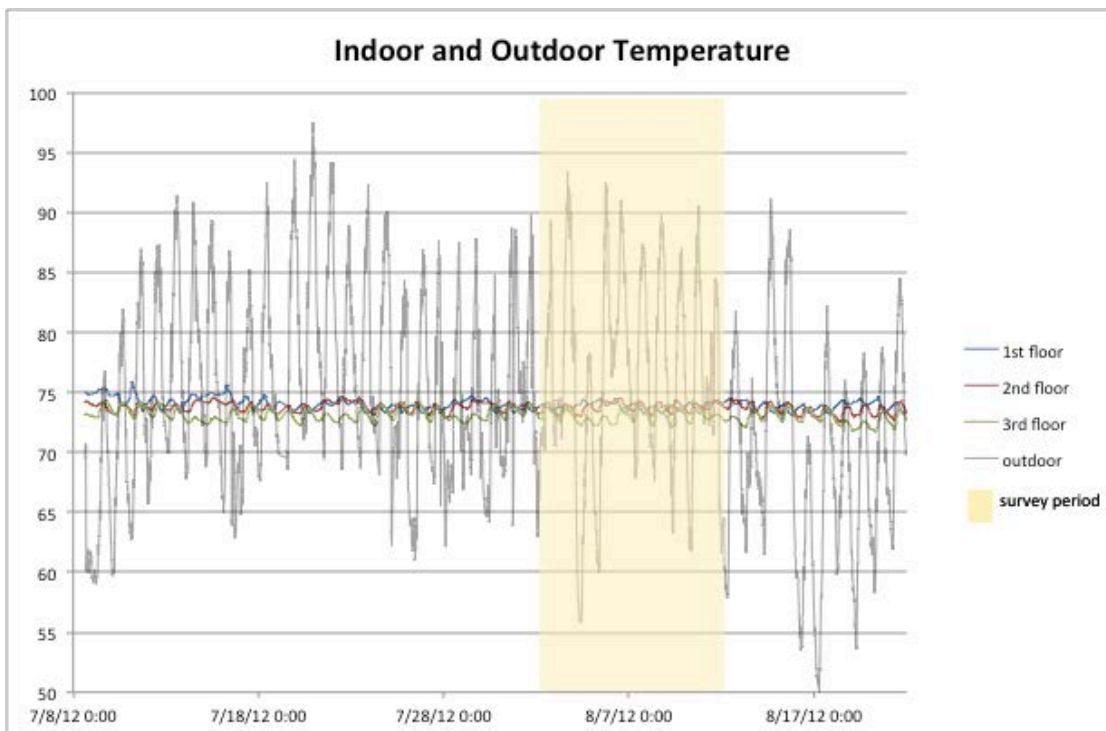


Figure 4. Indoor and outdoor temperature before, during, and after survey period.

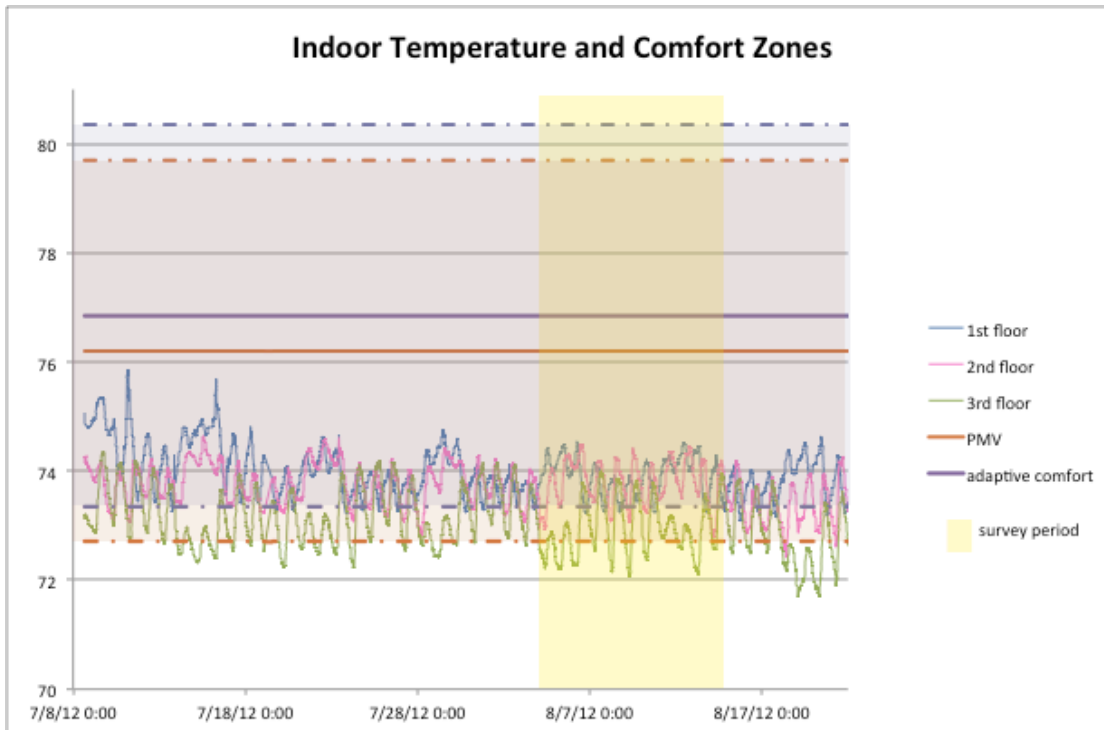


Figure 5: Indoor temperature and PMV and adaptive comfort zones

NOTE: PMV comfort zone determined using $met=1.2$ and $clo=0.6$
 Adaptive comfort zone determined using average measured outdoor temperature.

Satisfaction – Temperature – comparison to CBE database

- The graph below shows the thermal comfort satisfaction questions, presented as a cumulative ranking of all the buildings in the CBE database, and comparing the NREL-RSF to the database overall, as well as in relation to LEED, mixed-mode, and naturally ventilated buildings.
- RSF is performing very well, and is in the 92nd percentile of buildings in the CBE database in terms of thermal comfort.
- RSF has a higher temperature satisfaction rating than average LEED and mixed-mode, but not naturally ventilated, buildings in the CBE database.
- Note that these comparisons are for general reference. Given the small number of buildings in the naturally ventilated and mixed-mode categories, the comparisons are not meaningful without exploring in more detail the design and operating characteristics of these buildings.

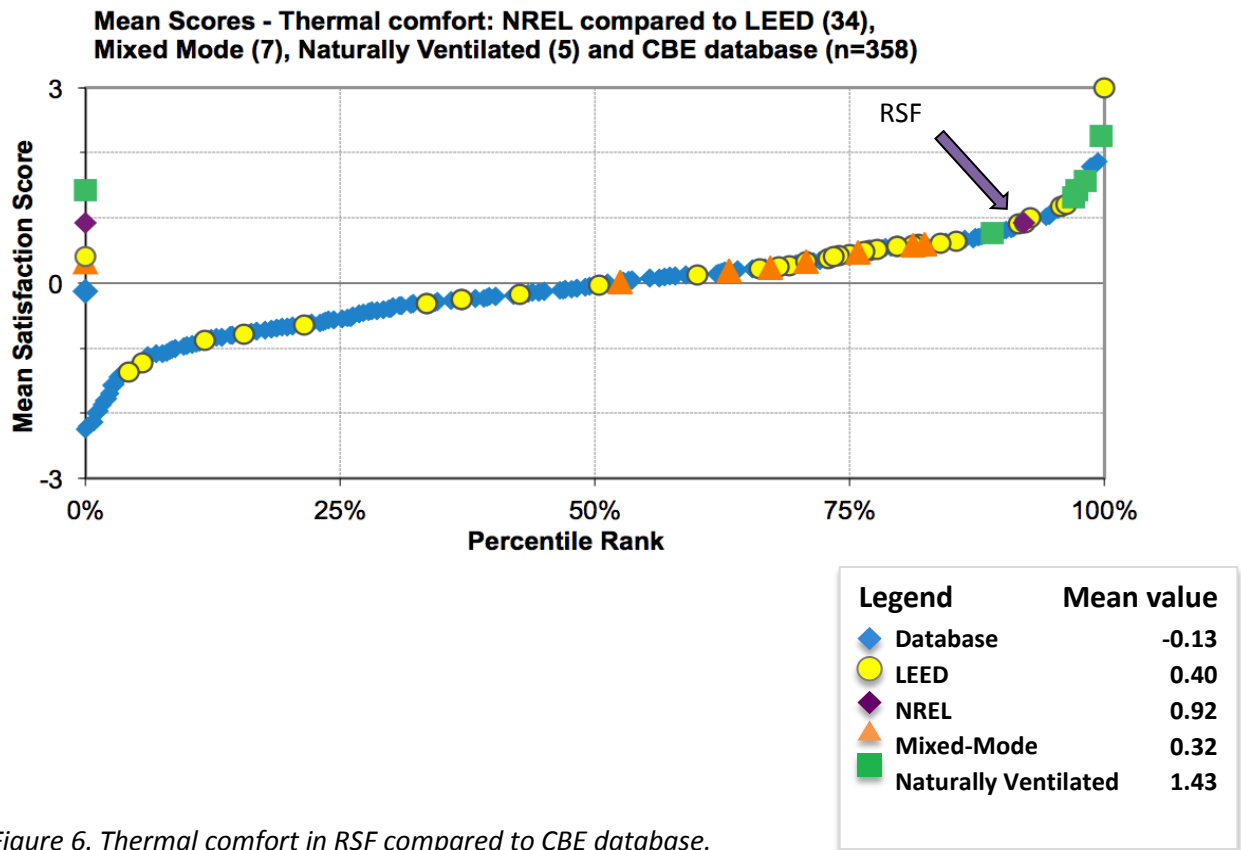
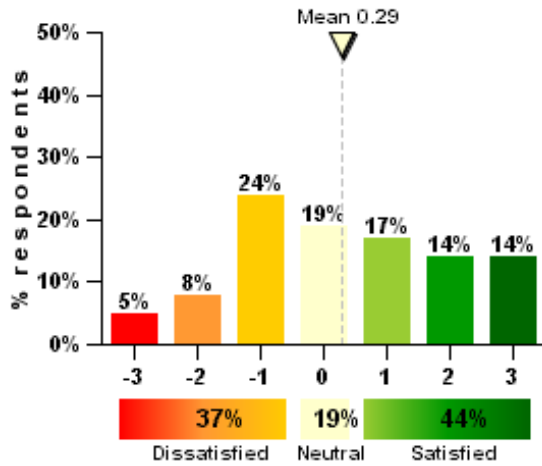


Figure 6. Thermal comfort in RSF compared to CBE database.

Satisfaction - Control of Temperature

- Results were mixed but more positive than negative, with 44% feeling satisfied and 37% dissatisfied with their ability to control temperature.
- Several of the comments mention not having much control of the temperature, but none of them thought that was a problem. In fact, one person said, “the thermal environment should not be user-controllable”.
- Overall, people are more satisfied with temperature than they are with their control over the temperature.
- Satisfaction with temperature is strongly correlated with satisfaction with the ability to control temperature (i.e., the more one is satisfied with the control one has, the more satisfied one tends to be).

How satisfied are you with your ability to control the temperature in your workspace?



N=59

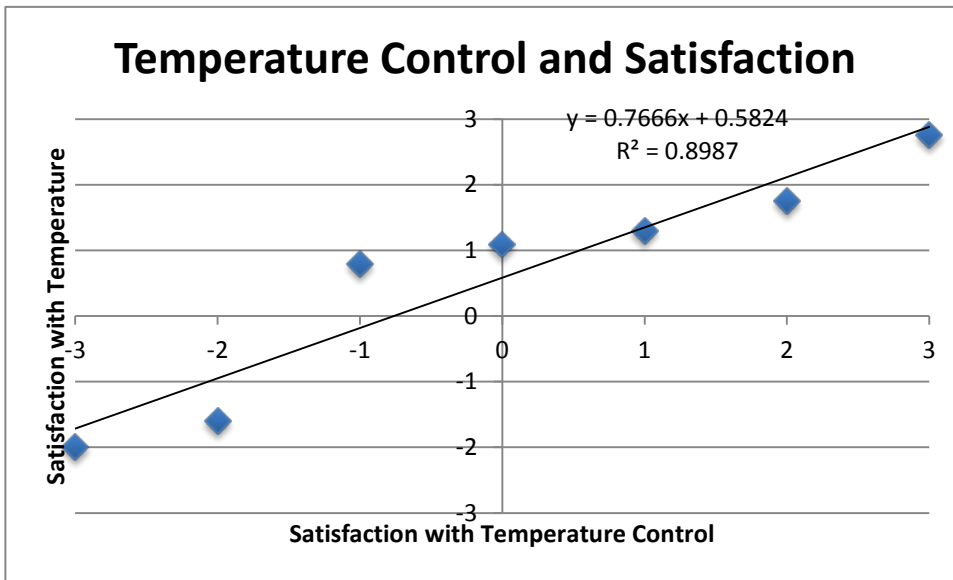
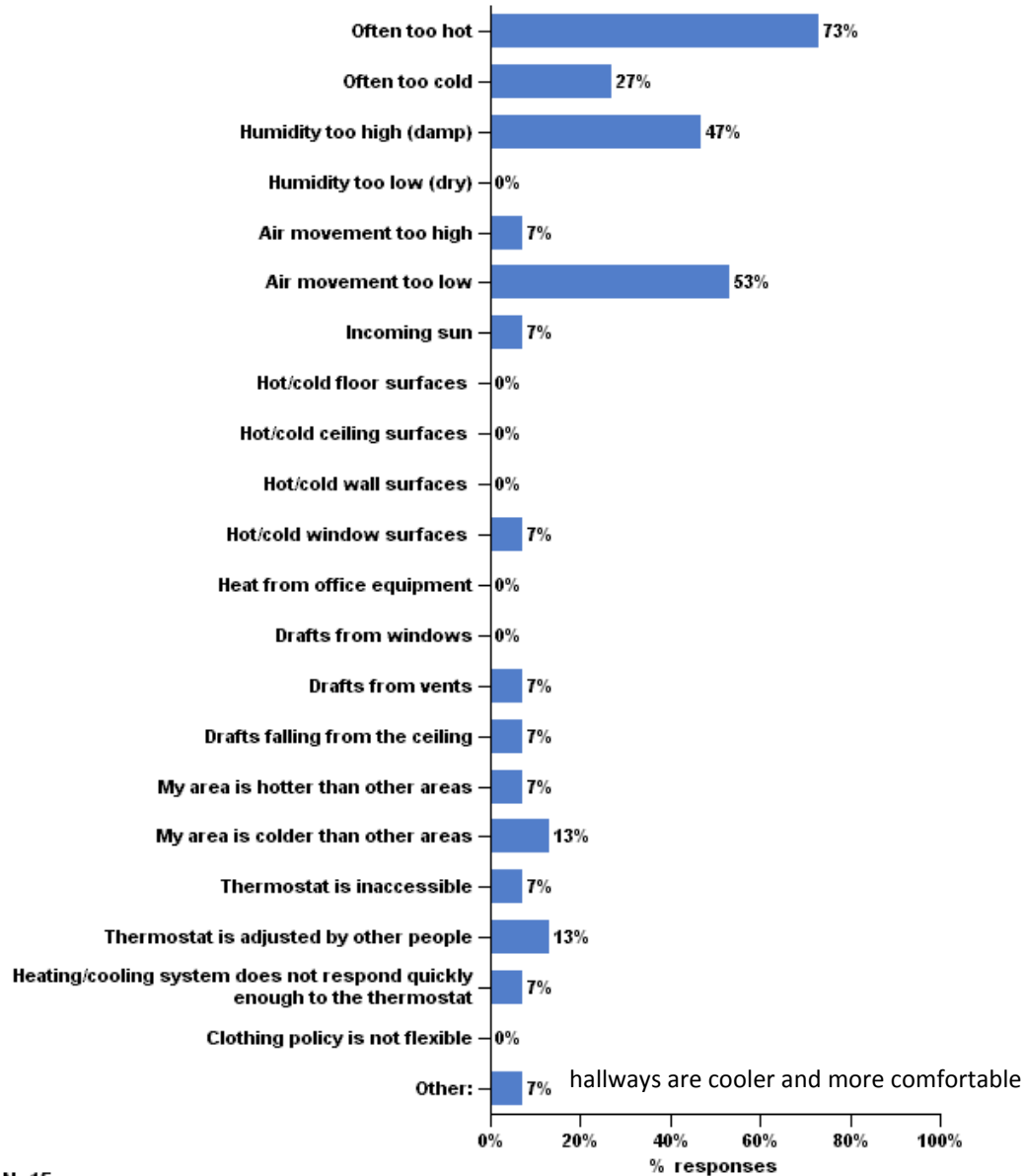


Figure 7. Satisfaction with temperature and ability to control temperature.

Sources of Dissatisfaction - Temperature

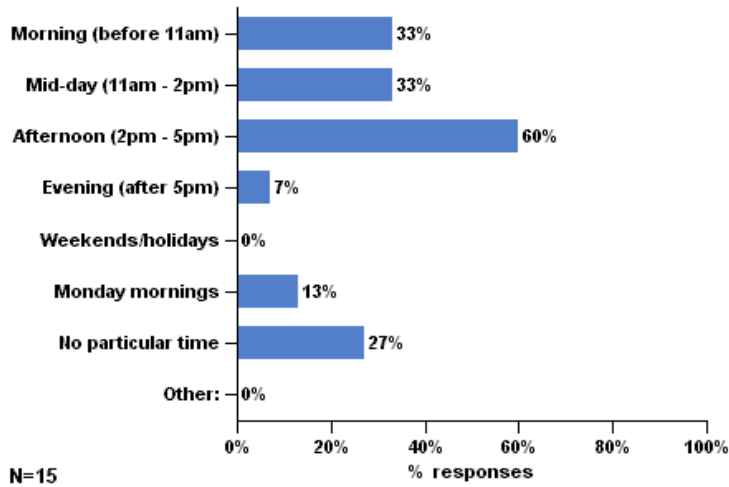
- The most cited reasons for temperature dissatisfaction were too hot, and air movement too low. These were followed by humidity was too high, and it was too cold.
- This survey was administered while the evaporative cooler was operating, so maybe that's why so many people said that high humidity is a problem.
- When dissatisfaction occurs, it most frequently happens in the afternoon, between 2 and 5 pm.
- When dissatisfaction occurs, results were mixed regarding how long the discomfort lasts, with approximately as many people saying that it lasts less than a hour, 1-4 hours and more than 4 hours.

You have said that you are dissatisfied with the temperature in your workspace. Which of the following has contributed to your dissatisfaction over the past month?

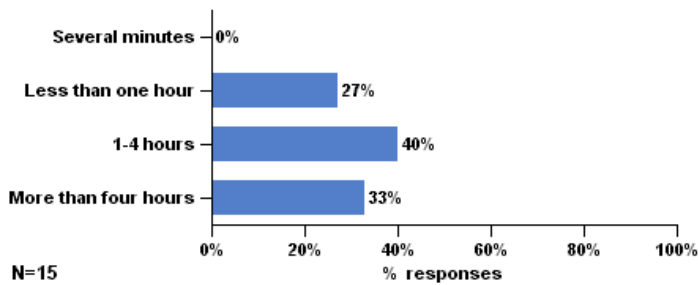


N=15

When is this most often a problem? (check all that apply)



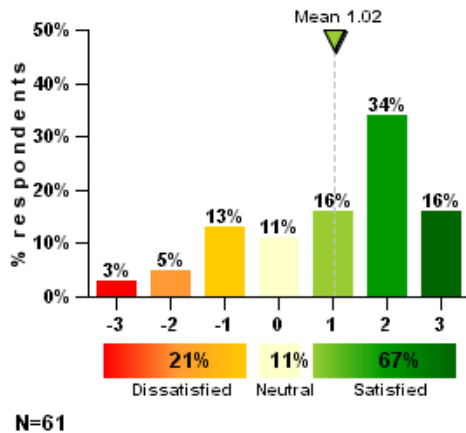
When discomfort occurs, how long does it typically last?



Satisfaction - Air Movement

- Approximately 2/3 of the people are satisfied with the amount of air movement.
- Later we will see whether the dissatisfied people had too little or too much.

How satisfied are you with the amount of air movement in your workspace?



Satisfaction - Air Movement - spatial distribution

Note that the color key refers to the 7-point satisfaction scale, with positive numbers (green) being satisfied, and negative numbers (orange-red) being dissatisfied.

- In 3 out of the 12 zones, more than 80% of the people are satisfied with the air movement. This is only half as many zones as for temperature.
- As we saw with temperature satisfaction, the people on the third floor are the most satisfied overall.
- The people on the fourth floor, with the exception of the south orientation next to the window, are the least satisfied.
- As noted, we were not able to get physical data for the 4th floor.

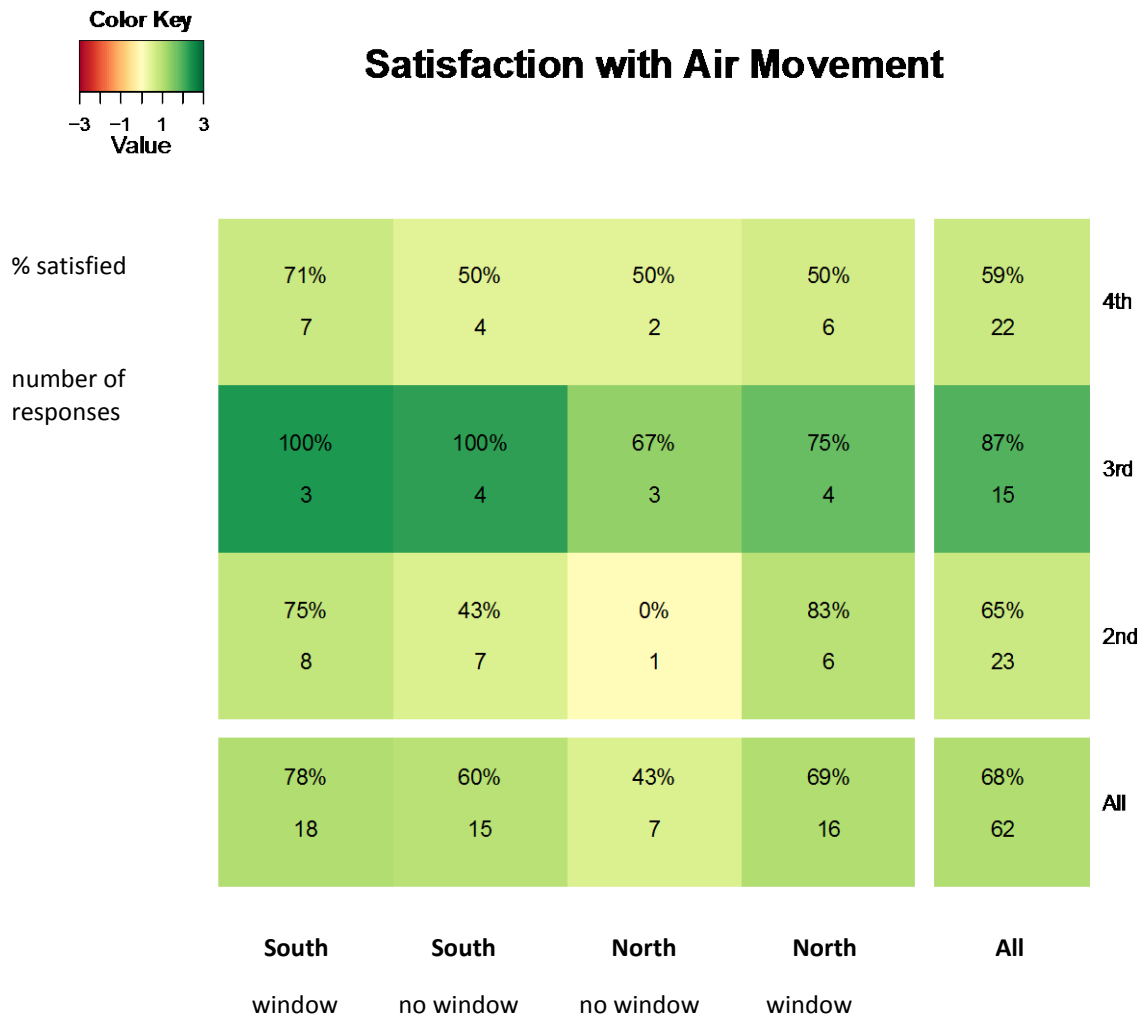
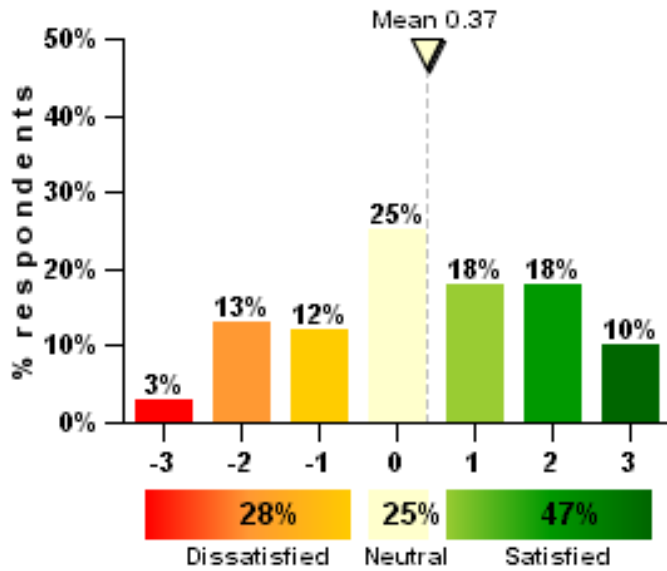


Figure 8. Air movement satisfaction by floor and orientation.

Satisfaction - Control of Air Movement

- Results were mixed but more positive than negative, with 47% feeling satisfied and 28% dissatisfied with their ability to control air movement. This was actually better than the ability to control temperature (44% satisfied / 37% dissatisfied).
- Overall, people are more satisfied with the amount of air movement than they are with their control over the air movement.
- Satisfaction with air movement is strongly correlated with satisfaction with the ability to control air movement.

How satisfied are you with your ability to control the amount of air movement in your workspace?



N=60

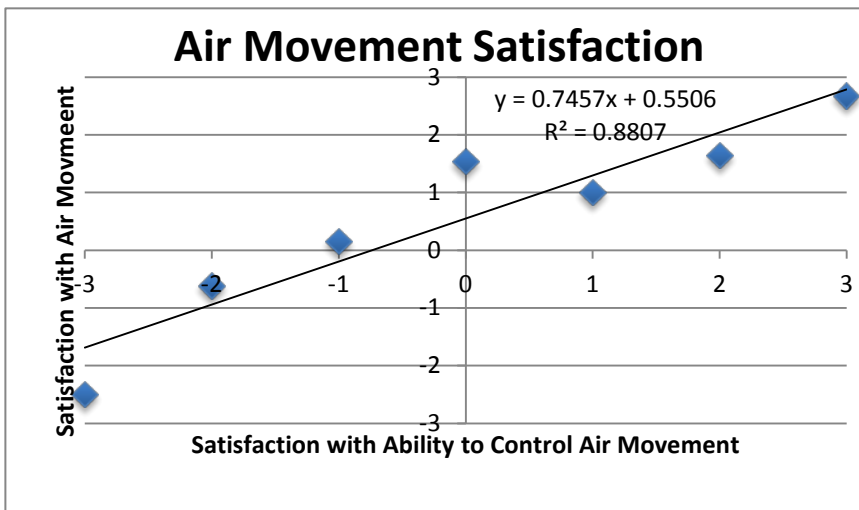


Figure 9. Satisfaction with air movement and ability to control air movement.

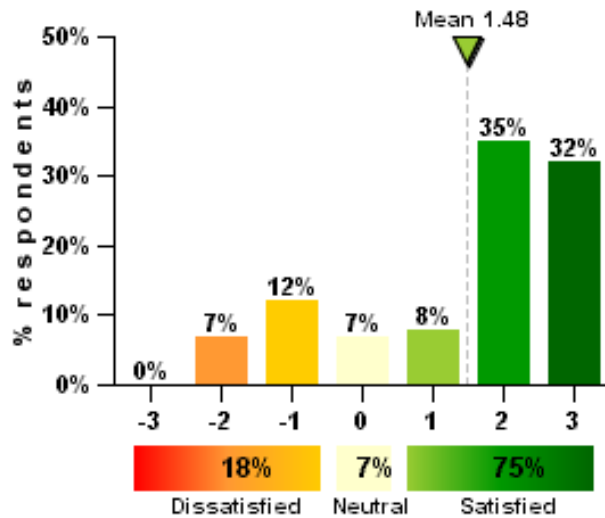
Sources of Dissatisfaction - Air Movement

- Of the people dissatisfied with air movement, 69% wanted “somewhat more” and 23% wanted “much more” air movement. Only 8%, or one person, wanted “much less air movement”.

Satisfaction - Air Quality

- These results were very positive, with 3/4 of the occupants being satisfied with the air quality.
- Overall, the satisfaction with air quality is the highest of the indoor environmental quality parameters.

How satisfied are you with the air quality in your workspace (i.e., stuffy/stale air, cleanliness, odors)?

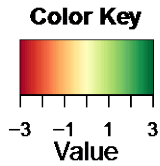


N=60

Satisfaction - Air Quality - spatial distribution

Note that the color key refers to the 7-point satisfaction scale, with positive numbers (green) being satisfied, and negative numbers (orange-red) being dissatisfied.

- In 5 out of the 12 zones, as well as overall, 73% of the people are satisfied with the air quality.
- The people on the third floor are the most satisfied overall.
- The people in the interior of the fourth floor are the least satisfied.



Satisfaction with Air Quality



Figure 10. Air quality satisfaction by floor and orientation.

Satisfaction – Air Quality – comparison to CBE database

- RSF is in approximately the 90th percentile of buildings in the CBE database in terms of air quality satisfaction.
- RSF has a similar air quality satisfaction rating to average LEED and mixed-mode buildings in the CBE database and a lower one than the naturally ventilated buildings.

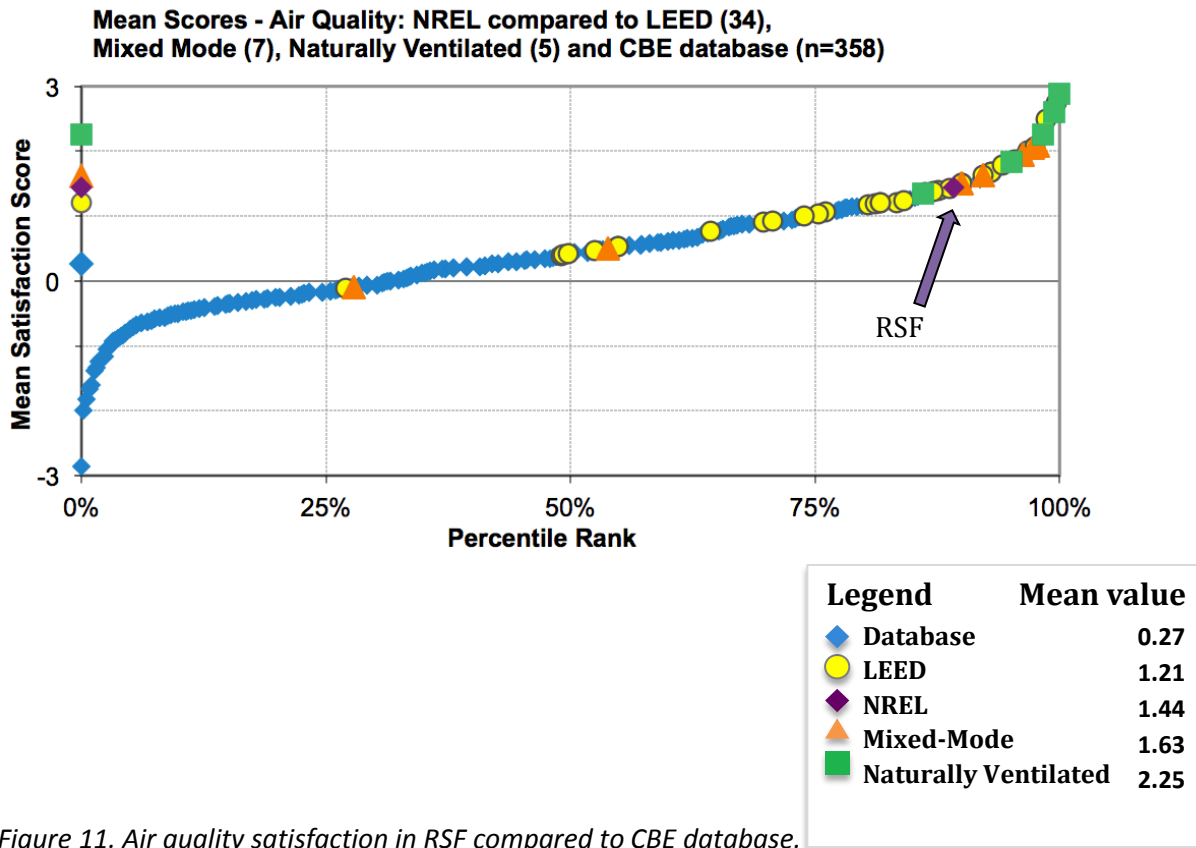
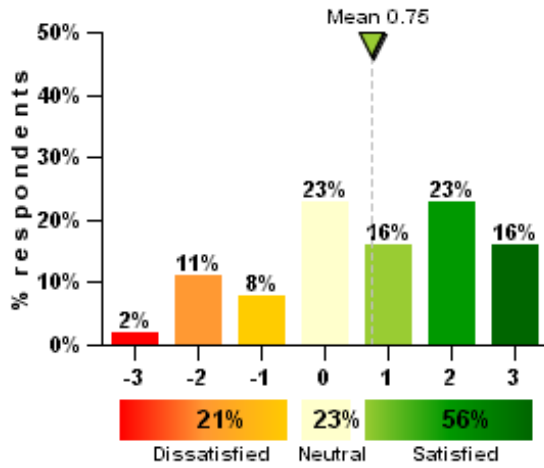


Figure 11. Air quality satisfaction in RSF compared to CBE database.

Satisfaction - Control of Air Quality

- Results were mixed but better than temperature or air movement, with 56% feeling satisfied and 21% dissatisfied with their ability to control air quality. This may be due to the operable windows, given that 89% of the people with access to a window said they opened their window for fresh air
- Satisfaction with air quality is strongly correlated with satisfaction with the ability to control air quality.

How satisfied are you with your ability to control the air quality/freshness in your workspace?



N=61

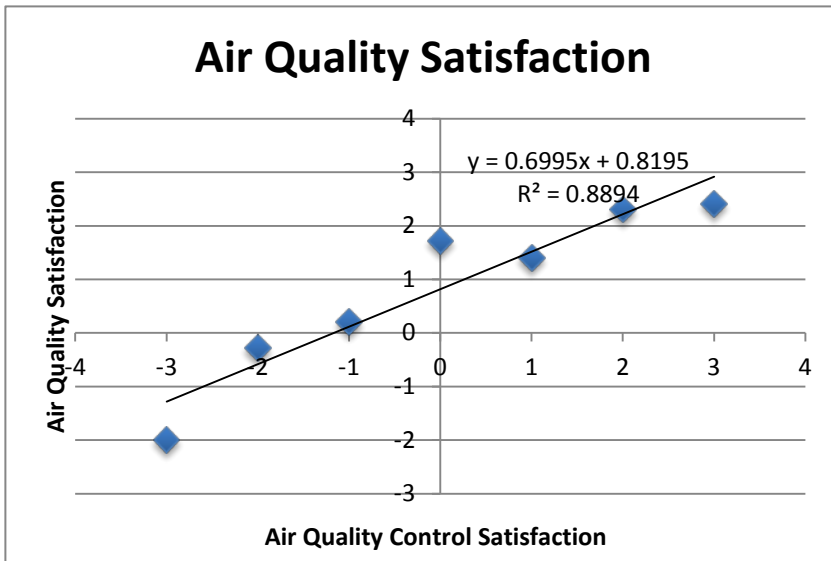


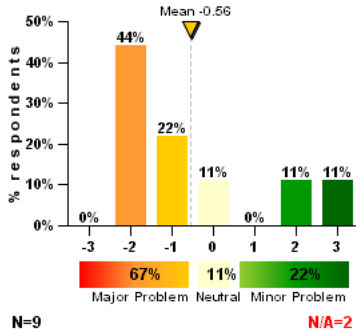
Figure 12. Satisfaction with air quality and ability to control air quality.

Sources of Dissatisfaction - Air Quality

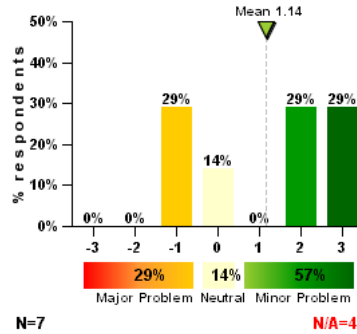
- The most cited reason for air quality dissatisfaction was that air is stuffy/stale.

You have said that you are dissatisfied with the air quality in your workspace. Please rate the level of each of the following problems:

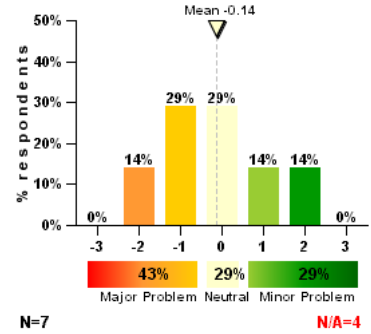
Air is stuffy/stale



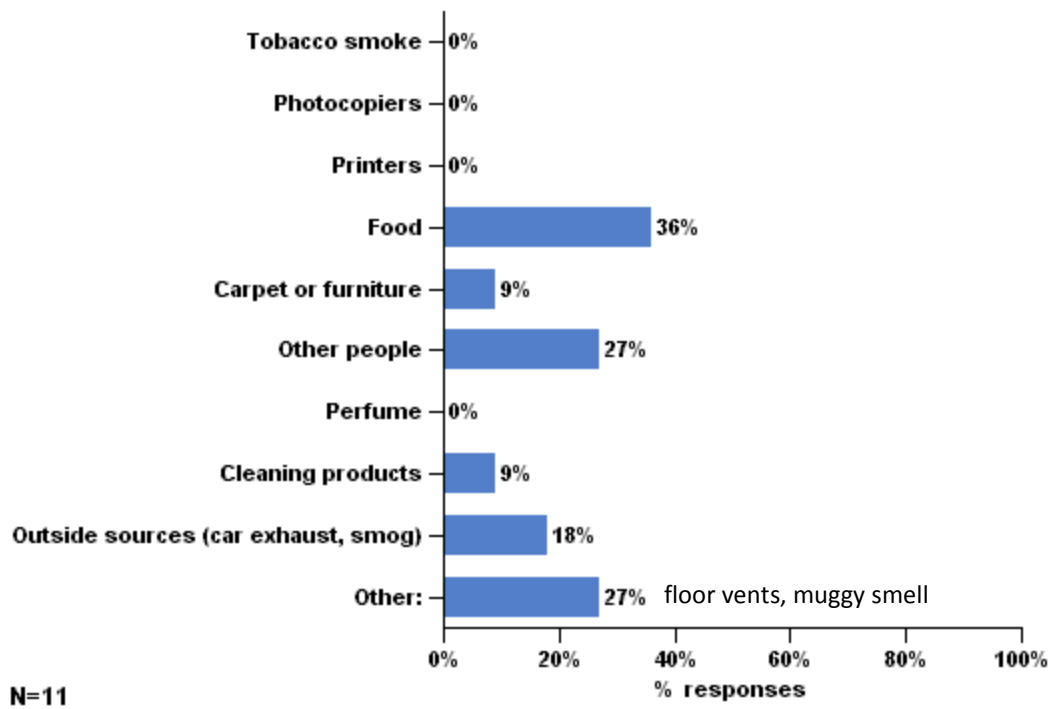
Air smells bad (odors)



Air is not clean



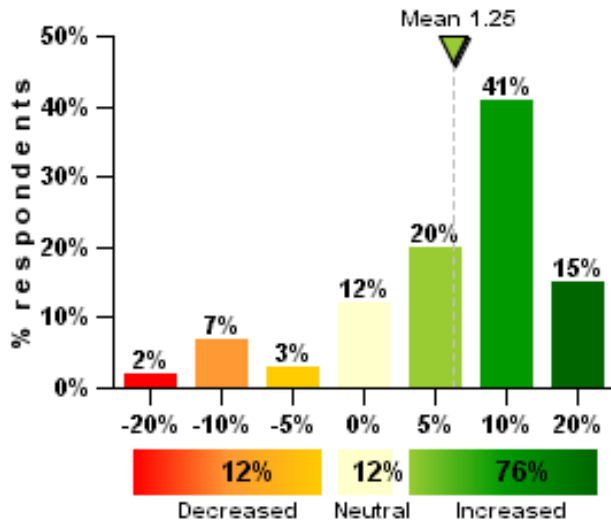
If there is an odor problem, which of the following contribute to this problem?



IEQ and Productivity

- 76% of the respondents felt that their productivity was improved by the IEQ conditions in the building.

Please estimate how your productivity is increased or decreased by the environmental conditions in this building (e.g., thermal, lighting, acoustics, cleanliness):



N=59

Correlations between different Indoor Environmental Qualities

- Satisfaction with the three components of the thermal environment is fairly well correlated—if you’re happy with the temperature, you’re likely to be happy with the air movement and quality too.
- Some general questions that arise from this, but that cannot be simply answered by a survey might be:
 - Is this because an area in the building that does well in one characteristic is likely to do well in the others?
 - Is this because some people are easier or harder to please?
 - Is this because people tend to group the three together as “being comfortable” and so really only have one answer?
- Satisfaction with temperature and the satisfaction with the ability to control temperature are strongly correlated. And the same is true for air movement and air quality.
- We would expect these measures of satisfaction to be correlated with some of the factors below. Our preliminary analysis (not shown) did not show any statistically significant correlations, but this may be a result of a low sample size. It may be something we can look at further after the 2nd survey following the controls intervention.
 - Access to an operable window
 - Frequency of operating a window
 - Number of people who share a window
 - Confidence that opening or closing a window will have the desired effect
 - Perception of a window’s responsiveness

- Feeling free to dress appropriately for the climate
- Controlling a vent
- Not controlling anything (window, vent, fan, etc.)

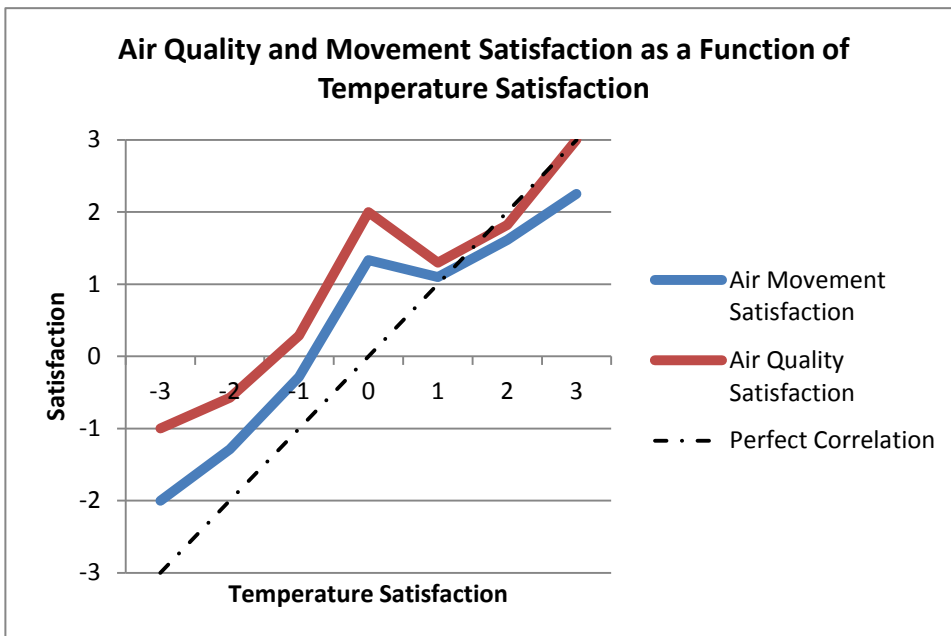


Figure 13. Relationship between satisfaction with IEQ parameters.

Influence of Location - floor

- The 3rd floor had the highest satisfaction for most of the criteria, especially for the workplace adjustability, general IEQ, temperature, air movement, and air quality.
- The 4th floor had the highest dissatisfaction, especially for the workspace adjustability and the ability to control the temperature.

Influence of Orientation - 4th floor

- There were very contrasting results between the north and south sides of the 4th floor
- For the 4th floor northern orientation, the users were generally satisfied with:
 - IEQ, temperature
 - Air movement
 - Air quality
 - Ability to control the temperature
 - Ability to control the air movement
 - Ability to control the air quality
- For the 4th floor southern orientation, the users were generally satisfied with:
 - Ability to control the air movement
 - Air movement,
 - Air quality
- For the 4th floor southern orientation, the users were generally dissatisfied with:
 - Workspace adjustability,

- Ability to control the temperature
- Ability to control the air movement
- Ability to control the air quality

Thermostat

- The thermostat is seen as not being very responsive. The building's high mass makes fast changes difficult, so changing the thermostat doesn't seem to change the temperature. People seemed to understand that but still complain a bit.

6. CONCLUSIONS

RSF performance

The occupants taking the survey were roughly evenly distributed on the 2nd, 3rd and 4th floors (with slightly less than 1/3 on the 3rd floor). Slightly more than half were on the south side of the building, with the rest mostly on the north. Approximately 66% are in cubicles with partitions lower than 5 ft, 20% are in enclosed, private offices, with the rest distributed in various other office types.

The survey allowed us to explore how people use their windows. Approximately 62% of the respondents say they are located within 15 ft of an exterior wall; 1/3 of the respondents have a window just to themselves, and the remaining 2/3 shares it between at least 3 people. 82% of the occupants felt that the management is very supportive of the use of operable windows. The windows were rated extremely highly in terms of accessibility, usability, responsiveness, and occupants also felt that management encourages the use of windows. In spite of these impressions, however, window use was lower than expected, with only 6% saying they adjust their windows on a daily basis, compared to 38% weekly and 41% monthly.

Windows are not used just for thermal comfort. The most frequently cited reason for opening windows is fresh air, followed by wanting to feel cooler, and then the desire to increase air movement. It is not apparent just from this question whether the desire for increased air movement is always associated with the desire to feel cooler, or just for the sake of air movement alone. Other reasons for opening and closing windows are unrelated to thermal comfort such as the desire to save energy or increase the connection with the outdoors.

The RSF is performing well for the occupants in terms of indoor environmental quality (IEQ), particularly with respect to air quality. The building scores in the 90th percentile of the buildings in the CBE database for thermal comfort and air quality satisfaction. Nevertheless, less than 80% of the building's occupants are satisfied with temperature, air movement, and air quality, so there is room for improvement to meet the code standard. People are more satisfied with aspects of the indoor environment that they are happy with their control over. So perhaps increasing occupant control would have a positive effect on satisfaction. Three quarters of the respondents felt that their productivity was improved by the IEQ conditions in the building. In the open-ended comments, most of the compliments about the building were related to daylighting, and most of the complaints were related to acoustics.

The most cited reasons for temperature dissatisfaction were "too hot", and "air movement too low", followed by "humidity too high", and "too cold". This survey was administered while the evaporative cooler was operating, so maybe that's why so many people said that high humidity is a problem. When dissatisfaction occurs, it most frequently happens in the afternoon, between 2 and 5 pm. Of the people dissatisfied with air movement, a significant majority wanted

“somewhat more” followed by “much more” air movement. Only one person wanted less air movement. The most cited reason for air quality dissatisfaction was that air is stuffy/stale, and previous research has found that these impressions are often associated with air movement being too low, rather than the quality of the air itself.

For all three indicators of indoor environmental quality studied, temperature, air movement, and air quality, the occupants on the third floor were the most satisfied and those on the fourth floor - particularly in the interior, away from the window, were the least satisfied. The northern side seemed to have the highest satisfaction with temperature, air quality and the ability to control the temperature. Perhaps this is related to the fact that the desks on the north side of the building are in enclosed offices that share an open ceiling with the open plan spaces. There were other results that were more confusing related to proximity to the exterior wall, leading us to develop revised methods to investigate these trends more carefully in the next phase of the study.

Research methods

As mentioned previously, one objective of this first survey was to pilot test the new methods and propose changes, where needed, for the second study that will be implemented following the new controls strategies. Some of these recommendations include:

- Return to using the core CBE survey rather than the significantly reduced subset used this time. This will allow us to better utilize our automated reporting tools and our benchmark database for comparison
- Consider adding the brief “right now” survey to enable us to match responses with simultaneous physical measurements
- Refine survey questions related to the dress code aspects of workplace culture, as well as the attributed of personal control (workspace adjustability, or what is sometimes termed “adaptive opportunity”)
- Add survey questions related to why people are not operating their windows (e.g. already comfortable, windows ineffective, windows too far away, etc.)
- Work with NREL to obtain more detailed data on the physical environment, or consider distributing our own network of continuous data collection sensors throughout the studied areas