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Window Signaling Systems: Control Strategies & Occupant Behavior

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ABSTRACT

Signaling systems that tell building occupants when to open and close windows have become a popular strategy for balancing the comfort benefits of manual windows with the efficiency benefits of automation in mixed-mode buildings. Data from surveys, interviews and site observations in 16 U.S. buildings reveal a diversity of design objectives, control sequences and circumstances to anticipate when designing buildings with window signaling systems. Signals influence window use patterns for a minority of occupants, although greater participation is possible if the signals are linked to an internal policy with clear, tangible comfort benefits. Low levels of participation likely occur because most occupants (though not all) tend not to pay attention to their windows, or the signals, unless they're uncomfortable, at which point it matters little what the signals say. However, occupants who do discover value in the signals are more likely to be more satisfied with their personal control.

KEYWORDS: mixed-mode, operable windows, personal control, behavior

Introduction

There is a broad, ongoing debate about the relative merits and challenges of manual versus automatic building controls, particularly applied to operable windows. These tradeoffs become even more complex when the building integrates operable windows with mechanical cooling, referred to as "mixed-mode" design. From the perspective of thermal comfort, there is a great deal of literature establishing a strong basis for improved thermal perception in buildings with operable windows, resulting from some extent to the greater sense of personal control and connection to the outdoor environment (Paciuk, 1990; Baker and Standeven 1995; de Dear and Brager 1998; Hellwig et al 2006; Huizenga et al 2006; Brager and Baker, 2008). There is also indication that operable windows may offer improved indoor air quality (Seppanen and Fisk, 2001). But trying to optimize the integration of operable windows with mechanical systems to achieve their full benefits for energy performance remains an unresolved challenge, often best achieved by downsizing cooling equipment and/or offsetting fan-driven ventilation (Daly 2002; Rowe 2003; Ogden et al 2004; Emmerich 2006. Overall, the benefits of operable windows are acknowledged by national building standards based on the adaptive comfort theory (de Dear and Brager 1998), and the Leadership in Energy and Environmental Design (LEED) rating system has embraced the operable window as a workplace quality amenity. But the question still remain - how does one balance manual vs. automatic window control?

Fully automated windows or vents are sometimes seen as more reliable and predictable; but they can also raise costs and remove the amenity of local, manual control. Another approach is to allow users to operate their windows at will, but to install sensors and controls that shut off the HVAC system when a window is opened; but this strategy works best in buildings where each occupied space is individually controlled, usually a prohibitive cost in office buildings. Signaling systems that inform occupants about when to open and close their windows (such as red/green lights or lighted signs) represent a compromise between the extremes of fully-automated vs. fully-manual windows. They have become a popular, low-cost solution that attempts to balance the benefits of manual and automatic control, and are based on the premise that information from the building can effectively influence behavior while retaining the fundamental benefits of personal control. However, little research has been done to characterize how these systems operate in practice, and whether they influence how occupants use their windows.

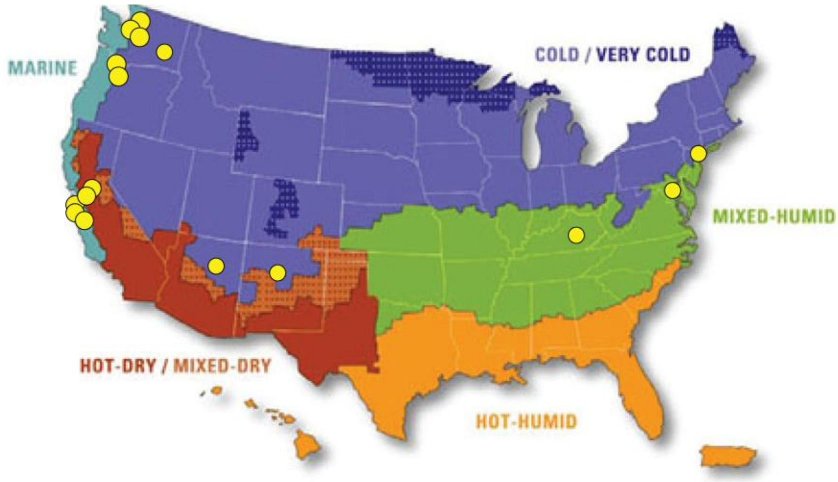
An investigation of signaling systems builds on two active fields of research. The first involves ongoing attempts to characterize and account for window control behavior in energy models (Rijal et al 2008; Humphreys et al 2008; Inkarojrit and Paliaga 2004, Warren and Perkins 1984), or investigations of important temporal and social dynamics that strongly influence window use patterns in offices (Bordass and Leaman, 1993, Yun et al 2008; Haldi and Robinson 2008; Herkel et al 2008). The second relates to research regarding the role of occupant education and information feedback in energy efficiency; feedback includes both "dashboard"-style information, the importance of giving peoplepositive feedback for their actions (Leaman et al 1998, 2006; Brown Dowlatabadi and Cole, 2009), and the idea of a psychological “forgiveness factor”` when people have greater feelings of control of the conditions in their building (Leaman and Bordass 2007).

This project takes a broad look at window signaling systems in existing buildings in the U.S. We investigated projects across the country to better understand a) why and how “open windows” signals are designed and implemented; and b) the extent to which the signals play a role in occupant behavior and response. The results from this project are intended to inform designers of best practices when considering signaling controls for operable windows. In addition, the signals provide a unique opportunity to investigate the ability for informational devices (or occupant education, more broadly) to bring design objectives and occupant control behaviors related to comfort and energy into better alignment.

Methods

We identified and recruited 16 office and mixed-use buildings in the U.S., drawing from existing databases of high-performance buildings and by reaching out to our industry partners. The type of workplace and size of subject population varied widely building to building. Data collection included occupant surveys, interviews, site observations, and specifications of control algorithms

Figure 1. Locations of 16 study buildings (basemap: U.S. Department of Energy)



Occupant Survey. In fall, 2009 we developed and pilot-tested a survey module as a part of the Center for the Built Environment's (CBE) online Indoor Environmental Quality (IEQ) Survey and received permission to administer it in 10 of the 16 buildings. A total of 604 occupants were surveyed, with response rates of at least 60%. The number of subjects surveyed in each building ranged from 19 to 156; with a median of 42. Only the full time office employees were surveyed. In the survey we ask occupants to reflect on:

- How frequently they actively respond to the "open" and "close" signals;
- How likely they are to open the window even in "close" mode;
- Whether the signals interfere with their sense of personal control; and
- To describe any conflicts that arose between the system and their own preferences.

Interviews. For all 16 buildings, we asked at least one member from the design team (architect and/or engineer) and at least one representative of the building (building coordinator, manager or operator) to describe the design intent and known operating issues.

Site Visits. We were able to visit 13 of the 16 buildings and record observations about the building, the office space and the placement of the signaling devices. In six of the buildings, we received permission to conduct brief, informal interviews with occupants to supplement the survey data. We were able to speak with 22 occupants, about evenly divided among the six buildings, and we asked them simply whether the signals played a role in how they use windows, and to elaborate as to why or why not.

Control Algorithms. We were able to collect the as-designed control algorithms for each of the 16 buildings, and we were able to verify the as-operated sequence in all but four of the buildings. We developed a graphic tool to visualize the differences among control strategies based on the main temperature criteria employed.

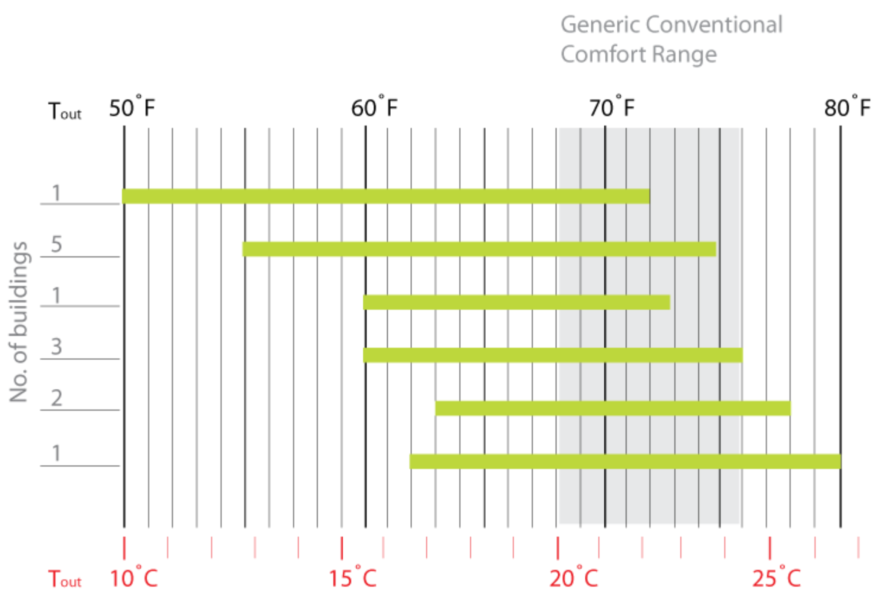
Results: Design & Operation of Signaling System

Reasons for Choosing Signaling Controls. Based on our interviews, we found differences in how the design teams understood the benefits and liabilities of operable windows, and these can be summarized into three primary reasons a signaling device was chosen:

1. **Moderating personal control**
   The client or architect valued operable windows as a workplace amenity, but they were a hard sell to engineers or facilities managers without some measure of oversight.
2. **Cost-effective natural ventilation**
   The design team intended for windows to offset mechanical cooling and ventilation, but automated controls were deemed too expensive and/or value engineered out of the project. Three projects decided on a signaling strategy post-design development.
3. **"Green" message**
   The client or design team thought the signals would make operable windows more visible to occupants or visitors. This was not a primary reason in any project, but it had equal importance in three projects.

Algorithms to Define "Open Window" Mode.
In virtually all projects, the algorithm for "open" mode was written based on outdoor temperature criteria. Figure 2 shows the variation in acceptable outdoor temperature ranges used in the algorithms for establishing "open" mode in the signals. The chart roughly differentiates strategies in which open windows are understood as part of the economizer mode (allowing window use at very cool temperatures), and strategies that adopt adaptive comfort principles (allowing higher indoor temperatures). These strategies are not always mutually exclusive. Naturally, the setpoints also differ according to building size, climate, and system design.

Figure 2. Variation in acceptable outdoor temperature ranges for opening windows



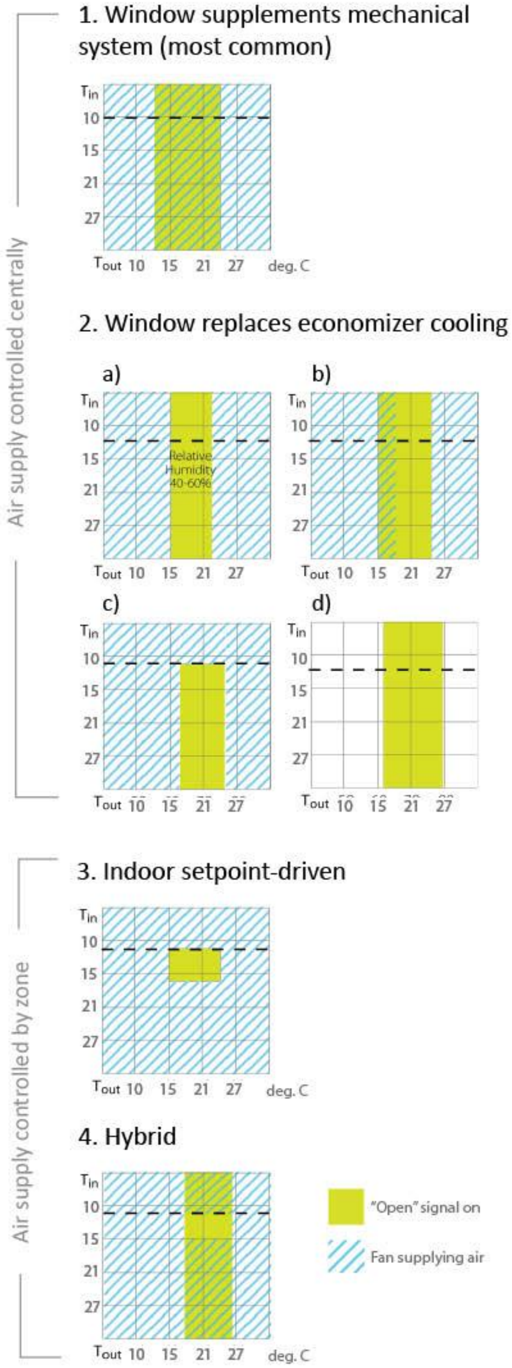
Depending on the extent to which the design team wanted the building to operate like a "change-over" mixed-mode building, some buildings chose to shut off all mechanical systems during "open windows" mode. For three of these buildings, the engineer felt it important to include additional indoor temperature limits. In four buildings, humidity, wind speed and CO_2 were additional environmental criteria that could over-ride temperature inputs for "open windows" mode.

We identified four distinct ways in which outdoor temperature limits were combined with indoor temperature criteria and air supply in the algorithms for "open" mode. It's important to note that control algorithms were not based on a narrow view of thermal comfort criteria. Rather, they reflected a more complex relationship of different ways in which designers understood the benefits and liabilities of operable windows. Typically, when the same engineers worked on different projects, they tended used the same strategy for all of the projects in which they used signals. This suggests that the algorithms might more strongly reflect a way of thinking, rather than sophisticated building-specific analysis.

We developed a graphic representation of the temperature criteria used in the control algorithms, and for simplicity show only seven examples of these in Figure 3 below, grouped into the four categories The "open" mode is denoted by a green zone confined by indoor (y axis) and outdoor (x axis) temperature limits. The blue hatching indicates whether or not air is mechanically supplied to the zone. Where there is green and no blue hatching, this means the air supply is shut off. The horizontal dashed line represents an indoor cooling setpoint. A more detailed explanation and comparison of these strategies is available in Ackerly and Brager (2011).

All four approaches have the potential to reduce mechanical cooling hours by allowing windows to dampen the effect of internal gains and delay mechanical cooling operation. As in any building, raising the cooling setpoint will further reduce cooling energy. The main variables potentially impacting occupant perception, participation, and energy use include: how frequently the signals turn on and off, how often occupants are encouraged to open windows at cool temperatures, whether there is an indoor cooling setpoint that overrides the signal, and how high the indoor and outdoor temperature limits are. The highest limit that was used was 82 °F (27.8 °C) (for both indoor and outdoor temperature). This was in a renovated historic building with perimeter fan coil units operated by occupants and no perimeter ventilation. Cooling setpoints of 78 and 80 °F (25.6 and 26.7 °C) were used in more conventional office spaces successfully.

Figure 3. Distinct approaches for setting signal control algorithms



- Windows are allowed when outdoor air can be used to cool the building, but air continues to be brought in through air handler during "open" mode.
- If T_{in} is *above* the cooling setpoint and T_{out} is between 55° F and 75 °F (13-24° C), the air handler is bringing in as much air as needed to cool and ventilate
- Open windows may reduce fan energy by reducing loads and return air pressure.
- Closed windows result in conventional building operation.
- A lot of open windows outside of "open" mode are viewed as an energy liability.

- When outdoor air is sufficient to cool the building, central air supply shuts off during "open" mode.
- At the low temperature range of the "open" mode, the central air handler may still provide economizer cooling (case b)
- An indoor setpoint override may be necessary for buildings with high internal loads (case c). It may be difficult to go back into natural ventilation mode once this has been reached.
- While in "open" mode, if T_{in} increases faster relative to T_{out} (due to high loads, low window use or low thermal mass), discomfort may result in buildings with all-air systems since the system won't turn on (cases a, b and c).
- In buildings with no perimeter ventilation (case d) , the potential for concurrent cooling and window use is possible.

- When T_{out}, T_{in} and CO_2 levels in a given building zone are all in an acceptable (comfortable) range, open windows are allowed and the mechanical system for that zone shuts off. (This example was a variable refrigerant flow (VRF) system with VAV air supply.)

- Windows are allowed when T_{out} is in an acceptable (comfortable) range
- Rather than the air handler remaining on, as in Category 1, the zone VAV fan will provide outside air only if needed for cooling or ventilation, otherwise the fan speed modulates to zero.

Signal Design and Placement. The range of signal designs is shown in figure 4. Of the 16 projects, eight use un-labeled red/green or amber/green indicator lights; three use indicator lights with explanatory text, two use un-labeled on/off green indicators, and three use on/off "open windows" signs. Typically, signals were distributed somewhat sparingly throughout open office floors, spaced anywhere from one per bay to one per floor. For buildings with private offices, signals were installed in individual offices in all but two, in which signs were posted in the corridors.

Our findings about the design making process behind these signaling systems was particularly revealing. Interviews suggested that in most cases, there was little systematic discussion about the design of the signaling device; instead, decisions were made either by impromptu judgment, cost, or previous experience. The vast majority of interviewees also indicated that the signals were intended as “guidance,” as opposed to an imperative, which lends a perspective later on how to interpret the findings about occupant use patterns.

Figure 4. Signal Interface types

Education of Occupants. We identified three “tiers” of education methods that were used to explain the purpose of the signals. At the base tier, the majority of projects (10 of the 16) relied solely upon an initial staff notice, usually in the form of an orientation given by the design team or building manager, which described the signaling system as one of the building’s “green” features, intended to save energy through natural ventilation. This explanation is very common, given that this is how the idea came about in the design process. In the next tier, a few buildings provided more targeted one-on-one explanation of the control strategies through a new-hire orientation with the building manager. In the third, highest tier, a building or office manager was active in an ongoing discussion with occupants, either in person or by email, regarding what was going on with the building. We found in one case that frequent emails sent automatically by the building management system were easily regarded as spam and ignored.

Results: Occupant Behavior

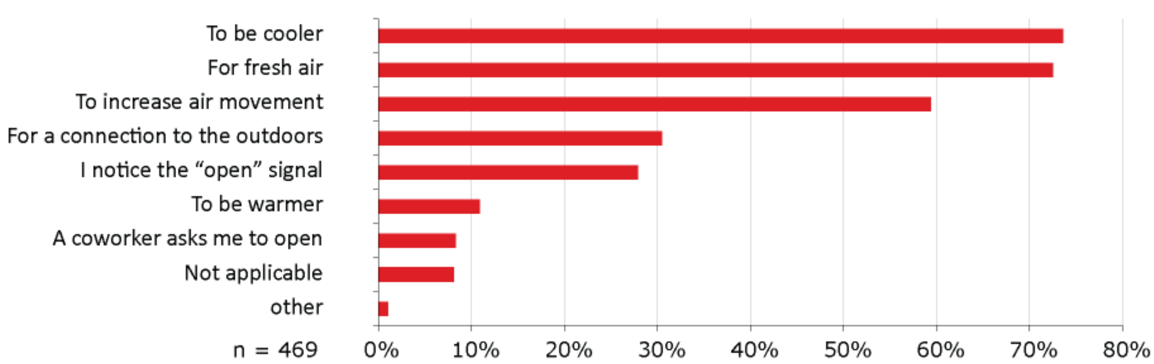
While thermal comfort research has traditionally focused on how people respond to a particular set of thermal conditions in which they are exposed, this paper focuses more strongly on why people use windows and how much an informational device influences behavior.

Personal reasons for using windows. Our survey revealed that, although respondents consistently value operable windows very highly, people use windows for different reasons. As shown in Figure 5, the desire for cooler and fresher air are by far the most common. A connection to the outdoors was selected by 30% of survey respondents, with a similar percentage citing the signals as a reason, although this average varies widely across buildings.

Similarly, of the 22 subjects interviewed during our site visits, seven (30%) said the signals played a role in how they use their windows, while 15 said they did not. The most common reason for not using the signals was simply a stated tendency not to pay attention to windows – or the signals - because they are generally comfortable and focused on other things.

Of the seven people interviewed who said the signals *did* play a role in how they use their windows, four expressed a general tendency to like to have their windows open for psychological reasons, and as a result were more likely to see the "open" signal as a "good reminder" or "a treat." Likewise, they were more likely to acknowledge the "close" signal (or wonder why it was on). Others found particular value in following directions, whether it was an opportunity to take a break from work, a reminder that it was nice outside, or a belief that following the system is important for the operation of the building.

Figure 5. Reasons for opening windows



Reported responses to the signals. In our survey, in seven of the ten buildings, a consistent minority of respondents – 10-20% – reported actively opening their window when the "open" signal was on, as shown in Figure 6. (We define "active" occupants as those who report acting on the signals "always" or "usually.") Three buildings stand out for having over 50% actively engaged with very low percentages of respondents in the "not aware" category, and these examples offer important lessons for future applications in that they share the characteristic of having some mechanism for ongoing reinforcement. In at least one of the buildings, occupants were unusually familiar with the intent of the system since they were an architects' office and were involved in the design; in the other two buildings, managers made an ongoing effort (tier 3) to share the importance of the signals.

Overall, the mean responses for acting on the "close" signal are higher and more variable, as shown in Figure 7. The projects for which “closing” responses are significantly lower than “opening” responses are those without a “close” signal (that is, “green only” signals that turn on and off: buildings #1,2,9). Those for which the importance of closing windows was particularly emphasized to occupants does show relatively higher response rates (buildings #6,7).

Figure 6. Occupant response to “open” signal

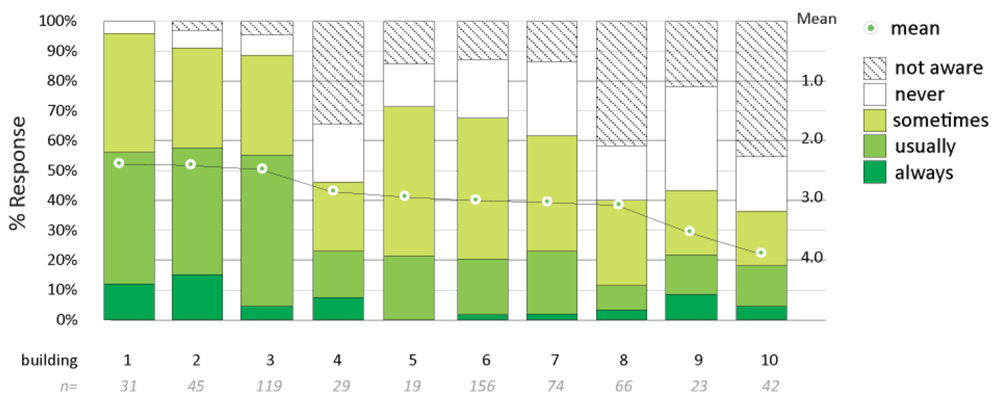
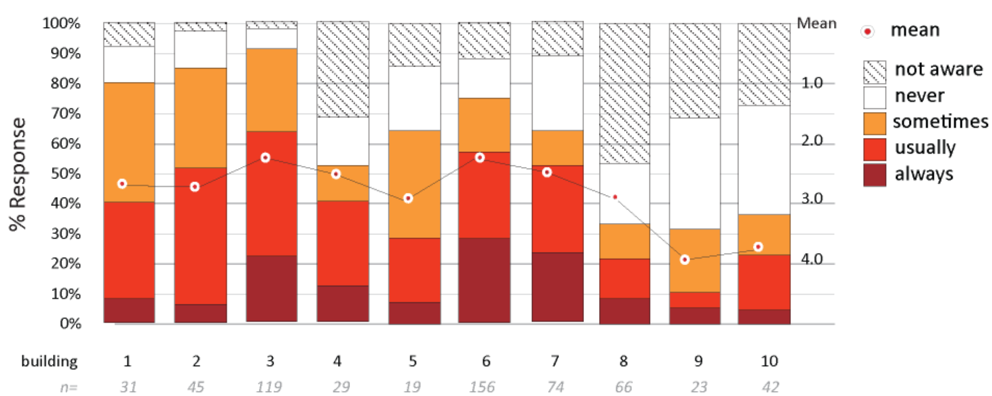


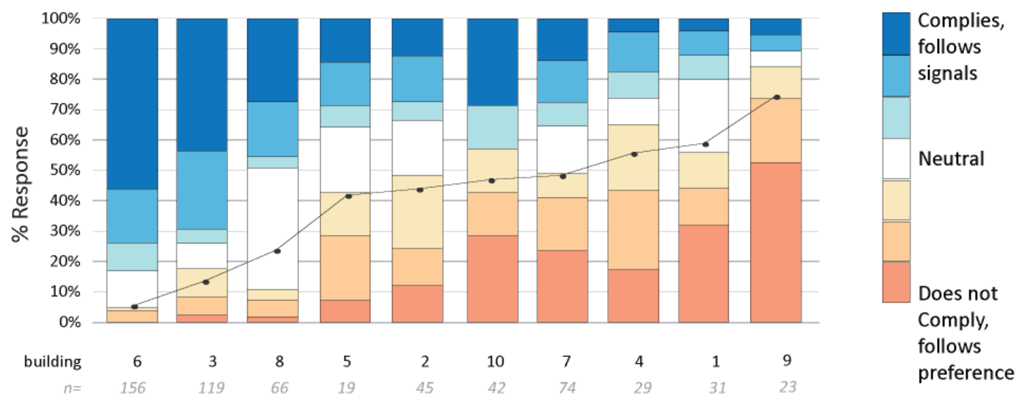
Figure 7. Occupant response to “close” signal



Occupants were also asked how likely they would be to open a window if they wanted to, even if they know the signal indicates otherwise. As shown in Figure 8, responses in the buildings represent a full spectrum of tendencies, from over 70% reporting being compliant in one building, to less than 10% in another. With the exception of these few extreme cases, generally 40-60% of occupants in any given building report adjusting windows as they see fit.

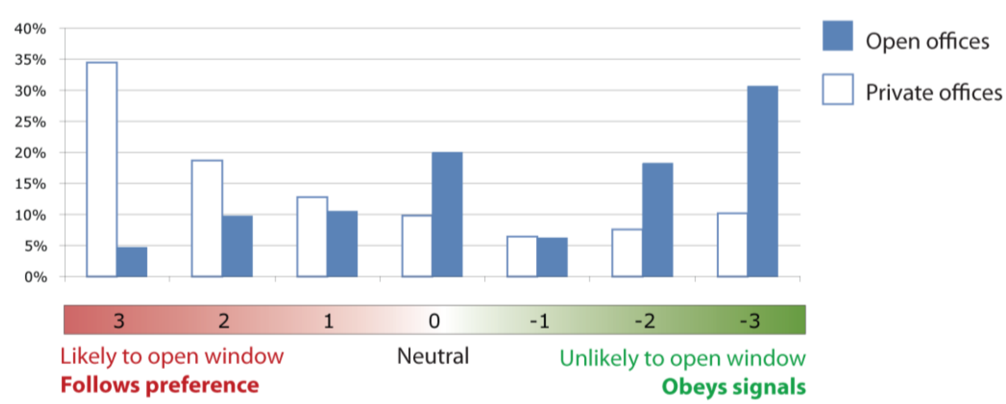
The results demonstrate that the mean responses range significantly building to building, and that most occupants are generally ambivalent; even in the most successful cases, mean responses for acting on the signals was never higher than “sometimes.” However, the risks of this general ambivalence may be reduced somewhat in open offices, where the ‘active’ users end up taking responsibility for a group of coworkers who share window access. Overall, people in private offices were less likely to actively respond to the signals, even though they generally had better access to both windows and an indicator installed within view. As shown in Figure 9, open office inhabitants were also much more likely to obey the signal than those in private offices.

Figure 8. Willingness to open on "close" signal



There are a number of possible explanations. Presumably, people with private access to a window will use it whenever they want, whereas window use in open offices is inherently more tied to the signals or other directives from coworkers. Social reinforcement in open-plan offices is likely stronger during "close" mode (when an open window is perceived by co-workers as "breaking the rules"), than in "open mode" (which simply validates the behavior of those who naturally like to have their windows open.) On the question of whether the signals enhanced or interfered with occupants' sense of personal control, most people selected "neutral". But among those who did have an opinion, people in open offices were much more likely to say that the signals enhanced their personal control, while those who said the signals interfered were predominantly in private offices.

Figure 9. Open versus private offices: Willingness to obey



The wide distribution in the mean responses reported building-to-building (e.g. Figure 8) does not necessarily indicate a failure of signaling systems. Instead, these results point to the importance of finding out why individuals observe or disregard the signals, and then determining which of these factors are in the control of the design team or building management. The basic differences in how people use windows is perhaps the most important factor. Attitudes, interfering circumstances and other conflicts that contribute to participation are discussed in the next section.

Factors contributing to participation. We asked occupants to comment on whether the signals coincided with their "own sense of when to open/close windows," and reviewed, coded and tallied the most common issues. A total of 274 comments were offered (roughly 20% of total survey participants), and responses were normalized by the number of occupants surveyed in each building. We identified the following key factors in how people used their windows in relationship to the control signals:

1. How often the "close" signal is on. Next to simply dismissing the signals, the most recurring reported issue was that the "close" signal was frequently on at times that seemed nice enough to use windows (15% of comments). In five buildings, a malfunction, mis-translation of the design intent, or operator adjustment resulted in the "close" signal always being on. For signals that were functioning as intended, this type of comment usually referred to the space being too warm and stuffy during times windows were not allowed.

2. The desire for fresh air. In the survey, the desire for fresh air rivals the desire for temperature adjustment when using windows. So it wasn't surprising that 10% of reported conflicts between behavior and signal instructions referred to the desire for fresh air when the "close" signal was on. In most cases, air movement and fresh air were coupled in the comment.

3. Visibility from workstations. Another 10% who offered comments about conflicts remarked that they may pay more attention if the signals were more visible from where they sat. This seems obvious, but the added cost often drove designers to install as few devices as possible. However, what is considered "visible" can be highly contextual; according to one case, PC task bar icons, which are low-cost and highly accessible, can easily blend into other desktop icons and get overlooked.

4. Unique situations. Most of the comments, even if they are not shared by other respondents in the study, point to the diversity of attitudes and preferences among office occupants as well as the range of local circumstances that affect comfort and can not be anticipated by a single control algorithm or window-opening policy. Aside from personal disposition, mood and personality, we documented extrinsic interfering circumstances including the location of furniture, the location of the thermostat, the presence of drafts from floor air diffusers (noted by several occupants), proximity to the façade, conditions directly outside (such as noise, wind, or pollen), surface temperatures, and direct sun exposure. In theory, these circumstances are the very justification for providing measures of personal control like operable windows. However, in many buildings, how the meaning of the signals is described to occupants does not go far enough to make allowances for these circumstances.

Discussion

While there were too many variables to draw any statistical correlations between the type of control algorithm used and occupant participation, our sense from these findings is that the programming of the system is less important than making sure they are visible and communicate a clear message. This way, occupants know how to manage their unique circumstances, which is critically important to maintain a sense of personal control, while also trying to manage the overall environmental conditions and energy use in the building. Our survey results suggest that occupants' reasons for opening windows may include the desire for fresh air or air movement, which is as important to them as temperature adjustment, but admittedly difficult to program into the controls. The hybrid approach (option #4 in Figure 3) is a good way to ensure good air quality during "open" mode, since air supply is modulated by zone based on need, and "open" mode corresponds to outside air temperature only. The fact that the mechanical system is making sure the space is comfortable may, however, prevent occupants from adapting to using their windows more.

Beyond better communication between building managers and occupants, improving control algorithms comes down to how temperature setpoints are established and how predictably and frequently the signals switch between "open" and "closed" modes. For buildings in mild, dry climates, signal algorithms based only on outdoor temperature allows the signal to clearly communicate the principle of when an open window will make you comfortable, and when it will be a less efficient form of cooling. In warmer or more humid climates, the algorithms may necessarily need to be more complex

The idea of exclusively using an "economizer" logic for the window signal algorithms can be problematic, because a) the quantity of airflow is not as precise with windows; and b) it can be uncomfortably cool to open windows at 55°F or 60°F (13-16 °C), even if occupants know it may minimize internal gains and cooling needs later in the day.

It is important that the controls are designed so that the effective result is not a default to "close" mode if occupants don't participate according to plan. In most cases where the "close" signal was on all the time or way too often, this was a result of programming errors, adjustements and overrides. However, including indoor comfort criteria limits in the operation of the signals may also result in the "close" signal being on too often (as in the indoor setpoint-driven approach, option #3 in Figure 3).

In all but one of the buildings using the option #2 approach, occupants were expected to act as "human actuators" for mode change-over, and operate windows that were not directly located in their own workstation, either in large banks or at clerestory level. This is an acceptable approach if occupants are well-informed, mode changes are reasonably predictable and frequent, and the building is built to dampen temperature swings enough to be resilient to low participation. But expecting high participation for windows not directly "owned" by an occupant (i.e., associated with their own workstation) is probably not feasible for a conventional office.

For the most part, none of the buildings we studied were "allowed to get uncomfortable" by design, although a few used relatively high setpoints that approach the temperatures you might find if the building didn't have a cooling system. Given the tendency for occupants to ignore their windows unless they're uncomfortable, one engineer said that going through a period in which occupants are exposed to a new routine with warmer conditions may be necessary to make signals truly meaningful as a way to prevent discomfort. Understanding how window signals might help occupants adapt is an interesting question for further research. It may be useful to conduct more detailed research on:

a) The option #2 (Fig. 3) strategy, in which the central mechanical system shuts off entirely based on outdoor temperature only. Where people are not expected to be human actuators, do they learn to use their windows to avoid high indoor temperatures? If so, how?
b) Adding an upper limit for "open" mode. In a building like Fig. 3, option #2(c), how high can the cooling setpoint be set to get people to adapt but not dissatisfied?

Turning now to occupant behavior, our survey results are as problematic as they are promising. Even in the most successful applications of the system, there is likely to be a substantial portion of people who are either unaware or ambivalent about the system; meanwhile, even in the least successful buildings, there is also a steady minority that do participate. This latter result could be an artifact of the survey method, in which subjects may report "good behavior" even if it isn't entirely accurate; however, the limited number of occupant interviews suggest that occupants' reasons for using windows is important.

In general, it appears to be typical for signals to be disregarded because the majority of office inhabitants have a tendency not to pay attention to their windows unless they're uncomfortable. So when they are comfortable, they are likely to maintain the status quo and not react to the signals. When they are uncomfortable, it matters little what the signals say. Therefore, it is the non-comfort factors – the psychological and social factors – that play a greater role in determining how occupants participate. In an open office, the signals appear to leverage and validate the behavior of those who tend to like to have their windows open, and to discourage "bad" behavior.

Despite these trends, our informal interviews suggest that, it is possible for occupants who normally wouldn't think about their windows to change their behavior if they find a meaningful link between the signal operation and the comfort routine they experience throughout a typical day. We hypothesize that such a change in behavior is probably associated with an increase in personal control, since those who follow the signals do so because they have discovered personal value in the system related to comfort.

Conclusion and Recommendations

This study provides a closer look at both the range of circumstances to anticipate when designing with operable windows as well as how successful an information system is in moving occupant behavior towards design team expectations.

Ultimately, signaling controls are used to balance competing objectives of energy and comfort, and building designers resolve tradeoffs differently. None of the designers we interviewed ever assumed that everyone in the building would follow the signals perfectly. By necessity, each building is designed so that window use transgressions don't pose any serious performance risks. As one building manager put it, "if you're serious about natural ventilation, you can't leave it up to the occupants." So why propose a signaling system at all, and how is money and time best invested? To harvest the potential of a signaling system, we highlight the following recommendations:

A. Simplify and test the control algorithms. Ideally, the "open" signal should have a very clear meaning associated with outdoor temperature and other meaningful conditions. Once the building is occupied, adjusting the setpoints and surveying occupants for their response would maximize effectiveness. Signal modes should be routine and not too frequent.

B. Make signals secondary to a stated policy. Because of the design process, signaling systems are often understood as a part of the building's controls, rather than an as an informational device reinforcing important concepts about maintaining comfort. Without a policy to support, the signals lack meaning. For example, in a large office building at Stanford University, the client opted not to install red/green lights. Instead, they spread the word to faculty not to open windows if the temperature is above 80 F outside, as this actually increases the load on the building.

Depending on the building and climate, the policy that is most important for changing control behavior may have nothing to do with outdoor weather patterns. For instance, in a faculty office building, where occupants have irregular schedules, making sure windows are closed when people leave their office can be more important than whether they open their windows between 65 and 78 °F (18.5 - 23°C).

Whatever the policy, it should be established during new hire orientations, or through periodic contact/reminders from the building manager.

C. Link the system to tangible benefits. The underlying message should also be communicated in terms of what occupants need to know so that *their* needs are met, rather than the building's needs. It has been found that generic values like "saving energy" or "being green" seldom motivate behavior change. (Abrahamse 2005; Gardener and Stern 1996; McKenzie-Mohr and Smith 1999; Stern 2002; Campbell et al. 2000; Staats et al. 2004). Based on input from our occupant interviews, personal benefits that could be highlighted when explaining the purpose of the signals include:

- a better understanding of how windows provide comfort (e.g. "if it's warmer than 80 °F (26.5°C), opening the window may actually make things worse.")
- the ability to *avoid* discomfort ("if you let the cool air in now, it will prevent overheating later"),
- the opportunity to take a mental break from work by opening the window
- an enhanced knowledge of the outdoor environment.

D. Make signals visible from individual workstations. Assuming people have found value in the system, direct visual access to the signal is important for taking action. Given that most people are occupied with their work, it seems reasonable that the signals should be understood as "reminders" of something they already buy into.

References

Abrahamse, W., L. Steg, C. Vlek, and T. Rothengatter. 2005. "A review of intervention studies aimed at household energy conservation." *Journal of Environmental Psychology*, 25, 273-291.

Ackerly, K.,and G. Brager, 2011. "Occupant Response to Window Control Signaling Systems," CBE Summary Report, April.). http://www.cbe.berkeley.edu/research/publications.htm

Baker, N.V. and M.A. Standeven. 1995. "A behavioural approach to thermal comfort assessment in naturally ventilated buildings." *In* Proceedings CIBSE National Conference, Eastbourne, Chartered Institution of Building Services Engineers, London.

Bordass, W. and Leaman, A. 1993. "User and Occupant Control in Buildings." *Proceedings of the International Conference on Building Design, Technology and Occupant Well-Being in Temperate Climates*, Brussels Feb 17-19, Atlanta, GA : ASHRAE. 1993, pps. 12-15.

Brager, Gail and L. Baker. 2009. "Occupant satisfaction in mixed-mode buildings."*Building Research & Information* 37(4): 369 – 380.

Brown, Z., H. Dowlatabadi and R. Cole. 2009. "Feedback and adaptive behaviour in green buidlings." *Intelligent Buildings International*.

Campbell, M, D. Buckeridge, J. Dwyer, S. Fong, V. Mann, O. Sanchez-Sweatman, A. Stevens, and L. Fung. 2000. "A systematic review of the effectiveness of environmental awareness intervention." *Canadian Journal of Public Health* 91:137-143.

Daly, A. 2002. "Operable windows and HVAC systems." *HPAC Engineering*, 12, 22–30.

de Dear, R.J. and Brager, G.S. 1998. "Towards an adaptive model of thermal comfort and preference", *ASHRAE Transactions*, vol 104 (1).

Emmerich, S.J. 2006. "Simulated performance of natural and hybrid ventilation systems in an office building." *HVAC&R Research*, 12(4): 975–1004.

Gardner, G. T., and Stern, P. C. 1996. *Environmental Problems and Human Behavior*. Needham Heights, MA: Allyn& Bacon.

Haldi F, Robinson D. 2008. "On the behaviour and adaptation of office occupants." *Building and Environment* 43: 2163–77.

Hellwig, R., F. Antretter, A. Holm, & K. Sedlbauer. (2008). The use of windows as controls for indoor environmental conditions in schools. *Proceedings of the Air Conditioning and the Low Carbon Cooling Challenge*, Cumberland Lodge, Windsor, UK; July 27-29 2008.

Herkel, S., U. Knapp, and J. Pfafferott. 2008. "Towards a model of user behaviour regarding the manual control of windows in office buildings." *Building and Environment* 43: 588-600.

Huizenga, C., S. Abbaszadeh, L. Zagreus and E. Arens, 2006. Air Quality and Thermal Comfort in Office Buildings. Results of a Large Indoor Environmental Quality Survey. *Proceedings, Healthy Buildings 2006*, Vol. III, 393-397, Lisbon, Portugal, June.

Humphreys, M.A., J.F. Nicol, P. Tuohy. 2008. "Modeling window-opening and the use of other building controls" *AIVC Conference*, Tokyo, Japan.

Inkarojrit, V. and Paliaga, G. 2004. "Indoor climatic influences on the operation of windows in a naturally ventilated building." In *Proceedings of the 21st international conference on passive and low energy architecture*, 19–22 September. Netherlands.

Leaman, A. and B. Bordass. 2007. "Are users more tolerant of ‘green’ buildings?" *Building Research & Information* 35(6): 662-673.

Leaman, Adrian; Bordass, Bill; and Cassels, Sam. 1998. “Flexibility and Adaptability in Buildings: the ‘killer’ variables.” London: Building Use Studies.

McKenzie-Mohr, D., and W. Smith. 1999. *Fostering Sustainable Behavior: An Introduction to Community-Based Social Marketing*. Gabriola Island, British Columbia, Canada: New Society Press.

Ogden, R.G., Kendrick, C.C. and Walliman, N.S.R. 2004. “Modelling of enhanced passive and conventional cooling systems.” *Building Research & Information,* 32(1): 17–26.

Paciuk, M.(1990), “The Role of Personal Control of the Environment in Thermal Comfort and Satisfaction at the Workplace”. *Coming of Age,* Environmental Design Research Association 21: 303-312.

Rijal, I.A., M.A. Humphreys, and J.F. Nicol. 2008. “Development of Adaptive Algorithms for the Operation of Windows, Fans and Doors to Predict Thermal Comfort and Energy Use in Pakistani Buildings.” ASHRAE (SL-08-056)

Rowe, D. 2003. “A study of a mixed mode environment in 25 cellular offices at the University of Sydney.” *International Journal of Ventilation,* 1, 53–64.

Seppänen, O. and W. Fisk. 2001. “Association of ventilation system type with sick building symptoms in office workers”, *Indoor Air,* 2001, pp. 98-112.

Staats, H., P. Harland, and H.A.M. Wilke. 2004. “Effecting durable change: A team approach to improve environmental behavior in the household.” *Environment and Behavior* 36: 341-367.

Stern, P.C. 2002. “Changing behavior in households and communities: What have we learned?” *National Research Council, New Tools for Environmental Protection: Education, Information, and Voluntary Measures*. Committee on the Human Dimensions of Global Change, T. Dietz and P.C. Stern, eds. Washington: National Academy Press.

Warren, P.R. and L.M Parkins. 1984. “Window-Opening Behavior in Office Buildings.” *ASHRAE Transactions.* 90 (1B): 1056-1076.

Yun, G.Y., Koen, S. and Baker, N. 2008. “Natural ventilation in practice: Linking facade design, thermal performance, occupant perception and control.” *Building Research and Information* 36(6): 608–624.