Human Behavior Meets Building Intelligence: How Occupants Respond to "Open Window" Signals

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ABSTRACT

Designs for low-energy buildings increasingly incorporate operable windows for the benefits of personal control, environmental quality, and architectural value. In practice, however, there are unresolved debates about whether operable windows can be integrated with mechanical systems to optimize both comfort and energy efficiency. Signals that inform occupants about when to open and close their windows (usually red/green lights) have become a popular solution. These systems essentially propose a compromise between manual and automatic control philosophies, asserting that information from the building can influence behavior while retaining the fundamental benefit of personal control. Results from interviews, site visits and surveys of 16 U.S. case studies show mixed results. Signals play a role in window use behavior for only a minority of occupants under normative management/education practices. However, greater participation is possible given efforts to communicate the tangible benefits of the devices. Office type (shared or private), visibility of the signals from workstations, reliability of the signal modes, and a range of personal circumstances (noise, wind, window hardware) also influence participation. If conceived as reinforcement to an internal policy rather than as an element of the building controls, this technology holds promise for a wide range of building and user types, and the programming can be flexible and adaptable as circumstances change in our rapidly changing built environment.

Introduction

Designs for low-energy office buildings increasingly incorporate operable windows for the benefits of personal control, environmental quality, and architectural value. There is a great deal of literature establishing a strong, if still theoretical basis for the idea that manually-operated windows enhance occupant comfort. Operable windows may offer improved indoor air quality (Seppanen and Fisk, 2001) and thermal perceptions (Baker and Standeven 1995; Brager and Baker, 2008; Brager and de Dear 1998; Hellwig et al 2006; Huizenga et al 2006; Paciuk, 1990), resulting from some extent to the greater sense of personal control and connection to the outdoor environment.

But integrating operable windows with mechanical systems to achieve their full benefits is an unresolved energy challenge. "Mixed-mode" design refers to the combined use of operable windows and a mechanical cooling system to optimize these benefits. Traditionally, mixed-mode buildings are classified as either "concurrent," in which operable windows and active cooling can occur in the same place at the same time; "changeover," in which the two modes occur in the same place but at different times; or "zoned," in which some select areas of the building are isolated and naturally-ventilated (Bordass 1994). In practice however, there is a wide range of technologies and control strategies that are used to integrate operable windows with mechanical systems (Brager, Borgeson and Lee, 2008). Achieving the energy-efficiency benefits of operable windows becomes a function of how well the HVAC system is designed to integrate with window use, and designers have limited tools for reliably accounting for the benefits of windows in the energy balance of the building. Some designers prefer using fully automated windows or vents because they are more reliable and predictable; but they can also raise costs and remove the amenity of local, manual control. In order to retain occupant control of windows, another control strategy is to install sensors and controls that shut off the HVAC system when a window is opened. However, this strategy works best in buildings where each occupied space is individually controlled, usually a prohibitive cost in office buildings. This approach also relies on the occupants using windows in an ideal way.

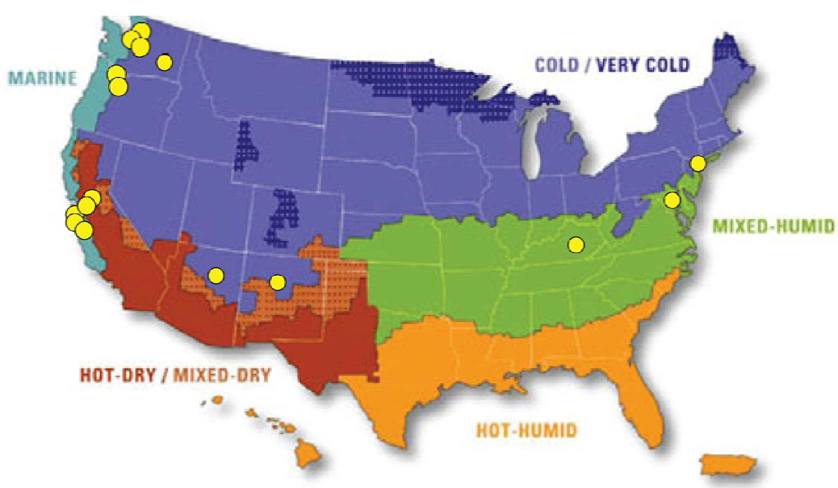
Signaling systems that inform occupants about when to open and close their windows (such as red/green lights or lighted signs) have become a popular, low-cost solution that addresses the shortcomings of other control strategies in balancing the benefits of manual and automatic control, in hopes of optimizing both comfort and energy performance. However, little research has been done to characterize how these systems operate in practice, and particularly whether they influence how occupants use their windows and perceive their environment. This project takes a broad look at window signaling systems in existing buildings in the U.S. We investigated 16 projects across the country to better understand a) why and how "open windows" signals are implemented; and b) the extent to which the signals play a role in behavior.

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 combined interview and survey data with site observations, covering a broad set of buildings and a wide range of variables. 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. We did our best to sample buildings from a range of geographic locations beyond California, as local weather patterns and culture are likely to influence occupant attitudes about windows and their behavior.

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. 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 arise between the system and their own preferences. In mixed-use buildings, only the full time office employees were surveyed.

Interviews. For all buildings identified, 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. Where possible, we conducted a few, brief informal interviews with occupants to supplement the survey data. We were able to speak with 22 occupants, about evenly divided among six of the buildings (where we had permission), 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.

Comparison of Signal Applications

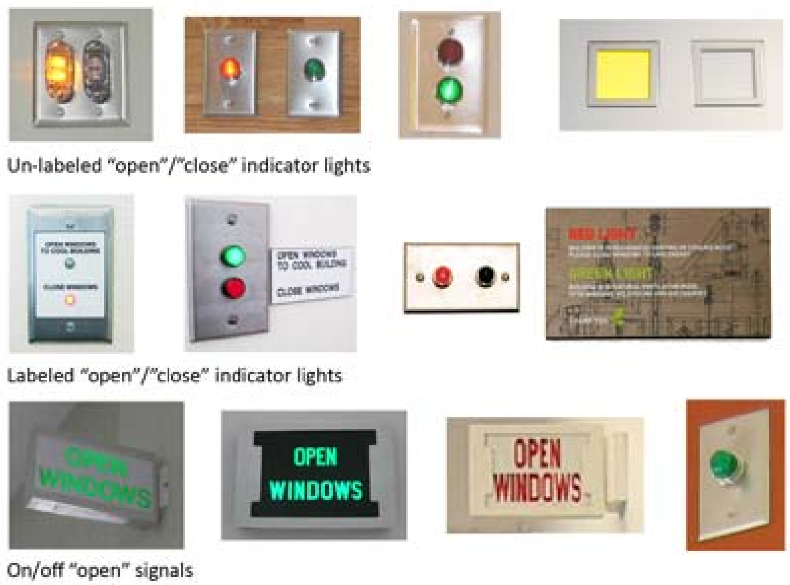
Reasons for choosing signaling controls. A comparison of the applications reveals differences in how the design team understood the benefits and liabilities of operable windows. From our interviews we found three primary reasons a signaling device was chosen:

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.

Signal design and placement. The range of approaches is shown in figure 3. Interviews revealed that in most cases there was little discussion about the design of the signaling device, either determined by "off-the-cuff" judgment, cost, or previous experience. Eight of the 16 projects used un-labeled red/green or amber/green indicator lights. For the vast majority of interviewees, the signals were intended as “guidance,” as opposed to an imperative.

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

Figure 3. 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.

Defining “open window” mode. Whether the decision to use operable windows was driven more by occupant comfort and satisfaction, or by energy reduction, translated loosely into how the “open” and “close” signals were defined in the building’s sequence of operations. In brief, in virtually all projects, the algorithm for “open” mode was written based on an outdoor temperature range, as a proxy for when natural ventilation is usable. But there were differences in whether or not air supply was interrupted during “open” mode, the use of an indoor temperature setpoint, and the role of additional environmental criteria such as humidity, wind speed and CO_2. A description of the control algorithms for the buildings is beyond the scope of this paper, but a detailed explanation and comparison is available in Ackerly and Brager (2011).

Results: Occupant Response

Acting on "open." Figure 4 shows the frequency with which occupants reportedly responded to the signals, ordered according to the mean response (4 – always; 1 – never). In seven of the ten buildings, a consistent minority – 10-20% – reported actively opening their window when they noticed the "open" signal was on. (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. These include two architects' offices located in the Pacific Northwest, and a university building in Kentucky. They share the characteristic of having some mechanism for ongoing reinforcement, in other words, they occupied the highest "tier" of educational approaches for some reason (see above). For the smaller of the two architects offices, the mechanism for greater awareness and buy-in was simply that the occupants were unusually familiar with the intent of the system since they were involved with the design; in the other two buildings, managers made an ongoing effort to share the importance of the signals.

Figure 4. Occupant response to the "open" signal

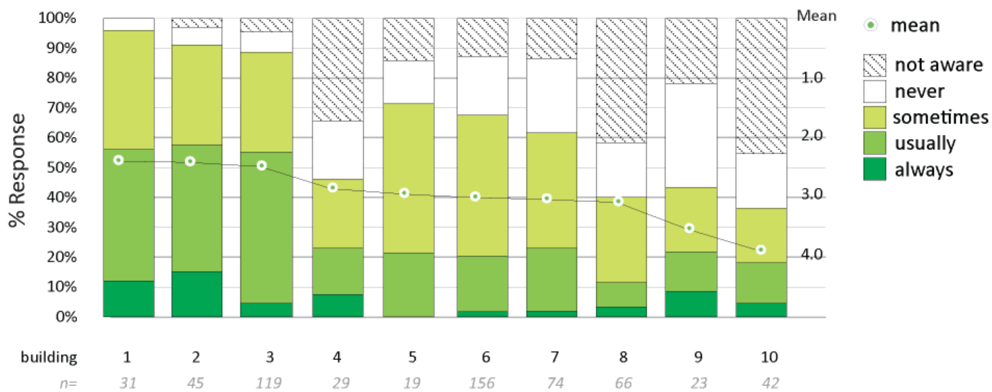
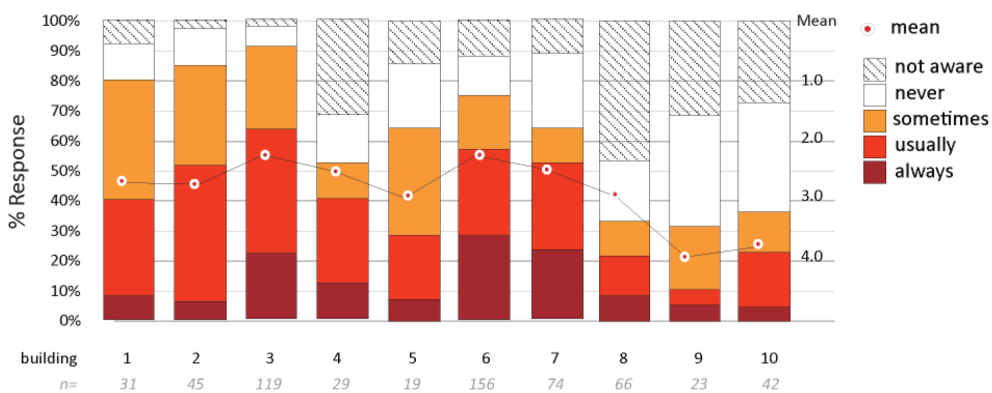


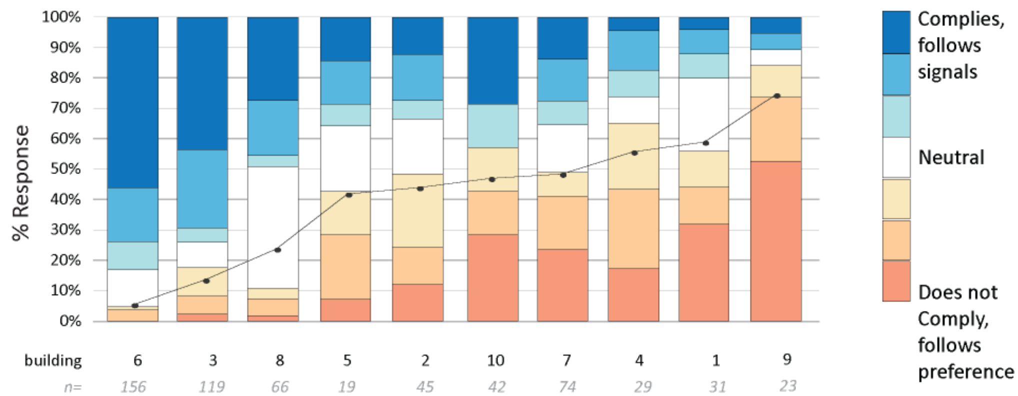
Figure 5. Occupant response to the "close" signal



Acting on "close." Overall, the mean responses for acting on the "close" signal are higher and more variable, as shown in Figure 5. 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: #1,2,9). Those for which the importance of closing windows was particularly emphasized to occupants does show relatively higher response rates (#6,7).

Willingness to *open* on "close." 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 6, responses in the buildings represent a full spectrum of tendencies, from over 70% reporting being compliant in one building (far left), to less than 10% in another (far right). With the exception of these few extreme cases, generally 40-60% of occupants in any given building report adjusting windows as they see fit. Note that the buildings have been re-ordered from the previous two figures (the building ID numbers have stayed the same).

Figure 6. Willingness to open on the "close" signal



Office type and personal control. The above 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 are less likely to actively respond to the signals, even though they generally have better access to both windows and an indicator installed within view. Open office inhabitants are also much more likely to obey the signal than those in private offices.

There are a number of possible explanations. During "close" mode, people may be more likely to be discouraged from "breaking the rules" in front of their coworkers. However, in "open mode," it does not appear that this kind of social reinforcement necessarily occurs. During interviews with occupants, a few people commented that the signals acted as a "neutral third party," giving *permission* to window-users who would otherwise be concerned about disturbing their coworkers. In a sense, signaling systems may be more successful in open offices not because they prompt a kind of "army mentality," (in the words of one building manager); but because they validate and leverage the behavior of those who naturally like to have their windows open. In fact, on the question of whether the signals enhanced or interfered with occupants' sense of personal control, most people selected "neutral," (perhaps because they were ambivalent or because they didn't understand the question.) 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.

This difference in disposition does not mean that people in open offices use their windows more often; in fact, if anything, people in open offices still reported using windows less frequently than in private offices. 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. Therefore, there still may be a trade-off between how much people use windows and the degree of oversight that is possible.

Factors Contributing to Participation

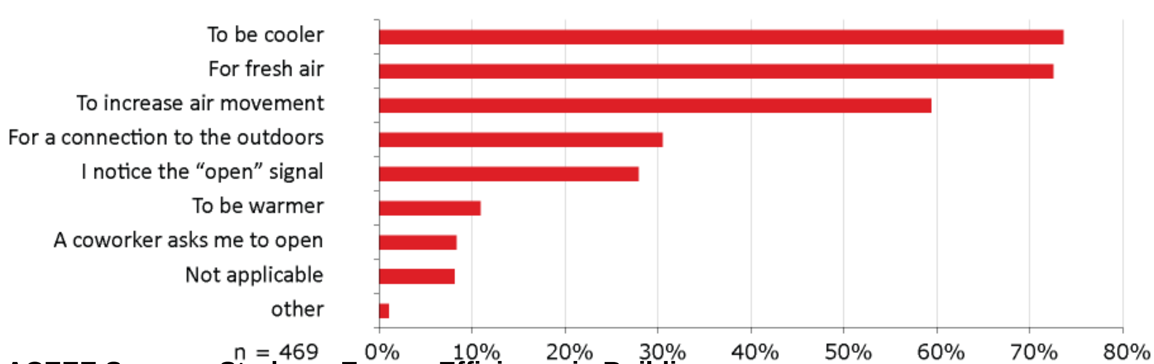
The wide distribution in the mean responses reported building-to-building (e.g. Figure 6) does not indicate failure, but points to the importance of finding out why individuals observe or disregard the signals, and then determining which of these factors are in the control of the design team or building management. We identified the following key factors affecting individuals' participation:

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 8, physiological comfort factors (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 latter average varies widely across buildings. This was true, as far as we could observe, in all buildings regardless of seasonal and daily weather patterns.

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, 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 8. Reasons for opening windows



How often the "close" signal is on. 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. 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.

The desire for fresh air. In the survey, the fact that the desire for fresh air rivals the desire for temperature adjustment when using windows is important since temperature is the primary factor used in window opening behavior models and in programming the signals. Temperature is a far simpler environmental parameter to measure and use as a proxy for comfort conditions. However, it wasn't surprising that 10% of reported conflicts 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. Research has shown that a perception of "stuffiness" is conflated with perceptions of air movement, humidity and temperature (Arens et al 2008; Fang et al 2000).

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 the minimum number of devices they felt were feasible, or led them to reason that visibility in corridors was sufficient. It should be further noted that what is considered "visible" can be highly contextual; for example, PC task bar icons, selected in one building for being extremely low-cost and highly accessible, easily blended into other desktop icons and got overlooked.

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

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. Although we can't quantifiably trust reported behavior, the variation of response patterns building to building and occupants' stated reasons however, occupants' stated reasons for using windows suggests that personal 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 observations also suggest that, given the right circumstances, it is possible to get occupants who normally wouldn't think about their windows *to start doing so*. This is done by a combination of making the system both more meaningful up-front, and more accessible by minimizing conflicts with occupant expectations. 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.

Although a detailed discussion of the control algorithms used to manage the open/closed signals in these buildings is beyond the scope of this paper, we can say that most conflicts between the signal message and occupant behavior were by and large malfunctions, misuses and over-rides. Consequently, it appears that most of these conflicts are probably best managed not through technology or operational changes, but instead simply by making the signals more visible from workstations and communicating their purpose clearly in a way that allows occupants to manage their unique circumstances. This includes the desire for fresh air or air movement, which is as important to occupants as temperature adjustment when operating windows, according to our survey. Seasonal and daily weather patterns are also

Conclusion and Recommendations

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

Quantifying the energy-efficiency benefits of signals as an emerging behavior-based technology was not the ultimate aim of this paper, mainly because the applications/intents were found to be so varied and too many easily-addressed operational issues interfered with achieving the highest possible potential in several individual cases. In fact, this study made it clear that signals are not a "widget" at all; rather buildings with signals fall on a spectrum of operational approaches and expectations for which it is difficult to establish a baseline for performance. 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? If signals are really about better aligning manual-automatic control dynamics with design team expectations, we highlight the following recommendations to maximize their energy-efficiency potential:

A. **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.

   The control sequence for the windows should be sensitive to the the kind of daily and seasonal opening and closing schedules that will result. While our results did not uncover any inherent regional difference in occupant disposition, it was clear that the signals can confront different expectations depending on location. For instance, for buildings in extreme climates, the green light may only come on for part of the day in the spring and fall and is red for much of the rest of the year. If occupants see "close" mode as the norm, they may come to regard the windows as inoperable; or, the green light becomes cause for celebration that spring has arrived. Likewise, in areas with pronounced swing seasons, where temperature variability throughout the day is unpredictable, we found examples of occupants ignoring the system if called on to make more than one or two adjustments over the course of a day.

   On the other hand, depending on the program of the building and how mild the climate is, the policy that is most important for aligning control behavior with automated system control may have nothing to do with weather patterns. For instance, in a faculty office building in Seattle, where occupants have irregular schedules, making sure windows are closed when people leave their office was of much greater concern to the building operator than whether they open their windows within a certain outdoor temperature range.

B. **Link the system to tangible benefits.** The underlying meaning assigned to the signals should also be communicated in terms of what occupants need to know so that *their* needs are met, rather than the building's needs. Assuming the building is well designed, these would coincide. It has been found that generic values like "saving energy" or "being green" seldom motivate behavior change. (Abrahamse 2005; Campbell et al. 2000; Gardener and McKenzie-Mohr and Smith 1999; Staats et al. 2004; Stern 1996; Stern 2002). 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, 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.

C. 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.

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