Title

Data Collection Methods for Assessing Adaptive Comfort in Mixed-Mode Buildings and Personal Comfort Systems

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Publication Date
2012-10-15

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Summary Report October 2012

Data Collection Methods for Assessing Adaptive Comfort in Mixed-Mode Buildings and Personal Comfort Systems

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October 2012

ABSTRACT

The Adaptive Comfort Standard in ASRHAE Standard 55 currently is applicable only to naturally ventilated buildings, and no guidance is given on its relevance to buildings that are mixed-mode (combining operable windows with mechanical cooling), or have other forms of personal comfort systems, such as workstation heaters, fans, or ventilators. For these types of buildings or systems, the extent to which people will find the conventional PMV-based or adaptive-based comfort zones acceptable has a lot to do with how the building is designed and how it is operated throughout the year. And this is simply not yet known. There is a need for more field studies in these types of buildings to assess the specific design and operating characteristics that might influence adaptive comfort. But to date there are no standardized methods for conducting such studies. The objective of this project was to identify a set of data collection protocols that would eventually allow us to investigate and potentially expand the adaptive comfort standards to account for mixed-mode and personal comfort system design strategies. To arrive at a proposal, we polled professionals for their own views on what data is needed, and also reviewed the literature comparing field methods used over the past decade that have expanded upon traditional thermal comfort field studies. We used two frameworks to organize the data. One was a “methods matrix”, describing the ways in which data can be collected, organized by background vs. real-time information, and objective building characteristics and environmental measurements vs. different kinds of surveys. The second framework was a list of six high-level topics that represent unresolved issues that should be addressed by future data collection. These issues include the need for improved methods to describe the building, document available controls, account for perceived control and thermal expectations, account for utilized control, determine the influence of outdoor conditions, and (re)define “comfortable”. This second framework is used for a lengthy discussing of the literature to to understand how far research has come in addressing these issues. This is later mapped onto the methods matrix in our proposal for new field study protocols.

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1. INTRODUCTION

ASHRAE Standard 55 (2010a) includes an Adaptive Comfort Standard (ACS) that specifies an extended range of acceptable indoor temperatures for naturally ventilated buildings. Mixed-mode (MM) refers to building strategies that include operable windows as well as any type of mechanical cooling strategy. Unfortunately, the current version of the standard does not offer much guidance on comfort in MM buildings, and there is also evidence to suggest that adaptation can occur in buildings without operable windows, where other forms of personal comfort systems (PCS) are provided, such as workstation heaters, fans, or ventilators. For MM and PCS, whether or not people will find the conventional PMV-based or adaptive-based comfort zones acceptable has a lot to do with how the building is designed and how it is operated throughout the year. And this is simply not yet known. There is a need to repeat the field studies that formed the basis of adaptive comfort models in a wide variety of building types and climates, using new methods designed to assess the specific design and operating characteristics of these building that might influence adaptive comfort.

2. OBJECTIVE

The objective of this project was to identify a set of data that, once collected from a large subject population, may expand the adaptive comfort standards to account for MM and PCS design strategies. To arrive at a proposal, we polled professionals for their own views on what data is needed, and also reviewed the literature comparing field methods used over the past decade that have expanded upon traditional thermal comfort field studies.

3. APPROACH

Our approach for developing a protocol was twofold:

1) develop a list of high-level, unresolved questions about thermal adaptation and the building control environment that would ideally be addressed in an expanded adaptive comfort standard;
2) determine which specific data items and collection methods would be best for assessing each.

We used two primary methods to generate our list of data needs: 1) outreach to professionals, and 2) literature search. For outreach, a kick-off meeting at the ASHRAE summer 2011 meeting in Montreal set the groundwork for a continuing dialogue about how to expand the adaptive comfort standard. The meeting featured a broad discussion about unpacking the factors of adaptation, which led to a short list of priority information future field studies should include. We then opened up this discussion via a survey to prominent researchers, consultants and designers, asking them to reflect on a) how the current adaptive comfort standard is used in practice, b) where standards should go in the future, and c) what data is needed to get us there.

The purpose of the literature search was to use recent findings about thermal adaptation to help us prioritize data needs, and to document different ways of gathering certain data (such as assessing a subject's "perception of personal control.") We found value in six types of literature:

A. EXISTING PROTOCOLS and STANDARDS
These documents establish context for approaching more recent field study methods.

B. CRITIQUES OF CURRENT STANDARDS
There are a few published papers that contribute a discussion about how comfort standards compare and ought to evolve.

C. CLASSIC ADAPTIVE COMFORT FIELD STUDIES IN DIFFERENT CLIMATES
Studies that aim to validate or modify adaptive models based on a new dataset in a specific region. Usually the methods they used are fairly conventional, but regional/climatic/cultural issues are often illuminated.

D. ADVANCED THERMAL ADAPTATION FIELD STUDIES
Studies that use traditional ASHRAE comfort metrics with additional data collection methods, usually to characterize the relationship between utilized control and comfort or to model behavior patterns.

E. RESIDENTIAL COMFORT FIELD STUDIES
This is a different building context, but there are some interesting methods to learn from.

F. POST-OCCUPANCY STUDIES OF CONTROL AND COMFORT SATISFACTION
Although not usually designed to collect real-time comfort data, these studies provide questions for general surveys.

In order to move from high-level issues down to a tangible protocol, we found it useful to use the thermal comfort section of the ASHRAE Performance Measurement Protocols (PMP) for Commercial Buildings (ASHRAE, 2010b) as a "baseline" framework. The PMP is a standardized, consistent set of protocols developed based on best practice that facilitates credible assessment and comparison of high performance buildings. As such it provides a place to start for distinguishing basic, recommended and advanced data that describe the thermal environment.

The PMP describes four data categories supporting a thermal comfort analysis (see Table 1). At the core of the traditional thermal comfort study is a correlation of real-time subjective comfort responses collected in a “right now” survey taken at discreet time intervals, to environmental measurements collected at the time of the survey or continuously from local multi-function monitoring stations. The core set of data, common to all thermal comfort studies, is listed in the first row of Table 1; it includes the six factors of thermal comfort along with an indication of thermal comfort, typically measured on a 7-point ASHRAE scale, and usually some basic demographic information.

It has also become increasingly common for thermal comfort studies to include a general survey administered one time or periodically, typically to a larger, transverse subject set. Similarly, some basic information about the building is usually collected. This "contextual" information is helpful in the development of a database, to parse and filter data, or to benchmark buildings according to particular results.

The PMP leads us to a "methods matrix" (Figure 1) that we use to organize our proposal. All four categories have seen a great deal of experimentation since the adaptive comfort standard was established, but the most diversity exists in the "background" data areas, as researchers seek to improve the description and resolution of situational factors, such as occupants’ access to controls, that may enhance or hinder adaptive opportunities. The task of this project is to learn from recent work and propose data collection methods that provide a more specific set of "recommended" data sufficient to describe and compare MM and PCS buildings.

Table 1. ASHRAE Performance Measurement Protocols (PMP) Chapter 6
Items included in "Intermediate level" thermal comfort analysis, unless noted. (ASHRAE 2010b)

	"Right now" survey	**Continuous local measurements**	**General occupant survey** (basic)	**Building characteristics documentation, Manager interview**
CORE	Clo (from garment checklist) Met (from activity checklist) Thermal sensation (ASHRAE) or Bedford scale comfort	Air temperature Globe temperature Humidity Air speed	Demographic information	
RECOMMENDED	Thermal sensation (ASHRAE) plus thermal preference Thermal acceptability (alt.) Bedford-scale comfort (alt.) Air movement preference Impact on job performance Sense of control (non-specific) Adaptive actions taken (non-specific) Body part sensitivities (advanced)	Solar radiation Recorded status of windows, shades/blinds (optional) Occupancy (optional) Vertical temperature stratification (advanced) Air speed distribution (advanced)	Office location, office type Office layout, space, privacy Office furnishings Thermal comfort satisfaction - source of discomfort - when discomfort occurs Air quality satisfaction Lighting quality satisfaction Acoustic satisfaction Cleanliness, maintenance General satisfaction	Year of construction Gross floor area Programmatic use (% areas) Start and end dates of data collection Hours of operation during test period: seasonal and weekly operating modes Percentage occupied Number of occupants or FTE Occupancy, lighting, and thermostat setpoint schedules Percentage conditioned floor area Site energy by fuel, peak demand, EUI and total energy cost

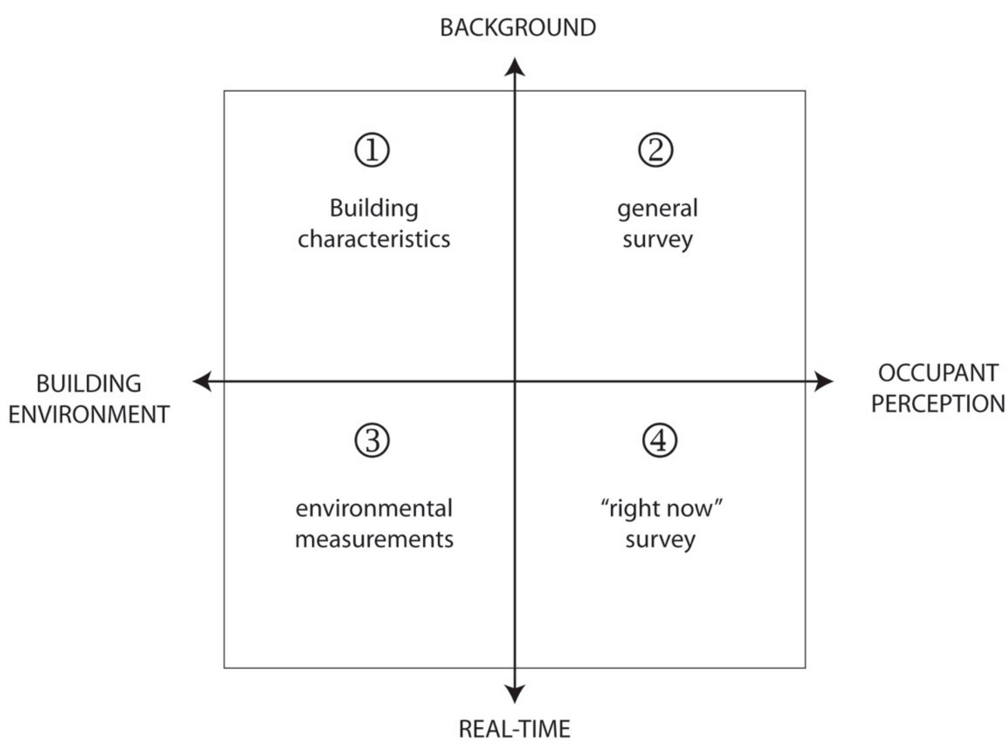

Figure 1. Methods Matrix

4. FINDINGS

4.1 Survey of professionals

Figure 2 shows the breakdown of people who responded to our Google survey.

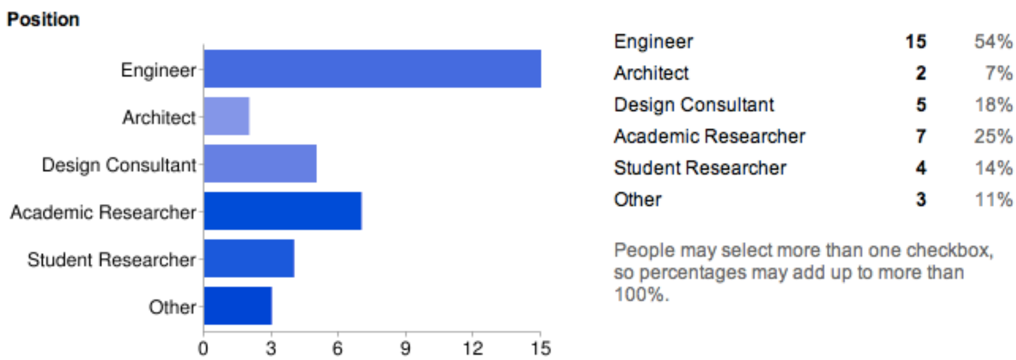

Figure 2. Survey results-occupations of responders

The first question asked all professionals (both researchers and practitioners) to select the ways they "most commonly see adaptive principles used" in real projects:

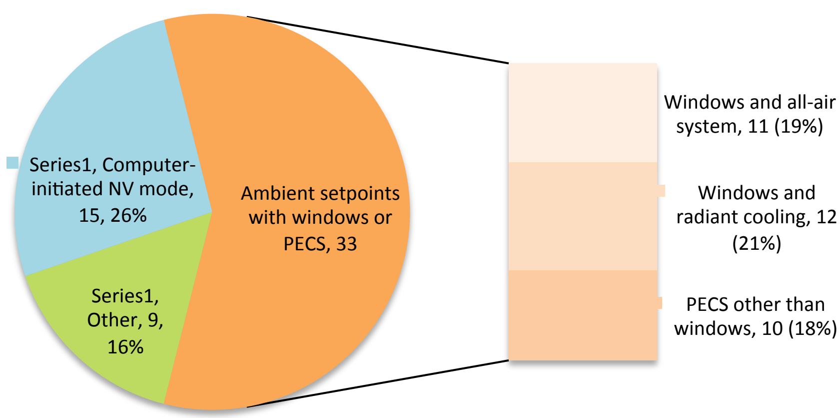

Figure 3. Survey results - uses of adaptive principles

Next, we asked them if the standards were to eventually address MM buildings or "task-ambient" approaches to thermal control, what guidance would be needed on applicability requirements, and what data would be needed to get us there. In general, both our survey and our workshop discussions revealed that professionals seek a more fluid, integrated assessment of thermal experiences and "control opportunity" that engages the whole building context; for example, this includes not just what controls are available, but how manual, passive and mechanical controls are balanced, and how this balance is managed and perceived by occupants. Below is a summary of the suggestions we received, organized in terms of our methods framework in Figure 1. This is just a first step in our development of a new protocol for collecting information about building and occupant characteristics that can then be used to analyze comfort responses in MM and PCS buildings. The comments are listed roughly in order of popularity within each category.

Data needs identified by professionals

① BACKGROUND / BUILDING ENVIRONMENT (Building characteristics)

- Document HVAC system types and associated environmental variability patterns: (temperature, humidity, air speed, radiant temperatures, and acoustics). These may include thermo-active building systems and thermal mass as a conditioning strategy.
- Identify the controls and setpoints determining mechanical and natural ventilation modes.
- Characterize the "innovation" level: how much do control setpoints or other aspects of system operation differ from normative practice for that building type, occupant type or region.
- Carefully document control opportunities *and* obstacles: direct, indirect, physical, and social-normative.
- Decide on standard climate description to track success rate by climate zone.

② BACKGROUND /OCCUPANT PERCEPTION (General survey)

- Assess expectations and acceptability of thermal variations
- Assess expectations of the level of building's automated control
- Assess level of knowledge of how heating/cooling/air is delivered
- Assess perceptions of degree of personal access to windows (private vs shared)
- Assess expectations of indoor conditions based on outdoor conditions
- Assess thermal disposition – *why* people report satisfaction at "too warm" or "too cool"

③ REAL-TIME / BUILDING ENVIRONMENT (Environmental measurements)

- Monitor actions that change the environment
- Include humidity limits in standard
- Record the environmental conditions at which people take action

④ REAL-TIME / OCCUPANT PERCEPTION ("Right now" survey)

- Assess frequency and reasons for using personal controls
- Improve ways we determine met and clo
- Use thermal acceptability questions in addition to thermal preference

4.2 Key issues for future data collection

A combination of the survey results and published critiques of existing adaptive comfort models led us to identify the following high-level, unresolved issues that should be addressed by future data collection. These topics will first be used as the framework for summarizing the results of our literature review. Later they will be mapped onto the methods matrix (Figure 1), which informs *how* we collect the data.

1. **Describe the building.** In order to provide guidance to designers through a standard or set of guidelines, one needs to better define the "type of building", in terms of the design and/or operating strategies that most affect adaptive opportunity and response.

2. **Document available controls**. One needs to determine better ways of characterizing the kinds of personal controls that are physically available, including social-normative opportunities and obstacles.

3. **Account for perceived control and thermal expectations.** It is well documented that occupant perceptions of their control, and their expectations of environment and service, play an important mediating role between the environmental conditions and comfort response. The literature shows a wide diversity of ways to address this, but they need to be developed into a set of standardized or prioritized methods.

4. **Account for utilized control (actions).** Researchers and practitioners alike call for better resolution data about the dynamics of control behavior and comfort, for example documenting why an action was taken, and what change was achieved.

5. **Determine influence of outdoor conditions**. The outdoor environment may have direct or indirect influence on thermal responses-either through operable windows that more directly connect the indoor and outdoor climates, or perhaps in influencing how people choose to dress on a particular day, which in turn influences how they respond to a given set of indoor conditions.

6. **(Re)define "comfortable."** Several researchers have questioned the way that comfort responses are collected. Building consensus about how to analyze thermal sensation, thermal preference and thermal acceptability would be useful in order to be specific about adaptive comfort.

4.3 Literature discussion

We searched available literature to understand how far research has come in addressing the above issues. Over the past decade, numerous thermal comfort studies have been conducted either to validate existing comfort models in new regions or to expand upon conventional thermal comfort field methods. We found studies in both commercial and residential settings to be useful in introducing new ways of gathering subject information. Other research has further explored the dynamics of personal control, knowledge and comfort. The key issues identified above will be used as a framework for discussing the literature.

4.3.1. Describe the building

The specific ways in which we classify MM and PCS buildings will both influence, and depend on, how a future standard might be structured to describe how the adaptive comfort zone is applicable to different building types, and how compliance paths are prescribed in design guidelines. These issues are currently unclear and are open for discussion.

Classification in current standards. Descriptions of mechanical systems are over-simplified in current thermal comfort field study datasets. The primary reason for this is simply that detailed descriptions of the buildings included in such datasets do not exist. de Dear and Brager (1998) based their adaptive comfort model on a set of naturally ventilated (NV) buildings in which occupants had access to operable windows and there was no mechanical cooling. Results were compared to a data set in what was termed "HVAC" buildings, which were sealed, centrally-controlled buildings where people had little or no control over their immediate thermal environment. Nicol and McCartney (2001) made a similar distinction between "free-running" and "heated/cooled" buildings in describing the SCATs database (The Smart Control and Thermal Comfort project, funded by the European Commission). Standards have interpreted these datasets differently in describing their limits of applicability. ASHRAE Std. 55 (ASHRAE 2010a) allows the adaptive approach only in buildings with operable windows, no installed mechanical cooling system, and when occupants are free to adapt their clothing to the indoor/outdoor thermal conditions. It is permissible to use mechanical ventilation with unconditioned air, but opening and closing of windows must be the primary means of regulating the thermal conditions in the space. In comparison, the main difference in the European comfort standards (EN 15251, 2007) is that it allows the adaptive model to apply in MM buildings but only during times when the mechanical cooling is not operating. This "temporal" interpretation (i.e. based on operating mode rather than the physical presence of equipment) has been supported by research (Deuble and de Dear 2012), but it introduces greater confusion for MM buildings about how operating set-points should switch between adaptive and traditional PMV/PPD-based comfort temperatures when system changeover occurs.

In 2004, the Dutch guideline for the interpretation of the international and European standard EN-ISO 7730 (ISO 2004) went a step further in interpreting existing datasets, allowing the indoor comfort temperature to vary according to outdoor temperature for *all* buildings, but defining two types, "Alpha" and "Beta," which have different slopes based on the results of de Dear and Brager (2002). A flow chart is used to sort buildings into these two types based on access to windows *or* local thermal controls, *and* flexible dress code (Figure 4) but regardless of HVAC system and distribution type.

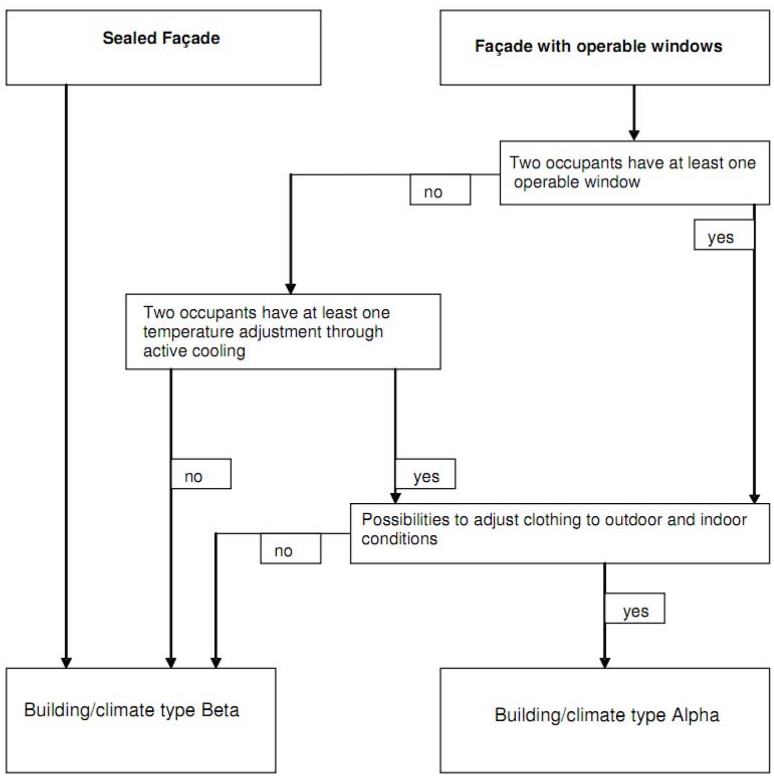

Figure 4. EN-ISO 7730 building/climate type determination (developed for the Netherlands) (van der Linden et al. 2006)

All existing standards provide 80% and 90% "acceptability limits" for adaptive comfort zones (Figure 5), allowing some degree of flexibility for designers to interpret how strict the comfort "deadband" requirements need to be in a given building. European standards EN 15251 and EN-

ISO 7730 include an added, 65% acceptability class, which is deemed acceptable for existing buildings, according to presumed comfort expectations.

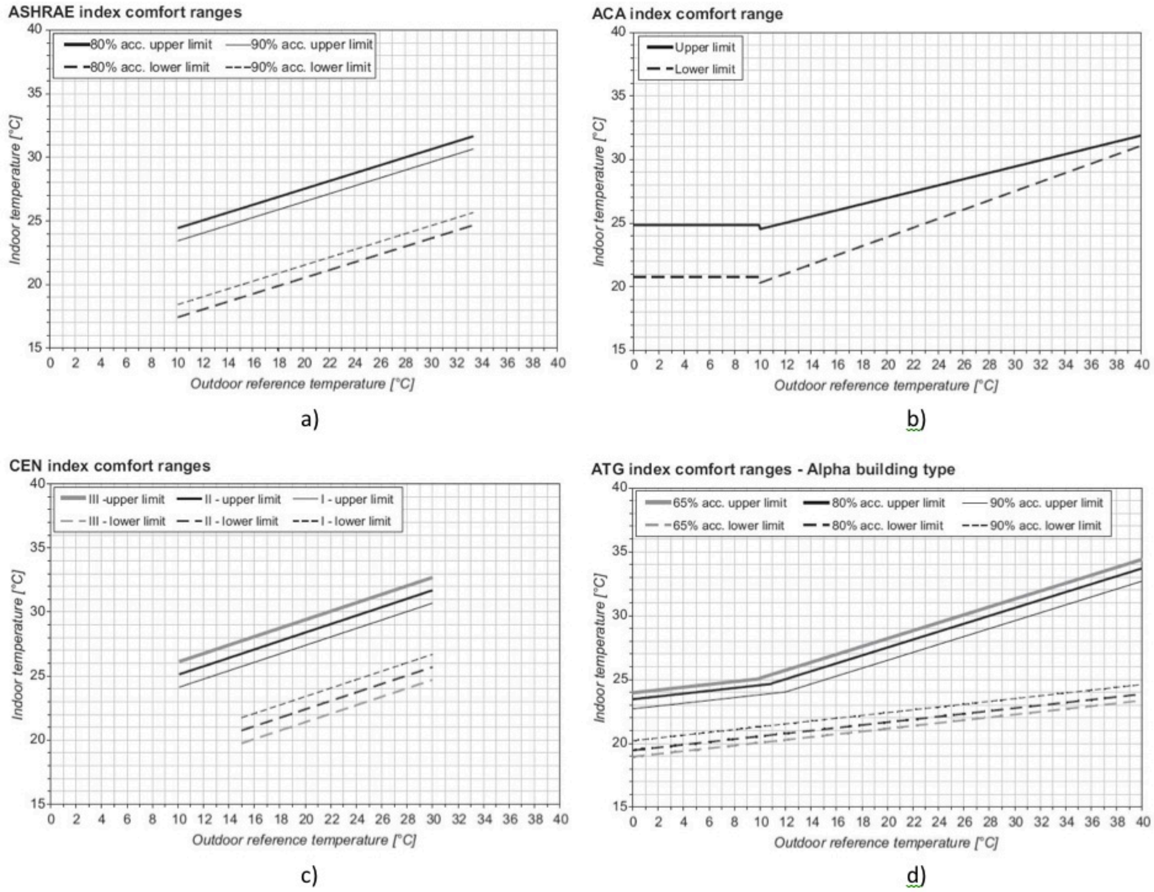

Figure 5 Acceptability limits according to a) ASHRAE index (2010); b) Adaptive comfort algorithm (Europe); c) CEN index (EN15251, 2007); and d) the ATG (Dutch) index (ISO 7730) (Ferrari and Zanotto, 2012)

The Dutch and German approaches of determining adaptive opportunity using a simple "decision tree" of building attributes (Figure 4) is an interesting model for including personal control in future comfort standards. An alternative approach is to add specificity to acceptability classes (categories I,II,III in EN 15251 and classes A,B,C in EN-ISO 7730) as proposed by Boerstra (2010). In his proposed framework, the existing classes A, B and C are re-cast in terms of general control scenarios and a corresponding "personal control bandwidth," which is the power of the control context to correct for temperature excursions. A proposed new "A+" category is added to describe sealed buildings with a workstation-level PCS system. Expanding existing classes by either approach would require support from a larger dataset that includes more detailed building attributes. In terms of a data collection protocol, this may be as straight-forward as documenting available controls (see next section). However, the balance of centralized and local control, particularly in MM buildings, can be complex, as discussed below.

Creating a building characteristics profile. A few studies have endeavored to find linkages between thermal perceptions, expectations and specific building design strategies in order to develop design-based metrics for predicting comfort (Wagner et al. 2007; Hellwig et al 2006). But due to the complexity of how different design strategies are combined in buildings, reliable indicators are difficult to find. However, these studies suggest that there are certain basic characteristics -- such as envelope mass, percentage of glazed wall area, the use of atria and exterior solar shading -- that may be worth documenting in addition to physical control opportunities and mechanical design characteristics.

There may be other physical aspects of an HVAC distribution system – namely, the type of distribution (radiant, forced air) and the placement of air inlet/outlets – that could influence occupant perception of control (Haigh 1981; Hellwig et al. 2006).

The effect of temperature dampening and use of thermo-active building systems (TABS) on comfort is also worth documenting. There is some evidence to suggest that if passive thermal control stabilizes indoor temperatures "too much," occupants will expect more consistent temperatures and be more sensitive to thermal excursions. A recent study compared two MM buildings with very similar adaptive opportunities, insulation, and heat gain risk but two different passive cooling concepts: mechanical night ventilation versus a TABS building with concrete-core conditioning and ground-water heat sink. The adaptive model predicted responses in the building with night ventilation, while the PMV was a better predictor for the one with a more stable, and un-noticeable TABS system (Pfafferott 2011).

One solution raised by a number of professionals in our discussions and survey, but not seen in the literature to our knowledge, is to develop a systematic way to describe a building's mechanical design based on the variability of environmental conditions that it achieves. For instance, one innovative idea was that temperature, humidity, air speed, radiant heat values and HVAC noise might be measured for a year and combined into an index. Unfortunately, this level of data collection is outside the scope of most thermal comfort studies, although some of this information might be attainable from the building management system (BMS), depending on how well-positioned sensors are. Furthermore, it may be difficult to untangle the effects from the use of local controls such as operable windows and fans, from many other factors that influence thermal response. But in recognition of the value of this level of data, we include continuous measurement of indoor variability as an optional method in our protocol.

Characterizing buildings by operating strategy. Simplified methods of classifying system types and their characteristic environmental impacts might be possible, but there are few precedents. Classification of MM buildings has only been described conceptually. The most accepted taxonomy differentiates three strategies: concurrent (where natural ventilation and cooling can occur in the same place at the same time); change-over (where they occur in the same place at different times); and zoned (occurring in different places) (Bordass et al. 1994). These classes have been a useful starting point for discussion of MM operating strategies, but they are insufficient to describe the elements of the system that may have an impact on occupants' comfort expectations. Examples of these elements include the type, familiarity and noticeability of cooling and air delivery systems, temperature dampening provided by the structure, the number of operational modes and when they're expected to occur, how cooling setpoints are chosen, and the degree to which occupants understand how to make themselves comfortable and are willing to play a role in managing their own environment. But all of these elements are complex, and therefore difficult to combine into a single taxonomy that would enable one to define alternate comfort predictions and compliance paths.

There is a continuum, rather than a prescribed set, of options for balancing manual and automatic environmental controls. These are often described in terms of the operable windows, but analogies can be made to other PCS systems as well. William Bordass of the Usable Buildings Trust suggested that MM buildings may be classified not in terms of specific technologies, but according to the level of conservatism with which natural ventilation is deployed in the design. He distinguished “traditional,” “integrated,” and “opportunistic” types, based on scenarios considered typical and representative but not prescriptive (Bordass 1996). While these categories are still not specific enough for the purposes we’re discussing here, it may be valuable to adopt a similar approach that captures how the design team understands natural ventilation in the context of the building's operating modes and the degree to which the mechanical design deviates from conventional practice. Based on this kind of thinking, researchers at the Center for the Built Environment have framed the following four operational approaches for MM buildings that move towards placing more emphasis on the extent to which passive operation/natural ventilation or mechanical ventilation and cooling act as the “default” state. Analogous schemes could be made for PCS buildings as well.

1. **Conventional.** Operate the building year-round to meet conventional setpoints (i.e., PMV-based comfort zone), no differently than if it were a sealed building. Operable windows are seen merely as an amenity, and at best function like an economizer cycle.

2. **Conventional / relaxed approach.** Again, start with the conventional, PMV-based comfort zone. Use a slightly relaxed deadband from the conventional setpoints while cooling equipment is operating. During times when the windows are open, expand the cooling setpoint by an additional small number of degrees in each direction. This is a compromise that allows for improved energy efficiency, while still allowing for relatively quick recovery when the equipment turns on.

3. **Adaptive / ramped approach.** While the spaces are conditioned solely by natural ventilation, interior spaces shall meet the ASHRAE Std 55 adaptive comfort criteria. If windows are then sealed and mechanical cooling is operating (changeover approach), the same criteria would continue to apply during a transition period. Once mechanical cooling has been operating for an extended period, conditions would ramp down to the top of the conventional PMV-based comfort zone.

4. **Adaptive / conserving approach.** In this approach, the adaptive comfort criteria are consistently maintained through alternative operation scenarios. Natural ventilation is used exclusively as long as conditions are maintained within the adaptive comfort limits, and mechanical cooling is used only as needed to ensure the building temperature does not rise above the adaptive comfort maximum temperature. This is likely our ultimate goal from a design perspective, and probably the most reasonable in concurrent mode, particularly if the active systems respond slowly and/or are unnoticeable (such as radiant systems). These designs may incorporate exceedance metrics to show the sensitivity of predicted comfort exceedance to whether conventional or adaptive comfort assumptions are used and what marginal benefits adaptive opportunities might offer. (Borgeson and Brager 2011)

In practice, approaches 1 and 4 are the most common. For future development of similar “profiles,” we propose in our protocol a series of questions that indicate how automatic and manual control are balanced (for both PCS and MM buildings). This includes rough determinations of building mass, unconventional system components or setpoints, and the visual or auditory presence of the mechanical system. For MM buildings, how natural ventilation is integrated into the building's operating modes and how occupants are made aware of a change-over, when explicit, is critical to include.

For any building with PCS, one would need to characterize the extent to which local controls are considered a supplement to the centralized controls; in other words, how much ambient conditions are allowed to float, thereby placing more responsibility on the PCS to maintain comfort.

4.3.2. Document available controls

Defining availability. The distinction between available, perceived, and utilized control was nicely articulated in the research by Paciuk (1990), and this distinction is very useful for our purpose here. But even starting with just available control, we find that descriptions can quickly become quite complex. Proposals to expand the acceptability of adaptive comfort criteria will require better documentation of available and exercised personal control opportunities. Some researchers assert that available control should be an explanatory variable, with comfort temperature varying based on some measure of availability (Haldi and Robinson 2010a). For example, one way of measuring availability may be the percentage of occupants with personal access to certain devices, normalized by floor area (Deuble 2012). However, personal controls defy easy classification, making "level of control" difficult to compare across buildings. The easiest distinction is between physical control devices and behavioral controls (control of dress, drinking beverages, frequency and freedom to move). For physical controls, some researchers have found use for a further distinction between "passive" controls (windows, doors, blinds) and "powered" controls (fans, heaters, thermostats) to separate components that are mechanized (or require energy) from those that aren't. Given that many fans are considered a hybrid or low-energy technology that assist with natural ventilation, even this divide can become problematic. Windows also require special attention since they can be considered either supplemental to, or integrated with, central conditioning strategies, depending on how they're integrated with the mechanical system.

Another distinction might be to separate "direct" controls, which can be understood as *supplemental* to centralized systems (windows, fans, blinds, foot-warmers), from "indirect" controls, which are controls that allow an occupant to intervene in the building operation (thermostats, floor air diffusers, radiant panel, perimeter fan coil unit). However, "direct" and "indirect" often carry connotations of *responsiveness,* which is an aspect of functionality, not availability. "Local" versus "ambient" may be preferable to "direct" and "indirect," as long as "local" is defined (does local refer to desktop, office bay or zone-level control?). Ideally, we could move towards a scheme that allows us to quantify how much of the variance between indoor and outdoor conditions is controlled automatically versus via occupant-operated devices, for a given building design. This would have to be assessed based on field data, which is of course affected by how much of the potential for occupant-driven control based on *availability* alone is actually *perceived* and *utilized*.

Another approach is to organize available controls by the environmental parameter itself, and the level of control or complexity available, for instance:

- Thermal control (window, passive conductive surface, powered heater, terminal unit, thermostat);
- Air speed control (window, desk fan, ceiling fan);
- Ventilation control (window, personal ventilator, operable floor air diffuser).

Further complicating the issue of availability, the relative comfort impacts of different devices vary substantially. Most studies about control and comfort focus on windows or fans (ceiling and desk fans). Local thermal controls (perimeter fan coil units, supplemental devices, thermostats) create adaptive opportunity according to the Dutch guideline; this is supported by a few studies (Barlow and Fiala 2007; Huizenga et al. 2006), but more field data is needed. To our knowledge, no one has tested whether having operable floor air diffusers in buildings with underfloor air distribution systems (UFAD) provides an adaptive comfort response in the occupants. Researchers at the Syracuse Center of Excellence have explored the thermal comfort and indoor air quality (IAQ) impacts of air delivered via terminal personal ventilation (PV) devices versus underfloor and overhead air diffusers (Ruizin et al. 2010). The studies find positive subject responses using a combination of PV and UFAD in terms of alleviating comfort issues; perceived control has not been explicitly studied. While we know that the means of air delivery does impact comfort, we also know that awareness, access and functional issues commonly interfere, particularly with floor air diffusers.

***Ways of assessing availability*.** Physical availability of controls can be documented in a site visit by the researcher, or collected via subjective responses from the occupants in a general survey. The advantages of assessing control availability subjectively through a general survey are to identify only the controls that occupants *know* are available to them, and then to find out about related characteristics. These might include which are most often used, specific obstacles, and perceptions about dress code and other social-normative restrictions as they are actually experienced (see discussion about "accounting for perceived control," below). However, there are a number of physical factors worth documenting.

First, to the extent that the number or type of controls (notably windows, ceiling fans, and some indirect HVAC controls) help to characterize the building, basic documentation is necessary. The building characteristics form currently supporting the CBE IEQ database includes operable windows as an item in a checklist of envelope characteristics, and then an option to select individual environmental controls: temperature, airflow velocity and airflow direction.

If controls are physically documented, it may be worth including some objective measures of the controls' accessibility and legibility as well. In *Controls for End-Users, a guide for good design and implementation*, Bordass (2007) calls for standard assessments of control design in terms of:

- Whether the range of available control is clear
- Whether user action is acknowledged by design (for indirect/HVAC controls)
- How long manual interventions last before being over-ridden

Secondly, there are certain non-physical indicators of control opportunity that may be useful to characterize a building, such as any official information regarding dress codes, operation instructions and security policies, and how they are communicated to occupants.

Finally, chronic control impediments such as outdoor noise, pollution, security policies, and window hardware may make sense to be documented physically by the researcher. In a study of adaptive behavior in apartments, Rajasekar and Ramachandraiah (2010) measured noise levels in 8 directions around the building to assess the building's "noise context." Other work has been done by Andersen et al. (2009). While this approach is valuable, it is more typical that impediments to control, such as noise, are assessed subjectively through the general survey (or sometimes a right-now survey that asks for reported actions).

4.3.3. Account for perceived control and expectations

Based on our discussions and literature search, psychological mechanisms of thermal adaptation have received a great deal of interest and experimentation in the field methods. Nikolopolou and Steemers (2003) outline several interrelated factors that have been identified in the literature, including perceived control, thermal experience, expectations, length of exposure to discomfort, environmental variability or stimulation, and "naturalness," which is the perception of an environment as being free from artificiality. Perceived control and expectations have become the primary focus of some researchers, as they has been successfully demonstrated to impact comfort satisfaction and possibly precede physiological or behavioral mechanisms (Brundrett 1977, Schweiker et al. 2012). This section also discusses the interrelated factors of knowledge and thermal experience in shaping perceptions and expectations.

Perceived control. Paciuk (1990) conducted a seminal study on the role of perceived control on thermal comfort. She found through a multiple regression analysis that “perceived degree of control” had the strongest effect on thermal satisfaction compared to available control (building components, HVAC components, and organizational norms); exercised control (environmental manipulations as well as personal adaptations); and thermal sensation (ASHRAE 7-point scale). She defined perceived control as a combination of knowledge about available controls and perceived effectiveness of environmental manipulations (as assessed via a one-time questionnaire). Exercised control showed negative effects, but the study did not differentiate actions that achieved desired results from those that did not.

A number of studies have since confirmed the finding that perception of control, and moreover the perceived effectiveness of control interventions, has a strong influence on thermal sensation and satisfaction (Baker and Standeven 1995, 1996; Bauman et al. 1998; Brager and de Dear, 1998; Brager et al. 2004; Hellwig et al, 2006; Wagner et al. 2007). Where studied, findings extend this phenomenon beyond thermal control and satisfaction to lighting and acoustics (Hellwig et al. 2006; Nikolopoulou and Steemers 2003).

Some studies emphasize the notion of perceived “access” or proximity as the determining factor of perceived control, as in Brager et al. (2004). In this study of a naturally-ventilated government building, the authors found clear differences between the reported neutral temperatures of subjects situated adjacent to, vs. one workstation removed from, the window. In an analysis of the Center for the Built Environment (CBE) survey database (215 buildings at that time, mostly in North America), Huizenga et al. (2006) found statistically significant differences in mean temperature satisfaction and percent satisfied votes for groups of occupants who reported being with and without access to a thermostat, operable window, portable heater or portable fan.

In a systematic study in controlled comfort chambers with operable windows, Schweiker et al. (2012), set out to develop an experimental design for determining the balance of psychological, physiological and behavioral adaptive processes in the field. The authors concluded that the “permission to use controls” (window or fan) by itself led to greater thermal satisfaction. When control behaviors were restricted, physiological adaptive responses kick in. The study used very simple metrics to assess each variable: whether behavior is "permitted or not permitted", whether the subject is or is not adapted to warm conditions, whether thermal conditions are "aligned with expectations" and whether perceived control is “sufficient” or “insufficient.” Results of using a similar method in a real building are not yet available.

Studies of the impacts of personal control extend to field studies in buildings without windows. In a controlled field intervention study, Bauman et al. (1998) compared 42 PCS workstations to a control group in the same building under three different setpoint conditions (normal, warmer, cooler) and found that thermal sensations among PCS workstations were neutral over a wider range of operative temperatures. Part of this perception was related to an impression of reliability and speed of response of the devices, even though most users (80%) adjusted their controls less than once a day.

Leaman and Bordass (2007), of the Usable Buildings Trust, discuss a “forgiveness factor,” which is a variable derived by dividing mean overall comfort scores for a building by the mean values for perceived environmental conditions over each season (temperature, air quality, lighting and noise). Values greater than 1 are taken to mean that occupants may be m ore tolerant or “forgiving” of those conditions. They found that occupants are more accepting of sub-optimal or more variable environmental conditions if: 1) the building includes features that occupants “intrinsically like” (such as views, more control, better management, good use of natural light); 2) the design intent is made clear to users, as it often is in “green” buildings; or 3) occupants’ feel their needs are met quickly and their work tasks are supported. These contextual variables are seldom evaluated in thermal comfort studies but are very common in building post-occupancy evaluation.

In a similar vein, Karjalainen and Koistinen (2007) interviewed 27 occupants in 13 Finnish buildings about the use of personal controls in the context of a private workspace, and inferred patterns in the behavior and satisfaction of occupants, given their overall satisfaction (which had an apparent relationship to gender), their use of controls, and perceived impediments. The researchers found that while 25 of the subjects had access to a thermostat or thermostatic valve, only 11 used them successfully. Approximately half of the subjects had access to an operable window, and this followed clothing as the most common action taken when feeling hot or cold. The most common impediments related to user interface and insufficient heating/cooling control range.

The CBE survey contains modules that can be added to the core set of questions in order to evaluate occupant interaction and satisfaction with specific features of a building, such as windows, blinds, and UFAD systems. Survey methods that ask occupants to report more specific impressions of a device’s ability to influence comfort have been successful in teasing out the impact of perceived control effectiveness. For example, in a study of Japanese residents, Shweiker and Shakuya (2009) found that occupants’ perception of whether their AC unit made conditions better, worse or neither had the same magnitude of influence on their behavior as external factors such as mean outdoor temperature (comfort was not analyzed). As an alternative approach, the Buildings in Use Studies (BUS) survey developed in 1981 in the UK (Bordass and Leaman 1993), includes scales to report the level of general effectiveness attributes of user controls – convenience, legibility and responsiveness – for different environmental conditions (heating, cooling, ventilation, lighting). The relative merits of assessing perceived control with respect to *devices* versus *environmental conditions* is an interesting methodological choice that to our knowledge has not been carefully examined.

Knowledge about controls. How occupants understand the controls available to them in the context of the building operations is believed by many to have a profound impact on perceived control and, by extension, comfort. In a study of 30 households in an apartment building, Chun et al. (2007) found that being given information about the building had a positive effect on residents’ knowledge, consciousness, and behavior, and consequently, led residents to control their indoor environment more actively in some cases. In a commercial context, Brown et al. (2009) used a modified BUS survey instrument to explore how feedback in two Canadian green buildings influenced the knowledge and behavior of occupants. They conclude that occupants draw from a range of sources to form opinions about how well they know their building and whether or not it is comfortable. Receiving positive feedback from adaptive actions is important for reinforcing accurate notions about how the building operates and their active engagement with controls. Correlation analysis was done to determine the strength and direction of relationships among variables including knowledge, comfort satisfaction, perception of control, utilized control, complaints, and perceptions about the building's "green-ness" and energy efficiency. Significant correlations between comfort, knowledge and perceived "green-ness" were found for individual buildings depending on the types of feedback provided in each building. Although this was not a traditional thermal comfort study, the methods and survey instrument used present interesting options for an expanded data collection protocol.

Thermal experience. Expectations about thermal conditions and the sufficiency of personal control are informed by knowledge about the current setting as well as by experiences in other spaces (e.g., home, previous workspaces). Wohlwill (1998) argued that thermal adaptation varies among people as a function of past exposure; and researchers have considered different timescales. The length of time exposed to one's current workplace is one example. A number of studies have explored the idea of thermal history using a variety of different methods. In a chamber study comparing responses of students from two different climates (Seoul, Korea and Yokohama, Japan), Chun et al. (2008) found subjects from the warmer climate of Yokohama responded with cooler overall thermal sensations in the chamber, even though both groups reported "neutral" temperatures throughout the previous day in a thermal diary. Subjects who used AC at home responded with warmer thermal sensations than the subjects who did not use AC.

Rajesekar and Ramachandraiah (2010) posit that "ambient micro-climates" (noise, pollution) as well as age, gender, economic status and thermal history played a role in comfort perception in 5 naturally-ventilated apartment complexes located in a hot humid climate (Chennai, India). Although a residential study with fairly generalized conclusions, their general survey (which is 27 questions fitting on a single page) included a number of interesting items relating to thermal control, and ideas about comfort relative to other spaces. Cena and de Dear (2001) introduce general questions about "environmental sensitivity" to air movement, light, air quality, temperature and noise, in addition to inquiring about the presence and use of AC in bedroom/living room and car, and the type of home AC.

Thermal variability**.** A subset of a person's overall thermal experience is the range and variation of conditions they find acceptable. As Nikolopoulou and Steemers (2003) explain, the hypothesis that variation in environmental conditions plays a role in thermal adaptation is initially based on observations of comfort in outdoor spaces. This idea is also supported by findings that office workers prefer intermittent periods of increased air movement. The success of the PMV model in a MM building that maintains very stable temperatures using TABS also supports this idea (Pfafferott 2011). However, there have been few attempts to assess perceived and preferred variability. Brager et al. (2004) included detailed questions in a general survey about perceived and preferred variability in temperature -- fluctuations, ramp rates, and peak-to-peak amplitudes of change. The authors found relatively little influence of these indices on neutral temperatures compared to a workstation's simple proximity to the window. However, the setting was in a fairly stable, mild climate (Berkeley, CA), and the methods may be worth further trial. It should also be mentioned that thermal variability may be a factor that is better assessed through long-term measurement and correlated directly with other subjective comfort indices.

The following table compares different methods of assessing control perception and thermal expectations that have been used in various surveys. The potential responses to these questions are provided when available (for example, some of the questions were suggested during our workshops, and were not yet in actual surveys with response options)

Table 2. Comparing survey methods for assessing control perception and thermal expectations

Issue	Survey question	Reference
Perceived control opportunity		
Perceived access	"How much control do you have over [heating, cooling, lighting, ventilation, noise]?" (1-7, "no control" to "full control")	BUS survey
	"Do you feel you have control over your temperature/air movement?" (yes, no)	Hellwig 2006
	"How satisfied are you with your degree of control/your ability to adjust your thermal environment?" (7-pt scale, very dissatisfied to very satisfied)	CBE survey Cena and de Dear 2001
	"Do you have the ability to adjust: windows, doors, blinds, ceiling fans?" (yes, no)	CBE survey
Social norms		
	"Do you feel free to dress as you like?"	Researcher suggestion
	"To what extent does building management encourage or discourage the use of windows?" (or other devices, or flexible dress) (7-pt scale, discourage to encourage)	CBE survey
Perceived effectiveness	"For actions you take, rate: accessibility" (convenient, inconvenient)	BUS survey
	"For actions you take, rate: usability" (understandable, not)	BUS survey
	"For actions you take, rate: responsiveness" (speed, effectiveness)	BUS survey
	"Overall, how effective is opening your window (or using x device) in helping you to stay comfortable?" (7-pt scale, very ineffective to very effective)	CBE survey
	"Please mark what effect do you think the window [AC unit; other] has on your comfort in winter [summer]." ("gets more comfortable", "there is no change", " it gets worse", "no idea".)	Schweiker and Shukuya 2009
	"Do you have confidence that X device will produce the desired effect?"	Workshop suggestion
Perceived impediments	"If you don't tend to use your window (or x device), what are the main reasons?" (multiple choice: access, knowledge, no need, upset coworker, security, hardware, pests, not aware)	CBE survey; Brown, et al. 2009
	"What constraints prevent you from opening windows/doors?"(multiple choice: noise, dust, visual privacy, safety, pests, non-availability, prefer AC, other)	Rajesekar and Ramachandraiah 2010
Expectations of environment and service		
General suitability	"To what degree do thermal conditions/noise level/location of workstation suit your expectations?" (0-100%)	Rajesekar and Ramachandraiah 2010
Thermal History	"Do you use AC in your home or car?" (yes/no)	Cena and de Dear 2001
	"Considering all of the other buildings you've worked in over the last five years, which of the following have you had?" (operable window, sealed windows, AC, thermostat, heating unit, personal heater and fan)	Brager et al. 2004
	"Did your previous workspace have AC?" (yes/no)	Rajesekar and Ramachandraiah 2010

	"Overall, how comfortable are you relative to your previous work environment?" (continuous scale, very uncomfortable to very comfortable)	Rajesekar and Ramachandraiah 2010
	a) "How did you get to work (Car, bus, bike, .../ conditioned, not conditioned)" "How did you sleep….." b) "….last night?" c) "…. the last 14 days? d) "….throughout your childhood?" (answers for b-d, window opened/ closed, heating/ cooling on/off)	Schweiker, KIT
Perception of thermal variability	"How much does the temperature in your workspace seem to vary over a typical day?" (scaled responses from a lot-a little-stable)	Brager et al. 2004 BUS
	"What is the pattern of temperature variation over a typical day?" (graphical answers, steady rise, fall, peak, up and down, stable)	Brager et al. 2004
	Satisfaction and preference for temperature variation (7-pt scale, very dissatisfied to very satisfied; 3-pt scale, prefer more variability, as is, less variability)	Brager et al. 2004
Awareness of mechanical system	Perceived/preferred amount of ambient/mechanical noise (positive-nuisance)	Workshop suggestion
Knowledge of how temperature is controlled	"How is heating/cooling/fresh air/lighting, provided?" (5-pt scale, not at all knowledgeable to very knowledgeable)	Brown, et al. 2009
Perceived share of thermal variation addressed passively, automatically and manually	"Who is responsible for controlling heat/cooling/fresh air/lighting?"	Brown, et al. 2009
	"What do you expect the building to do when it gets a) hot? b) stuffy?" etc	Workshop suggestion
Perceived/preferred duration of conditions or modes	"How long does discomfort last when it occurs?"	Workshop suggestion
	"How much time does your building spend in a 'passive' operating mode?" "Do you think you could spend more/less time without air conditioning?"	Researcher suggestion
Perception of building performance	"How would you rate this building in terms of energy performance (green-ness)?"	Brown, et al. 2009
	"How would you rate this building in terms of overall performance/ability to provide comfort?"	Researcher suggestion
Manager reliability, responsiveness	"When you have a problem with comfort in your workspace, do you feel your needs are addressed?"	Researcher suggestion
Self-identified attitudes, values		
Perceived knowledge of controls	"Do you feel you are knowledgeable about how building provides comfort?" (5-pt scale, not at all knowledgeable to very knowledgeable)	Brown, et al. 2009
Preference for learning more about controls	"Would you like to learn more?" (yes, no)	Brown, et al. 2009
Importance of personal controls	"How important is it for you to have operable windows?" (or other)	CBE survey
	"Do you enjoy making adjustments to your environment?"	Workshop suggestion, no precedent
	"Do you expect this building to make you comfortable 100% of the time?"	Workshop suggestion, no precedent

4.3.4. Account for control actions (utilized control)

There are three issues to address related to utilized control in a data collection protocol: 1) what actions (or environmental variables) to focus on; 2) what influencing factors lead people to exercise control; and 3) what are the environmental effects of those actions. Depending on the aims of a particular study, data on control actions can come from physical monitoring or from reported habits or attitudes via occupant surveys.

In an early post-occupancy study of 5 UK schools, Haigh (1981) pointed out the importance of understanding the “fine-grain experiential issues that influence control response,” which included vertical temperature gradients, patterns of air flow determined by the HVAC distribution system, and direct insolation. None of these are typically included in thermal comfort field studies. To better understand control actions, it is difficult to know which parameters are best assessed using subjective surveys, or real-time field measurements. General survey questions about reasons for using and not using devices can be very informative, as are questions about behavior sequencing (e.g. “when you get hot, which of the following actions do you take first?”) or interaction among different devices (e.g. "when you open a window, do you also adjust the radiator?"). The difficulty for analyzing this type of question is specifying the starting conditions, of which there are numerous combinations, (e.g., what do occupants do first when it is winter, the occupant is cold, and the window is open?) Perhaps the highest priority and biggest challenge for a new thermal comfort field study protocol is deciding how to generate high quality data about why actions are taken, and whether the expected result was achieved. For these objectives, a combination of real-time measurements and survey questions are most reliable.

Much of the research on control actions comes from attempts to account for the energy impact of using windows, which date back to the 1950s. Early studies found that outdoor weather (temperature, humidity, wind) could explain a majority of window interactions (Dick and Thomas 1951; Brudrett 1977; Warren and Parkins 1984)

Until recently, subsequent attempts to characterize and predict window operation have been based exclusively on outdoor and/or indoor temperatures (Fritsch et al. 1990; Nicol 2001; Raja et al. 2001; Nicol and Humphreys 2004; Inkarojrit and Paliaga 2004). The resulting behavior models are based on empirical data of control actions collected predominantly from buildings without cooling systems in Europe and the UK. The focus on temperature makes intuitive sense given that windows aren’t likely to be opened if it is too hot or cold outside, and given the important role of indoor temperature in maintaining occupant comfort. Furthermore, perceived air movement, air quality, or other comfort factors are subjective and difficult to measure. However, although the correlations with temperature are significant, available models are not agile enough to address interacting factors that inevitably influence behavior, particularly in MM buildings, such as non-temperature comfort factors, pro-active (rather than reactive) actions, environmental constraints, or psycho-social and cultural factors.

Schweiker and Shakuya (2007, 2010) found that temperature alone does not necessarily cause the majority of actions that occupants take to influence the built environment, and that indoor air quality in particular plays an equally important role in window-opening behavior (this latter result was also reported in Ackerly and Brager 2012). In their 2010 paper, Shweiker and Shakuya administered a web-based survey with numerous questions relating to the purpose of different behaviors, including a reflection on past expectations and future motivations; the order in which actions are taken, and attitudes and experiences with home and childhood living conditions. The researchers found a range of personal differences in the how occupants associate the use and state of open windows or running devices with attributes such as “goodness,” health, comfort, energy use and convenience. In terms of which devices occupants use first, second and third, there was no one device used first by more than 60% of subjects. On average, clothing was the first action, followed by mechanical devices and windows.

Researchers have begun to understand the dynamic interactions of environmental conditions and control behaviors in naturally-ventilated offices based on statistical models. The primary purpose of the work was to generate algorithms for predicting window-opening behavior, for example in simulation programs. But the methods that have been developed for collecting real-time data are worth noting in terms of future thermal comfort field studies, and for predicting comfort (Rijal et al., 2007, 2009). Window opening behavior was determined by a longitudinal survey which asked about occupants use of building controls using a simplified questionnaire filled in four times a day (these questions were in addition to the traditional questions about satisfaction, clothing and activity)

As another example, Haldi and Robinson (2008) conducted a longitudinal (3-month, summer-long) field survey in 8 office buildings in Switzerland in order to predict the probability of occupants' actions, both personal (clothing, activity and drinking) and environmental (windows, doors, fans and blinds) based on environmental conditions. They begin to explore how interactions among different environmental conditions and different controls might behave in a model by computing the relative relevance of indoor and outdoor temperatures for the adjustments of windows, fans, blinds, doors, clothing, and consumption of cold drinks. The authors have deployed a similar, simple electronic survey (Figure 6) on a number of projects, administered four times per day for up to a full year. It includes questions about visual and olfactory sensation in addition to thermal sensation, activity and clothing. They depend on subjects to report any interaction with controls (window, door, ceiling fan, curtain) including eating/drinking cold or hot things over a given time interval, but the actions are bi-modal ("did you open/close"). Other researchers have asked for higher resolution data on the status of the window. For instance, Brager et al. (2004) ask occupants to specify the action: opened the window; increased the opening, partially closed, or completely closed. Similarly, fans are reported as off, on (low speed), or on (high speed).

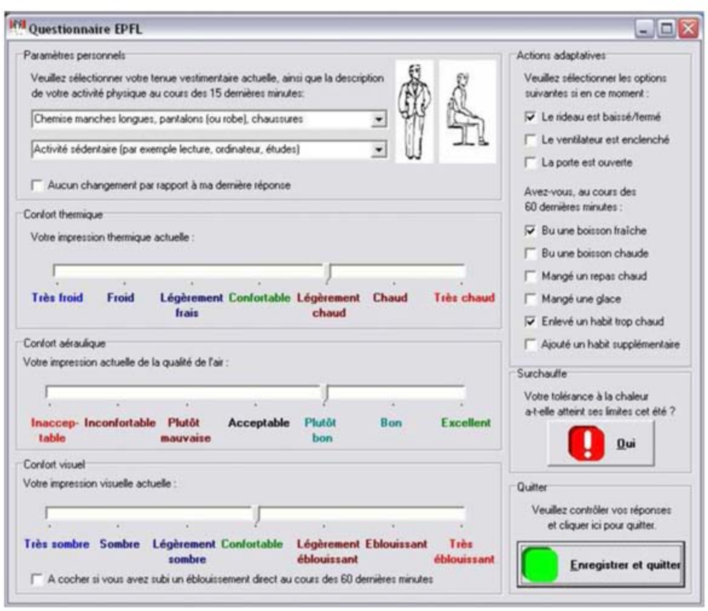

Figure 6. Electronic Survey (Haldi and Robinson 2010a)

As noted in Haldi and Robinson (2008), the areas calling for further research include the incorporation of thermal stimuli other than temperature (relative humidity, radiant temperature, air speed), how occupants sequence or prioritize different devices, and how to characterize the "inertia" of control actions (for example, glare may provoke a more immediate action than thermal changes).

The extent to which occupants understand the results of their actions can intermingle with overall thermal perceptions, which can make data difficult to interpret. Cena and de Dear (2001) found a tendency for subjects to report their comfort according to the *meaning* of an adaptive action rather than its positive benefit (i.e. “I took off my sweater therefore I am warmer than neutral” compared to “I took off my sweater and now I am more comfortable”), and also a tendency for subjects not to differentiate overall thermal acceptability from acceptability “right now.” Wagner et al. (2007) found that comfort satisfaction increased with the number and success of actions taken.

Questions about control "effectiveness" overlap with control "perception," as discussed in the previous section. The question can be addressed in a general way (e.g. BUS methodology) or a "right now" basis. For example, Brager et al. (2004) provide a simple list in the "right now" survey of possible control actions, whether they were taken in the last hour, and whether or not the results were "satisfactory" or "unsatisfactory."

4.3.5. Determine influence of outdoor conditions

The current adaptive comfort standards define acceptable temperatures based on monthly or running mean outdoor temperature, usually taken from Typical Meteorological Year (TMY) or similar data files. It is important to note that weather files may be very rough generalizations of the local climate characteristics of the site, especially adjacent to the building.

The current standards typically apply to buildings with operable windows, in which outdoor and indoor temperatures are arguably coupled. However, when applying the standard to MM and PCS buildings, indoor comfort temperature may be more strongly associated with the *mean indoor conditions*.

Humphreys and Nicol (2002) found a systematic bias in the PMV equation related to the influence of outdoor temperature in all real environments, including both AC and NV buildings. They argue that PMV is not intrinsically more valid for AC buildings; the method is merely more successful at predicting comfort in buildings that maintain a narrow range of indoor thermal environments, suggesting that this diminishes the rationale that it’s due to personal control or adaptive “opportunity.” For instance, it may be possible to program an AC building to maintain a more variable indoor environment without negatively impacting thermal comfort (Nicol et al. 1994).

Their findings point out that more research is needed to assess the degree to which subjects are acclimated to their indoor versus their outdoor environments. One aspect of this assessment is physical acclimatization to whatever environment a person spends the most time in. In a large study of AC office buildings in Kalgoorlie-Boulder, which is in a hot-dry area of Australia, Cena and de Dear (2001) found the PMV model to very closely predict comfort response, even though they expected neutral temperatures to be slightly cooler than predicted given the warm climate. They posited that thermal experience, such as the “cocooning” of people in air conditioned homes and cars, was likely to play a major role in the acclimatization of subjects to indoor conditions. Another factor is habituation, the psychological and behavioral adjustment based on repeated exposure to a particular condition (i.e. learning that the office is over-cooled and dressing accordingly).

A major gap in our understanding is the extent to which the amount and nature of exposure to outdoor conditions influences our comfort perceptions indoors (for instance, are variables such as humidity, diurnal variation, seasonal weather extremes worth noting?). Related to this is getting a better understanding of the time scales by which people are able to adjust their expectations.

Findings of Deuble and de Dear (2012) compared how comfort responses changed between AC and NV modes in a MM building in Sydney Australia. The building was designed to provide AC only when indoor temperatures rose above 25°C (77°F), and it was typical for the mode to change multiple times per day. They found a strong difference in comfort response based on operating mode despite negligible differences in the measured indoor conditions. The adaptive model (which is based on outdoor temperature) was found to strongly predict thermal sensations during natural-ventilation mode, while in AC mode occupants were more sensitive to temperature fluctuations. These results were true regardless of how much time had elapsed in each mode (although this information was not precisely collected). It was speculated that the occupants' expectations and the ability to control their windows (or at least knowledge of this ability once the building was in NV mode) were the reasons why thermal sensations during NV mode were more adaptive compared to those in AC mode. The occupants were able to view a display panel that showed which mode the building was in upon entering the corridor to their office, and knew they could open their windows in NV mode if they sat in the perimeter zones. Once the occupants knew they had control of their windows during NV mode, their expectations of the thermal environment may have shifted to allow for a greater range of acceptable indoor temperatures that could be accommodated through use of their operable windows (Deuble and de Dear 2012). These results are some of the best that demonstrate not just that expectations are adaptable, but how rapidly occupants can adjust their expectations based on their understanding of how the building operates and perceived control in each mode.

***Climate, clothing choices and thermal perception*.** A number of studies have focused on clothing behavior and its relationship to both indoor and outdoor climate, and resulting thermal expectations (De Carli et al. 2007). In general, much of the research shows that outdoor conditions are primarily responsible for clothing worn indoors except when subjects are subject to workplace dress norms, and that clothing adjustments are rare throughout a given day. Haldi and Robinson (2010b) found a strong correlation between clothing choices and outdoor temperature in the LESO building, Laussane Switzerland, and that clothing adjustments were rare throughout the day. Barlow and Fiala (2007) similarly found that over a three-month period, people changed clothing to reflect external temperature, but less than 4% of respondents changed clothing during any given day of the study, despite noteworthy differences between morning and afternoon temperatures. Schiavon and Lee (2012) found that clothing is mainly related to outdoor air temperature and indoor operative temperature

In certain building types, dress norms can be of greater significance than weather. Morgan and de Dear (2003) found that subjects' clo levels tracked with weather in a commercial office only on Fridays when casual attire was permitted. Women were more variable in their clo levels and appeared to be more responsive to weather. The results also conclude that "outdoor conditions" relate to a combination of "weather memory" (expectations of today's conditions based on yesterday's) and "weather forecast" (media-distributed weather predictions).

4.3.6. Define "comfortable"

Indoor comfort temperature has been defined based on the idea of "neutral" temperatures, which lie in the center for the 7-point ASHRAE thermal sensation scale from "very warm" to "very cool." These scale values are the basis for both the PMV index and the SET* model of thermal comfort prediction; therefore, this 7-point thermal sensation scale is an important standard metric. However, the application of this scale in comfort standards is typically based on an assumption that ideal comfort corresponds to the feeling of being thermally "neutral," and this can be part of the source of some discrepancies between actual responses and PMV calculations in the field. It has become common practice to collect thermal sensation votes alongside a thermal preference scale (warmer/no change/cooler) in order to better associate sensation votes to ideal comfort. But thermal sensation and thermal preference can both be difficult for subjects to interpret, and a number of researchers have demonstrated systematic differences in the way subjects respond. While beyond the scope of this investigation, interested readers can find further discussions about the challenges of thermal comfort semantics, and associated problems of translating scales to other languages (Humphreys and Hancock 2007; Humphreys 2008)

There are good arguments for requiring thermal acceptability in future thermal comfort questionnaires. It can be asked in a binary form (acceptable-unacceptable) or on a continuous scale (clearly unacceptable-unacceptable-just unacceptable-just acceptable-acceptable-clearly acceptable). The PMP recommends this continuous scale approach, with a break between "just acceptable" and "just unacceptable" to force the subject to make a judgment. This will allow us to move away from the assumption that "neutral" is always the preferred sensation in all circumstances.

Finally, interactions between thermal perception and the individual effects of other indoor conditions – air quality, air movement and humidity in particular – have rarely been captured in existing datasets beyond integrating these factors into the PMV and SET* indices. One exception is a study in Germany, where Wagner et al. (2007) found that temperature satisfaction in winter had a strong relationship to perceived dryness of indoor air, while in summer perceived indoor air quality impacted thermal perception, and perception of humidity in summer was less significant. These results may be particular to the climate in which the study was conducted.

5. CONCLUSION - PROPOSED PROTOCOL

While our review of the current thermal comfort study methods described in the literature was quite comprehensive, it also revealed that, beyond the most basic questions and measurements, there is lack of consistency in the more innovative data collection methods that people are using. We see our proposal as a first step in moving towards greater consensus in the next generation of thermal comfort field study methods.

The protocols requiring the most expansion for application in MM and PCS buildings are those for collecting "background" information: building characteristics data templates and one-time occupant questionnaires. These protocols are necessary to capture the available and perceived control characteristics that may have an influence on real-time comfort responses.

Our final protocols, shown in the Appendix, are based on the building characteristics form and IEQ survey currently administered by the CBE. We use these tools as a foundation, given that the core questions are not significantly different from similar background data collection tools used by other researchers. We are not necessarily suggesting that the particular wording or organization of the CBE survey is superior to other methods. However, the CBE survey questions do have the added advantages of having been carefully tested, being open-source, and being associated with one of the largest databases of existing post-occupancy satisfaction data.

The CBE survey was designed to support broad IEQ post-occupancy feedback, diagnostics and benchmarking rather than thermal comfort alone. Since the purpose of this project was to propose new protocols specifically for thermal comfort field research, we have omitted the less relevant questions and added new questions developed through this project. (Of course, anyone interested in the broader dimensions of IEQ - lighting, thermal, indoor air quality - are encouraged to include the original CBE survey questions as well).

In the surveys shown in our Appendix, the new questions that have not previously been used in CBE's survey are shown in red and are accompanied by vertical lines in the margin. These proposed new questions underwent a detailed peer review process, in which 18 people from both the research and professional communities reviewed an even broader set of questions and offered ranking votes, suggestions and comments. These responses were then used to help us develop the final protocols shown in the Appendix.

The Appendix includes three proposed templates, corresponding to three of the four major data collection methods noted below:

1. **Building characteristics**
   The proposal is designed to provide more detailed and organized characterization of building features, particularly the means of HVAC generation and delivery, and important control features. We believe this is critically important information for future thermal comfort field studies, and addresses what has traditionally been a real gap in our understanding. There's been a movement to study comfort in the real-world context of occupied buildings instead of controlled laboratories, yet we often neglect to understand enough about the very context in which we're collecting data. There are a wide continuum of buildings that can be labeled as "mixed-mode", ranging from 1) buildings that are primarily operated in natural ventilation mode, with the mechanical cooling only being used when and where it is needed, to 2) buildings where the mechanical cooling is being operated in conventional ways, similarly to sealed buildings, but there are some windows that might be open occasionally. There are also a wide range of systems and devices that provide people with various forms of personal control over their local thermal conditions. For all of these situations, we need to better understand what is it about the design and operational characteristics of the buildings that produce comfort responses consistent with adaptive comfort models.

2. **General background survey**
   The proposal includes a few questions directed at understanding the perceived control of subjects. The centerpiece is a one-page (optional two-page) module for asking questions specific to a device. As a general note, the background survey has been reformatted as if administered during a specific season or study period. Where the questions state "…in cool (warm) weather…" this language would be replaced by whatever language is most appropriate to describe the study period. For studies of PCS especially, there are opportunities to include sensors in devices (such as fans) in order to record adjustments real-time, which can then integrate directly with "right now" survey instruments

3. **Environmental measurements**

There is no specific proposal for this category provided in the Appendix. Instead, we refer people to the very detailed methods in the Performance Measurement Protocol (PMP) (ASHRAE, 2010b). We recommend taking physical measurements at least at the intermediate level in the PMP, namely air temperature, globe temperature, humidity and air speed logged at 1-15 minute intervals. Beyond these, other real-time data collection methods are often specific to the particular characteristics of the building. Wherever possible, real-time data collection should document utilized control. For conditions at the perimeter, control actions such as the use of windows, shades and blinds, can be assessed through photography or visual observation. For studies of PCS, there are opportunities to include sensors in devices (such as fans) in order to record adjustments real-time, which can then integrate directly with "right now" survey instruments. Environmental measurements might also incorporate higher resolution data on outdoor conditions, and both indoor and outdoor measurements can be combined with survey responses to improve the definition of "comfort". However, we consider these to be optional, or higher-tier elements in the protocol, that would depend the the research questions being asked.

4. "Right now" survey

Our proposed "right now" survey begins with the most essential questions about perceived temperature, air movement and air quality, with a focus on thermal "acceptability" and preference. There is an additional branching section including some basic questions about personal control actions taken.

The proposal in the Appendix is intentionally not extensive. This is because, when it comes to collecting survey data on reported control actions, the questions that will be most effective in a right-now questionnaire tend to be specific to building features and the given research objectives, and are also particularly subject to concerns of survey fatigue. The scope of a right-now survey is also highly influenced by researchers' decisions regarding the survey interface, time interval, and how it is administered. As examples, will the subject be responding to questions on a fixed time interval, or does the survey appear as a "pop-up" in response to a monitored action, or do they response on a voluntary basis whenever they feel like it?

The Appendix includes what we feel are essential questions, focusing specifically on windows as an example. Those questions would, of course, be modified accordingly if one was assessing the use of PCS devices. In addition to those questions, we encourage researchers to consider the following types of question that have been commonly used by researchers assessing actions through longitudinal surveys, and determine which are appropriate for their particular type of study:

1. Current state of subject: activity (met) and clothing level (clo)

2. Current state of the device(s) (open/closed, or intermediate states)

3. Actions taken in the given time interval, including:

    a. Personal adjustments (eating, drinking, adding/removing clothing, previous activity)

    b. Device adjustments (window, door, fan, heater, window AC, etc.)

For the latter actions, it may be important to include options that acknowledge shared operation or non-binary operation (partially open, multi-speed devices, etc)

4. Reasons for making adjustments

5. Result of adjustments (was it effective?)

Finally, methods should take care to address the challenge of interpreting the feedback effects between control actions and thermal perception. For example do thermal comfort responses correspond to the sensation the subject experienced before or after taking any actions? (i.e. the notion “I put on a sweater because I am cold”). Again, the protocol provides only a very basic example of questions designed to collect data on behavior, and they should be tailored according to the situation in each particular building

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6. ACKNOWLEDGEMENTS

Special thanks are due to the CBE Industry Partners for their financial support of the research. We are also grateful for the generous contributions from our research and design colleagues who participated in our workshops, reviewed the draft protocols, and provided us with other feedback along the way. With apologies to anyone we might have missed, we thank the following people who attended workshops or answered our initial survey: Peter Alspach (*Arup*), Fred Bauman (*CBE*), Corinne Benedek (*Arup*), Atze Boerstra (*BBA Indoor Environmental Consultancy*), Sam Borgeson (*UC Berkeley*), Charles Chaloeicheep (*WSP Flack and Kurtz/Built Ecology*), Andrew Corney (*WSP Flack and Kurtz/Built Ecology*), Richard de Dear (*University of Sydney*), Spencer Dutton (*Lawrence Berkeley National Laboratory*), Glenn Friedman (*Taylor Engineering*), Frederic Haldi (*Gartenmann Engineering*), Randall Higa (*Southern California Edison*), Don Horn (*GSA*), Reza Jamalirad (*Arup*), Connor Jansen (*WSP Flack and Kurtz/Built Ecology*), Vivian Loftness (*Carnegie Mellon*), Fergus Nicol (*London Metropolitan University*), Gwelen Paliaga (*Taylor Engineering*), Jens Pfafferott (*Fraunhofer ISE*), Peter Rumsey (*Integral Group*), Mat Santamouris (*NKUA University of Athens*), John Stoops (*KEMA*), Paul Switenki (*Arup*), Steve Taylor (*Taylor Engineering*), Brad Tully (*Price Industries*), and Hui Zhang (*CBE*)

We’d like to acknowledge and add an extra dose of appreciation to those who took time to review our report and provide detailed, thoughtful feedback that led to our final protocol: Ed Arens (*CBE*), Francesco Causone (*Foster and Partners*), Alan Daly (*Taylor Engineering*), Max Deuble (*Macquarie University*), Stephanie Gauthier (*Loughborough University*), Gregor Henze (*University of Colorado, Boulder*), Michael Humphreys (*Oxford-Brookes University*), Pierre Lombard (*Saint-Gobain Recherche*), Erin McConahey (*Arup*), Ashak Nathwani (*University of Sydney*), Stefano Schiavon (*CBE*), Marcel Schweiker (*Karlsruhe Institute of Technology*), Fionn Stevenson (*University of Sheffield*), Ryan Tanner (*University of Colorado, Boulder*), and Andreas Wagner (*Karlsruhe Institute of Technology*).

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Appendix A
Building Characteristics Form

This proposal is designed to provide more detailed and organized characterization of building features, particularly the means of HVAC generation and delivery, and important control features.

The new questions that have not previously been used in CBE's Building Characteristics form are shown in red and are accompanied by vertical lines in the margin.

Building Characteristics Form

To be completed by building manager, owner's rep and/or operator

General Information

Building name:

Year building opened:

Year of last major renovation (if applicable):

Level of commissioning: LEED additional CX

Address

Location description: - choose one -

Address:

City:

State/Province:

Zip/Postal code:

Country: United States

Design Team

Primary architect:

Other architect:

Mechanical engineer:

Electrical engineer:

Structural engineer:

Landscape architect:

General contractor:

Ownership and Occupancy

Owner:

Owner occupied?:

Government owned?

Tenancy:

Number of occupants:

Maximum occupancy:

Occupant access to facility manager [options: email, phone, in-person (anytime), in-person (periodic)]

Please check any policies/instructions that have been communicated to occupants (one-time, upon hire or periodically)

- Dress code
- Window operating instructions; please specify method: [options: hire orientation; wall-mounted signal, email notification/reminder, desktop indicator, dashboard, verbal reminders]
- Operating instructions for other control devices (fans, thermostats, etc)
- Indoor environmental quality policies (food/odors, dust, etc)
- Safety/security policies or instructions
- Other(please specify):

Sustainability

LEED Product:

LEED Version:

LEED Rating:

- None
- Pending
- Certified
- Silver
- Gold
- Platinum

What education do occupants receive about sustainable ("green") features? none [options: orientation at move-in; orientation upon hire; regular reminders; none; i don't know]

Building Features

Construction + Site

Gross building area (non-parking): (ft²)

Floor-to-floor height (ft) 0 (in)

Floor-to-ceiling height (ft) (in)

Number of floors, total

Number of floors, occupied

Predominant exterior wall material: - choose one - [masonry/siding/metal panel/concrete panel/glass]

Window glass (% of wall area): 51-75%

Window head height (from floor): (ft)

Use

Principal activity:

- Office (professional services, government offices, non-profit)
- Commercial (retail, pharmacy, TV & radio stations)
- Educational (child care, schools, university classroom, libraries, museums)
- Public order and safety (courthouse, correctional, police/fire stations)
- Health care (hospitals, medical offices, laboratories, rehab, nursing)
- Public Assembly (religous, sports facilities, performing arts, entertainment)
- Laboratory (research labs)
- Hospitality (hotels, motels, restaurants, commercial kitchens)
- Residential (single family, townhouse, duplex, condos, apartments)
- Transportation (parking garage, airports & terminals, train and bus stations)
- Industrial & storage (factories, warehouses, agricultural)
- Other (please specificy):

Systems

Building Envelope (check all that apply):

	Yes	No	Don't know
Insulating glass (i.e. 2 or more panes)	●	○	○
Tinted glass	○	●	○
Reflective glass	○	○	●
High performance glass	○	○	●
Fixed exterior shading	●	○	○
Automated exterior shading	●	○	○
Manual (or override) exterior shading	○	●	○
Fixed Interior window blinds	●	○	○
Automated interior window blinds	●	○	○
Manual (or override) operable windows	●	○	○
Automated operable windows or vents	●	○	○
Atrium or gallery for ventilation	●	○	○
Acoustics (check all that apply):			
Electronic sound masking	○	●	○

Control features

☐ Individual or shared HVAC control: # workstations per control

☐ Temperature

☐ Airflow velocity

☐ Airflow direction

Daylighting controls ●

Occupancy sensors ●

HVAC System
(Do not complete unless knowledgable about the design and operation of the HVAC system)

Mechanism for HVAC delivery (Check all that apply)

	Yes	No	Don't know
CAV air distribution	◉	○	○
VAV air distribution	○	◉	○
Underfloor air distribution	○	○	◉
Dedicated outdoor air system	○	○	◉
Window air conditioners	◉	○	○
Perimeter heating unit	◉	○	○
Radiant panel	○	◉	○
Radiant slab	◉	○	○
Chilled beam	◉	○	○

Source(s) for cooling (Check all that apply)

	Yes	No	Don't know
Chilled water	◉	○	○
Evaporative cooler (direct)	◉	○	○
Evaporative cooler (indirect)	◉	○	○
Heat pump	◉	○	○
Economizer	◉	○	○
Mechanical ventilation	◉	○	○
Fan-assisted NV mode	◉	○	○
Passive NV mode	◉	○	○
Night purge/mass ventilation	◉	○	○
Custom	◉	○	○

NV mode overrides (mixed-mode only)

	Yes	No	Don't know
Indoor zone temperature	◉	○	○
Indoor zone CO2	◉	○	○
Indoor RH	◉	○	○
Outdoor wind speed	◉	○	○

Other controls

	Yes	No	Don't know
Demand-controlled ventilation	◉	○	○
Energy management system (e.g, EMCS, BAS, EMCIS, EIS/DR)	◉	○	○

Zone control

Nominal Zone size (s.f.)

Major zone description	Weekday hours	Weekend hours	Occupied temp	Unoccupied temp	other mode temp

Mized-mode Classification

	Conventional setpoints (70-76 F)	Relaxed setpoints (68-80 F min.)	Both: Setpoint change/ramp between modes
Conventional AC with personal convenience windows (no automated switch-over)	○	○	○
Designed for natural ventilation with supplemental AC back-up. Indoor conditions determine mode.	○	○	○
Centralized switch-over from natural ventilation to AC based on outdoor conditions	○	○	○
Predominantly naturally-ventilated space with radiant cooling assistance	○	○	○
Central heating and ventilation without cooling	○	○	○

Appendix B
General Background Survey

The proposed survey includes a questions directed at understanding the perceived control of subjects. The centerpiece is a one-page (optional two-page) module for asking questions specific to a device.

As a general note, the background survey has been reformatted as if administered during a specific season or study period. Where the questions state "…in cool (warm) weather…" this language would be replaced by whatever language is most appropriate to describe the study period.

The new questions that have not previously been used in CBE's IEQ Survey are shown in red and are accompanied by vertical lines in the margin.

The questions deleted from the original CBE IEQ Survey that address broader dimensions of IEQ (lighting, acoustics, air quality) are not indicated here

Background

How long have you been working at your present workspace?

- ○ Less than 3 months
- ○ 4-6 months
- ○ 7-12 months
- ○ More than 1 year

In a typical week, how many hours do you spend in your workspace?

- ○ 10 or less
- ○ 11-30
- ○ More than 30

Considering all of the buildings you've worked in over the last five years (other than this one), which of the following have you experienced in those buildings? (check all that apply)

- ○ Not applicable (I haven't worked in any other building besides this one during the last 5 years)
- ○ Operable window (direct control, I can open or close the window when I like)
- ○ Operable windows (indirect control, I need to ask a co-worker to open or close the window)
- ○ Sealed windows
- ○ Air-conditioning
- ○ Thermostat that I can adjust
- ○ Permanent baseboard heater or radiator that I can adjust
- ○ Personal heater
- ○ Personal fan

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)?

Not influenced  Very influenced

Please describe any other issues related to how free or restricted you feel about clothing at work.

For pilot purposes to tune the above question

What is your age?

- ○ 30 or under
- ○ 31-50
- ○ Over 50

What is your gender?

- ○ Female
- ○ Male

Personal Workspace

On which floor is your workspace located?

Choose one

In which area of the building is your workspace located?

Choose one

To which direction do the windows closest to your workspace face?

Choose one

Are you near an exterior wall (within 15 feet)?

- ○ Yes
- ○ No

Are you near a window (within 15 feet)?

- ○ Yes
- ○ No

Which of the following best describes your personal workspace?

- ○ Enclosed office, private
- ○ Enclosed office, shared with other people
- ○ Cubicles with high partitions (about five or more feet high)
- ○ Cubicles with low partitions (lower than five feet high)
- ○ Workspace in open office with no partitions (just desks)
- ○ Other: ____________

Workspace Adjustability

Which of the following do you personally adjust or control in your workspace? (check all that apply)

- ○ Window blinds or shades
- ○ Operable window
- ○ Thermostat
- ○ Portable heater
- ○ Permanent heater
- ○ Room air-conditioning unit
- ○ Portable fan
- ○ Ceiling fan
- ○ Adjustable air vent in wall or ceiling
- ○ Adjustable floor air vent (diffuser)
- ○ Door to interior space
- ○ Door to exterior space
- ○ None of the above
- ○ Other:

Referring to the question above, which item do you adjust most frequently, in cool (warm) weather?

Choose one: [ ]

If and when there is a problem with comfort, how satisfied are you with the response from the building manager or operator?

Very Satisfied  Very Dissatisfied

Not Applicable: ☐

Please describe any other issues related to how well the building system or management meets your comfort needs.

For pilot purposes to tune the above question

This can be adapted as a two-page module for any personal control device about which environmental motivations are important

Operable Windows

You said that you had access to an operable window. The following questions address your experiences with the window(s) that you have access to.

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, in cool (warm) weather? (check all that apply)

- O To feel cooler
- O To feel warmer
- O To increase the air movement
- O To let out indoor smells, dust or other pollution
- O To conserve energy
- O To hear outdoor sounds
- O To let in fresh air
- O To experience the variety of the outdoor climate
- O For nighttime cooling
- O A co-worker requests that you open the window
- O Management requests that you open the window
- O Other:

When you open the window, what confidence do you have that your action will have the desired effect?

Very sure ☐ Very unsure Not Applicable: ☐

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, in cool (warm) weather? (check all that apply)

- O To feel cooler
- O To feel warmer
- O To reduce the air movement
- O To keep out outdoor smells, dust or other pollution
- O To keep out bugs
- O To conserve energy
- O To reduce outdoor noises
- O For safety or security reasons
- O The outdoor temperature is getting warmer than indoors
- O A co-worker requests that you close the window
- O Management requests that you close the window
- O Other:

When you open the window, what confidence do you have that your action will have the desired effect?

Very sure ☐ Very unsure Not Applicable: ☐

Operable Windows (contd.)

How often do you typically adjust your window in cool (warm) weather?

- ○ Daily (typically every day)
- ○ Weekly (1-3 times a week)
- ○ Monthly (1-3 times a month)
- ○ Less than once a month
- ○ Never

Who has access to open and close your window(s)?

- ○ I am the only person who has access to the window(s)
- ○ I share control of the window(s) with [ ] people other than myself (please enter the number).

Please describe any other issues related to negotiating control of your windows with coworkers:

For pilot purposes

When you go to adjust the window, rate your impression of its:

Accessibility

Very convenient — Very inconvenient

Usability

Very clear to operate — Very confusing to operate

Responsiveness

Very fast or reliable — Very slow or unreliable

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

Encourage — Discourage

Please describe any other issues related to your operable window(s) that are important to you.

This can be adapted as a one-page module for any personal control device

Thermostat

How often do you typically adjust your thermostat in cool (warm) weather?

- O Daily (typically every day)
- O Weekly (1-3 times a week)
- O Monthly (1-3 times a month)
- O Less than once a month
- O Never

Who has access to adjust your thermostat?

- O I am the only person who has access to the thermostat
- O I share control of the thermostat with [ ] people other than myself (please enter the number).

Please describe any other issues related to negotiating control of your thermostat with coworkers:

For pilot purposes

When you go to adjust the thermostat, rate your impression of its:

Accessibility

Very convenient — Very inconvenient

Usability

Very clear to operate — Very confusing to operate

Responsiveness

Very fast or reliable — Very slow or unreliable

To what degree does the building management encourage or discourage the use of local thermostats?

Encourage — Discourage

Please describe any other issues related to your thermostat that are important to you.

Indoor Environmental Quality

Please reflect on only cool (warm) weather when answering the following:

How satisfied are you with the temperature in your workspace?

Very Satisfied — Very Dissatisfied

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

Very Satisfied — Very Dissatisfied

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

Very Satisfied — Very Dissatisfied

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

Very Satisfied — Very Dissatisfied

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

Very Satisfied — Very Dissatisfied

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

Very Satisfied — Very Dissatisfied

Any additional comments or recommendations about how the thermal environment is controlled in your workspace or in the building overall?

Temperature

You have said that you are dissatisfied with the temperature in your workspace. Which of the following has contributed to your dissatisfaction in cool (warm) weather?

- Often too hot
- Often too cold
- Humidity too high (damp)
- Humidity too low (dry)
- Air movement too high
- Air movement too low
- Incoming sun
- Hot/cold floor surfaces
- Hot/cold ceiling surfaces
- Hot/cold wall surfaces
- Hot/cold window surfaces
- Heat from office equipment
- Drafts from windows
- Drafts from vents
- Drafts falling from the ceiling
- My area is hotter than other areas
- My area is colder than other areas
- Thermostat is inaccessible
- Thermostat is adjusted by other people
- Heating/cooling system does not respond quickly enough to the thermostat
- Clothing policy is not flexible
- Other:

When is this most often a problem?

- Morning (before 11am)
- Mid-day (11am - 2pm)
- Afternoon (2pm - 5pm)
- Evening (after 5pm)
- Weekends/holidays
- Monday mornings
- No particular time
- Other:

When discomfort occurs, how long does it typically last?

- Several Minutes
- Less than one hour
- 1-4 hours
- More than four hours

Please describe any other issues related to being too hot or too cold in your workspace.

Air Movement

**You have said that you are dissatisfied with the air quality in your workspace.
On average, which would you prefer to have:**

- Much more air movement
- Somewhat more air movement
- No change
- Somewhat less air movement
- Much less air movement

Please describe any specific issues related to air movement in your workspace that are important to you.

Air Quality

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

Minor problem ... Major problem

☐ **Not a problem**

Air is not clean

Minor problem ... Major problem

☐ **Not a problem**

Air smells bad (odors)

Minor problem ... Major problem

☐ **Not a problem**

If there is an odor problem, which of the following contribute to this problem? (check all that apply)

- ○ Tobacco smoke
- ○ Photocopiers
- ○ Printers
- ○ Food
- ○ Carpet or furniture
- ○ Other people
- ○ Perfume
- ○ Cleaning products
- ○ Outside sources (car exhaust, smog)
- ○ Other:

Please describe any other issues related to the air quality in your workspace that are important to you.

Appendix C
Right-Now Survey

Our proposed "right now" (longitudinal) survey begins with the basic questions on perceived temperature, air movement and air quality, with an emphasis on "acceptability" and preference.

There is also an example branching section including some basic questions about personal control actions taken.

Additional questions one might ask tend to be very building-specific, and are discussed further in the report

"Right Now" Survey

1. THERMAL ENVIRONMENT

Right now, how acceptable is the thermal environment at your workspace?

Very acceptable ○ ○ ○ ○ ○ ○ ○ Not at all acceptable

You feel: (Please mark anywhere on the scale)

Cold	Cool	Slightly cool	Neutral	Slightly warm	Warm	Hot

You would prefer to be:

Warmer	No change	Cooler
○	○	○

2. AIR MOVEMENT

Right now, how acceptable is the air movement at your workspace?

Very acceptable ○ ○ ○ ○ ○ ○ ○ Not at all acceptable

You would prefer:

More air movement	No change	Less air movement
○	○	○

3. AIR QUALITY

Right now, how acceptable is the air quality at your workspace?

Very acceptable ○ ○ ○ ○ ○ ○ ○ Not at all acceptable

4. THERMAL ADJUSTMENTS

During the last (time interval), have you taken any of the following actions (check all)

- ○ Drank a cold beverage
- ○ Drank a warm beverage
- ○ Added a layer of clothing
- ○ Removed a layer of clothing
- ○ Adjusted the window
- ○ Adjusted the thermostat
- ○ Adjusted the fan
- ○ Other action: ______

[example branch]

What adjustment was made to the window?

- I opened a window that was previously closed
- I increased the opening of a window that was already open
- I partially closed the window that was already open
- I completely closed a window that was previously open

Please identify your primary reason for adjusting the window.

- To feel cooler
- To feel warmer
- To increase the air movement
- To let out indoor smells, dust or other pollution
- To conserve energy
- To hear outdoor sounds
- To let in fresh air
- To experience the variety of the outdoor climate
- For nighttime cooling
- A co-worker requests that you open the window
- Management requests that you open the window
- Other:

How effective was opening your window in achieving the desired result?

Very effective ○ ○ ○ ○ ○ ○ ○ Not at all effective