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ASHRAE's Thermal Comfort Standard in America: Future steps away from energy intensive design

Stephen Turner, P.E.

Abstract

The USA experience with ASHRAE Standard 55-2004 Thermal Environmental Conditions for Human Occupancy [1] (ASHRAE 55-2004) is discussed in relation to key questions including:

- When is heating or air-conditioning essential?
- What conditions should be provided?
- Can adaptive behavior influence air-conditioned and naturally ventilated buildings?
- How can thermal comfort standards support more sustainable buildings?
- How can Standards for comfort, indoor air quality, and energy be better correlated?

First, certain implications of the Adaptive Method introduced in ASHRAE 55-2004 are discussed. This method provides a valuable design approach in certain low energy or high performance buildings. Along with the introduction of the Adaptive Method, certain problems have arisen related to the presentation of the Adaptive Method in the standard, not the underlying method. These problems, their short term resolution, and lessons for the long term are detailed.

These include:

- Determining in what locations designers may apply the Adaptive Method year-round
- How to determine what time of year the Method is allowed in temperate climes
- Limitations on applying the Method to mixed mode designs
- Unfamiliar calculations and compliance requirements for the Method

Next, ways in which future thermal comfort standards can support more sustainable buildings are explored in light of four years experience with ASHRAE 55-2004. This paper does not address the practical issues relating solely to conventional application of Predicted Mean Vote – Predicted Percent Dissatisfied (PMV-PPD) in accordance with the Graphical Method and the Computer Model Method in the standard. Rather, issues arising on high performance projects are examined including temporal and spatial uniformity, mixtures of natural and mechanical systems, and the role of individual versus group control.

Some aspects of early experience with a thermal comfort standard that includes both PMV-PPD and the Adaptive Method are summarized here from the perspective of Standing Standards Project Committee (SSPC) 55, the cognizant ASHRAE committee that also hears inquiries and requests for interpretations about the Standard. Resolving these issues can help make future versions of ASHRAE 55 more supportive of a less energy-intensive and unsustainable future.

ASHRAE standards reconceived

In 2004, the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) added the Adaptive Method to its thermal comfort Standard 55. The Adaptive Method provides a relaxed thermal comfort zone for users of the standard to consider for certain naturally ventilated spaces. It also sets aside certain local discomfort and personal factors that must be considered when using the other approaches in the standard. These other approaches, the Graphical Method and the Computer Model Method (predicted mean vote/predicted percent dissatisfied), are aligned with ISO 7730 [2]. The Adaptive Method is proving to be a valuable tool. It provides the basis in an industry standard to users of the standard – particularly owners, designers, and contractors – for lower energy approaches to indoor thermal comfort that incorporate passive natural ventilation systems.

At a Board of Directors meeting in 2006, ASHRAE adopted Sustainability among its other strategic goals. A perspicacious Board member dampened the celebratory rhetoric by noting that the organization was in fact discussing becoming less unsustainable. ASHRAE has historically concerned itself with the means to design, construct, and control indoor thermal environments that are inherently relatively resource (and energy) intensive.

The Adaptive Method in Standard 55-2004 generated early experience with ASHRAE standards reconceived to move more aggressively towards a less carbon-intensive future. The inclusion of the Adaptive Method in Standard 55-2004 brought American practitioners – and SSPC 55 – face to face with a future where ASHRAE standards encompass less resource intensive approaches including passive control of indoor thermal environments.

ASHRAE Standard 55-2004: Impacts and issues

A series of successive limiting points in applying ASHRAE 55-2004 exist: first, mean monthly outdoor temperatures limit the applicability of the Adaptive Method; second, the need to provide indoor conditions within the limits of the Adaptive Method may require mechanical heating systems; third, inability to provide indoor conditions within the limits of the Adaptive Method without mechanical cooling systems may require cooling systems; fourth and finally, when the Adaptive Method does not apply, systems are required to provide indoor conditions within the limits of the PMV-PPD approach. As each of these points is passed, a successively more energy intensive building is required.

When are active systems required?

When is mechanical heating or air conditioning required in a building? How will owners and their project teams determine the answer, so fundamental to energy intensity? In the USA the framework for these decisions is likely to be ASHRAE Standards including 55-2004. With its introduction of the Adaptive Method, certain buildings can be designed to comply with the Standard without necessarily including active mechanical systems, or with less energy-intensive systems in certain cases. The main limitations on using the Adaptive Method are climate and the range of permissible indoor conditions.

Monthly outdoor mean temperature

Very few locations in the world have climates that are conducive to achieving indoor conditions within the limits of the PMV-PPD approach without active mechanical systems. If the mean monthly outdoor temperature is between 10°C (50°F) and 33.5°C (92.3°F), project teams may consider applying the Adaptive Method under ASHRAE 55-2004. This method allows access to less restrictive indoor operative temperature limits, but its climate-based applicability criteria can be restrictive.

Few locations fall within these outdoor limits for twelve months of the year. If the mean monthly outdoor temperature is less than 10°C (50°F) or greater than 33.5°C (92.3°F), users of the standard must use the PMV-PPD method with its more restrictive criteria. Where the upper limit is exceeded, the Adaptive Method is no longer applicable. This is because mechanical cooling will be required, and when such a system is installed the method no longer applies.

Those locations that exceed only the lower limit may still avail themselves of the Adaptive Method for other months of the year, even though a heating system may be required and the methods based on the PMV-PPD approach would apply during the months with mean monthly temperatures below 10°C (50°F). Applicability of the Adaptive Method in these locations is limited to those months where the mean outdoor temperature is above 10°C (50°F) and to those times when indoor conditions can be maintained within the limits of the Adaptive Method without using the heating system.

The Standard does not currently define any limits on calculating mean monthly outdoor temperature. Can one calculate mean temperature based on calendar months, rolling months, or other creatively defined "months" to avoid exceeding limits in the Adaptive Method? This question has yet to be posed to SSPC 55 for formal interpretation, but seems worth addressing. For now, no clear guidance is provided in the Standard. Other potential issues may require treatment in the standard or in formal interpretations: statistical methodology issues such as allowable error in mean data when using non-ASHRAE sources, and the impact of climate change on the validity of predicting weather based on historical data.

Indoor conditions

If passive approaches cannot provide thermal environmental conditions that allow project teams to claim conformance to the standard, then active systems are likely to be included in the project. (Many projects of course do not even pause at this check step – no shame in the many instances where factors of size, occupancy, or climate preclude passive or ultra-low energy solutions.) The requisite indoor thermal conditions when the Adaptive Method does not apply are, of course, those in accordance with PMV-PPD, except where climate conditions allow the alternative Adaptive Method to be applied.

Air-conditioning proscribed?

One central provision of the Adaptive Method has great impact: there must be no mechanical cooling system for the space. Certain projects that might otherwise operate in a passive, natural ventilation mode for much of the time, equipped only with

supplemental cooling for peak periods, must resort to the more restrictive PMV-PPD methods at all times as a result. As outlined above, the approach to heating systems is less restrictive. Heating systems may be installed, but when they are in use the Adaptive Method is not applicable.

What conditions should be provided?

According to ASHRAE 55-2004, indoor conditions are to be in accordance with PMV-PPD, except where the Adaptive Method can be applied with its less restrictive and "sliding" range of thermal limits. (With higher mean monthly outdoor temperatures, the allowable indoor operative temperature range "slides" higher.) Much of the discussion in SSPC 55 today revolves around the virtues of accessing less restrictive thermal comfort zones where applications and situations permit. Current focus is on defining situations in which elevated air speed can appropriately extend the comfort range of operative temperature.

ISO 7730 provides three classes of thermal environment. ASHRAE 55-2004 corresponds closely to "Class B" conditions. Class A conditions can be achieved under ISO 7730 only by constricting the ranges of key thermal environmental factors. Might not an individual in conditions corresponding to Class B, when given individual control of one or more key factors, report thermal comfort commensurate with that in a Class A environment *without* such control? The ergonomic view of more narrowly constrained conditions as the only path to "better" thermal environments seems disconnected from the moral imperative for high performance buildings and their occupants' desires.

Passive systems and occupant controlled operable windows may be capable of maintaining operative temperatures in the sliding range of the Adaptive Method. But if space operative temperature is out of the applicable range, or is predicted to be out of range during design, then the standard abruptly forces the design approach – and presumably the control sequence and operating approach – back into the PMV-PPD method.

One opportunity for refinement in ASHRAE 55 is to clarify the evaluation required to test against the Adaptive Method's limits on outdoor temperatures, as well as the prohibition on its use when mechanical cooling systems are provided for the space.

Mixed mode

Another opportunity for refinement is to avoid requiring abrupt changes in the thermal comfort conditions indicated by the Standard, not only in the context of design but particularly in terms of implications for operating criteria. Under ASHRAE 55-2004, certain key requirements accompany the Adaptive Method. It is not applicable when mechanical cooling systems are provided. Operable windows must open to the outdoors and be readily adjustable by occupants. Furthermore, any heating system installed must not be in operation.

So the Adaptive Method does not apply when engineered natural ventilation systems are not readily adjustable by occupants. Nor does it apply when conventional operable

windows are not readily adjustable by occupants. Can the Method apply when large spaces are naturally ventilated, but only a portion of occupants have access to the adjustments? A less profound question: can "operable" doors or dampers be considered "windows" for the purposes of the Standard?

Designing for "mixed mode" under ASHRAE 55-2004 means operating either with mechanical heating within a more restrictive range of indoor thermal conditions, or without mechanical heating within an expanded range. Does this mean that one is required not only to start mechanical heating to "trim" when passive approaches alone cannot keep conditions within the Adaptive Method range, but also to quickly change the space conditions so that they are within the narrower PMV-PPD range? Such an abrupt transition does not appear consistent with occupant perceptions of thermal comfort. And what control sequence could possibly be devised to "release" the building from PMV-PPD based control and return it to occupant control per the Adaptive Method?

The aspects of ASHRAE 55-2004 which may force a space to veer between disparate comfort ranges present opportunities for future improvement: allowing mixed mode in the simultaneous, rather than sequential, sense; and allowing "trim" with cooling systems as well as heating systems. If true mixed mode operation were allowed, more projects could justify such an approach, and supportive use of mechanical conditioning could lower the energy intensity of their operations.

How can future thermal comfort standards support more sustainable buildings?
Thermal comfort standards can be made conducive to sustainable approaches in design, construction, operation, and modification in several ways:

- By describing any wider ranges of combinations of thermal conditions that may still provide comfort
- By realistically treating transitions between operating states
- By recognizing additional climate, building, and system types where adaptive approaches may apply
- By making it easier for conformance with thermal comfort standards to be demonstrated over a wider range of system types and applications

Thermal comfort standards currently describe certain requisite thermal environmental factors. Exploring the interactions between factors will reveal further opportunities to provide comfort while lowering external environmental impacts. As is well known and accepted in hot climates, draft risk is not a significant concern in many conditions and applications. Rather, occupant control of elevated air speeds allows a higher upper operative temperature limit in many situations. Currently, SSPC 55 is working to incorporate research in this area to modify the treatment of elevated air speed interactions with operative temperature. Valuable work is being performed at the Center for the Built Environment in Berkeley, CA in this area.

Methods of control are addressed in a rudimentary fashion through simplistic limits on temperature drifts and ramps. The language in ASHRAE 55-2004 on drifts and ramps promotes spatial uniformity and temporal constancy, but it may not suffice for those

seeking to apply advanced control techniques to reduce energy intensity without compromising thermal comfort.

And in SSPC 55 there is much interest in the relationship of Heschong's concepts of "Thermal Delight" with the desirability of challenging and exercising occupants' physical regime for thermal control [3]. The author is currently commissioning complex high performance university research facilities with transitional spaces such as semi-outdoor spaces in atria and winter gardens. The LEED® credits that hinge on "meeting" ASHRAE 55-2004 are perversely driving project teams towards increasing the energy intensity of the semi-outdoor spaces in an attempt to document thermal comfort in accordance with the Standard in at least some of these areas. Perhaps the design team could ensure that some percentage of the floor area would provide conditions that conform to the Standard at any given time. But this approach is not guaranteed to earn the project the associated LEED credits. Can future standards incorporate these concepts? This is important because LEED is striving to reference whole standards, not to say "use part of the standard and then deviate to meet our green building goals."

Also unaddressed are interface factors such as the degree of access to shared or individual controls. What is meant by the Adaptive Method's requirement for windows to be "readily adjustable" by occupants? Why must the windows open to the outdoors? Could an engineered atrium adjacent to an office space fitted with operable windows provide the same mechanisms that allow the relaxed comfort zone?

Adaptive behavior in air-conditioned & naturally ventilated buildings

The psychophysiology of self-assessed comfort is complex enough in the context of fully conditioned spaces. Introduce the mitigating effect of self-action provided by occupant control and adaptive effect, and these complexities multiply. What are the key mechanisms underlying adaptive behavior, and how can understanding them help us tailor future Standards better to create more sustainable buildings?

If it is connection with the outdoors that predominates, can that connection be provided in the presence of mechanical cooling, or in the absence of readily adjustable windows to the outside? If it is an individual's access to control that predominates, can a future Standard acknowledge that individual control provides access to relaxed thermal comfort ranges?

Furthermore, in environments where clo (and even met) adjustments by individuals are less restricted, can this notion be incorporated in future Standards? Perhaps such an approach could help resolve an inherent shortcoming in today's treatment of thermal comfort. Restaurants are an example of spaces where different occupants (workers and customers) can have significantly different clo values and met rates. Is there a design approach that can be applied to develop a "compromise" thermal comfort range? Or is the only solution for the designer to simply ask their client which occupant group is to be made comfortable?

Standards for comfort and energy use in buildings

The separation of thermal comfort issues in Standards from issues of indoor air quality and energy use is quite artificial. In reality, trade-offs and interactions in these areas are so extensive that separate treatment is probably a disservice to users of the current Standards.

For many projects, the following dilemma can only be a thought experiment today. Nonetheless, ponder this dilemma. Suppose an owner was presented two competing design options:

- Option One requires more energy intensive systems but provides thermal comfort consistent with ASHRAE 55-2004 (substitute ISO 7730 Class B if you wish, or even Class C to create a similar dilemma)
- Option Two does *not* provide thermal comfort consistent with ASHRAE 55-2004 but provides individual control, elevated air speed in summer, and lower energy intensity

A decision to knowingly create an indoor thermal environment inconsistent with ASHRAE 55-2004 would require considerable courage in the USA today. The outcome could be quite different if the second option could avail itself of a different design path within the Standard, rather than appearing inconsistent with the Standard. To pave the way for a better future, the next generation ASHRAE thermal comfort standard should not create such a false dilemma, but should provide a large enough framework to accommodate a variety of design solutions.

Disintermediated Control

Currently, occupants must "fool" the controls of mechanical systems into providing conditions they find comfortable, where they are afforded control at all. When third parties such as operations or maintenance personnel control conditions, they may have to choose between energy considerations and complaint minimization. Control approaches that bridge this intermediate party such as voting schemes launched in occupants' "system tray" or desktop may require new language in thermal comfort standards. Smart badges encoded with occupants' thermal comfort preferences could allow presence-based control *combined* with individual preferences. Rather than relying exclusively on existing methods in thermal comfort standards, future approaches may be required to address future methods of control.

Conclusion

Since analysis with respect to ASHRAE 55-2004 may drive a project team otherwise inclined to adopt higher energy solutions, the Standard is obviously ripe for improvements that give greater scope to lower energy solutions without compromising thermal comfort. Such improvements could lower the energy intensity (and installed capacity with associated environmental burden) of projects at the borderline of requiring additional systems. As sufficient experience with the Adaptive Method is gained, widening its applicability should reduce the energy and environmental impacts of space conditioning. In this and other ways, thermal comfort standards can continue to evolve in ways that support the evolution of buildings towards a more sustainable future.

References

[1] ANSI/ASHRAE (2004). Standard 55-2004, Thermal Environmental Conditions for Human Occupancy. ASHRAE, Atlanta, USA.

[2] ISO (2005). Standard 7730-2005, Ergonomics of the thermal environment - Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria. ISO, Geneva.

[3] Heschong, Lisa (1979). Thermal Delight in Architecture. MIT Press, Cambridge, USA.