

Improving the Weather:

On Architectural Comforts and Climates

INTRODUCTION

Architecture improves the weather. That is, the indoor climate created by buildings is intended to increase human health, productivity, and happiness while decreasing disease and discomfort. We are more comfortable inside than out. Yet, given comfort's fundamental role to architecture, architects typically outsource its creation to mechanical engineers, who in turn base their designs on the Predicted Mean Vote (PMV) comfort standard. This standard restricts comfort to a narrow band of temperature and humidity that requires significant amounts of energy to maintain.

Global climate change is heightening our collective consciousness of comfort. It is becoming increasingly difficult to separate stable interior climates from changing exterior ones. This growing awareness of comfort has led some building researchers to question the dominant PMV approach. The Adaptive Thermal Comfort (ATC) model is a promising step in this direction. ATC holds that, by allowing indoor climates to change in ways that reflect outdoor ones, the design team can improve building comfort and reduce energy use. ATC currently exists largely as a building standard. Its observations have yet to be embraced by architects as design opportunities to shape building environments. Similarly, ATC researchers have not fully considered how the formal, spatial, and material intelligence architects bring to the design process can further advance the goal of a more comfortable, less energy-intensive architecture. This chapter connects ideas from adaptive comfort research to examples of building design. It demonstrates how architects can consciously improve the weather in ways that relate architecture's material dimensions to its environmental ones.

The 20th-century engineering definition of comfort focused the attention of building professionals on a narrow yet politically effective definition of *comfort*. This limited definition became a discursive vehicle for naturalizing comfort into a matter of technical and legal fact captured in building standards and embodied in the buildings they governed. Yet, when seen historically, comfort appears as a sociotechnical concept that links cultural norms, expectations, and differences on one hand with technical and natural systems on the other. This history shows that the concept of comfort is a rich locus of ideas that is both fundamental to architecture and part of larger interdisciplinary debates. Comfort reflects how the built environment affects health and creates pleasure. It manifests cultural conventions, from temperature preferences and seasonal traditions to notions of privacy and gender identity. It reflects important technical developments that have accelerated since the 19th century and architectural traditions that have faded during this same period. Perhaps most importantly for the challenges facing architecture today, building comfort reflects the social construction of energy use (Shove, 2003). As such, understanding how comfort came to be what it is today provides insights into how it can continue to evolve to address today's unique challenges.

This chapter briefly traces the development of architectural comfort from the 19th century through the one-size-fits-all PMV comfort standard to the bespoke comforts provided by an adaptive approach. It has a hybrid structure. The first part, which outlines the development of a comfort standard in America, is a historical account based on scientific and industry literature regarding comfort. What emerges is a narrative of changing comfort ideals rather than the fixed, "scientifically" determined ideal comfort. The second part is structured around four contemporary buildings that embody ideas of adaptive comfort without explicit reference to contemporary comfort research. These examples flip the narrative of thermal comfort in the 20th and early 21st centuries, defining it through architectural design rather than scientific research. They demonstrate how comfort can be operative in design in ways that affect poetics and performance. The chapter's hybrid approach is intended to overcome the seeming difficulty of translating comfort research into practice. As prominent researcher Richard de Dear recently noted, "A somewhat depressing deduction from the comfort research community is that instead of innovation in

indoor environmental design assimilating our incrementally expanding knowledge of human thermal comfort, the technology itself is driving our concepts and models of thermal comfort” (2011, p. 10). Indeed, the dominance of a technological narrative around comfort skews much architectural writing about the interior environment. To cite a well-known example, the term *well-tempered* figures prominently in the title of Reyner Banham’s *The Architecture of the Well-Tempered Environment* (1969). Yet the book’s focus was an optimistic assessment of the technology of comfort rather than the evolving environmental ideas of comfort itself. To that end, this chapter demonstrates that, for architects to help improve the weather outside of buildings, we must pay more attention to the weather we help to create inside of them.

AN OUTLINE OF ARCHITECTURAL COMFORT STANDARDS

The development of the thermal comfort standards follows a similar trajectory to other engineering standards. The construction historian Bill Addis outlines this process as progressing from empirical rules that capture collective experience to design rules grounded in scientific understanding, and then to scientific rules that specify performance in quantitative terms (2007, p. 610). For comfort, the empirical rules began with building ventilation. In the second half of the 18th century, public health researchers established an experimental link between disease outbreaks and air quality. Prevailing medical theories of the day held that foul or “vitiating” air resulted from people breathing inside enclosed spaces. As one ventilation engineer put it, “Our breath is our own worst enemy” (Leeds, 1871, p. 13). In order to improve the environmental quality inside buildings, early building researchers, including doctors, chemists, and engineers, focused on quantifying ventilation rates, that is, the amount of fresh air that needed to be supplied to indoor spaces (Addington, 2001).

The English engineer Thomas Tredgold was the one of the first to propose ventilation and temperature guidelines based on a scientific understanding of human physiology and building physics. In his *Principles of Warming and Ventilation* (1824), Tredgold combined conventional wisdom with his own experimental results, providing practical “rules” for architects and engineers to calculate, among other

things, the amount of fresh air needed to properly ventilate interior spaces. His recommendation of four cubic feet of fresh air per minute per person was one of the earliest quantitative building ventilation requirements (Tredgold, 1824, pp. 69–73). Tredgold’s discussion of ideal building temperature was less specific. He based his recommendations on building type and gave them in relationship to exterior temperature. Tredgold advised that during the winter dwellings be kept at 60°F, hospitals at 50°F, and prisons left unheated, and during the summer interior temperatures be limited to 5°F above exterior conditions by using fans to increase air movement.

In the latter half of the 19th century, Hermann Rietschel applied the newly understood principals of thermodynamics to ventilation and temperature standards. As chair of heating and ventilation at the Royal Technical School in Berlin, Rietschel held the first academic position in the field and established one of the first academic research laboratories to study these issues. He published his findings in German in 1894, and they appeared in English in 1927 as *Heating and Ventilating: A Handbook for Architects and Engineers*. There Rietschel gives ventilation rates based both on rules of thumb and on his own research in an auditorium affiliated with his laboratory. These rates were generally higher in the summer, presumably to increase cooling by increasing airflow (Rietschel, 1927, p. 129). Despite Rietschel’s greater understanding of the mechanisms of heat transfer, he based his approach to temperature standards on “customary” practice. In the *Handbook*’s opening chapter, Rietschel provided a list of desirable indoor temperatures that, like Tredgold’s, was organized by building type. Churches and jails (for “overnight use only”) were to be kept at 50°F; lecture rooms, prisons, and business offices at 65°F; and bathrooms at 72°F. In a brief commentary on these temperature guidelines, Rietschel recognized the impact of humidity, air movement, and radiant heat on comfort conditions without quantifying how they would alter target temperatures. He ended the chapter in an otherwise scientifically based book by stating ideal comfort conditions could be described by the popular expression “warm feet and cool head” (Rietschel, 1927, p. 4).

Tredgold’s and Rietschel’s approaches to the indoor environment combined scientific rules and research with common practice to propose building ventilation rates and temperature guidelines. While

standard ventilation rates were quantitatively specific, temperature standards were based on common practice and varied depending on use and the weather outside. It would take both technological developments and social forces at the start of the 20th century for these factors to coalesce into the idea of a comfort standard expressed in quantitative terms and based on scientific rules.

ASHVE Comfort Research

The American Society of Heating and Ventilating Engineers (ASHVE) was formed in 1895, in part to establish a scientific basis for heating and ventilation practice in the United States. This included incorporating the new technology of air conditioning into engineering practice. Initially developed for humidity-sensitive industrial processes such as printing and food processing, air conditioning was increasingly being used in spaces designed for human occupancy such as department stores and cinemas. Unlike industrial processes, where interior climate standards were set based on the efficient production of a product, comfort cooling for people had no objective metric on which it could be based. ASHVE members saw the development of such a comfort standard as an important goal for their organization. As a commentator in an industry journal, *The Weather Vein*, noted, “One of the Engineer’s most effective safeguards against loss of public confidence is the development of fixed, rational standards and determination of precise finite values that he may express himself with an exactness which ensures understanding” (Cooper, 1998, p. 70). In building public trust through such an engineering standard, ASHVE took comfort standards to the next stage outlined by Addis, with scientific rules used to specify performance in quantitative terms.

The research used to establish such a comfort standard was conducted in a climate chamber at ASHVE’s Research Bureau, which opened in 1919 at the Bureau of Mines in Pittsburgh, Pennsylvania. *Climate chambers*, also called *psychrometric*, *environmental*, or *air conditioned chambers*, were well-insulated, windowless, and air conditioned rooms in which temperature and humidity could be precisely set and independently controlled. They developed in the early 20th century as an essential piece of laboratory equipment for the new academic field of industrial hygiene. Industrial hygiene researchers

studied how the environmental conditions found in factories and on job sites affected workers' health, from extremes of temperature and humidity to chemical exposures (Sellers, 1977, pp. 141–186). Climate chambers allowed industrial hygiene researchers to recreate industrial environments in a laboratory setting, where the response of subjects could be closely studied. Unlike the extreme industrial environments of blue-collar work, ASHVE researchers used their climate chamber to identify ideal conditions for white-collar office environments.

The premise for ASHVE's research was that comfort resulted from the heat balance between a body's interior environment and the external environment surrounding it. This idea built on French physiologist Claude Bernard's concept of the "*milieu intérieur*," the body's internal environment, which was separate from the environment in which it lived (1879). The American Walter Cannon later elaborated on this idea of self-regulation with the concept of *homeostasis* in his poetically named book, *The Wisdom of the Body* (1932). Homeostasis described how a living organism maintained a steady-state internal condition despite being part of a dynamic, open system. Although Bernard and Cannon related their idea to a variety of biological functions, ASHVE researchers were interested in how it applied to temperature regulation in the body. They reasoned that when the heat produced by metabolism was balanced with a room's environmental conditions, people felt comfortable. Based on this connection between a body's physiological functioning with the building's mechanical system, lab researchers hypothesized that there must be different combinations of temperature and humidity that produced equally comfortable conditions. To test this hypothesis, researchers had test subjects stay in their climate chambers under a variety of environmental conditions. Initial experiments tested different combinations of dry bulb temperatures and relative humidity, which they synthesized into the new scale of "effective temperature." (Later experiments tested other environmental parameters, including air speed and radiant heat.) Upon exiting, subjects were asked to rate how comfortable they found those conditions. By 1924, researchers published a Comfort Zone Chart that organized their results graphically onto a psychrometric chart. This showed a limited band of effective temperature in which half of the subject felt comfortable,

as well as a comfort line at which 97% of them considered themselves comfortable (ASHVE, 1924).

[Figure 1. Caption here.]

Buildings soon began to resemble climate chambers where interior environments were thermally separated from exterior ones. This played out in greater attention to building wall insulation (Moe, 2014), airtightness, and most visibly, windows. As one ASHVE commentator memorably put it, when a building has operable windows and no air conditioning, employees tend to blame nature for their discomforts. But when a building has air conditioning, they blame the building's management (Leopold, 1947, p. 304). Tenants in the Milam Building in San Antonio, Texas (1928), the first air conditioned office building, were prohibited by lease agreements from opening their windows because it made managing the air conditioning system too difficult. [Figure 2. Caption here.] Individual comfort control was instead surrendered to a building engineer who was responsible for managing the comfort of all building occupants. In more extreme examples, windows themselves were eliminated from buildings. The first windowless office building was built in 1935 for the Hershey Chocolate Corporation in Hershey, Pennsylvania. [Figure 3. Caption here.] Touted as “the latest contribution of science to business” and for its energy efficiency, the building was thought to create a healthier work environment at lower costs. Weather information was communicated to building occupants through colored lights beneath wall clocks.

By 1938, ASHVE fulfilled one of the original goals for the Research Bureau when, together with the American Society of Refrigerating Engineers (ASRE), it issued the “Code for the Minimum Requirements for Comfort Air Conditioning.” The document set out minimum design requirements for air conditioned spaces, including design temperatures and relative humidity ranges. In doing so, it translated the scientific research conducted by ASHVE into engineering practice. By putting the comfort conditions in the language of a building standard, the groups aimed for their large-scale adoption by the building industry. (ASHVE merged with ASRE in 1959 to form ASHRAE, the American Society of Heating, Refrigerating and Air-Conditioning Engineers.) By 1966, ASHRAE revised and reissued this material as *ASHRAE Standard 55-66: Thermal Comfort Conditions*. This ASHRAE standard later served as a model

for the International Organization for Standardization's comfort standard, *ISO 7730: Ergonomics of the Thermal Environment*.

Predicted Mean Vote Comfort Research

Despite ASHVE's and later ASHRAE's extensive comfort research, conclusions about ideal comfort conditions became less certain. By 1961, their comfort chart included the qualification that "there is no precise physiologic observation by which comfort can be evaluated" (Nevins, 1961, p. 68). This uncertainty led to growing frustration among the organization's members, who wanted clear direction upon which to base their mechanical designs. By the early 1960s, ASHVE recognized that the comfort zone had lost the authority it once held and began planning a comprehensive reevaluation.

This goal was realized by the end of the decade with Danish researcher P. O. Fanger's Predicted Mean Vote (PMV) comfort model, a more sophisticated and decidedly more useful model than had been previously proposed. Working at Kansas State University's Institute for Environmental Research and later at the Technical University of Denmark, Fanger established a comfort model based on climate chamber research and useful to the building industry. Like ASHVE before him, Fanger based his work on the premise that comfort resulted from the heat balance between a body and its environment. Unlike the graphic method of depicting comfort on a psychrometric chart that included two variables, dry bulb temperature and relative humidity, Fanger's "comfort equation" addressed six: dry bulb temperature, relative humidity, mean radiant temperature, and air velocity, as well as two personal variables—activity level and the insulation value of clothing. Using early computer technology, researchers could solve this equation to determine which combinations of variables created heat balance between the subject and environment. Fanger also went a step further, reorganizing this data to predict how many people would find specific combinations of conditions thermally acceptable. Referred to as Predicted Percentage Dissatisfied (PPD), Fanger considered conditions comfortable when 80% or more of occupants were satisfied with the building's interior climate. Importantly, such satisfaction reflected a condition of thermal neutrality, where building occupants did not object to interior environmental conditions, rather

than one of thermal pleasure. In his book *Thermal Comfort* (1970), Fanger claimed there were no national, geographic, or seasonal variations in these ideal comfort conditions. In fact, he asserted that any deviation from a quasi-steady-state thermal environment would only result in a greater number of people being dissatisfied (Fanger, 1970, pp. 85–95).

In 1992, Fanger’s PMV model was adopted into the *ASHRAE 55* comfort standard. With this addition, it became a scientific rule that specified performance in quantitative terms, the last stage outlined by Addis. Starting in the 1960s, ASHRAE’s focus on comfort shifted from laboratory research into ideal comfort conditions to political advocacy promoting its comfort standard within the building industry. As one ASHRAE member commented, “Adoption and implementation [of standards] are fundamental to achieving the purpose addressed by ASHRAE standards because until a standard is formally codified and adopted it is voluntary and has no major bearing on technology or construction practice” (Comstock, 1995, p. 106). It would take another research method, one that expanded upon the heat-balance basis for comfort, to challenge the dominance of the PMV model.

New Perspectives on Thermal Comfort

As Fanger was advocating for the thermal neutrality of sealed building enclosures, another group of researchers was investigating an adaptive approach to comfort that linked interior conditions to exterior weather. This approach developed from field studies in which researchers asked building occupants to assess how comfortable they found their interior environments. Unlike the laboratory-based climate chamber work, field studies reflected the real-world conditions found in existing building with a diversity of populations. Generally, these studies demonstrated a connection between preferred interior climates and the weather outside. A group of ASHVE researchers had conducted similar field studies in the early 1940s and were aware that they showed different preferred comfort conditions than had been found with climate chamber research. A 1942 report on the field studies recognized that comfort preferences could vary based on age and gender and that people accustomed to different exterior climates had different interior comfort expectations. The report concluded, “The impossibility of pleasing everyone is evident in

air conditioned buildings” (Chester, 1942, p. 122). It would take several decades for such observations to be formulated into a new comfort model.

Adaptive Thermal Comfort

Starting in the 1970s, a new generation of university-based comfort researchers began to develop the Adaptive Thermal Comfort (ATC) model. Led primarily by Fergus Nicol and Michael Humphreys in England, and later Gail Brager at the University of California, Berkeley, and Richard de Dear in Australia, researchers found that occupants of naturally ventilated buildings considered themselves comfortable over a wider range of temperatures than were anticipated by the PMV model (de Dear & Brager, 1998; Nicol, Humphreys, & Roaf, 2012). [Figure 4. Caption here.] In other words, the PMV model lost its predictive ability when interior climates were connected to exterior ones. To explain this, ATC researchers proposed that there were adaptive factors affecting comfort beyond the body’s heat balance with the surrounding environment. These researchers attributed thermal adaptation to three different processes: behavioral adjustment, physiological acclimation, and psychological expectation. Behavioral adjustments included changes a person might make to their immediate environment, such as opening a window, taking off a sweater, or taking a break from work in the heat of the day. Physiological adjustments were changes to how the body reacts to the thermal environment. These ranged from acclimatization that can happen in a matter of weeks to genetic changes that happened on an evolutionary time scale. Psychological changes are the result of altered perception of and reaction to thermal information based on past experiences and expectations. The adaptive approach recast building occupants as active agents in shaping their comfort through these processes rather than as passive recipients of comfort conditions as implied by the PMV model.

ATC researchers also demonstrated that connecting interior comfort conditions to exterior weather saved energy. An adaptive comfort approach reduced building energy use since it allowed temperatures to float over a wider range that more closely followed exterior conditions. Later research qualified that, in commercial buildings, for each 1.8°F shift out of the thermally neutral zone, energy

required to condition interior spaces was reduced by roughly 7% (Arens, Humphreys, de Dear, & Zhang, 2010, p. 5).

Like ASHRAE researchers before them, proponents of ATC looked to building standards as a way to turn scientific research into building practice. But, unlike the PMV model, the ATC standard has not been widely adopted in practice. Due largely to the efforts of Brager and de Dear, the Adaptive Thermal Comfort model was included as an alternative compliance method starting in the 2004 version of the *ASHRAE 55* standard. However, the language adopted in the standard specified that the adaptive option was only applicable to buildings without mechanical cooling systems. It further stipulated that the standard could be used only when the prevailing mean outdoor temperature fell between 50°F and 92°F, and the heating system was not in operation. Such restrictions significantly limited when and where the ATC model could be used. They also suggested a crude bifurcation between air conditioned buildings designed with the PMV standard and naturally ventilated ones designed with the ATC model. This false dilemma stymied design teams exploring hybrid or complementary uses of these two approaches, such as mixed-mode buildings that can operate with either natural or mechanical ventilation, depending on exterior conditions. Instead of becoming part of a design choice about how to integrate comfort decisions into the form and operation of the building, *ASHRAE 55* suggested that comfort was the choice of a single standard.

Alliesthesia

Despite the limited application of ATC through *ASHRAE 55*, adaptive comfort researchers have continued to expand our understanding of the thermal environment in ways that are suggestive to architects. Recent research has examined the physiological basis of thermal pleasure through the idea of *alliesthesia*.

Alliesthesia describes how a stimulus can be experienced as either pleasant or painful, depending on a subject's internal state. Initially proposed by the French physiologist Michel Cabanac, the term comes from *allios*, meaning “changed” and *esthesia*, meaning “sensation” (1971). In psychological terms, *alliesthesia* describes the mechanism of perception—the interpretation of a stimulus—rather than that of

sensation—the recognition a stimulus. Take, for example, two subjects, one with an elevated body temperature and the other with a lowered body temperature. If both subjects were to put their hands into water at 110°F, both would sense that the water was warm. However, the subject with the lowered body temperature would find the perception of warmth pleasant due to their lower body temperature, while the subject with the elevated body temperature would find it unpleasant due to their higher body temperature. As Cabanac writes, “Pleasure is actually observable in transient states, when the stimulus helps the subject return to normothermia,” that is, normal body temperature (2000, p. 41).

Adaptive comfort researchers became interested in alliesthesia to explain why people could have different reactions to the same environmental conditions. That is why occupants of naturally ventilated spaces found specific conditions acceptable while occupants of air conditioned buildings found these same conditions unacceptable. Behaviorally, physiologically, and psychologically adaptive processes explained how this happened; alliesthesia explained why.

In reconsidering Cabanac’s work, comfort researchers have extended his observations to distinguish between spatial and temporal alliesthesia (Parkinson, de Dear, & Candido, 2016). *Spatial alliesthesia* refers to the experience of different thermal stimuli on parts of the body, such as the “warm feet and cool head” that Hermann Rietschel had used to describe ideal comfort. It recognizes the skin as a “sensory bellwether” that anticipates the future thermal state of the body. *Temporal alliesthesia* refers to temporary variations in thermal experiences over relatively short periods. Such experiences form part of the thermal texture of everyday life, such as moving from a patch of shade into the sun on a winter walk, or rounding a street corner and stepping into a cool breeze on a humid summer day. We can also find such transient thermal experiences in building spaces such as vestibules, lobbies, and even parking garages that serve as transition spaces between interior and exterior climates.

An important conclusion drawn from alliesthesia research is that thermal pleasure is unattainable in a thermally neutral state. That is, the static conditions prescribed by the PMV model are incapable of providing thermal pleasure because they are based on maintaining a static heat balance between the body and the environment. In fact, the spatial and temporal variations that alliesthesia describes as sources of

pleasure are discouraged by the PMV model. Vertical air temperature differences, asymmetrical radiant fields, and local convective cooling (labeled “drafts”) are considered “localized discomfort” and should be eliminated under PMV conditions. Alliesthesia, on the other hand, shows that there needs to be a thermal difference, however small, between subjects and their thermal environment in order for the subjects to experience pleasure.

In a certain sense, the insights of comfort research over the past 50 years have moved in an opposite direction from the PMV model found in ASHRAE’s comfort standard. Adaptive thermal comfort and alliesthesia have linked interior comfort to exterior weather, energy savings, and thermal pleasure, while the PMV model has restricted comfort to the energy-intensive, artificial conditions of thermal neutrality. As Richard de Dear has lamented, our expanding knowledge of thermal comfort has unfortunately not translated into innovative environmental design. Instead, design teams rely largely on building equipment to drive concepts of comfort. Yet this is not entirely true. Some contemporary architectural practices are connecting architecture’s material qualities with its environmental ones. Instead of the one-size-fits-all approach to comfort of Fanger’s model, these architects are designing bespoke comforts that connect the physical but invisible aspects of comfort to a building’s formal, spatial, and material choices in ways that improve the weather both inside and outside of buildings.

BESPOKE COMFORTS

Comfort is typically seen as an unremarkable dimension of architecture. When historians and critics attempt to define what is essential to architecture, what makes it different from other arts, they often focus on form, space, and materials. Comfort is not seen as an essential quality. This lack of attention may be related to the modern habit of connecting comfort largely with mechanical equipment rather than with architectural design. A seldom-noted paradox of architectural modernism is that while new materials, such as steel, reinforced concrete, and plate glass, visually connected indoor and outdoor spaces, contemporary environmental technologies thermally separated indoor and outdoor climates. Regardless of its origin, this limited understanding of comfort is ripe for redefinition. In the second half of this chapter, I

shift narrative registers from a historical account of comfort research to a reading of four contemporary projects and their different design-based approaches to comfort. These projects are emblematic of how some architects are creating bespoke comforts that are integral to a building's design. I chose this set of examples in part because of their diversity. They have different forms, sizes, material assemblies, clients, programs, sites, and geographic regions. Such diversity demonstrates that designers can think with comfort in many different contexts. I also chose these projects because each has received the attention of design juries and critics, some of whom acknowledge the importance of comfort to the individual project. In highlighting the role of comfort in each project and connecting the projects to other works by the architects and by others, I argue that comfort can and should be seen as an essential architectural quality. Such a reading recognizes the cocreation of architecture and its environment and follows a vein of recent scholarship in architectural history that incorporates insights from the environmental humanities (Hochhäusl et al., 2018).

Combining these historical accounts and project narratives is an attempt to bridge the gap between comfort research and architectural design. Comfort standards have clearly been an effective technique in promoting the wide-scale adoption of a steady-state thermal comfort model. But they have been considerably less effective in promoting a more nuanced idea of adaptive comfort. Approaching comfort through architectural design offers another avenue to advance this important set of ideas. These examples highlight how comfort is an essential quality of architecture in two important and related ways. First, they position comfort as a cultural value for architecture. This insight recalls Lisa Heschong's argument in her soft manifesto, *Thermal Delight in Architecture*. There she argues that the thermal environment has the potential for "sensual, cultural roles and symbolism that need not, indeed should not, be designed out of existence in the name of a thermally neutral world" (Heschong, 1979, p. 17). Framing comfort as a cultural value that is socially defined moves it beyond the largely scientific and technical understanding of the term that has grown over the past century to encompass a broader, historically nuanced meaning. While Heschong illustrated her appeal largely with biological and anthropological examples, here I extend her appreciation of thermal delight to contemporary architectural projects where

the overlapping concerns of comfort and construction can be clearly seen. Second, by making explicit connections between the interior climate and the exterior one, comfort can be another way to bring architecture into larger environmental discussions about climate change beyond current approaches to energy efficiency. In changing the indoor climates in ways that reduce energy use and improve comfort, architects can simultaneously help to positively improve the weather outside by reducing carbon emissions associated with buildings.

Life Science Building (2024)

The proposal for a new university Life Science Building by the French practice Bruther in collaboration with the Belgian firm Baukunst engages adaptive ideas of comfort through its formal organization and material selection. Won through an invited competition, the project is located on the campus of the University of Lausanne, next to the Swiss Federal Institute of Technology, and close to SANAA's Rolex Learning Center (2010). This strategic location, with views south toward Lake Lemman and north toward the Alps, was chosen to unite the two campuses using a shared program dedicated to research and teaching.

The building is a compact 290,000-square-foot cubic volume over seven floors. Floors 2 through 6 contain a central laboratory zone surrounded by a wide ring of classrooms, meeting rooms, and offices. These are evenly divided in two, with one half dedicated to teaching chemistry and biology, and the other to neuroscience and microbiology research. [Figure 5. Caption here.] This intermediate zone is surrounded by a wide perimeter ring for circulation and public spaces that features several sculptural stairs for interfloor circulation. The six floors of classrooms and offices intersect three double-height perimeter spaces, which bring light into this intermediate ring of the plan through internal windows. [Figure 6. Caption here.] The top floor houses an auditorium and restaurant under a series of narrow gable roofs. The building is clad with a largely transparent greenhouse-like skin with large operable panels and integrated sun shading. The building's structure and services are clearly separated to allow for future

reconfiguration as teaching and research needs change, a decision for which the architects cite the influence of British high-tech architecture, specifically the work of Richard Rogers.

The Life Science Building is organized like an environmental onion, where nested layers of climate control relate to spatial and programmatic organization. Here the laboratories, which have the strictest environmental requirements, are located in the center surrounded by the classrooms, meeting rooms, and offices with looser requirements. These in turn are encircled by the perimeter zone, which serves as a permeable layer between the exterior and interior climates. Part winter garden, part social condenser, the perimeter zone mixes the climatic and the communal. This multiheight area thermally buffers indoor spaces from less favorable weather outside, or it can be opened through operable windows on the façade to mix these two climates. Bruther designed similar compact, flexible spaces in its award-winning New Generation Research Center in Caen, France (2015). Beyond Bruthers' own buildings, these climatically flexible spaces recall the work of the French firm Lacaton & Vassal. Their use of industrial materials and "extra space," from the small-scale Latapie House (Floirac, France, 1993) to recent public housing transformations in Bordeaux (2016), has influenced a younger generation of architects who consider the interior climate as part of a design brief.

The Life Science Building's layered organization and permeable perimeter provide a variety of adaptive comfort opportunities. The operable façade allows occupants to adjust the immediate climate in the perimeter. Additionally, as the sun moves across the sky during the day, making brighter and warmer areas and putting other areas into a cooler shade, people can experience a range of climates simply by walking around the perimeter. Moving radially through the different layers of the environmental onion also creates different comfort conditions. Researchers, who spend a majority of their day in the central windowless laboratory's controlled climate, could alleviate their thermal boredom by leaving the lab, going through the intermediate ring and into the perimeter zone, with each successive layer bringing greater thermal texture. Moving in the opposite direction, students coming to class or lab would experience a moment of acclimation in the perimeter zone before moving into the more protected central areas. While comfort researchers could describe such experiences with the terms *temporal alliesthesia*,

behavioral, and *physiological adaptation*, here the architects have foregrounded comfort for a diverse population of faculty, researchers, and students as an essential feature of their project's spatial, formal, and material organization.

International House Sydney (2017)

A university building with diverse programs and environmental requirements offers many opportunities for bespoke comforts, but commercial office space is much more homogeneous, and the industry is resistant to non-PMV comfort conditions. ASHRAE and ISO standards contain three categories of environmental quality for mechanically cooled office buildings. The higher the class, the smaller the deviation allowed from “ideal” environmental conditions and the greater the amount of energy required (Arens, Humphreys, de Dear, & Zhang, 2010). Given the more challenging parameters of this project type, the International House Sydney (2017) by Tzannes takes an innovative approach to indoor comfort through its material choice of timber. [Figure 7. Caption here.]

The International House Sydney was the first commercial engineered-timber building of its size and type in Australia. It was built and is managed by Lendlease, an international construction, property, and infrastructure group headquartered in Sydney. The site, located on Darling Harbor, was formerly a dockland where timber wharves and warehouse buildings stood. It now sits on the western edge of the city's central business district. The 75,000-square-foot building has five floors of office space supported by spruce and beech glulam columns and beams, with CLT (cross-laminated timber) walls and floors. This wooden structure sits on top of a two-story commercial base with a conventional concrete structure and a colonnade made from raked solid ironbark columns. The timber frame is clad with a low-iron glass façade that showcases the wood within. Interior stairs are located on the building perimeter and are designed to be an inviting alternative for vertical circulation. On the interior, the wood structure dominates, while exposed ducts, conduits, and pipes hung from the ceiling are painted a matte black. Chilled radiant beams provide cooling. Together with a decoupled outside air supply system, these systems create a more varied interior climate than the typical air conditioned office.

The exposed timber frame forms the building's exterior image and helps to shape its interior environment. Viewed in the context of downtown Sydney, the wood contrasts with the surrounding palette of aluminum and steel, creating the building's unique identity. In its marketing literature, Lendlease claims that the building's wood interior is beneficial to the health and well-being of its tenants. There are some indications that wood has a positive psychological impact, but its effect on the comfort of building occupants is not well studied (Nyrud & Bringslimark, 2010). Recent research has looked at how people experience building materials through a combination of tactile and visual senses. It has shown that the impression of warmth corresponds largely to visual perception, which is directly affected by color and indirectly affected by a material's thermal effusivity, that is, how quickly heat transfers from one material to another. (Wastiels, Schifferstein, Heylighen, & Wouters, 2012). Architect and theorist Kiel Moe has argued that a material approach to comfort that links tactile and visual perception on one hand with physical material properties like thermal effusivity on the other points toward a larger agenda for energy in architecture through "thermodynamic depth" (2014, pp. 188–227). Certainly, given the increasing use of wood in large-scale commercial and residential buildings, architects need to ask how the experience of this "sustainable" material affects thermal comfort. Comfort researchers could also contribute to this investigation by considering how psychological adaptation to wood may affect the perception of comfort. While the International House Sydney relies on mechanical systems to connect interior and exterior climates (albeit unconventional ones), Tzannes makes a compelling case for the role of material experience as an underexplored avenue to provide novel comforts in the conservative context of commercial real estate.

House for Trees (2014)

The Vietnamese architect Vo Trong Nghia has built a substantial body of work that finds adaptive opportunities for thermal pleasure in the country's tropical climate, a climate historically considered "uncomfortable" by comfort researchers and the air conditioning industry (Chang, 2016). Nghia built the House for Trees (2014) in the Tan Binh district, one of Ho Chi Minh City's densest residential

neighborhoods. The single-family house consists of five individual volumes, informally arranged around an irregularly shaped interior courtyard. [Figure 8. Caption here.] These volumes also act as “pots” for large trees, which give the house its name. Each structure contains a single program on each of its two levels. These include a kitchen, dining room, and library on the first floor and separate bedrooms on the second. The external walls are made from concrete cast in bamboo-lined formwork, giving them a highly textured surface, and a withe of local brick lines the interior. The extended family can use the outdoor spaces for more than circulation, occupying these unprogrammed areas as they choose and as the weather allows.

Nghia links the House for Trees to Ho Chi Minh City’s tropical urban climate through what he calls “green architecture” (Harikae, 2016, p. 8). This approach directly integrates plants into a building’s appearance and performance. Yet Nghia’s ambition for the idea extends beyond individual projects. With rapid urbanization, cities in Vietnam have lost much of their open space. Nghia calculates that Vietnam has the lowest amount of green space per capita of any East Asian city (2016). With his “green architecture,” Nghia wants to use buildings to bring greenery back into cities in a way that reaffirms their tropical character. Nghia has built many such “green” buildings, from private homes like the recent Breathing House (2019) and the Stepping Park House (2018) to the larger Atlas Hoi An Hotel (2016) and the Nanoco office building (under construction). The House for Trees was one of the first such projects, and one for which he developed a novel plan strategy.

The domestic garden typically acts as an outdoor foil to interior spaces, while at the House for Trees, the garden and interiors work together to form a matrix-like plan. In his essay on domestic space, the critic and historian Robin Evans contrasted Renaissance matrix plans, where enfilade connections between rooms provided for social mixing, with 19th-century corridor plans, where separate rooms fostered privacy and independence (1997). Evans argued that matrix plans encourage “passion, carnality, and sociality” and that corridor plans encourage “segregation” of people and uses. Pavilion-type matrix plans can be found elsewhere, most notably in SANAA partner Ryue Nishizawa’s Moriyama House (2005) in Tokyo (Cruse, 2019). (Nghia received his architectural training in Tokyo.)

At the House for Trees, Nghia uses the matrix plan to extend his idea of “green architecture” to integrate architecture and landscape and to create a variety of adaptive comfort opportunities. The rooftop trees shade the volumes and the outdoor spaces below, providing welcome coolth while the buildings’ thermal mass further buffers the tropical conditions. Exterior spaces connect to interior ones through doors and large operable panels. Moving between inside and outside, residents acclimate to small but significant yearly changes in the weather. Living space can expand or contract as furniture is moved between inside and out during different times of the year. Even the green roofs are occupiable as part of this domestic landscape. When the exterior climate become too extreme, such as during the summer rainy season, the interiors can become thermal refuges by closing the doors and turning on the air conditioning.

Beyond Nghia’s impressive portfolio, a younger generation of Vietnamese architects—including Tropical Space, Sanuki Daisuke Architects, a21studio, and NishizawaArchitects—are making buildings marked by the meteorological effects of a tropical climate. Historically, colonial powers have taken a negative view of tropical regions, seeing them as disease-ridden with economically backward, lethargic populations. With a postcolonial perspective, these Vietnamese architects are using their buildings, and the adaptive opportunities for comfort they provide, to create positive images and experiences of this same climate. In doing so, they demonstrate that comfort reflects climatic and cultural conditions.

Lleialtat Santsenca Civic Center (2014)

Harquitectes’ Lleialtat Santsenca civic center (2014) transforms a historical structure in Barcelona’s Sants neighborhood by connecting adaptive reuse to adaptive comfort. Built within the shell of a former workers’ cooperative, the architects kept the building’s civically important façade while removing the roof and interior walls. They then reorganized the interior using a linear atrium to create an open circulation spine under a new translucent roof. [Figure 9. Caption here.] The atrium is lined on one side by the existing load-bearing masonry wall. On the other side, Harquitectes inserted a scaffold-like steel and wood structure that encloses fixed programmatic spaces, including meeting rooms, classrooms, and a large performance hall.

The building's new roof connects the atrium's interior climate with the mild Mediterranean climate outdoors. Its gabled shape spans the shell of the existing building with open web steel joists. These are covered with translucent polycarbonate panels on the south-facing slope and opaque insulated metal panels on the north. In the winter, sun through the polycarbonate helps to warm the atrium, which has no active heating system. In the summer, hot air is exhausted through operable panels at the roof's peak, driving the stack effect and drawing in air below to ventilate the atrium. Solar curtains beneath the roof can be used to adjust the interior climate, either to reflect away unwanted solar radiation or to trap warm air below. Relying on the roof to mediate between indoor and outdoor climates works well in a dense urban context where adjacent buildings and other constraints limit what can be done with the wall surfaces. Harquitectes later used a similar lightweight performative roof on top of a largely historic masonry shell at their Cristalleries Planell civic center (2016), also in Barcelona.

The climate of the Lleialtat Santsenca atrium is used to buffer the more tightly controlled program space inside the steel and wood addition. This new volume has an air conditioning system for heating and cooling, and sits under its own interior roof. Depending on the weather outside and conditions in the atrium, either tempered exterior air from the atrium is drawn into the rooms, or the rooms exhaust conditioned air into the atrium where it is drawn out of the building through the roof. Formally, this relationship inverts the nested layers of an environmental onion, where less controlled rings surround a central protected zone. Here the central zone of the atrium acts like a lung for the building, connecting the exterior climate to the controlled spaces along the building's edge. Neighborhood residents walking into the Lleialtat Santsenca from the street would first experience the thermal pleasure of temporal alliesthesia in the atrium's tempered climate. Depending on their plans, they might remain there, using one of the informal meeting areas along the length of the atrium. Or they might go into one of the climate-controlled rooms for an event or performance.

In their essay "Organizing Matter," the four founders of Harquitectes explain their approach to using the solid material of architecture to shape the fluid flows of air and energy. One can easily understand this material-focused approach as creating a variety of climates and comforts. Referring to

spaces like the Lleialtat Santsenca atrium, they write, “We like these intermediate spaces, where users feel a proximity to exterior conditions, but with added improvement” (Harquitectes, 2016, p. 151). Here the building’s material and formal organization literally improves the weather. This organization of matter, which combines adaptive reuse and adaptive comfort, recalls critic and architect Luis Fernández-Galiano’s metaphorical description of an “architecture of rehabilitation” as an “architecture of the second principle” (2000). This comparison between the energetic process of entropic degradation and the reuse of old buildings focuses attention on how the embodied energy of architecture also embodies the cultural values of memory and history. At the Lleialtat Santsenca, adaption is an energetic and a cultural process.

The four examples discussed here create bespoke comforts by integrating adaptive ideas with a diversity of design approaches. These range from the compact formal organization of the Life Science Building to the dispersed one of the House for Trees. The material palette can be limited as in the International House Sydney or expansive like the Lleialtat Santsenca civic center. The concept of comfort even stretches beyond the immediate context of the buildings to say something about larger climatic and social conditions, as in the case of tropical Vietnam and historical Barcelona. All the projects provide a uniform level of comfort through artificial climate control when and where it is needed, but each creates connections between interior and exterior climates in unique ways that are integral to their specific conditions.

Seen collectively, these visually appealing projects demonstrate that adaptive comfort can contribute to architecture’s image-based aesthetic culture. One should not underestimate the importance of giving a contemporary visual identity to the experience of comfort through projects such as these. As historians of technology remind us, there is no innovation without representation. In order for adaptive ideas to gain attention within the design community, architectural comfort needs to be recognized and celebrated through such images.

CONCLUSION

Architecture improves the weather through attention to comfort. To do this, architects need to understand comfort in new, more expansive ways. During the 20th century, comfort became understood through the narrow but politically effective PMV model. This prescribed a limited band of environmental conditions that a majority of people were expected to find thermally neutral. Such conditions were provided almost exclusively by mechanical equipment and largely without the design input of architects. Spread through the wide-scale adoption of ASHRAE's comfort standard, this limited understanding of comfort became naturalized as a matter of technical and legal fact. Comfort researchers unhappy with this limited idea of comfort developed an adaptive approach that reduced energy demands while allowing for experiences of thermal delight. The emergence of the ATC model highlights the fact that comfort is historically conditioned by social circumstances as well as by technical developments. Comfort ideals change over time and when considered by different groups.

The historical account and contemporary examples presented here demonstrate how architects think about comfort in ways that are different from but complementary to how comfort researchers think about it. Ideas originating in the research community should be of interest to the design community. Spatial and temporal alliesthesia can engage architects' spatial and temporal intelligence and imagination in the design process. Behavioral adaptations rely on architectural choices such as flexible plan configurations and operable façade elements. And psychological adaptation can be triggered by diverse environments within a building's interior climate. Similarly, essential elements of architecture such as massing, spatial organization, and material choices deserve to be considered by researchers for their effects on comfort. Clearly, there needs to be more dialogue between these two groups, establishing a common ground between their different areas of expertise. For architects, consciously addressing comfort as a fundamental design consideration can expand their professional purview to directly shape interior environments and to improve buildings' energy performance. For comfort researchers, understanding how adaptive comfort opportunities are embedded in building design can help to direct research in ways that are more readily translated into practice. Collectively such work counters the dominant narrative that energy savings result in reduced comfort while sharing a commitment to a more thermally pleasurable

and less energy-intensive architecture. In recognizing these common goals, both groups can work to bring this expanded notion of comfort to a wider group that includes manufacturers, clients, and building occupants.

Comfort is good to think with. A design-based approach to comfort can improve the impoverished sensoria commonly created in building interiors. It can activate architects' environmental imagination to propose novel design solutions that address the pressing challenges of climate change. And it can demonstrate not only how architecture improves the weather but how the weather can improve architecture.

REFERENCES

- Addington, D. M. (2001). The history and future of ventilation. In J. D. Spengler, J. M. Samet, & J. F. McCarthy (Eds.), *Indoor air quality handbook* (pp. 2.1–2.16). New York, NY: McGraw-Hill.
- Addis, B. (2007). *Building: 3000 years of design, engineering and construction*. New York: Phaidon Press.
- Arens, E., Humphreys, M. A., de Dear, R., & Zhang, H. (2010). Are 'class A' temperature requirements realistic or desirable? *Building and Environment*, 45(1), 4–10.
- ASHRAE. (1960). *Heating, ventilating, air conditioning guide*. New York, NY: ASHRAE.
- ASHVE. (1924). Celebrate thirty years of progress. *Journal of the American Society of Heating and Ventilating Engineers*, 30(3), n.p.
- Banham, R. (1969). *The architecture of the well-tempered environment*. Cambridge, MA: MIT Press.
- Bernard, C. (1879). *Leçons sur les phénomènes de la vie communs aux animaux et aux végétaux*. Paris: J. B. Baillière.
- Cabanac, M. (1971). Physiological role of pleasure. *Science, New Series*, 173(4002), 1103–1107.
- Cannon, W. B. (1932). *The wisdom of the body*. New York, NY: W. W. Norton.
- Chang, J.-H. (2016) Thermal comfort and climatic design in the tropics: An historical critique. *The Journal of Architecture*, 21(8), 1171–1202.

- Chester, Thomas, et al. (1942). Comfort with summer air conditioning. *ASHVE Transactions*, 48, 107–122.
- Comstock, S. (1995). *Proclaiming the truth: An illustrated history of the American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.* Atlanta, GA: ASHRAE.
- Cooper, G. (1998). *Air-conditioning America: Engineers and the controlled environment, 1900–1960.* Baltimore, MD: Johns Hopkins University Press.
- Cruse, A. (2019). The temperature of a SANAA. In B. Wilke (Ed.), *Ryue Nishizawa / SANAA: Grace Farms* (pp. 62–69). New York, NY: Applied Research and Design.
- de Dear, R. (2011). Revisiting an old hypothesis of human thermal perception: Alliesthesia. *Building Research & Information*, 39(2), 108–117.
- de Dear, R. J., & Brager, G. S. (1998). Developing an adaptive model of thermal comfort and preference. *ASHRAE Transactions*, 104(1), 145–167.
- Evans, R. (1997). Figures, doors and passages. In *Translations from drawing to building*. Cambridge, MA: MIT University Press, 54–91.
- Fanger, P. O. (1970). *Thermal comfort: Analysis and applications in environmental engineering.* Copenhagen, Denmark: Danish Technical Press.
- Fernández-Galiano, L. (2000). *Fire and memory: On architecture and energy* (G. Cariño, Trans.). Cambridge, MA: MIT Press.
- Harikae, A. (2016, July). Vo Trong Nghia Architects. *Architecture and Urbanism*, 550.
- Harquitectes. (2016). Organizing matter. *2G: Harquitectes*, 74.
- Heschong, L. (1979). *Thermal delight in architecture*. Cambridge, MA: MIT Press.
- Hochhäusl, S., Lange, T., Adams, R. E., Barber, D. A., Bierig, A., Cupers, K., ... Vronskaya, A. (2018). Architecture and the environment. *Architectural Histories*, 6(1), 1–13.
- Houghten, F. C., & Yaglou, C. P. (1923). Psychrometric chart with equal comfort lines or effective temperatures for still air. *ASHVE Journal*, 29, 165–176.
- Leeds, L. (1871) *Treatise on ventilation*. New York, NY: John Wiley & Sons.

- Leopold, C. S. (1947). Conditions for Comfort. *ASHVE Transactions*, 53, 295–306.
- Moe, K. (2014). *Insulating modernism*. Boston, MA: Birkhäuser.
- Nevins, R. (1961). Psychrometrics and modern comfort. *ASHRAE Transactions*, 67, 609–621.
- Nghia, V. T. (2016, December). *Lifestyles in Asia in the future—Ideas from history, culture and the environment* [Video file]. Retrieved from <https://www.youtube.com/watch?v=PSdD16ox48s>.
- Nicol, F., Humphreys, M., & Roaf, S. (2012). *Adaptive thermal comfort: Principles and practice*. New York, NY: Routledge.
- Nyrud, A. Q., & Bringslimark, T. (2010). Is interior wood use psychologically beneficial? A review of psychological responses toward wood. *Wood and Fiber Science*, 42(2), 202–218.
- Parkinson, T., de Dear, R., & Candido, C. (2016) Thermal pleasure in built environments: Alliesthesia in different thermoregulatory zones. *Building Research & Information*, 44(1), 20–33.
- Rietschel, H. (1927). *Heating and ventilating: A handbook for architects and engineers* (C. W. Brabbee, Trans.). New York, NY: McGraw-Hill.
- Sellers, C. (1977). *Hazards of the job: From industrial disease to environmental health science*. Chapel Hill: University of North Carolina Press.
- Shove, E. (2003). *Comfort, cleanliness and convenience: The social organization of normality*. New York, NY: Berg.
- Tredgold, T. (1836). *Principles of warming and ventilation*. London, England: M. Taylor.
- Wastiels, L., Schifferstein, H. N. J., Heylighen, A., & Wouters, I. (2012) Relating material experience to technical parameters: A case study on visual and tactile warmth perception of indoor wall materials. *Building and Environment*, 49(1), 359–367.
- Yaglou, C. P. (1932). How to use the effective temperature index and comfort charts. *ASHVE Transactions*, 38, 411–423.

ADDITIONAL READING

- Brager, G. S., & de Dear, R. J. (1998). Thermal adaptation in the built environment: A literature review. *Energy and Buildings*, 27(1), 83–96.

- Brager, G. S., & de Dear, R. J. (2003). Historical and cultural influences on comfort expectations. In R. J. Cole & R. Lorch (Eds.), *Buildings, culture and environment: Informing local and global practices* (pp. 177–201). Oxford, England: Blackwell.
- Chang, J.-H., & Winter, T. (2015). Thermal modernity and architecture. *The Journal of Architecture* 20(1), 92–121.
- Chappells, H., & Shove, E. (2004, March). *Comfort: A review of philosophies and paradigms*. Retrieved September 2019 from http://www.lancs.ac.uk/fass/projects/futcom/fc_litfinal1.pdf.
- Crowley, J. (2001). *The invention of comfort: Sensibilities & design in early modern Britain & early America*. Baltimore, MD: Johns Hopkins University Press.
- de Dear, R. J., Akimoto, T., Arens, E. A., Brager, G., Candido, C., Cheong, K. W. D., ... Zhu, Y. (2013). Progress in thermal comfort research over the last twenty years. *Indoor Air*, 23(6), 442–461.
- Murphy, M. (2006). *Sick building syndrome and the problem of uncertainty: Environmental politics, technoscience, and women workers*. Durham, NC: Duke University Press.
- Prieto, E. (2014). The welfare cultures: Poetics of Comfort in the Architecture of the 19th and 20th Centuries. In F. Graf and G. Marino (Eds.), *Les dispositifs du confort dans l'architecture du XXe siècle* (pp. 58–67). Lausanne, Switzerland: Presses Polytechniques et Universitaires Romandes.
- Shove, E., Walker, G., & Brown, S. (2014). Material culture, room temperature and the social organization of thermal energy. *Journal of Material Culture*, 19(2). 113–124.

KEY TERMS AND DEFINITIONS

Adaptive Responses: Factors that affect thermal comfort beyond the body's heat balance with the surrounding environment. There are generally considered to be three adaptive responses: behavioral adjustment, physiological acclimation, and psychological expectation. The response recasts building occupants as active agents in shaping their comfort rather than as passive recipients of comfort conditions.

Climate Chamber: A windowless room in which temperature and humidity can be precisely set and independently controlled. Also called *air conditioned*, *environmental*, or *psychrometric* chambers.

Heat Balance: A mechanistic approach to comfort based on the idea that when the heat produced by metabolism is balanced with a room's air temperature and humidity, people feel comfortable.

Predicted Percentage Dissatisfied (PPD): An estimation of how many people will find PMV comfort conditions thermally satisfactory. Danish comfort researcher P. O. Fanger, who developed the PMV comfort model, considered conditions acceptable when 80% or more of occupants were satisfied with the building's interior climate. Importantly, such satisfaction reflected a condition of thermal neutrality, where building occupants did not object to interior environmental conditions, rather than one of thermal pleasure.

Predicted Mean Vote (PMV) Comfort Model: Developed by comfort researcher P. O. Fanger, the PMV comfort model equates comfort with the heat balance between a body and its immediate environment. It is based on the four environmental variables of dry bulb temperature, relative humidity, mean radiant temperature, and air velocity, as well as the two personal variables of activity level and the insulation value of clothing. It is typically associated with cool, dry still air provided by air conditioning in which people are largely sedentary and wearing typical business attire.

Spatial Alliesthesia: The experience of different thermal stimuli on parts of the body as captured by the folk expression describing comfort as resulting from "warm feet and cool head."

Temporal Alliesthesia: The experience of temporary variations in thermal experiences over relatively short periods of time, such as moving from a patch of shade into the sun on a winter walk, or rounding a street corner and stepping into a cool breeze on a humid summer day.

Figure 1. Comfort Zone for Humans at Rest, 1924. (Credit: ASHVE [1924]. Celebrate thirty years of progress. Journal of the American Society of Heating and Ventilating Engineers, 30[3], n.p.)

Figure 2. Milam Building, San Antonio, TX, 1925. George Willis was the architect and Willis Carrier oversaw the design and installation of the air conditioning system. (Credit: Author's collection.)

Figure 3. Modern office building, Hershey, PA, 1935. Designed by D. Paul Witmer. (Credit: Author's collection.)

Figure 4. The PMV comfort model loses its predictive ability in naturally ventilated buildings. While in a centrally controlled HVAC building (left), predicted comfort conditions match what was observed in field studies; in a naturally ventilated building (right), field studies showed building occupants preferred a wider range of temperatures than predicted by the PMV model. (Credit: de Dear, R. J., & Brager, G. S., [1998]. Developing an adaptive model of thermal comfort and preference. ASHRAE Transactions, 104[1], 145–167.)

Figure 5. Schematic plan for the new Life Science Building (Bruther and Baukunst, 2024 anticipated). The plan is organized as an environmental onion, with the spatially nested layers of thermal control related to programmatic organization. (Credit: Bruther.)

Figure 6. Proposed view into the perimeter zone of the Life Science Building (Bruther and Baukunst, 2024 anticipated). Part winter garden, part social condenser, this buffer space allows for the mixing of interior and exterior climates. (Credit: Bruther.)

Figure 7. Exterior view of the International House Sydney (Tzannes, 2017) in the new Barangaroo area of the city's central business district. (Credit: TKTGTK.)

Figure 8. Exterior view of the House for Trees (Vo Trong Nghia Architects, 2014). Each of the house's five volumes acts as a planter for large trees that shade the buildings and garden spaces beneath. The unprogrammed courtyard spaces serve a variety of uses as part of the house's matrix plan. (Credit: © Hiroyuki Oki.)

Figure 9. Atrium view looking toward the main entrance of Harquitectes' Lleialtat Santsenca (2014).

(Credit: Harquitectes.)