A Possible Connection between Thermal Comfort and Health

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ABSTRACT

It is a well-established fact that cardiovascular health requires periodic exercise during which the human body often experiences significant physical discomfort. It is not obvious to the exerciser that the short-term pain and discomfort has a long-term positive health impact.

Many cultures have well-established practices that involve exposing the body to periodic thermal discomfort. Scandinavian saunas and American Indian sweat lodges are two examples. Both are believed to promote health and well-being. Vacations often intentionally include significant thermal discomfort as part of the experience (e.g., sunbathing, and downhill skiing). So people often intentionally make themselves thermally uncomfortable yet the entire foundation of providing the thermal environment in our buildings is done to minimize the percentage of people thermally dissatisfied. We must provide an environment that does not negatively impact short-term health and we need to consider productivity but are our current thermal comfort standards too narrowly defined and do these standards actually contribute to longer-term negative health impacts?

This paper examines the possibility that the human body thermoregulatory system has a corollary relationship to the cardiovascular system. It explores the possibility that we have an inherent need to exercise our thermoregulatory system. Potential, physiological, sociological and energy ramifications of these possibilities are discussed.

Background

Since the creation of thermal environments that foster the survival of human beings is a critical development for our species, it is almost certain that the informal study of what thermal comfort requires predates all written history. In the archaeological record we see evidence of central hearths in early buildings and evidence of fire is almost universal when we find remnants of early buildings. Usually the fires are associated with cooking, but especially in the temperate climates it is most probable that the fires also provided heat. Archaeological/anthropological recreations of these early habitations provide good examples of how the buildings created thermal environments which if not providing real comfort at least provided acceptable thermal environments for life. The archaeological record indicates that when a particular solution had been reached in some historical society, the patterns were repeated. It is probable that the design solutions were passed from one generation to the next in a combination of oral and practical manner. Since most of these early examples predate written language there is no written record of the rational for selecting particular design solutions.

From one culture and climate to another the solutions can be quite variable. Hot desert climates will often have very ingenious solutions for localised cooling with enhanced ventilation and evaporation of water. Buildings in the tropics can show wonderful solutions for protection from rainfall while enhancing the natural movement of air currents for cooling. The use of passive solar energy was widespread across many parts of the world. Cultures that had to cope with cold climates developed complex solutions, combining clothing, buildings for groups of individuals and controlled fires for artificial heat. Some of the first documented formal studies are concerned with the creation of improved fireplaces and stoves. The American inventor and statesman, Benjamin Franklin developed a cast iron fireplace insert, which significantly improved both combustion efficiency as well as providing enhanced radiative heat transfer.

Prior to the development of the scientific method these early studies are poorly documented and almost certainly rather haphazard in their methodologies. However, when modern researchers have examined some of the historical approaches that were applied by ancient societies to provide artificial cooling it is clear that they were fairly advanced (Berger, 1998). Roman aqueducts were used not simply to supply fresh water for drinking but also to supply excess water for gardens and fountains that provided shade and evaporative cooling which significantly lowered the air temperature of Roman cities during the hot summers of the Mediterranean region.

More formal work on human comfort began in the early 1900's. Much of the early work focused on human physiology and performance rather than on thermal comfort. Similar work to improve understanding of the actual physical processes that allow the human body to adapt to different temperatures continues to this day. Much of that work is focused on the performance of soldiers in extreme conditions.

A common early reference in thermal comfort literature is Bedford (1936). The seven-point thermal sensation scale he developed for that study is still in use; however the ASHARE (1993) seven-point scale has found wider application in recent studies. Bedford's work was a survey of factory workers and he measured both the physical characteristics of their environment as well as their perceptions of that environment. Very similar studies of this type continue to the present.

It is logical to study thermal comfort by conducting surveys of real occupants in real buildings since the whole purpose of HVAC systems in buildings is to satisfy the requirements of the occupants. There are however complications with field studies that make the drawing of definitive conclusions difficult. Real conditions and real people in real buildings have so many simultaneous variations that it is difficult if not impossible to really isolate the driving variables. To help solve that problem, laboratory studies have been conducted. Generally these laboratory-based studies have taken a more theoretical approach than field studies. The ability to more closely control variables in the laboratory settings made this possible.

Thermal comfort criteria, as imbedded in standards ASHRAE Standard 55 (ANSI/ASHRAE 1993) and ISO Standard 7730 (ISO 1994) are based on a long-standing research tradition of the need to provide thermal environmental conditions in buildings that minimize thermal discomfort. The standards refer to this as minimizing the percentage of people dissatisfied (PPD). The research behind the numbers imbedded in the standards was conducted in comfort chambers under carefully controlled conditions (Fanger 1970, Doherty 1988, Oseland 1995). Ole Fanger conducted the initial research and documented it as part of his PhD thesis. The original comfort chamber exposures were conducted in Kansas and Denmark. Initially young male graduate students, subjected to three hours exposure wearing a standard suite of casual American clothes, dominated the subjects. Subsequent work was extended to include more females and samples of older individuals. The results appear to be repeatable and have been generalized in the standards. In many places, e.g., Scandinavia and much of the United States, the building occupants appear to be reasonably satisfied with the thermal environments specified by the standards.

However, the comfort chamber environment is an abstraction of reality. Individuals wear an artificial set of clothes. For repeatability the same shirts and khaki trousers used in the initial exposures in Kansas in the late sixties are still used. The subjects sit in a closed room for a few hours, doing artificial tasks periodically answering a thermal comfort questionnaire. There is no press of daily business, no distraction from co-workers or traffic and the subjects are focused on their thermal environment. Considering the artificial nature of the environment characterized by the exposure experiments, one could be surprised that the results provide thermal guidelines that have been successfully applied in real living and working environments.

Field research on the subject is not as definitive. Some field studies have revealed that in some cultures building occupants are thermally satisfied with conditions outside of the conditions predicted by current theory (Humphreys 1976, Baker 1995, Sharma 1986, Busch 1992). To date there is no consensus providing uniform explanation for field studies with thermal comfort results outside of those conditions predicted by the standards. A proposal is making its way through the approval process to modify ASHRAE Standard 55, allowing wider temperature variation for buildings that are naturally ventilated as an effort to make allowance for field observed thermal comfort variations (Brager 2000). Some researchers believe that occupants in building with natural ventilation accept a different set of thermal conditions compared to occupants in buildings with mechanical ventilation, which is reflected in the proposed standard modification (Humphreys 1981, Busch 1992).

The theoretical foundation behind existing thermal comfort standards is a physics-based description of a social science experiment. Individuals expressed satisfaction or dissatisfaction with thermal environments that Fanger summarized in a set of equations. This set of equations establishes a theoretical human body in thermal equilibrium with its environment. Metabolic based heat gains are offset with heat losses through conduction, convection, radiation and evaporation. The thermal comfort equations account for variations in activity level, posture, clothing insulation, air movement, plus dry bulb, wet bulb and radiant temperatures (Anderson 1999). The theory is well developed and widely accepted yet cannot adequately explain anomalous field experiments. The calculation is also relatively difficult to make under conditions often found in the field. In practice, simplifying assumptions are employed to enable calculations of estimated thermal comfort. One possible explanation of apparent anomalous results is that the assumptions imbedded in the particular calculation were incorrect and not reflective of the actual situation as expressed in the theory. Still, the theory falls short in providing any easy answer to the anomalous field results (de Dear 1998, Schiller 1990).

We know from the geographical dispersion of the human species that mankind can accommodate to widely varying temperatures. Without any modern thermal conditioning machinery, humans populated much of the world, from the artic, through temperate regions to the tropics. This was accomplished through the use of clothing, controlled fire and relatively simple shelters. Successfully living in the artic or the tropics does not imply that the inhabitants of those regions were thermally comfortable in historical periods, but they established successful populations and apparently prospered. It is possible that some of the racial variation seen in the human species may be explained by evolution to accommodate different climate conditions. The minimal trunk perspiration seen in Inuit populations and nighttime skin cooling variation found in Australian aborigines are two examples (Ruff 1994).

We also know that humans can adapt to different thermal environments. There is short-term adaptation where the body adjusts metabolism, blood flow and sweat glands production. Research by the military has demonstrated that soldiers living and training in one thermal environment need about ten days to achieve full performance in a significantly different thermal environment (Prosser 1958). There is also evidence that a longer-term adaptation occurs, some of which may be nonreversible. For example, individuals raised in hot dry climates have a different distribution and use of sweat glands compared to individuals raised in temperate environments (Roberts 1978). Limited research has been conducted on longer-term thermal adaptation so there may be other changes that are not yet recognized.

Even with the recognition that short-term and long-term thermal adaptation occur, ASHRAE 55 and ISO 7730 provide a single set of standards for all populations in all climates. This simple contradiction may be the single most important element driving a reexamination of the fundamental theory. Because human physiology and behavior adapts, a standard based solely on physics may not be adequate.

Compounding the problem is the fact that thermal environment satisfaction is impacted by expectations. The field studies research illustrates that different cultures may have different thermal comfort responses (Humphreys 1976, Stoops 2001). These different comfort responses appear to include the occupants' thermal expectations. The motivating factor or factors behind those thermal expectations remains unanswered. Some aspects of changing expectations over time in modern culture are discussed in Shove (2003). She points how conceptions of normality can change over time and have profound impacts on how humans deal with their daily life.

The very nature of thermal comfort research is based on assumptions that some may find peculiar. Comfort itself is an abstract concept relating to contentment and well-being. When faced with measuring thermal comfort it is necessary to first think about thermal discomfort. The typical 7-point thermal comfort scales range from hot to cold. Thermal comfort is expressed as a perception of thermal neutrality. In other words, an individual is thermally comfortable when they feel neither too hot nor too cold. It is not the temperature one may prefer to experience; it is the temperature one does not complain about. Temperature standards for buildings are designed to minimize those dissatisfied (PPD) not maximize the percentage of people thermally content. Dissatisfaction is probably inherent in human psychology and projecting onto one's thermal environment is likely unavoidable to some degree.

Cardiovascular Analogy

Over the last few decades, medical science has firmly established the connection between regular vigorous exercise and cardiovascular health. The exact amount and level of exercise necessary has yet to be established with certainty, but there is essentially uniform agreement that a healthy heart requires regular exercise. Diet, overall body weight, and exposure to risk factors (like smoking) are also important elements, but exercise is one of the critical factors (Wasserman 2002).

Often, this exercise experience can be less than pleasant to the exerciser. The saying used by weightlifters, "no pain no gain," has an element of truth. The exercise to condition the heart must be sufficiently robust to increase the pulse and respiration rate for a significant period of time. At a minimum, the exerciser is aware of exerting physical effort and in fact could be said to be performing a kind of physical work. Current medial and scientific knowledge agree that a healthy cardiovascular system requires that the system be exercised. There is not agreement regarding the degree of exercise necessary to realize health improvements. Some would say the exercise must be at level sufficient to cause some level a discomfort, while others suggest that even moderate exercise will have a positive impact on health. If asked during the exercise – are you comfortable – the exerciser would likely answer in the negative. Post exercise, there may be other feelings. If the exercise is sufficiently severe, the body may have released endorphins, which provide the exerciser with a calm feeling of satisfaction. This is sometimes called the runner's high. However during the exercise period itself, some feeling of discomfort is to be expected

Like the cardiovascular system, the thermoregulatory system is controlled by the sympathetic autonomic nervous system. In fact the two systems are interrelated. Increases in exercise levels that drive increased cardiovascular activity also increase metabolic heat output that must be balanced by the thermoregulatory system. However, unlike the cardiovascular system, there is no scientific recognition that the thermoregulatory system may itself require exercise for health. In fact, our entire effort in conditioning our living and working environments is to provide thermal conditions that minimize thermal discomfort. We therefore are intentionally minimizing the use of our thermoregulatory system with the way we build and condition our buildings.

We have no real health-based physiological reason to condition the buildings in the manner laid out in ASHRAE Standard 55 and ISO Standard 7730. Both these standards are built around the assumption that the goal should be to minimize thermal discomfort of building occupants. It is obvious that we need to provide conditions in our buildings that avoid hypothermia and hyperthermia yet we condition much beyond those needs. We also need to consider productivity in our buildings and that likely will require significant heating and cooling. However, it could be questioned that the standards go too far, limiting the thermal stimulation to occupants that they could actually need for long-term health. There is no current scientific justification for this alternative scenario, but it deserves further examination since the existing theory falls short of providing explanations with complete consensus.

Evidence of the Need for Thermal Stimulation

Besides the field studies noted above where building occupants appeared thermally neutral under conditions outside of that predicted by the thermal comfort equations there are other pieces of evidence. The Building Owners and Management Association (BOMA) periodically surveys occupants in member buildings (BOMA 1997). Invariably the top two complaints deal with thermal dissatisfaction i.e., building spaces are too hot or too cold. So even with the considerable effort and resources devoted to providing thermal comfort in modern buildings, occupants are not satisfied. This is especially interesting when cultures with close thermal control in buildings (Scandinavia) are compared to cultures with less stringent thermal control (Southern Europe). There does not appear to be direct relationship between improved thermal control and improved thermal satisfaction (Stoops 2001).

One can also think more abstractly about thermal satisfaction. Consider for example, how and where people choose to spend their time away from their every day lives. I.e., where do they spend their vacation? And perhaps even more telling, when they spend money for voluntary travel, where do they go? The author could not locate specific travel destination statistics but asks the reader to consider the following thoughts and to compare them with their own experiences.

It is not uncommon to intentionally take a vacation to a place where relatively extreme thermal conditions will be experienced. For example, the Greek Islands are a dream destination for many. On this vacation, the typical day might be spent in air temperatures and direct radiant conditions so severe as to induce removal of essentially all clothing to minimize overheating. To offset the overheating that still occurs, the vacationer would likely periodically submerge the whole body in cool water, likely leading to overcooling. The overheating and overcooling cycle could be repeated several times a day. Compounding the discomfort is the likely sunburn causing thermal discomfort sensations and sub-dermal pain even under neutral thermal conditions. People choose to do this and often do it repeatedly over a lifetime. Of course there are other reasons for going to the Greek Islands such as food, history and lack of urban bustle. However, it appears that the thermal aspects are important to many vacationers. There are other locations one could choose to vacation that would include everything except access to beaches for sunbathing but they are not as popular as those locations that include the opportunity for sunbathing.

Going to the other extreme, consider a vacation in the mountains in the winter. Temperatures can be so cold that hypothermia is a real danger unless proper clothing is worn and precautions are taken. Vacationers often choose to spend all day outside, exposing themselves to rapid air movement aggravating their thermal sub-cooling as they glide down the mountain on their skis. After spending the day on the slopes, literally freezing certain parts of their anatomy, they will then sit for hours in front of an open fire subjecting the same or other parts of their body to severe radiant overheating. Or perhaps they may choose to overheat in a hot tub or maybe a sauna. Based on experience and conversations with colleagues, a winter skiing vacation can be an absolutely wonderful experience. Again, the thermal discomfort aspects may be an element in the pleasure one experiences.

Many cultures have traditions, some of which even have spiritual elements that encompasses a kind of hot air bathing. Finnish sauna, Turkish hamman, Native American sweat lodge or inipi, Russian bania, and Japanese mushi-buro or furo are examples. Since saunas have become relatively wide spread through marketing, the word sauna is used more or less generically to describe hot air bathing. A common belief for hot air bathers in all these cultures is that they receive health benefits from the sauna experience. Practioneers can develop a strong devotion to what they perceive as the positive benefits they receive with a regular sauna. The spiritual element may have at its foundation this extreme devotion to the personal benefits some practioneers believe they experience. Consider the extreme thermal conditions found in a sauna. It is typically completely off thermal comfort charts, yet individuals actively and positively choose to subject themselves to these conditions.

The belief in the health benefit from saunas is strong enough to have driven some research. The increased thermal stress does induce an increase in the pulse rate as the body moves fluid about in a effort to maintain thermal equilibrium. This illustrates the close connection between the thermoregulatory and cardiovascular systems. One can induce heart muscle exercise by overheating the body. If the devotee takes regular saunas, it is possible that cardiovascular health benefits are received. Other studies, with less conclusive results have tried to quantify the flushing from the body of harmful substance with the extra perspiration induced by the sauna experience. The sauna is used in some recognized detoxification programs that make use of this phenomenon (Finnish Medical Society 1988).

Of course there is a strong element of choice relating to these examples of humans intentionally exposing themselves to thermal discomfort. In addition these exposures are generally for limited time periods and there is usually the opportunity to easily retreat to a more neutral thermal environment. Still it provides an interesting contrast to modern societies' generally accepted goals for building environments. Humans often choose to expose themselves to thermally uncomfortable conditions and after those exposes can feel recharged or invigorated. Even something as simple as a walk outside in cool air can provide a delightful change in a person's attitude and ability to work effectively.

Ramifications

If there is a basic need or perhaps even only a marginal health benefit from exercising the thermo-regulatory system, what would that mean? It could change our understanding of human health and the impact on health from the environments we create for ourselves. It could also impact how society views those environments and the kinds of things we do to create and maintain the thermal environment in our buildings. It could also impact our need and use of the natural resources we consume to create and maintain those environments.

Physiological

We know that a purely physics based model of thermal comfort falls short of fully explaining the thermal comfort response we see in building occupants. We also know that there remains significant dissatisfaction with the conditions we provide in buildings. In extreme cases, we also know that modern buildings can have a negative impact on the health of their occupants, expressed as sick building syndrome (SBS). Some sufferers of SBS seem to develop something akin to an allergy to the indoor environment of a building or buildings (Burt 1999). Often, increased ventilation will remediate the problem but we continue to lack full understanding of the SBS phenomenon. Building occupants often complain about the temperature, or stale air, or lack of the ability to open fenestration. Could all these occupant complaints relating to indoor environments be unconscious efforts at expressing a more fundamental need for thermal stimulation? Does this lack of stimulation somehow contribute to SBS?

Is the basic need for thermal stimulation the reason humans use saunas and seek thermal discomfort experiences as part of recreation activities? We know that cardiovascular health requires exercise and that the thermoregulation and cardiovascular systems are closely related. It is almost counterintuitive that cardiovascular health requires efforts that induce physical discomfort. It is not unreasonable to therefore postulate that we also need to exercise our thermoregulatory system as part of a healthy lifestyle.

The author has not identified any research project where these possible physiological connections have been examined with the central premise being that humans have an inherent need to exercise their thermoregulatory system. Lisa Heschong (1979) identified a possible alternative approach, postulating that thermal stimulation could be desirable in the same way that strong and interesting flavors can provide a positive sensual experience but her work falls short of an actual health connection. With the evidence in hand and the lack of complete success from existing theory, explorations following a new avenue like this would be appropriate. At a minimum, this issue should enter the current dialogue as another potential element of understanding the relationship between humans and the indoor environment we create in buildings.

Sociological

If the existing thermal comfort standards are indeed based on incorrect or incomplete theoretical foundations, it presents rather unique and interesting social challenges. It seems inconceivable that a standard would be promogulated that would intentionally induce thermal discomfort in building occupants. It may be that the occupants' health could be positively impacted by such a standard, but the mechanism and justification whereby it would be required to make building occupants uncomfortable for their own good would be very difficult or even impossible in today's society.

Even with the knowledge of the lifestyle (food, exercise, minimize inhaled pollutants, etc.) required for a healthy cardiovascular system, there is widespread disregard of these claims by much of society. Without extremely strong evidence that some kind of periodic thermal discomfort is necessary for health, it is extremely unlikely that standards like ASHRAE 55 and ISO 7730 will be modified in a way that would allow or even encourage thermal discomfort. Potentially, norms could be adjusted and expectations shifted, but it would likely be a difficult and slow process. A start would be definitive research of the issues and questions outlined in this paper. However we should also note that pursuing such a research path implicitly assumes that the pursuit of health maximization is desirable, regardless of the costs.

The entire question of involving social science in the issue of thermal comfort may be the first and most difficult barrier. The engineering community accepts the existing standards because they are based on physics. Physics is perceived by many as the purest and most definitive science. Engineers can therefore readily accept physics based standards, even if the applications result in occasional problems. But the focus of what we're doing with the environments we create in buildings should be the people for whom they are created. To involve people means we must include the richness and variability of humans and their societies. We must involve the social sciences and that will always mean the answers will be complex and hard to express with mathematic equations. It will be difficult to include social aspects; whether it is adaptation, expectation or some other "soft" concept in a standard that must be developed, accepted and used by engineers.

Energy

Maintaining the thermal conditions mandated by ASHRAE 55 and ISO 7730 require significant expenditures of energy. Any control strategy that allows temperatures to vary more than allowed by the standards could reduce energy consumption (Zmeureanu 1992). It is also possible that the research will demonstrate that the thermal stimulation is required in a way that would increase energy consumption, for example, occasional overheating in the winter. It seems probable that some thermal stimulation could be achieved by simply allowing the building to more closely track the outdoor temperatures in all seasons with occasional naturally occurring warm spikes due to solar gain and occasional cool spikes driven by local conditions of temperature and wind. In a way, the building could emulate the conditions seen in naturally cooled buildings that field research has demonstrated as having acceptable thermal environments outside of that predicted by the current standards. If indeed, this kind of buffered, yet floating within bounds thermal environment is acceptable to occupants, it would reduce energy consumption compared to buildings controlled within a narrow temperature dead band. A buffered temperature control standard should also reduce the peak energy demands and overall capacity of the heating and cooling systems,

Heating and cooling represents only a fraction of total building energy consumption. Most studies have estimated this fraction be from one-third to one-half of total building consumption with significant variation across climates. Prior examinations of floating/buffered indoor temperature control resulted in between five and ten percent total energy reductions. Peak reductions would be a larger percentage since heating and cooling represents a larger fraction of peak loads compared to average loads.

Discussion

The basic premise of the need to provide closely controlled thermal environments in modern buildings is widely accepted, even if as illustrated in this paper the scientific foundation is less than conclusive. Questions relating to the potential desirability of thermal stimulation by providing an environment outside that established by the current standards have not been explored. Building occupants have persistent and growing problems with indoor environments, yet the scientific community is reluctant to question the very foundations of the need for providing the currently recommended thermal environment.

Rather than continue to explore the requirements and need for the environments we provide in our buildings, current response to emerging problems is to believe it is necessary to control the environment even more stringently. The current explanation and focus of sick building syndrome is the need to provide higher fresh air flows. This is done in face of the evidence that occupants desire naturally ventilated buildings and more direct control of their environment with operable windows and easy to use daylighting.

Hopefully this paper can serve to inspire the questioning at a fundamental level, the current assumptions about indoor thermal comfort. Clearly our current understanding and explanations are not adequate yet there is little current research asking basic questions. We need to examine basic assumptions about the indoor environment we recommend in our standards and implement in our buildings if we ever hope to reverse the growth of occupant dissatisfaction. Sick building syndrome could simply be a symptom of much more basic issues and sets of human needs that our buildings are not satisfying.

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