Auteurs Susan Roaf[1] en Fergus Nicol[2]

1. Emeritus professor Heriot-Watt Universiteit (BAHons, AA Dipl, PhD, ARB, FRIAS)
2. Professor London Metropolian en Oxford Brooks Universiteit

Acceptabele temperaturen in natuurlijk geventileerde gebouwen

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Acceptable Temperatures in Naturally Ventilated Buildings

Susan Roaf and Fergus Nicol

Introduction: The Natural Ventilation Imperative

In a Post-COVID-19 world we must move towards a time when most buildings are naturally ventilated, liberated from 20th century narratives of 'ideal comfort temperatures' and motivated by the growing imperatives to design for:

1) Lowering CO_2 emissions: Driven by higher energy demand in 2018, energy-related CO_2 emissions rose 1.7% to a historic high of 33.1 Gt CO_2 globally[i]. Up to 40% of these emissions come from buildings. Over the past three decades, homes and offices have become ever more light-weight, unshaded, over-glazed, tight-skinned and mechanically air-conditioned and ventilated. They increasingly lack thermal mass to absorb, release or store excess heat for zero-energy night-time heating or day-time cooling[ii]. Pitifully few have effective natural ventilation systems, either simple or advanced[iii], and sensible opening windows. The fastest way to dramatically reduce CO_2 emissions from, buildings would be to mandate safe opening windows in all new buildings, and refurbishments, to enable them to be run for as much of a day and a year as possible on free, natural, energy[iv]. Studies show up to 80% of building energy running costs can be achieved by this one step alone[v]. However, despite vast investment in 'energy efficiency' programmes, the opposite of this is still happening with building regulations and standards pushing us into ever higher energy buildings[vi], with catastrophic climate consequences as emissions continue to rise across the world[vii].

2) Preventing Over-heating. Efforts to limit global temperature rises to 1.5^{0}C are failing badly, and the above-mentioned flaws in modern buildings often cause chronic over-heating, or cooling, resulting in either high energy bills to solve the problem mechanically, or alternatively occupant discomfort. Over-heating is now becoming a monetised, global, problem. In 2016 HKS Inc. and Skidmore, Owings and Merrill settled out of court for millions of dollars in a suit brought by the Beacon Residential Community Association, occupants of a 595-unit luxury condominium complex in San Francisco. Some units there were so over-glazed, with insufficient opening windows to provide relief cooling, that they became un-occupiable once the sun came out. The suit deemed that the architects were responsible, culpable and had a responsibility to provide 'fit-for-purpose' accommodation both now and for the future[viii]. The quickest way to modify overheating in most climates is to open an effective window to let the heat out, and/or the cooling breezes in.

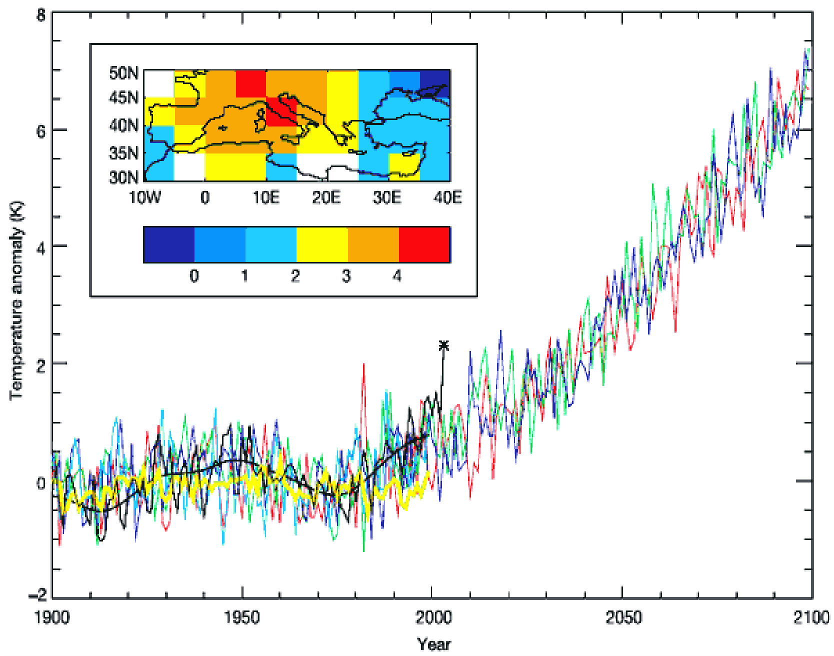

Figure 1. The black temperature outlier marked x is the extreme European heatwave of 2003 in a graph. According to this prediction published in Nature, by 2050 this extreme summer will be considered a cool one. Some 52,000 across Europe died during this event, many of them in buildings (Source: Stott et al., 2004[ix]).

3) Economic drivers. The trend towards energy hungry, modern buildings[x] has been reinforced by ideas of *energy efficiency,* heavily managed and lobbied for by machine manufacturers with regulators and standards organisations. Regulations, underpinned by crude simulation packages, and developer and industry-backed rating systems, have been made mandatory through the regulations process and now act to inhibit the use of passive design features in *energy sufficient* buildings[xi]. Many people, and populations, will be much poorer after COVID outbreak, making energy costs increasingly critical for families and businesses alike. The enormous benefits for much of the year, of heating, cooling and ventilating buildings by simply opening, or shading, a window, will become potent drivers for the move back towards natural ventilation.

4) Building Resilience. Sealed buildings are highly vulnerable to extreme events, and the growing occurrence of external threats like droughts, bush fires, floods, heatwaves and extreme windstorms that can not only physically destroy buildings, but also trigger power outages and cutting energy supplies, so capable of rendering buildings without opening windows, uninhabitable[xii]. During Hurricane Sandy in New York some larger buildings rapidly became too hot and fetid to safely occupy, resulting in the city's Urban Green Forum asking that in future all residential buildings in New York have at least 25% of their windows openable[xiii]. Internally spread bio-security threats like the anthrax threats after 9/11, or, bacterial or mould infections of mechanical systems[xiv] could be avoided in buildings with closed radiant heating and cooling systems and opening windows.

5) Infection reduction. Contagion spread via HVAC systems came to international attention in COVID-stricken cruise liners, where passengers were infected despite strict self-isolating practices. On the 6th July 2020, 239 academics from around the world signed a letter pointing out that aerosol spread of the COVID-19 was also a potent transmitter of the virus, along with droplets spread and the touching of surfaces.[xv] Within three days the World Health Organisation had changed their advice adding aerosol spread as a recognised infection pathway. The opening of windows to purge hospital wards of viral load is now widely discussed along with the considerable barriers to doing so[xvi].

In modern hospital HVAC systems attempts are made to kill, remove or constrain pathogens with high-energy systems using air extraction, high temperature sterilisation and ultra-violet. Research shows that hospitals with good opening windows reduce cross-contamination between patients within, or between, wards. Traditional hospitals were built with high ceilings and large windows to ensure the removal of infectious pathogens away from patients[xvii], and to reduce cross infection rates[xviii]. Scientifically robust studies show that pressurised ventilation and drainage systems have been linked to the spread of a range of infectious diseases including MRSA, MDRBT, SARS[xix] and Tuberculosis in a range of different building types. These can be caused by faulty mechanical systems, inaccessible and dirty ducts, poor maintenance, or physical and managerial factors that influence the transmission rates through ducts, and between occupants. Mechanical ventilation of high-risk clinical areas requires flow rates of around 6–12 ACH[xx], supplied by systems that can be prohibitively expensive to install and run, noisy, and difficult to clean and maintain. Simply opening windows and doors achieves far greater ventilation rates if well designed, providing increased protection against airborne infection[xxi]. A major reason that modern hospital design trends increase patient risk is financial. Smaller rooms (which more easily become stuffy and overcrowded) are cheaper to build and mechanically heat or cool but are more likely to become toxic sources of cross-contagion. The inclusion, and use, of opening windows to reduce indoor infection loads in hospitals and other buildings including offices now needs urgent attention.

Barriers to Natural Ventilation

All the above are potent drivers for a move back to the use of natural ventilation but many obstacles slow progress to the common-sense adoption of open window solutions. Both architects and engineers now have limited education training in how to design effective air flow and supply systems through buildings to promote the health, well-being and comfort of occupants. A fundamental lack of understanding of what constitutes thermal comfort for real people in real buildings has been perhaps the largest barrier to their adoption, promulgated by the global mechanical ventilation and conditioning industries[xxii]. Their calculations, and the mechanical control systems are simply not designed to be used in mixed-mode buildings, in which machines are only used when, and where, necessary during the hottest and coldest times of day and year. A fundamental flaw in their assumptions is that those controls have no way of assessing what a particular cohort of building occupants will actually find to be acceptable, or comfortable, temperature ranges. The time has come to counter this ignorance on what constitutes acceptable temperatures in buildings, to underpin a common-sense move back to 'opening the windows', for economic, environmental and health, safety and comfort reasons.

What is Comfort?

Engineer's Comfort

The *Engineers Approach* to comfort originated in the need to set a thermostat for heating, cooling and ventilation systems at a certain temperature that would keep as many people as possible from complaining. *Engineering Comfort* is delivered as a *product,* in units that can be measured and adjusted by the HVAC equipment controls, to heat or cool buildings. This approach is based on a US/Euro-centric idea of comfort that has been defined using laboratory derived 'Steady State' calculations that mandate the use of the very limited range of 'comfort temperatures'. For instance the .most widely used building simulation program for LEED-certification that are now internationally sought in commercial building markets, *DesignBuilder*, uses 22 ^{o}C in winter and 24 ^{o}C in summer as the default temperature set-points. This means that both simultaneous heating and cooling, and high heating and cooling loads are highly promoted. However such narrow comfort bands have had damaging, non-trivial, consequences including[xxiii]:

1) Comfort standards push designers into having to install mechanical systems.
2) The emphasis on mechnical systems has resulted in ever poorer standards of the climatic design of buildings, as more money is spent on systems, less goes on the quality of the form and fabric of the building itself.
3) Running costs in year round mechanically heated and cooled buildings are significantly higher so organisations are increasingly forced into making difficult decisions, like being forced to spend money to keep patients, pupils or other building occupants in mechnically controlled indoor climates, rather than paying teachers, doctors, nurses and employees salaries.
4) Post-COVID economic conditions will mean most of us are poorer, so higher energy costs in buildings where occupants, particularly middle class ones, are forced to use mechancial systems, rather than rely on free natural ventilation, will push more people into social deprevation with broad ranging societal impacts.

The focus of legistators in mitigating the impacts of buildings on the climate, and vice versa, is on challenging[xxiv], or nudging[xxv], the heavily lobbied regulations and standards, to enable them to appear to remain relevant to the evolving socio-econommic, political and climatic conditions of the 21st century. The current European legislative framework, promoting energy efficiency over better passive builing design, is predicated on an unquestioning acceptance of the engineer's approach to comfort, and tells us nothing about what acceptable temperatures in buildings actually are, or how they might be most cost-effectly created.

Adaptive Comfort

The *Adaptive Approach* to understanding comfort looks at the thermal experiences of people in their everyday lives indoors, using occupants as the guages of what temperatures are acceptable in particular buildings and particular places. The Adaptive approach provides a people-centred, not a machine-facing view of the world and is based on the Principal that "*If a change occurs that produces discomfort, people react in ways which tend to restore their comfort*"[xxvi]. This approach has been developing over the last a century, based on field work done in countries, cultures, and climates around the world[xxvii]. The Adaptive approach enables people to design mixed-mode and naturally ventilated buildings, and still conform to the local buildings regulations for many times of day, year in most climates. While standard regulation and rating systems linked to simulation packages like *DesignBuilder* often also include mixed-mode, natural ventilation and adaptive comfort evaluation options within them, but these are crudely stimulated, in such a way as to largely not encourage their use. The Dutch Building Services Research Institute tried to circumvent this fundamental flaw in their regulations in 2014 when they upgraded their ISSO 74 (ATG) design guideline to enable a 'hybrid' approach to comfort that combined elements of traditional nonadaptive comfort standards with elements of adaptive standards, and allowing indoor temperatures to float between 18^{0}C – 28^{0}C while remaining acceptable within the guidelines[xxviii].

For more information on the methods and processes involved Adaptive Comfort read our books on the subject listed in the references below, but here we offer you three very basic lessons designers need to know about comfort, in relation to the natural ventilation of buildings.

Three Key Lessons you need to know about Comfort:

1. People Adapt to those Temperatures they Normally Occupy in Buildings – between 10^{0}C-35^{0}C

In the 1978 Michael Humphreys first published data showing strong links between the outdoor temperatures, and reported comfort temperatures inside[xxix] from field studies around the world. The strength of this linear relationship shows unequivocally that the hotter it is outside, the higher the comfort temperatures are inside, for adapted populations. This relationship informs international and European comfort standards like ASHRAE 55 [2004][xxx] and EN15251 [BSI 2007][xxxi] which are widely used to predict comfort conditions in naturally ventilated buildings.

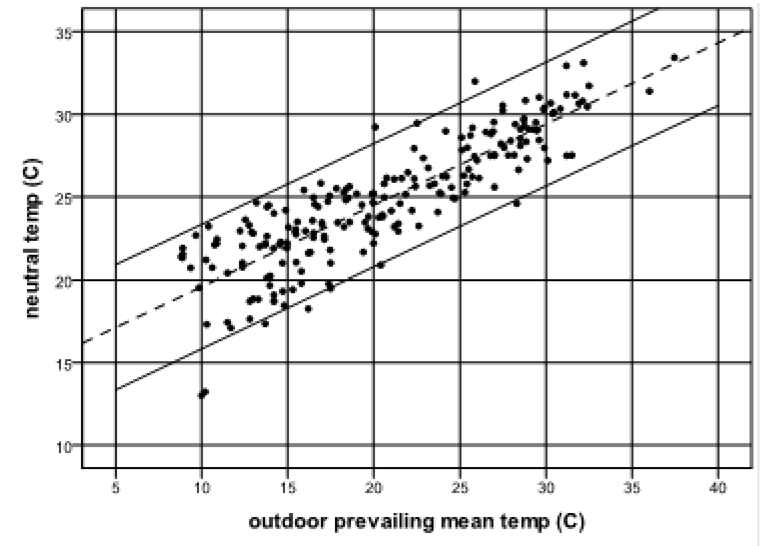

Figure 2. The relationship between the temperature at which building occupants will be most likely to vote 'neutral' on the ASHRAE comfort scale and the outdoor temperature. In this graph all the buildings are in 'free-running' mode meaning that no mechanical heating or cooling is in operation at the time of the survey. This shows that the hotter it gets, the higher the neutral temperature is. (After Humphreys 1978)

More recently, Nicol has developed the idea of 'temperature clouds' derived from the data from field studies. These clouds show, for a particular building, or group of buildings in a field study, the indoor temperatures which actually occur at the concurrent outdoor temperature as individual data points rather than, as in previous statistical analysis methods, reducing a wide spread of field data to standardised comfort responses recorded as normalised neutral temperatures[xxxii]. In Figure 3. you can see the spread of responses for populations in free-running buildings in Pakistani cities, showing that even in different climatic regions, some people at the same outdoor temperatures, are living in, and finding acceptable, different indoor temperatures, a result of the building they occupy, or their own personal preferences, o behaviours, or other reasons.

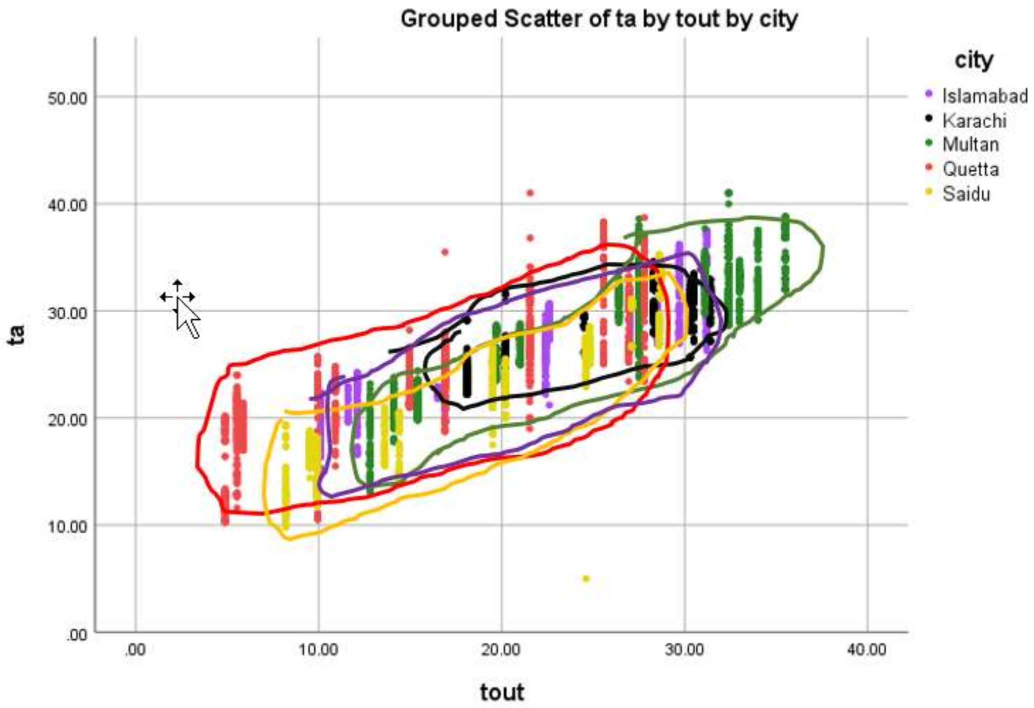

Figure 3. Temperature clouds for five different cities in Pakistan. Every different geographical location has a different outdoor climate that is reflected in the rough cloud for each city. Note that the hottest city (Multan) (green) includes the highest temperatures and the coolest (Quetta) the lowest temperatures. Karachi has the smallest range of both outdoor and indoor temperatures (Source: Nicol, 2017).

Comfort Clouds also highlight that in tightly regulated, mechanically heated and cooled, office buildings in Europe indoor temperatures are inevitably leveled, so for instance offices in colder Sweden, or hotter Portugal, are adjusted to run at similar indoor temperatures, with commensurate energy penalties that increase the further away from the regulated indoor temperatures norms for the climate outside. People in warmer climates also adapt to being cold during their working day in air-conditioned offices while reverting to occupy much higher temperatures routinely in their own homes, and vice cersa in colder climes[xxxiii]. People adapt to the temperatures they choose, or have to, occupy.

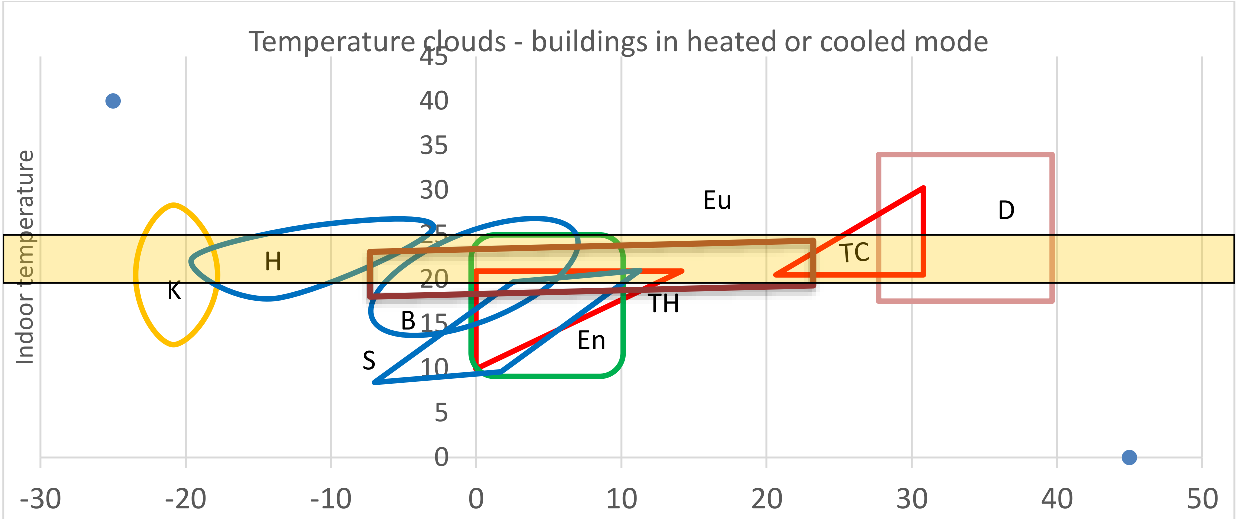

Figure 4. Temperature clouds from surveys in various parts of the world from buildings which were mechanically cooled or heated at the time of the survey. Key: blue: China (Harbin (H), Beijing (B), Shanghai (S) in winter (Cao et al 2016), yellow Eastern Russia (Khabarovsk winter (K) Borovikova 2013), green England (En) (Kelly et al 2013), red Japan (Tokyo (TH heating, TC cooling) Rijal et al 2015), Brown Saudi Arabia (Dammam (D) Alshaikh 2016), Purple European offices E (McCartney et al 2002). Most comfort standards are concentrated in the 20-25^{0}C temperature band (yellow). Most of the results are from dwellings except the Chinese data (H, B and S) which are from educational buildings and the European data (E) which is from offices (Source: Nicol 2019[xxxiv]).

Comfort Clouds developed for a huge range of different climates and locations show robust results indicating that acceptable indoor maximum indoor temperatures, for acclimatised building occupants, is around 35°C. The minimum indoor temperature acceptable indoors in both conditioned and naturally ventilated buildings for appropriately acclimatised subjects is around 10°C although results from some places, like upland Nepal[xxxv] suggest that appropriately adapted subjects can find even lower temperatures comfortable if they are wearing appropriate clothing. Roughly the same temperature limits apply, surprisingly, in both conditioned, and naturally ventilated buildings.

Notice that whilst most of the temperature clouds in Figure 4 touch on, or pass through, the indoor temperature range 20-25^{0}C at some time, this is not always the case. Most of them spend long periods of time outside this narrow range, especially if there is a large seasonal temperature range, so it should not be taken for granted that the 20-25^{0}C is necessarily the temperature range to aim for. At some times of year, or in particular buildings and places, it may be found uncomfortable. In addition, it is generally accepted that providing a constant indoor temperature can be costly in energy, and may in some instances be unhealthy[xxxvi].

2. There is no such thing as a single 'Comfort Temperature'. Everyone is different. Every culture in every climate is different.

Comfort is both a cultural construct ,and a personal one. The ability of individuals to become, and remain, thermally safe, and acceptably comfortable, is powered by a feeback system[xxxvii] of involuntary processes in the bodylike shivering or sweating aimed at maintaining the core temperature of a body at around 37^0C, and voluntary interactions by a person, and between them and their environment enabled, or hampered, by the available adaptive opportunties[xxxviii].

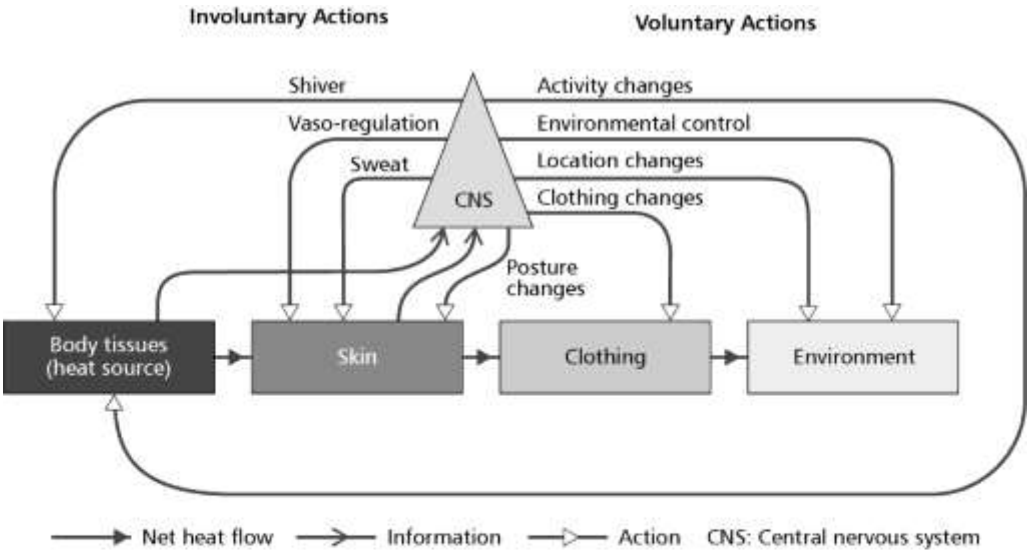

Figure 5. Mechanisms to keep core body temperature constant at about 37°C are controlled by the Central Nervous System (CNS) and include involuntary physiological actions including shivering, sweating, vaso-regulatory responses and voluntary actions (Source: Fergus Nicol [xxxix]).

Cultural lifestyles evolve to connect people to their environments and climates, in the form of local vernacular buildings, clothing and seasonal and daily routines and customs. People harvest heat or coolth from the thermal landscapes of the buildings they occupy[xl]. A designer in Northern Europe might say "it is impossible to be comfortable in 10^0C or 35^0C indoors" but they are just being parochial in that assertion, possibly knowing absolutely nothing of the ways of life, or expectations, of people from very different places, and walks of life, who at various times of the day or year, consider such temperatures acceptable.

There are of course physiological limits to what temperatures a body can cope with, and the recent growth if research into the Thermo-Neutral Zones of people has been useful in exploring these limits.

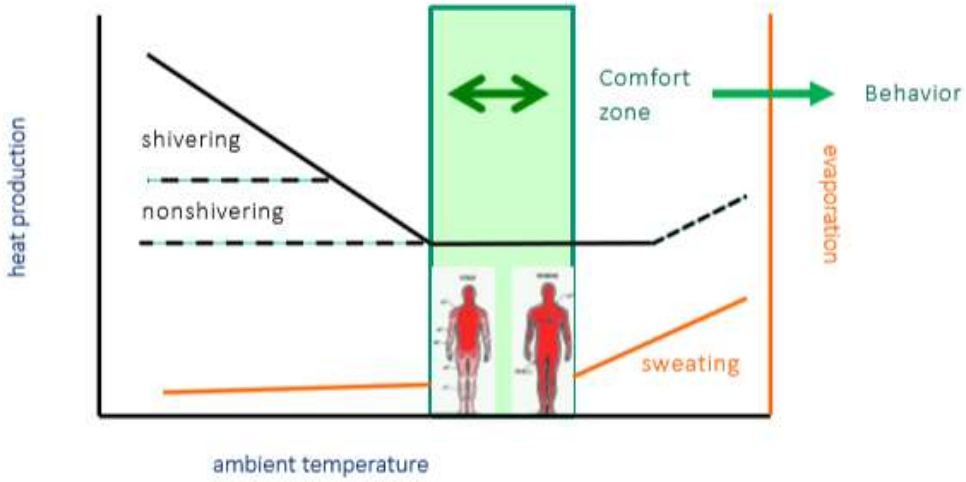

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Figure 6. The Thermo-Neutral Zone for an animal is where they expend the least energy to maintain their core body temperature (van Marken Lichtenbelt and Kingma[xli]).

We all have a thermal 'sweet spot' at which a naked body, at rest, out of the sun, will need to expend little or no energy, neither sweating nor shivering, to maintain homeostasis, thermal stability in the body, resulting in a safe core temperature. This sweet spot is known as the Thermos-Neutral Zone (TNZ), and its temperature limits in the individual will depend on factors such as weight, BMI, health, degree of thermal adaptation etc., but it hovers actively around the range of 26^{0}C-33^{0}C. Engineers who set thermostats at 18^{0}C-20^{0}C in warm climates not only waste huge amounts of energy but too often increase discomfort, not least in organisations that encourage scanty dressing. In colder conditions, at least, lower temperatures can be compensated for by wearing more or thicker clothes. In the heat more clothes can often not be taken off.

3. Air Flows can Chill, or Cool

Eliminate 'chilling air flows' from this discussion. Drafts have confused, and been used to do so, the natural ventilation debate for a century. Draft problems can be solved by tackling infiltration problems in buildings, shutting openings, placing screens or barriers to airflows, or changing clothing appropriately. At higher temperatures, around and above the TNZ, air movement over the skin is the pre-eminent way of removing heat from the body by convection drawing heat from the skin, and by facilitating the evaporation of moisture / sweat from the skin in an endothermic (heat absorbing) process. The faster the air moves over the skin, the more heat is lost from the body, initially by heat transfer to cooler air, and then increasingly by sweat evaporation. People around the world, wearing similar clothing ensembles, start to open windows at roughly similar temperatures because they share similar metabolisms and need to loose heat at similar temperatures to remain in homeostasis - a stable, safe, thermal equilibrium.

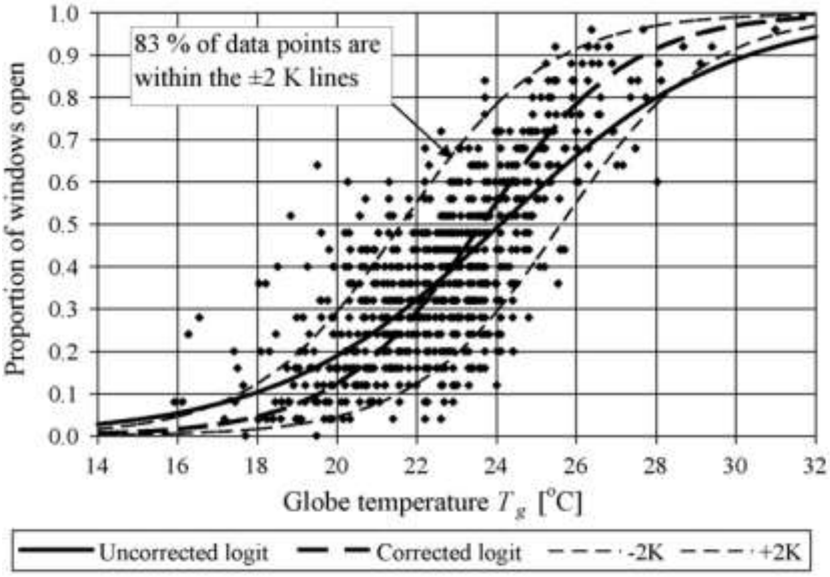

Figure 7, shown the distribution of the likely number of open windows in buildings at different indoor temperatures in the UK. Such a distribution curve can be used to estimate energy use and comfort in a group of buildings with opening windows. The air movement measured in any building tends to rise as the temperature increases as a result of the adaptive behaviour of occupants in opening windows and using fans (Source: Hom Rijal[xlii]).

What are Acceptable temperatures in Naturally Ventilated Buildings?

Figure 8. A bright sunny day in Antarctica in February 2019. All the doors of our living pod open in an average temperature of plus 3^0C air temperature, and we were very comfortable working and resting inside, and out (Source: Roaf).

The air-conditioning industry defines comfort in terms of what they can deliver: a limited air temperature band, controlled air speed, and perhaps humidity regulation. The truth is that different people, and populations, find a huge range of indoor temperatures acceptable, and recent research involving comfort clouds have shown that indoor temperatures from 10^0C to 35^0C are comfortably occupied in homes around the world. The concocted myth of the standardised 'Comfort Temperature' has led to the closing of windows in buildings, the de-skilling of designers and to a generation of poorer, less resilient buildings. Real *resilience* in a species must lie in their ability to *bounce forwards* to survive in a rapidly evolving world, not to bounce backwards to a failed state in an already vestigial socio-economic landscape[xliii]. The time has surely come when we must now insist that all buildings have opening windows, although most will obviously also need heating and cooling at certain times of the day and year. People should have the right not to use energy if they do not need to, and to occupy the temperatures they choose to. Locking people in buildings where they need mechanical systems 24/7/365 must no longer be acceptable, especially if those buildings are potentially unaffordable to run, contagious and fail during extreme events. We don't need other people to tell us what is comfortable for us in our own lives and buildings. Instead we need the adaptive opportunities to hand to make ourselves comfortable in the buildings we live, and work in. We need designers to re-learn how to successfully naturally ventilate buildings, and control air flows in them to maximise the benefits involved in using local outdoor air supplies to heat and cool both people and buildings. The design of effective and appropriate natural ventilation systems for all buildings, and the different spaces within, them must be a core topic for research for the decades to come, energised by being liberated from the debilitating 20th century, machine-centric, narratives around what constitutes comfort.

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