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Thermal comfort and climatic design in the tropics: an historical critique

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This paper explores how climatic design for the tropics was socio-technically constructed at its moment of inception in the mid-twentieth century by two of its best known proponents: George Atkinson at the Tropical Building Division, Building Research Station and Otto Koenigsberger at the Department of Tropical Studies, the Architectural Association.

I argue that undergirding Atkinson's construction of climatic design for the tropics was a mechanistic and reductive understanding of thermal comfort based on the research done by the air-conditioning industry in the United States in the early twentieth century. Not only did the reductive understanding of thermal comfort ignore local cultural norms and social practices in maintaining comfort, it also indirectly helped to further metropolitan interests in the tropics. In the case of Koenigsberger's construction of climatic design, I show that he was influenced by the mid-twentieth century researchers in hot-climate physiology. These researchers combined nineteenth-century colonial medical ideas of the tropics as a torrid zone with the early twentieth-century industrial physiologists' understanding of the correlation between environmental conditions of thermal stress and low productivity. They assumed that labourers in the tropics worked under perpetual thermal stress and became easily fatigued, thus hindering the socio-economic development of the tropics.

By foregrounding the entanglements between climate and economy, comfort and development, and nature and culture, this paper follows the Anthropocene thesis that invalidates the ontological distinction between human culture and nature. In doing so, this paper also complicates the recent call for a return to climatic design and its low-energy passive means of cooling.

Introduction

The Anthropocene thesis and the planetary crisis of anthropogenic climate change have encouraged architects and others connected to the building industry and the built environment to focus on issues surrounding architecture and carbon emission. Buildings today are responsible for a significant portion of all the energy used and as most of the energy is still inefficiently generated from fossil-fuel sources, buildings are indirectly responsible for a substantial percentage of global carbon emissions. Much of the energy a building consumes is used for air-conditioning, and critics have argued that the design of many air-conditioned buildings is poorly conceived, leading to unnecessarily high cooling loads and even greater energy profligacy.[1]

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Research has also shown that many air-conditioned buildings are overcooled, producing uncomfortable and even unhealthy interiors. In view of anthropogenic climate change, many scholars and researchers argue that there is an urgent need to rethink our current energy-profligate way of designing comfortable interior environments.

Besides adopting a more appropriate thermal comfort model and its standards, and using more energy-efficient mechanical cooling systems, some have argued that we should learn from past exemplars of climatic design and use low-energy passive means of cooling in place of the energy-intensive active cooling of mechanical air-conditioning.[2] The argument of learning from past exemplars of climatic design is premised on a narrative of loss and return – the loss of a more climatically and culturally sensitive way of design and comfort provision, the erosion of architects' ability to design climatically appropriate building with the rise of air-conditioning and the need for architects to retrieve these lost traditions and skills.

This paper complicates this narrative of loss by examining climatic design for the tropics at its moment of inception in the mid-twentieth century. It explores the work of two key individuals at two of the leading institutions responsible for the dissemination of climatic design in the 1950s and 1960s—George Atkinson at the Tropical Building Division of the Building Research Station, and Otto Koenigsberger at the Department of Tropical Studies at the Architectural Association. I show that undergirding Atkinson's construction of climatic design for the tropics was a mechanistic and reductive understanding of thermal comfort that was, paradoxically, borrowed from the laboratory-based research carried out by the air-conditioning industry. Not only did this reductive understanding of thermal comfort ignore local cultural norms and social practices in the tropics for maintaining comfort, it also indirectly helped to facilitate the export of metropolitan expertise and products to the tropics. Through Koenigsberger's teaching of climatic design, I show that climatic design was shaped by deep-rooted colonial medical and political ideas of the tropics as an unhealthy, uncomfortable and backward geographic region. The tropics was seen as not just a hot and humid zone, but also as one where inhabitants suffered from frequent discomfort and thermal stress that inhibited productive labour. In this context, climatic design was seen as a way of ameliorating the discomfort and thermal stress of living in the tropics, which in turn would enable greater productivity and socio-economic development.

The entanglements between climate and economy, comfort and development, nature and culture, environmental history and socio-economic history foregrounded in this paper show that climate and the natural environment were not just unchanging backdrops to unfolding human activities. Following scholars in humanities and social sciences who have drawn from the Anthropocene thesis to invalidate disciplinary assumptions inherited from modernity, such as 'the ontological distinction between human culture and nature' and the 'age-old humanist distinction between human and natural history', I argue that the binaries of nature and culture, climate and architecture have to be breached in order better to understand the history of climatic design.[3]

To be sure, I do not disagree with the need to question our current over-reliance on the energy-profligate model of air-conditioning. Nor do I discount the relevance of climatic design for a low-carbon architecture that we urgently need in the face of anthropogenic climate change. What I hope to do in this paper is to complicate the aforementioned narrative of loss and return. Instead of a return *to*, I argue at the end of the paper for a reconstruction *of* climatic design based on a critical understanding of the social, cultural and political entanglements of comfort and climate.

George Atkinson, thermal comfort and climatic design for the tropics

George Atkinson was a key figure behind the mid-twentieth century institutionalisation of tropical architecture in the British Empire. He was first appointed in 1948 as the Colonial Liaison Officer to lead the Colonial Liaison Unit within the Building Research Station (hereafter BRS) to advise the Colonial Office in London and in the various colonies on matters relating to building and housing. As many territories in the British Empire gained independence and the Empire became the Commonwealth, Atkinson's unit was renamed the Tropical Building Division and he led the Division till 1961, when he was promoted to the position of Chief Architect in the BRS. In his thirteen-year stint, Atkinson travelled extensively to survey and advise on colonial building problems, and lectured and published widely to promote the techno-scientific approach to building in the tropics. He was instrumental in establishing building research and standards in British tropical territories, and he worked closely as a consultant to British architects such as Maxwell Fry, Jane Drew and the Architects Co-partnership that were designing in the tropics.[4]

When Atkinson was appointed as the Colonial Liaison Officer, he identified 'thermal comfort and the design of buildings in the tropics' as one of the four main areas of research.[5] In 1950 and 1953, he published two of the earliest papers on climatic design for the tropics—'Building in the Tropics' and 'Warm … Climates and Building Design'.[6] In these papers, he sketches out the basic climatic types from the perspective of building design and presents them in relation to the thermal comfort zone. These seemingly immutable categories of climatic types and thermal comfort zones were, however, articulated differently in the two papers. In the 1950 paper, Atkinson presents three tropical climatic types and a thermal comfort zone of between 78 and 84 degrees Fahrenheit, whereas in the 1953 paper, he puts forward four tropical climatic types and a thermal comfort zone that not only varies with relative humidity but is also much lower. For example, at a relative humidity of 60 percent, the comfort zone is 67 to 79 degrees Fahrenheit.

The variation could be attributed to the fact that building climatology as a field of research was still in its infancy, and researchers were unsure how best to classify the various climatic types for the purpose of building design. Furthermore, there was no agreement on what constituted the thermal comfort zone. Even the books at that time by the leading physiologists in the field—such as Charles-Edward Amory Winslow and L. P. Herrington's *Temperature and Human Life* and Thomas Bedford's *Basic Principles of Ventilation and Heating* that Atkinson cited—concur that there was no agreement on thermal comfort. In his book, Bedford noted that the 'diversity of opinion as to what constitutes [comfort] … is sometimes very wide'.[7] Winston and Herrington wrote that '[t]he diversity of the findings [on thermal comfort] is altogether understandable when the complexity of the factors involved is kept in mind'.[8] If there was no agreed standard for thermal comfort for the temperate climate of North America and Europe in the mid-twentieth century, there was bound to be greater uncertainty with regards to thermal comfort standards for the tropics, as the region was much less researched.

In his articles, Atkinson acknowledges as much, though he mentions the work initiated on 'hot climate physiology' and comfort zone by a number of researchers in the British Commonwealth in the post-war period.[9] For example, C. G. Webb's work with acclimatised experimental subjects in Singapore and J. W. Drysdale's findings with Australians in sub-tropical Queensland were discussed in the 1953 article. Atkinson noted that Webb's research showed evidence for a relatively high effective temperature of 79–80 degrees Fahrenheit for comfort. In fact, Webb found that under certain indoor conditions of air velocity and relative humidity, the air temperature could go up to around 84 degrees Fahrenheit before his subjects felt any discomfort.[10]

Despite Atkinson's discussion of these works based on field measurements in the tropics, he wrote that the 'most important experimental work has been carried out in the United States' by ASHVE (American Society of Heating and Ventilating Engineers) researchers on 'problems of summer cooling by air-conditioning'.[11] In fact, Atkinson used the comfort chart first published by ASHVE in 1932 as the basis for the psychometric chart that was prominently featured in his 1953 paper (figs 1, 2).[12] The original ASHVE chart has two comfort zones, one for winter and the other for summer. Atkinson used the comfort zone for summer, which has a range of 66 to 75 degrees Fahrenheit on the Effective Temperature (ET) scale. ET was first developed by ASHVE researchers at their research laboratory in Pittsburgh to represent combinations of air temperature and relative humidity that produce similar sensations of warmth. The ET is also a scale of thermo-equivalent conditions that 'determines the physiological effects on the body induced by heat and cold'.[13] The summer comfort zone on the ASHVE chart was based on studies carried out by Constantine Prodromos Yagloglou and Philip Drinker in the 1920s at the Harvard School of Public Health.[14]

Juxtaposed with this thermal comfort zone are the climatic data of three cities in British tropical territories: Freetown, Kano and Nairobi, representing the three main tropical climatic types of hot and humid, hot and dry, and upland respectively. As the ASHVE thermal comfort zone has a rather narrow range with low values in air temperature—around 66 to 78 degrees Fahrenheit at a relative humidity of 70 percent —and excludes the possibility of thermal comfort if the humidity exceeds 70 percent, the hot and humid, and hot and dry climates of Kano and Freetown are rendered as uncomfortable most of the time. Furthermore, ASHVE's thermal comfort zone was premised on still air, it did not

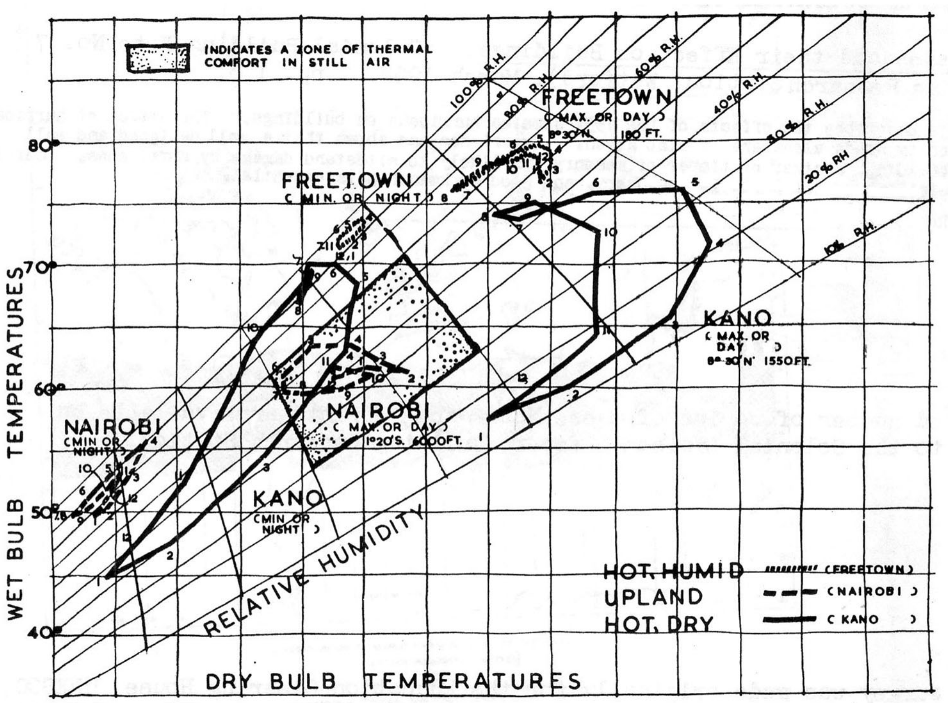
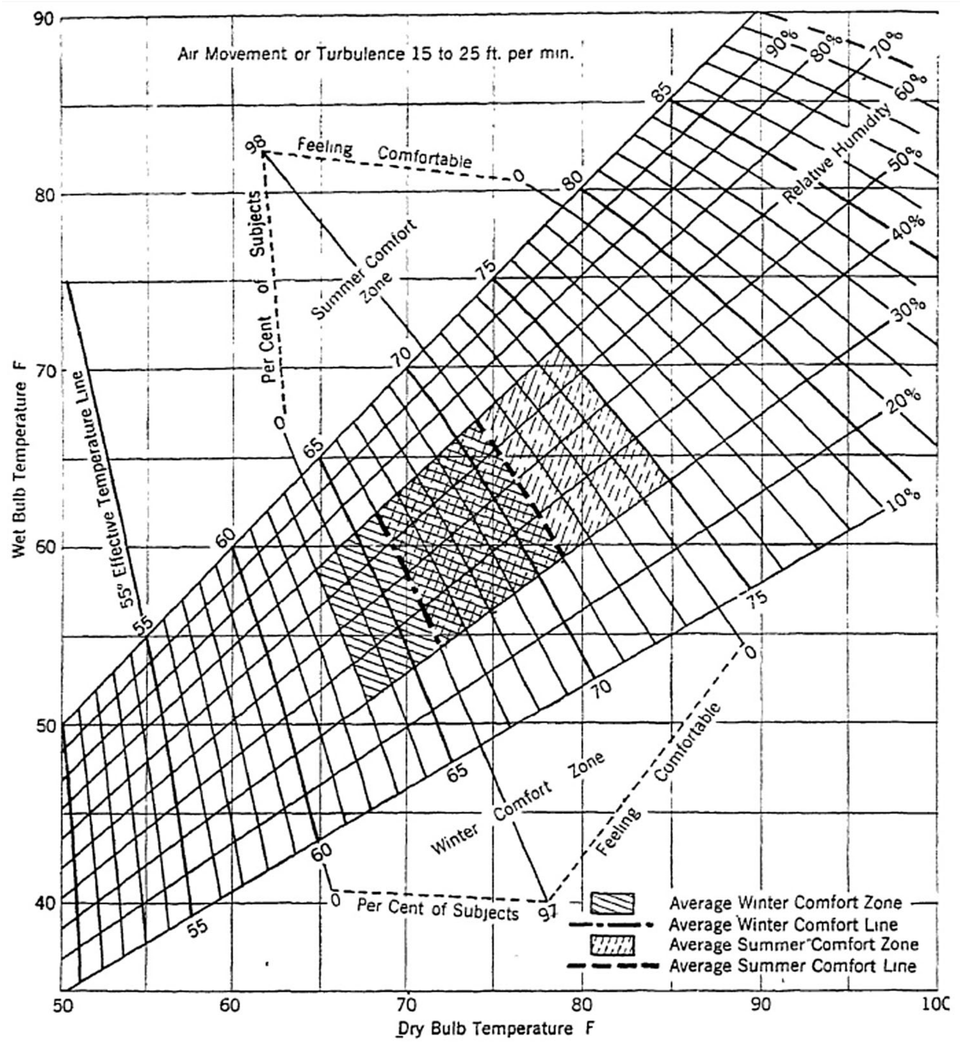


Figure 1. Comfort chart first published by ASHVE in 1932.

take into consideration the cooling power of moving air, which subsequent research has established to be central to comfort in the hot and humid tropics. Given such a narrow understanding of the thermal comfort zone, it is not surprising that the only comfortable tropical climatic type, according to Atkinson's analyses, is the upland, the high-altitude region where the British built their hill stations to escape from the tropical heat and humidity.

One of the effects of juxtaposing the ASHVE comfort zone with the different tropical climates was to reinforce colonial constructions of the tropics as a torrid zone with high heat stress.[15] Whatever Atkinson's intention, the use of the ASHVE comfort zone is understandable given that much research, with its attendant requirements for facilities and expertise, is required to arrive at thermal comfort zones. In the early 1950s, the Colonial Liaison Unit headed by Atkinson was still a very small set-up without funding to carry out its own research. Whereas ASHVE, with the financial support of the air-conditioning industry and subsi-

Figure 2. Atkinson's psychometric chart rominently featured in his 1953 paper.



dies from the U S Bureau of Mines, had its own research laboratory, established in Pittsburgh since 1919.[16] Besides carrying out its own experiments, ASHVE also had agreements to collaborate with engineers and physiologists from major universities —such as Harvard, Yale, Wisconsin and Illinois—to carry out related experiments and provide training for students.[17] As such, they were able to arrive at well-substantiated, purportedly objective and detailed specifications for thermal comfort from the 1920s onwards. In the mid-twentieth century, ASHVE was still the authority in the field of thermal comfort research. The ASHVE thermal comfort zone, however, was fraught with methodological and epistemological problems, particularly pertaining to its reductivism.

Measuring comfort, simplifications and commodification

One reason that the ASHVE thermal comfort zone was so different from the findings by Drysdale and Webb was that their research was based on measurements taken in the field while ASHVE findings were based on experiments conducted in a thermally regulated laboratory, known variously as a psychometric room or an environmental laboratory in the earlier literature, and as a comfort chamber in the later literature.[18] As Webb noted in one of his articles, field measurement of indoor environmental conditions presents many difficulties:

> The familiarity of the problem of warming a room, and the immediate availability of a rough and ready solution to it, concealed the scientific difficulties. The room itself contains the four three-dimensional fields, of which two, temperature and humidity, are scalar, but the others, air movement and radiation, are partly vector; none of them is constant or uniform, as a rule, and much of the variation is local, transient, complex, and interrelated.[19]

By contrast, the transient and fluctuating qualities of the four environmental variables that affect thermal comfort—air temperature, relative humidity, air movement and radiation—in 'real-world' conditions could be carefully isolated, controlled and rendered intelligible and precisely measurable in a comfort chamber. The comfort chamber is a hermetically sealed laboratory where all four factors can be independently manipulated and the natural fluctuations eradicated through mechanical means (figs 3, 4). The earliest chambers were built at the U S Bureau of Mines, Yale and Harvard universities in the 1910s and 1920s by researchers connected to ASHVE. Although attempts were made to recruit a diverse group of people—young and old, male and female—as experimental subjects for the tests conducted in these chambers, most of the subjects enrolled were students, and they were mostly young white men and women (Fig. 5).[20] Different types of experiments were carried out with these subjects to test various aspects of thermal comfort. In some of these experiments, the experimental subjects were clothed to different extents, including stripping to just underwear, and asked to carry out various repetitive tasks while the atmospheric conditions of the chambers and their physiological responses were measured by precise instruments. It was these experiments, in highly controlled experimental setups, that led to an exact numerical and universal standard for thermal comfort.[21]

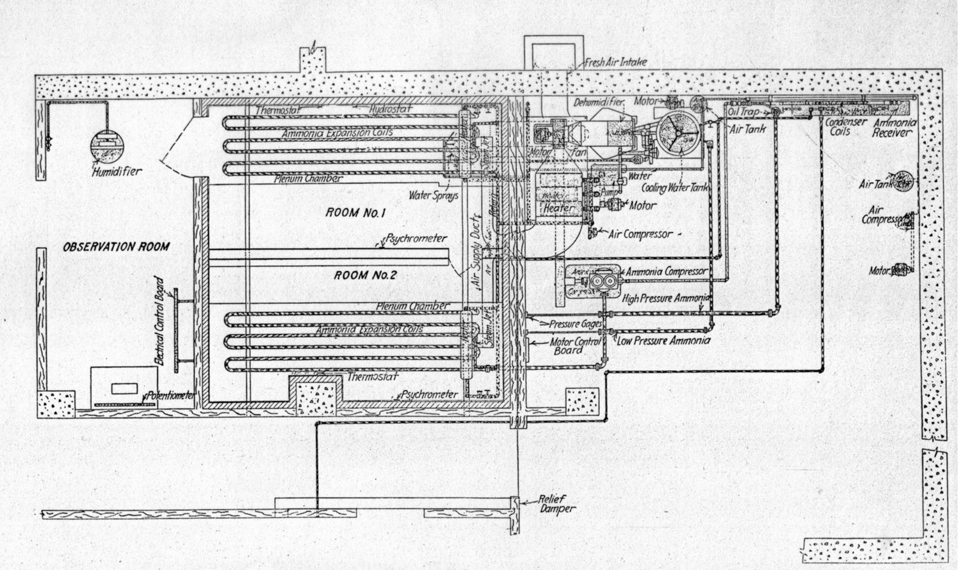


FIG. 1. PLAN OF PSYCHROMETRIC CHAMBER AND AUXILIARY EQUIPMENT IN ADJOINING ROOMS

Figure 3. Plan of psychrometric chamber.

As Science and Technology Studies scholars such as Bruno Latour have argued, 'universal' scientific standards become so due to the conditions that allow for their replications in multiple sites and different locations.[22] Like other scientific standards, the replicability of the ASHVE thermal comfort standard was achieved through a highly controlled experimental setup that isolated certain environmental variables that could be measured in a consistent manner. At the ASHVE laboratory at Pittsburgh, the equipment in the refrigeration plant used to manipulate the environmental variables of the 'cold room'— ie, the well-insulated climate chamber—was donated by ventilation and air-conditioning companies such as Carrier Engineering Corporation and York Manufacturing Company.[23] It followed that the environmental variables, air temperature, relative humidity and air movement, that could be adjusted in the experiments were precisely those that the ventilation and air-conditioning companies associated with ASHVE could control with their mechanical systems. The environmental historian Michelle Murphy has argued that these variables belong to a 'regime of perceptibility' that any experimental assemblage and its attendant knowledge practices would inevitably produce. Any regime of perceptibility obviously also produces its own realm of imperceptibility. In this case, the

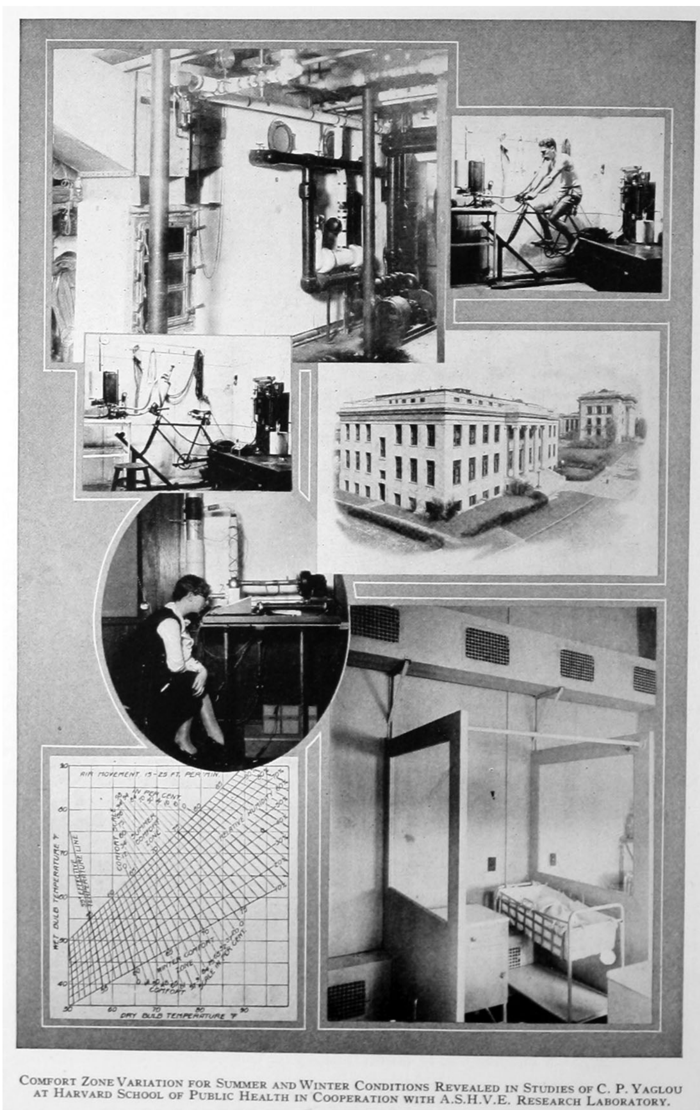
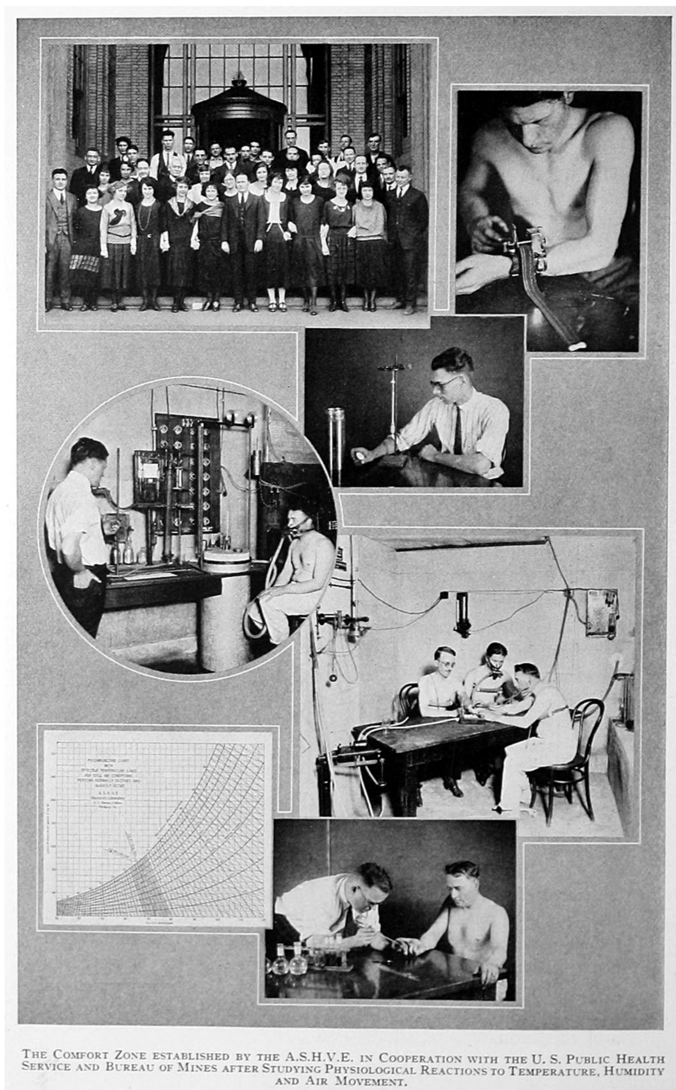


Figure 4. Comfort zone variations for Summer and Winter: studies at Harvard School of Public Health in cooperation with ASHVE.

Figure 5. Experimental subjects for the tests.



realm of imperceptibility included the undetected chemical properties of air, the disengaged broader fields of embodied social practices of keeping comfort and various cultural understandings of comfort.

According to Murphy, the comfort chamber was a ‘mechanistic microcosm of how building-machines ideally connected to bodies’ with the ‘building-machine presuppos[ing] a body-machine’.[24] This mechanistic microcosm, also known as the heat-balance model, was based on a combination of physics and physiology, the two main disciplines of the researchers who were mostly either engineers or physiologists. In this heat-balance model, ‘[h]uman comfort or discomfort’, in the words of the pioneer thermal comfort researchers F. C. Houghten and C. P. Yagloglou, ‘depend largely on the relation between the rate of heat production and dissipation’.[25] The human body was seen as a heat-regulating machine, balancing between what the prominent researcher on hot-climate physiology, Douglas H. K. Lee, saw as ‘gains of heat on the one hand and losses on the other’. [26] In such a model, thermal comfort could be ascertained by measuring inputs: in terms of environmental conditions—and outputs: in terms of physiological responses. In order to measure these inputs and outputs, the body-machine was not merely a metaphor, it was a body literally extended by various mechanical and electrical contraptions as it was the only way the body’s thermal sensations and physiological responses could be measured and made known.

The complex thermal comfort experimental assemblage produced a reductive and mechanistic understanding of thermal comfort, which did not remain unchallenged at that time. For example, at the 1952 conference on ‘Housing and Building in Hot-Humid and Hot-Dry Climates’, where Lee and Atkinson, along with other international climatic design experts such as the Olgyay brothers, presented papers, dissenting views were expressed by some of the participants. One of the speakers, Albert Mayer, who had worked extensively as an architect-planner in India and was involved in the planning of Chandigarh before Le Corbusier, noted:

> Comfort conditions and requirements are not wholly based on physical measurements. Physical comfort is by no means the only measure of working and living efficiency. Attaining the maximum in these respects may involve considerable effects in social relations, in alignments or misalignments which may be psychologically disturbing. Our own western culture places far greater emphasis on purely physical and material comforts than others. Our emphasis may elsewhere be over-emphasis.[27]

In his paper, Mayer went on to discuss how social practices and cultural norms affect tropical living and should be considered by architects in their design for these places. Mayer’s argument was supported by fellow conference participants Buford Pickens, then Dean of the School of Architecture at Tulane University, and James Fitch, then architecture editor of *House Beautiful* magazine who participated in the ‘climate control’ project. Pickens urged the Building Research Advisory Board, which organised the Conference, ‘not to neglect … the historical and even anthropological aspect of climate control’ although these aspects might not ‘lend themselves to that kind of research' and could not be 'reduced to charts and graphs'.[28] Fitch concurred with Pickens, and agreed on the lessons of climate control that could be drawn from 'pre-scientific' or 'primitive' building technology even though he admitted: 'It occurs to me that all of us American technicians, blinded by the splendour of our own technology, might be apt to overlook what Buford Pickens called attention to.'[29] Mayer, Pickens and Fitch's recommendations were, however, precisely those factors that were rendered imperceptible under the regime of perceptibility that experiments in comfort chambers produced.

The social and cultural aspects of thermal comfort that Mayer, Pickens and Fitch highlighted could be discerned with the help of *in situ* field surveys. But even advocates of this method admitted that findings from field surveys were only applicable to the conditions surveyed, as '[i]t is virtually impossible to accurately extrapolate those results to fit the conditions that exist in another location and site'.[30] Unlike the laboratory-based survey, the context-specific field survey could not yield universal and widely applicable findings. Therein lay what was seen as the strength of the laboratory-based method despite its reductive approach: through simplification, the laboratory-based method could produce purportedly universal and widely applicable standards that would in turn legitimise certain expertise and facilitate certain forms of commodification.

When Houghten and Yagloglou presented their ground-breaking findings on thermal comfort in 1923, Willis Carrier, widely regarded as the 'father of air-conditioning', emphasised during the subsequent discussion 'the importance of [Houghten and Yagloglou's] research to us engineers'. Noting that as engineers, '[w]e want to know … when we cool air, how much we are going to increase the comfort or whether we are going to increase it at all', Carrier argued that the precise quantitative data yielded by the research 'proves conclusively that [air-conditioning] does increase the comfort and shows to what degree the comfort is increased'.[31] In other words, Carrier was suggesting that having conclusive evidence of the kind that Houghten and Yagloglou presented helped to validate the air-conditioning engineer's expertise and thus improve the standing of the relatively new profession at that time. In the early twentieth century, the engineer played a central role in the air-conditioning industry as air-conditioning at that time was a complex assembly of parts and components manufactured by various companies that the engineer had to customise specially for a particular installation.[32]

Later, in the mid-twentieth century, when air-conditioning technology became 'a complete installation as a pre-assembled package', the precise definition of thermal comfort played a different role. It helped to promote the new packaged air-conditioners that could be easily installed by any lay person without the need to engage an engineer.[33] On the whole, scholars of the history of air-conditioning, such as Gail Cooper and Elisabeth Shove, noted that 'definitional instability' as to what constitutes ideal environmental conditions for thermal comfort was 'decidedly unhelpful in constructing markets for the fledging air-conditioning industry'.[34] But when the ideal environmental conditions for thermal comfort was techno-scientifically constructed and quantitatively defined, the air-conditioning industry was able not only to construct but also to expand markets through the mass-commodification of comfort. When the ASHVE thermal comfort standard became the measure, 'natural climate was found wanting ... [as] no natural climate could consistently deliver perfect conditions' that mechanical air-conditioning could produce. Accordingly to Shove, '[w]hen no town could deliver an ideal climate, all towns became potential markets for air-conditioning.[35]

If the ASHVE thermal comfort standard was instrumental in validating the expertise of air-conditioning engineers, the commodification of comfort and the expansion of the air-conditioning industry, what did it do for climatic design when Atkinson applied it to the different tropical climates of the British Empire/Commonwealth? As noted earlier, Atkinson's use of the ASHVE thermal comfort standard in the psychometric chart that accompanied his 1953 paper on climatic design in the tropics meant that most of the tropical climates were rendered uncomfortable most of the time. It might thus reinforce the perceived importance of climatic design in these tropical climates, so as to ameliorate the purportedly uncomfortable environmental conditions. Emphasising the centrality of climatic design in the tropics helped Atkinson to promote the service of British architects in these tropical territories, as they alone were deemed to have the requisite expertise.[36]

Besides promoting the expertise of British architects, Atkinson was also indirectly prescribing a vision of modern tropical architecture through climatic design, one that helped to create the demand for certain British manufactured building components that were integral to the aesthetics and also the purported performance of modern tropical architecture. These components ranged from parts such as Henry Hope and Son's aluminium sun breakers, that were widely advertised (Fig. 6), to whole prefabricated aluminium buildings such as Booth & Co's 'Overseer Tropical II' that was especially designed and detailed to suit hot and humid climatic conditions (Fig. 7).[37] Most of these factory-fabricated building components were in aluminium because they were primarily manufactured in facilities converted in the post-war years from 'available capacity in aircraft and other surplus war production factories' in Britain.[38]

Otto Koenigsberger, industrial physiology and the other model of thermal comfort

Otto Koenigsberger helped to establish the Department of Tropical Studies (DTS) in 1953 and taught there from 1956 to 1971, when it joined University College London as the Development Planning Unit (DPU).[39] Konigsberger is widely regarded as a key figure in the theory and practice of tropical architecture in the mid-twentieth century because of the various roles he played: as an influential educator at the DTS, as a UN technical expert advising different developing countries and as a prolific writer who produced important publications.[40]

In the DTS curriculum planned by Koenigsberger, he emphasised that the students should understand the 'special problems which arise in the tropics' and grasp the fundamental principles of climatic design.[41] Koenigsberger argued that DTS's 'foremost task is to teach architects to produce

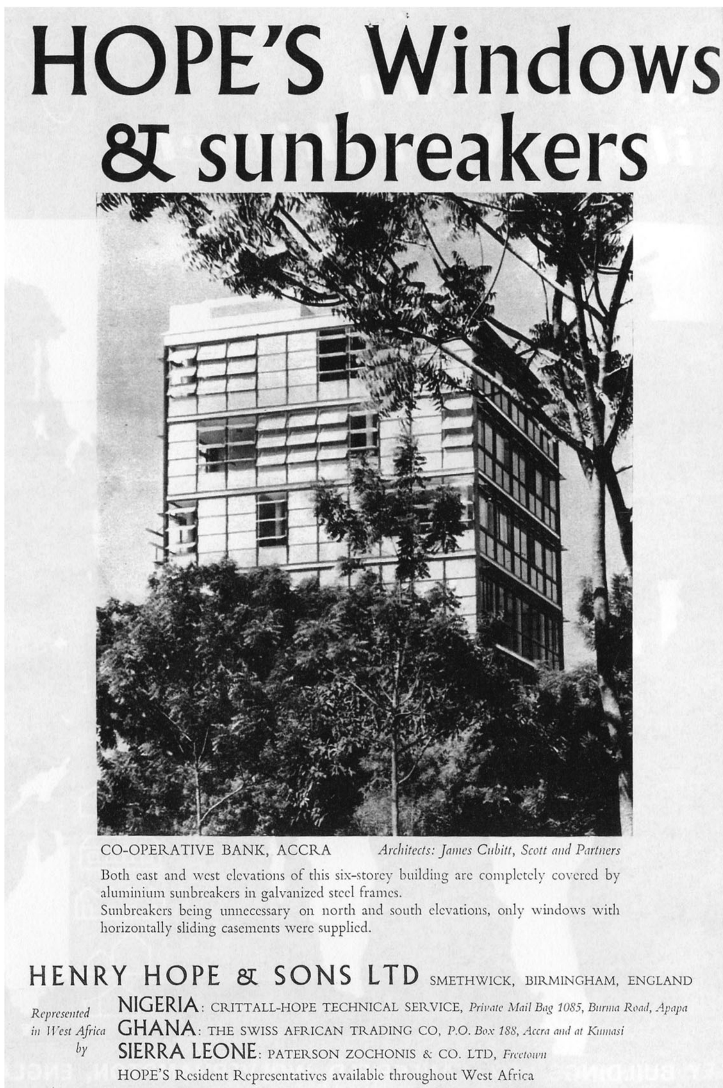


Figure 6. Henry Hope and Son's aluminium sun breakers.

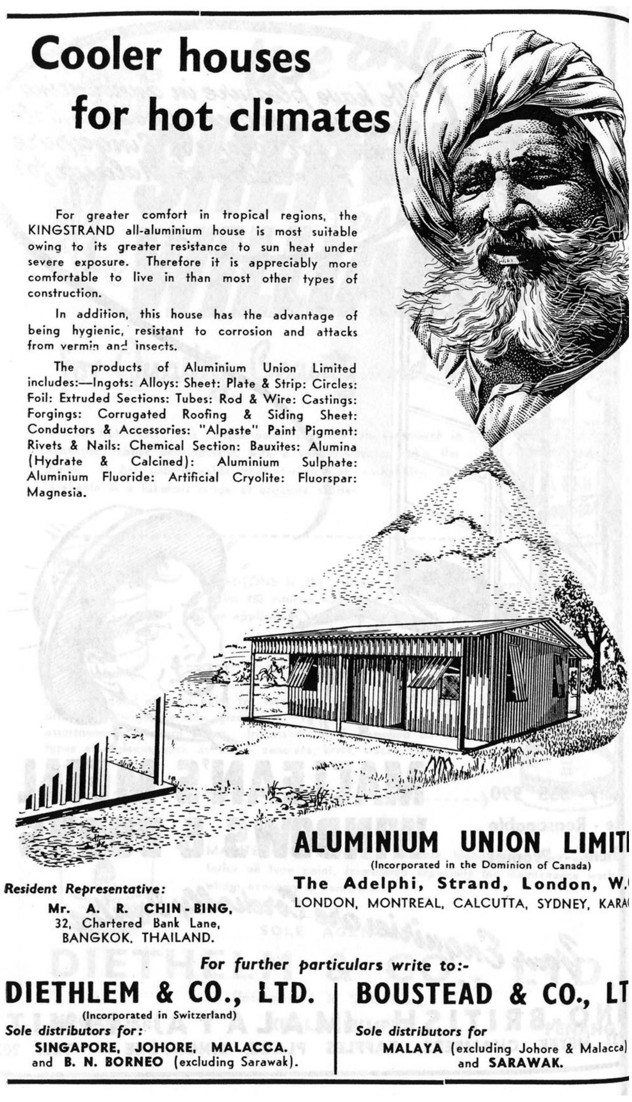


Figure 7. Advertisement for aluminium 'Cooler houses for hot climes'.

"climate-conscious" buildings'.[42] He was adamant that air-conditioning was not the solution as it was an expensive technology that only a privileged minority, ie, the wealthy, could afford. In Koenigsberger's view, the role of an architect in the developing countries was to, in his words, '[i]mprove the [indoor] environment for all with "natural means"'.[43]

Unlike Atkinson, who relied exclusively on laboratory-based findings in his construction of thermal comfort, Koenigsberger also utilised the findings from field surveys in his teaching of climatic design and thermal comfort. Specifically, Webb's Equatorial Comfort Index, based on his fieldwork research carried out in Singapore, was cited in the *Manual of Tropical Housing and Building*, a textbook co-authored by Koenigsberger and based on the lecture notes that he and his colleagues developed at the DTS.[44] Furthermore, in contrast to the mechanistic and reductive understanding of thermal comfort that underpinned ASHVE's laboratory-based findings, in his lectures Koenigsberger took into account the effects of socio-cultural adaptation and acclimatisation by long-term inhabitants of the tropics. He noted that these inhabitants felt comfortable at higher temperature ranges than the summer comfort zone prescribed by ASHVE.

Koenigsberger's use of field findings and his sensitivity to socio-cultural adaptation in his understanding of thermal comfort could be attributed to his background. Before Koenigsberger joined the DTS, he was a research fellow at the London School of Hygiene and Tropical Medicine (LSHTM). He was acquainted with physiologists at the LSHTM—such as G. P. Crowden, who also lectured at the DTS, and Thomas Bedford—and the thermal comfort research they had done. Furthermore, Koenigsberger's private collection of papers include extensive notes on physiology and thermal comfort, particularly articles written by Bedford and Crowden.[45] He was thus undoubtedly shaped by the thermal comfort model that these physiologists constructed. Webb and Drysdale's research on thermal comfort was, likewise, influenced by the work of these physiologists, particularly Bedford and his senior colleague and former collaborator, H. M. Vernon. Bedford and Vernon were pioneers in the field of industrial physiology active in the early- to mid-twentieth century. Not only did Webb and Drysdale draw heavily on Vernon and Bedford's research, they also operated in a similar manner to the pioneer industrial physiologists in that they collected their data primarily in field conditions.

In the British context, the beginning of industrial physiology could be traced to the work of H. M. Vernon and Major Greenwood under the auspices of the Health of Munition Workers Committee (HMWC) that was established during the First World War. The HMWC investigated working conditions in the numerous factories involved in the production of munitions, which was a massive operation employing 3.4 million workers by the end of the War. Due to the pressure to produce, working conditions were often appalling and the hours of work very long. Through field investigations, the HMWC found that shorter hours would improve the physical health of the workers and their efficiency.[46] Moreover, and most relevant here, their findings 'indicated the direct correlation between good working conditions—especially adequate light, ventilation, washing, sanitary and safety provision, seating arrangements, and clothing—and productivity'.[47]

In 1918, the Industrial Fatigue Research Board (IFRB, 1918–47) was established to continue the work began by HMWC. Amongst other things, the IFRB studied 'the conditions of temperature and ventilation in factories, workshops and mines compatible with human comfort, efficiency and health' (figs 8, 9). [48] Much of the research focussed on labour under the conditions of high thermal stress that were not only detrimental to the comfort and efficiency of the worker but could, in extreme cases, also be lethal.[49] The high thermal stress produced was typically due to a combination of the heavy muscular work involved and the ambient environmental condition that had low 'physiological cooling power'. As Crowden noted: 'In heavy muscular work a man may generate waste heat at the rate of 30 to 40 British Thermal Units per minute and this will cause the body temperature to rise to dangerous heights if he cannot get rid of it to his working environment.'[50]

Due to the differences in the site and context of investigation, the industrial physiologists had a different fundamental understanding of thermal comfort from the air-conditioning researchers. First and foremost, they had a different index of comfort. Most of them adopted 'cooling power', as measured by a kata-thermometer, as an index of comfort. In contrast to the air-conditioning researchers' thermal comfort zone, which considered only variations of temperature and relative humidity of air but not air movement, cooling power considered air movement to be a major factor in comfort.[51] Thus, industrial physiologists such as Vernon and Bedford were 'thoroughly in favour of employing natural systems of ventilation as against artificial ones'. Not only was natural ventilation cheaper, it was also deemed 'more pleasant and more healthy' and 'created a greater sensation of freshness'.[52]

Unlike the air-conditioning researchers who equated thermal neutrality with comfort and prescribed thermal steady-state conditions for comfort—ie, thermally monotonous conditions of constant air temperature and relative humidity—the industrial physiologists preferred thermally diverse conditions as they regarded such conditions as more stimulating. This was clearly spelt out in the final report of the HMWC, which stipulated that the desirable atmosphere in a workplace should be '[d]iverse in its temperature in different parts and at different times rather than uniform and monotonous' and 'moving rather than still'.[53] The recommendations on improving thermal comfort in the different reports of the IFRB thus focussed primarily on enhancing the existing arrangement of natural ventilation. Rather than replacing natural ventilation with mechanical ventilation and cooling, the recommendations focus on improving the designs and configurations of windows and skylights, or supplementing them with mechanical fans.

These recommendations and their underlying assumptions could be traced to the pioneering work of Leonard Hill, Professor of Physiology at London Hospital Medical School and Director of the Department of Applied Physiology and Hygiene, Medical Research Committee. Hill, who came up with the concept of cooling power and invented the kata-thermometer to measure it,

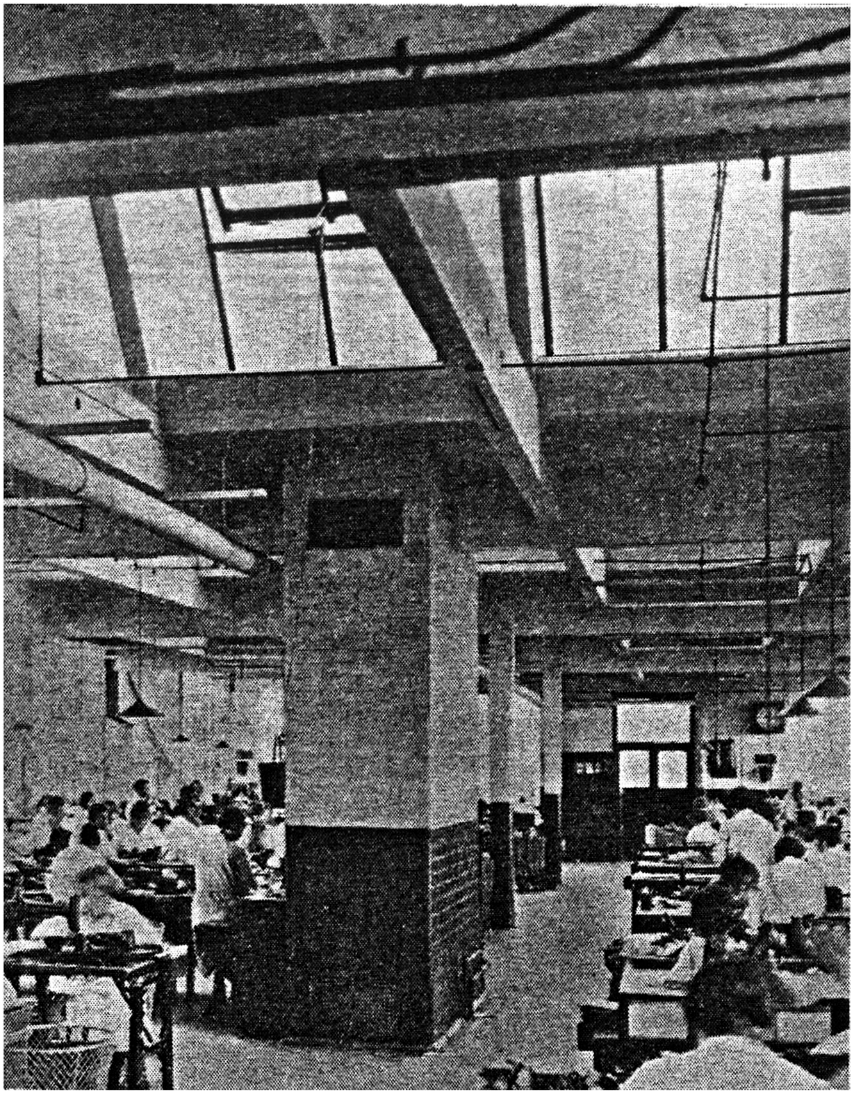


Figure 8. Typical factory premises.

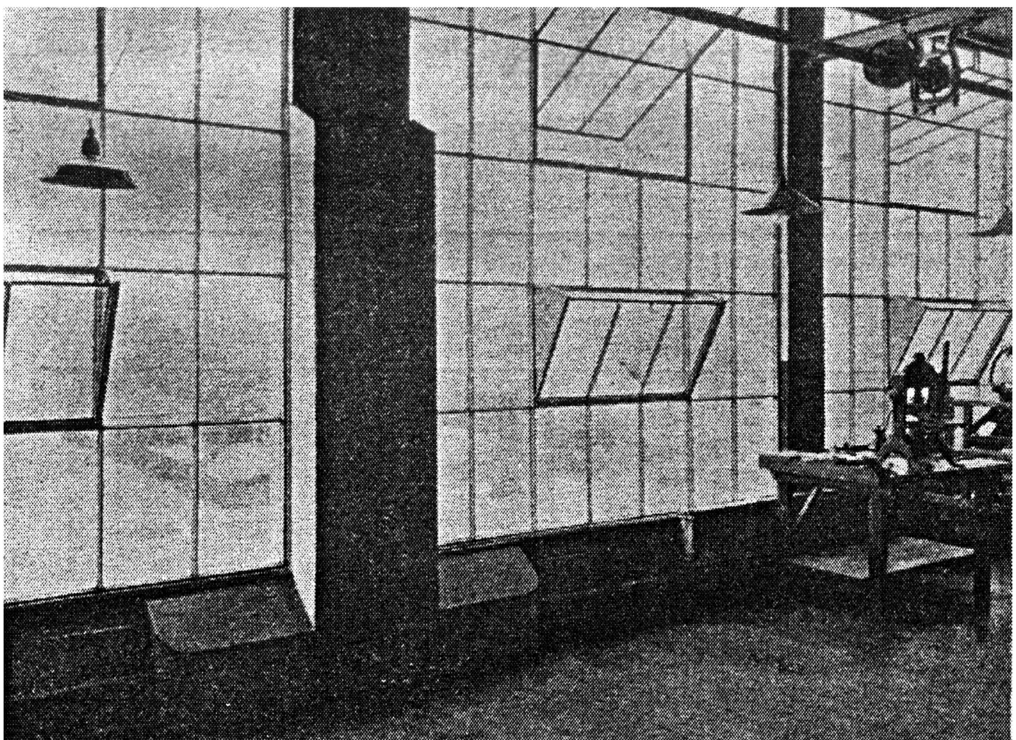


Figure 9. Factory glazing with ventilation.

argued that one of the 'great illusions' of ventilation engineers was to equate a healthy and comfortable interior environment with 'a uniform, draughtless, summer temperature'. Hill noted:

> Life is the reaction of the living substance to the ceaseless play of the environment. Biotic energy arises from the transformation of those other forms of energy—heat, light, sound, etc.—which beat upon the transformer, the living substance. Thus, when all the avenues of sense are closed, the central nervous system is no longer aroused and consciousness lapses … The changing play of wind, of light, of cold and warmth, stimulate the activity and health of mind and

body. Monotony of occupation and external conditions for long hours destroy vigour and happiness and bring about the atrophy of disuse.[54]

The emphasis on natural ventilation, and the variability that comes with it, by Hill and the industrial physiologists in their recommendations for comfort contrasts sharply with the notion of thermal comfort presented by the air-conditioning researchers. This contrast can be understood in at least two different ways. First, Hill and the industrial physiologists were primarily medical researchers. They were not related to the ventilation and air-conditioning industries, thus they did not have any vested interest in promoting mechanical ventilation and cooling. Secondly, the industrial physiologists carried out their field studies in existing factories and observed the physical exertions of manual labourers. These were conditions where labourers worked under conditions of thermal stress related to heat produced by machines and muscular activities. It is therefore unsurprising that they prioritised the cooling power of naturally ventilated cool air.[55] Unlike experimental subjects carrying out sedentary activities in climate chambers, a draught of cold air was more likely to be perceived as stimulating and refreshing rather than uncomfortably cool in these conditions.

Influenced by the research findings of Hill, Bedford, Vernon and other industrial physiologists, Koenigsberger taught his students that many acclimatised subjects in the tropics felt comfortable at air temperature and relative humidity levels higher than those prescribed by ASHVE based on results derived from comfort chamber experiments. Koenigsberger and his colleague also fully embraced cooling by 'natural' means, especially the use of natural ventilation for the hot and humid tropics. This included the acceptance of not just the 'cooling power' but also the desirability of variable natural breezes. However, besides accepting the above aspects of the alternative model of thermal comfort, Koenigsberger might have also internalised and even controversially amplified the correlation, if not causality, between environmental condition and productivity assumed by the industrial physiologists, as will become clear in the next section.

Fatigue, thermal stress and civilisation in the Tropics

Industrial physiology in Britain developed within the broader context of industrial physiology in Europe. As Anson Rabinbach has shown in his seminal book *The Human Motor*, fatigue was 'discovered' in the late nineteenth century in Europe by industrial physiologists. Seen as a nemesis for Europe's industrialisation, industrial physiologists sought to understand it scientifically in order to overcome it. Predicated on the understanding of the human body as a machine of energy conservation and conversion, fatigue was seen by industrial physiologists as a matter of inadequate power or improper usage of power. Rabinbach argued that, as a result, industrial physiology turned labour into a question of human power, which had the effect of depoliticising work, stripping labour of its social and cultural dimensions and presenting it as something independent of class and political interest.[56]

Paralleling the concern with fatigue and industrialisation in Europe in the early twentieth century was the debate on whether Europeans could live and thrive in the tropics. In the tropical territories of British, French, Dutch and American empires, experts in tropical medicine did not agree if 'white men' could acclimatise and adapt to the hot tropical climates or if the white men were a 'doomed race' that would experience racial degeneration in the tropical heat.[57] Behind this debate were two different theories of race—the monogenic and polygenic theories—and the related assertions about fundamental biological differences between the races. [58] This debate led to various medical, including physiological, research on the comparative health, well-being and productivity of the European and indigenous populations in the tropics. Medical theories about various tropical pathologies, such as tropical neurasthenia, a form of nervous breakdown, and tropical fatigue, which purportedly plagued the Europeans in the tropics, were also put forward. These pathologies were often attributed to living and labouring in the enervating climate of the tropics.[59]

The tropical medical experts were like the British industrial physiologists in that they were concerned with the effects of thermal stress. Whilst the industrial physiologists examined the thermal stress caused by the indoor environmental conditions of factories and mines, the tropical medical experts studied the thermal stress in the tropics caused by natural climatic conditions. And whilst the former examined the thermal stress limited to a small proportion of indoor conditions in the temperate climate of European and American contexts, the latter dealt with the inescapable and all-pervasive climatic conditions of the tropics. When the earliest field investigations of thermal comfort in the British tropical territories were carried out in the 1940s and 1950s by researchers influenced by industrial physiologists, these investigations inevitably also inherited the underlying assumption that thermal stress was intrinsic to tropical climate. One of the earliest research projects was carried out by the Royal Naval Tropical Research Unit on the thermal comfort of soldiers working on the decks of war vessels in the tropics. It was concerned specifically with how tropical heat combined with their muscular activities to produce thermal stress and other physiological effects in the soldiers that might adversely affect the 'fighting efficiency of the Fleet'.[60] Although Webb and Drysdale did not examine extreme physiological cases, the underlying assumption of inevitable thermal stress in the tropics remained. For example, Webb noted in his study of the colonial:

> The populations of the tropics are peculiarly subject to thermal discomfort, due basically to the warmth of the climates in which they live … This fact coupled with the prevalence of overcrowding in tropical cities, has long been recognized as constituting, in relation to human happiness and even to health, a problem of some magnitude … [61]

Koenigsberger's emphasis on climatic design and thermal comfort in the tropics was predicated on similar concerns with the implications of widespread thermal discomfort in the tropics caused by the heat. Koenigsberger's affinity with Webb's findings on thermal comfort in the tropics went beyond accepting his fieldwork-based research methodology. Koenigsberger also shared Webb's assumption about the correlation between thermal comfort, human physiology and happiness. Koenigsberger noted in a co-authored housing manual:

> The study of design in relation to climate must begin with the question "How does climate affect the human body?" This question is answered best by reference to an observation of the great French physiologist Claude Bernard, who found that *happy and healthy human life is possible only as long as the temperature inside the human body is kept constant within fairly narrow limits*.[62] [My emphasis.]

Whilst the human being is a homotherm, ie, he or she can maintain a relatively constant body temperature even though environmental temperature fluctuates, Koenigsberger noted that constant body temperature might only be achieved with much external assistance—through clothing and housing—and at the price of inactivity and discomfort, especially when the environmental conditions are not ideal.[63] This was especially so in the tropics, characterised by Koenigsberger as 'parts of the world where heat is the dominant problem'.[64] According to Koenigsberger, the 'slow cumulative effect of heat strain' in the tropics would not just create feelings of discomfort, it might also increase fatigue, decrease work efficiency and affect health and happiness.[65]

Not unlike the industrial physiological research in Europe that had broader concerns beyond the fatigue of individual workers, the research on thermal comfort in the tropics also had implications beyond individual bodies. The American geographer Ellsworth Huntington drew on the findings of physiological research on the performance of factory workers and students under different climatic conditions in North America, but employed dubious if not erroneous methods of interpreting the data.[66] From these data, Huntington argued that climatic conditions affected the global distribution of 'human energy'. The hot and humid climate of the tropics was deemed to have given rise to 'tropical inertia' amongst those who lived there and it was manifested in their 'lack of industry' and their various forms of intemperance (Fig. 10).[67] Thus, Huntington deemed the tropics as a region that had low energy and civilisational attainment.

Sydney Frank Markham, a British politician, extended Huntington's arguments in *Climate and the Energy of Nations*. In this book, he reviewed scientific research done on thermal comfort and summed it up as indicating that a temperature range around 60 to 70 degrees Fahrenheit was the ideal zone for attaining high civilisation.[68] In Markham's sweeping account of the history of world civilisations, climatic condition was attributed much causal power, though it was not as overwhelmingly deterministic of civilisational outcomes as it was in Huntington's account. Markham left more room for human agency and technological innovations, including architectural ones, to modify and even control climatic conditions, particularly indoor climatic conditions. For example, he argued that Roman civilisation was assisted by the invention of the hypocaust system of heating, and sought to show that '[i]t was the chimney, the grate and the use of coal, combined with new developments in architecture, which changed the whole history of mankind' from around the 1300s onward.[69]

The new developments in architecture that Markham referred to were 'the rediscovery of brick-making and window glass-making' that helped to produce the 'sealed house'. Not only did that combination contribute to the Renaissance,

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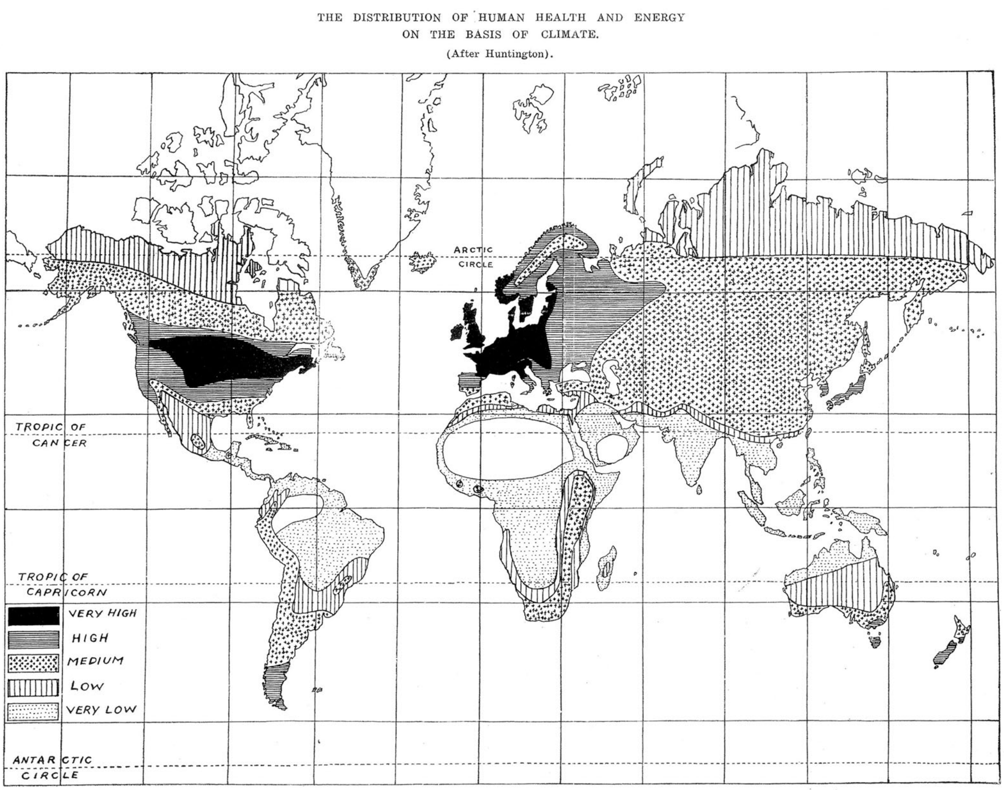

Figure 10. The distribution of human health and energy on the basis of climate (after Huntington).

Markham claimed that it laid the foundation for the invention of the stove in the fifteen century that provided a warm indoor temperature approximating to the ideal range most conducive for 'mental work'. Markham heralded this as the arrival of a 'new indoor civilization' in Northern Europe that became the basis for industrial revolution. As this new indoor civilisation was also made possible by the extensive use of coal as a fuel source, Markham christened this the 'coal civilization'. Further technological innovations in the coal civilisation—such as gas heating and lighting, steam heating and hot water systems—during the nineteenth century further enabled Europeans to control the indoor climatic conditions that would climax in European Imperialism (Fig. 11). Markham's account of the entanglements of climate with comfort, technology, architecture and civilisational development would

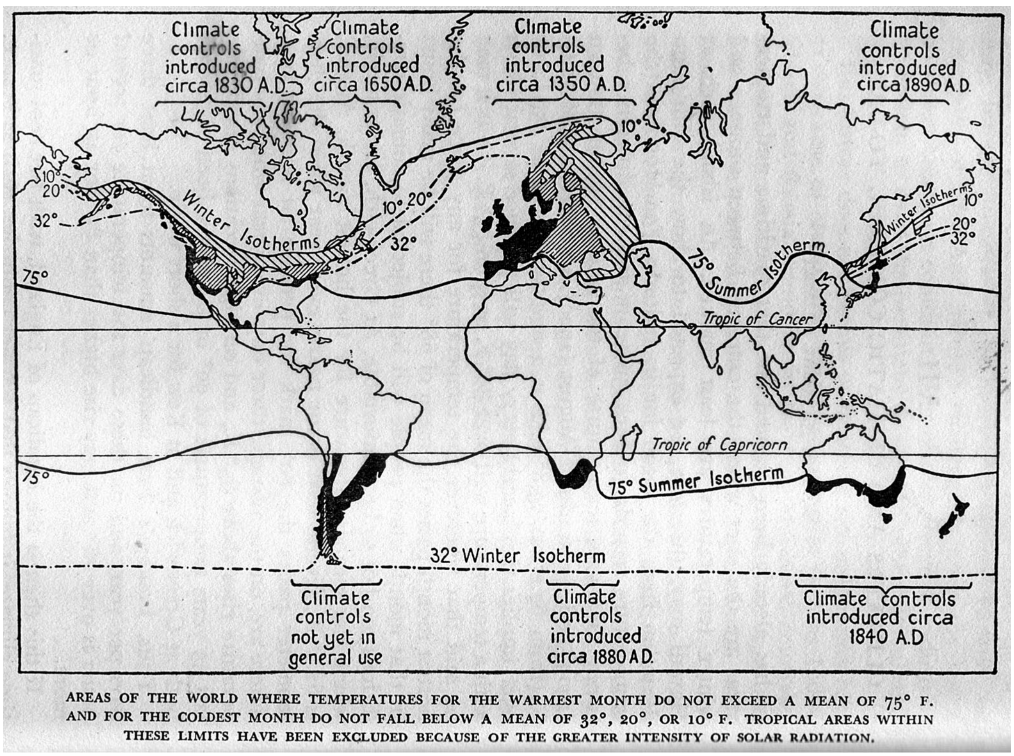

Figure 11. Global map identifying the development of climate control activity over time.

profoundly shape the architectural discourse of climatic design, particularly in the case of Koenigsberger at the DTS.

Koenigsberger drew on Huntington's, and especially Markham's accounts to expand on the earlier argument regarding the negative impacts of hot tropical climates on the comfort and happiness of individuals, which he and other researchers influenced by industrial physiology put forward. In justifying the teaching of climatic design at the DTS, Koenigsberger claimed that climate affected the energy of nations and even shaped the development of civilisation.[70] Adapting Markham's historical account, Koenigsberger argued that although human beings first emerged in 'zones of favourable climate', that is the tropics, civilisations developed in regions with 'ideal climate'.[71] By ideal climate, Koenigsberger was referring to the temperate climate because 'since man mastered fire, we can heat and dry, but not cool'[72] and, thus, those who lived in temperate climate were more likely to attain comfort, be more energetic and productive at work. However, this climatic determinist account was modified by another account on the emergence of various technologies of environmental control in Europe—such as the invention of the grate in the thirteenth century and the Dutch stove in the fifteenth century—and how these technologies allowed indoor work during the cold months, which in turn set the stage for the advancement of Northern civilisation. He argued that the 'beginning of architects' mastery over cold climate' marked also the 'beginning of European political predominance, power and colonization'.

Markham's historical account provided Koenigsberger with even more compelling reasons for teaching climatic design. First of all, Koenigsberger used Markham's central thesis that 'one of the basic reasons for the rise of a nation in modern times is its control over climatic conditions: that the nation which has led the world, leads the world, and will lead the world, is that nation that lives in a climate, indoor and outdoor, nearest the ideal'[73] to justify the teaching of climatic design and the privileging of climatic conditions as the prime determinant of architectural form. The conjoining of climate control with the fate of a nation might have proven to be especially seductive at a time of decolonisation and the prevailing concern with national development. Equally significant was the conceptual space that Markham's account opened up for architectural intervention in modifying the indoor climatic conditions and transforming the fate of nations. It allowed Koenigsberger to claim that the 'historical role of architecture [is the] controller of climatic environment and thereby influences the fate of nations'.[74] Coupling the agency given to architecture, and thus architects, with the political economic imbalances created by Western imperial dominance and the mastery of climatic conditions meant that Koenigsberger could arrive at the rather simplistic conclusion that glossed over the intricacies of colonial/Western dominance: 'If this historical analysis is correct, it is time for architects to learn to master hot climates to restore the "balance of power."'[75]

Whilst Koenigsberger's use of Markham's and, to a lesser extent, Huntington's narratives of climate and civilisation could be seen as an empowering one of giving the architects working in the tropics agency in transforming the fates of these nations, he also unwittingly inherited the underlying assumptions behind these narratives: climatic determinism and the association of the tropics with thermal stress. Even though Koenigsberger did not subsequently include these narratives in his *Manual of Tropical Housing and Building*, they formed an integral part of his lectures at the DTS up until at least the late 1960s. Moreover, Huntington's *Civilization and Climate* (1915) and Markham's *Climate and the Energy of Nations* (1947) were also among the five books on climate and civilisation that he assigned to his students at the DTS to discuss and debate, although we do not know the outcomes of these debates.[76] Koenigsberger's decision to omit these narratives from his published *Manual* might suggest that these controversial climatic determinist narratives were not well received by his students. Or, they might even have been discredited.

Although few other advocates of climatic design in the mid-twentieth century shared Koenigsberger's meta-narrative that extended from individual physiological comfort and productivity to climate and civilisation in a world of nations, quite a few shared his implicit climatic determinist assumptions about thermal stress in the tropics and underdevelopment. For example, in a passage from the section entitled 'The tropics (climate and its attendant ills)' in their seminal book on tropical architecture, Fry and Drew wrote:

> Caught within the magic circle of growth, lulled by its constancy … the people of the tropics have slumbered on for centuries, little touched by what took place in the world outside them, maintaining themselves in varying balance against the forces of nature at once so propitious yet so insidious.[77]

In *Design with Climate*, another seminal book on climatic design, the Olgyay brothers used Huntington's argument on the correlation between climate and energy to substantiate their point about the effects of climate on man, noting in particularly 'that in certain climatic areas, where excessive heat or cold prevails, energy is diminished by the biological strain of adaptation to extreme conditions.'[78]

Conclusion: reconstructing climatic design

When Atkinson and Koenigsberger promoted climatic design in the mid-twentieth century, they were part of an international network of architects, educators and technicians who produced a large number of passively cooled and heated buildings. However, this movement of climatic design was soon displaced by the ascendancy of air-conditioned buildings following increasing affluence and the widespread availability of cheap fossil fuel to power the air-conditioners.[79] Despite temporary disruptions by the oil crises in the 1970s, air-conditioned buildings have continued to proliferate until today.[80] In the face of the challenges brought about by anthropogenic climate change and in response to architecture's energy profligacy through its over-reliance on air-conditioning, many sustainability advocates in the past two decades or so have been calling for societies to wean themselves from their addiction to air-conditioning and for a return to bioclimatic design and buildings that use non-air-conditioned technologies.

But to which practices should these societies be returning? Many advocates see this as a return to nature or, more accurately, a recourse to a 'natural' state of things. I have argued that climatic design, as constructed by Atkinson, was underpinned by overly narrow understanding of thermal comfort—based on that devised by the researchers associated with the air-conditioning industry—and would render most of the tropical territories uncomfortable most of the time. Surely we are not returning to a thermal comfort model that was based on a mechanistic and reductive understanding of bodily thermal comfort that underpinned the early discourse of climatic design? Certainly we should not be returning to the widely held but seldom acknowledged colonial understanding of the tropics as a site of thermal stress and underdevelopment that justified the privileging of climate as the prime determinant of architectural form, as was evident in the case of Koenigsberger's pedagogy at DTS?

Rather than a return to 'nature' that relies on a binary conceptions of our built environment and its environmental technologies—such as active versus passive cooling, modern technology versus timeless tradition, and universal techniques versus place-based culture—what is needed now is a new socio-technical assembly that reconfigures the previously mechanistic and reductive understanding, and opens it up to reconsider the various social, cultural, political and technological entanglements of comfort.

Earlier I discussed the experiments on thermal comfort carried out by Webb and Drysdale in the field. Whilst the findings of these field studies, which show that many subjects felt comfortable at much higher air temperature and relative humidity as compared to results from experiments done in comfort chambers, were ignored by Atkinson in his discussion of climatic design for the tropics, findings from similar field studies have recently been embraced by both building scientists and sociologists and used as the basis for developing a much more nuanced and sophisticated context-dependent model of thermal comfort. This new thermal comfort model—known as the 'adaptive model' of thermal comfort—envisages occupants not as passive recipients but as actors that actively control and modify their immediate surroundings to attain comfort. Thus, thermal comfort is understood not just as an environmental attribute but as a socio-environmental or socio-technical achievement.[81] Advocates for the adaptive thermal comfort model have noted that it would lead to a revision of indoor environmental standards that would in turn permit the implementation of less energy-intensive cooling technologies, such as natural ventilation and mixed-mode cooling, and bring about substantive energy savings.[82]

The adaptive thermal comfort model is certainly a good start but it is probably inadequate. In order for such a model to gain acceptance by inhabitants in the tropics and for them to rely on natural ventilation for cooling on a more regular basis, two inter-related sets of underlying issues have to be interrogated. The first are the deeply rooted neo-colonial socio-cultural constructions of the tropics as a zone of thermal stress and discomfort. The second are the social practices and cultural norms with ingrained dependency on mechanical cooling that have emerged from these deep-seated negative perceptions of the tropical climate. The failure of tropical architecture, or climatic design in the tropics, in the mid-twentieth century could arguably be attributed not to any inherent deficiency in the architecture prescribed but primarily to its underlying assumption that the tropics constitutes a site of thermal stress and discomfort. Partly due to these negative assumptions, when parts of the tropics became sufficiently affluent and could afford the costly and energy-intensive technology of air-conditioning, many inhabitants there immediately embraced it. In order to dismantle the hegemony of air conditioning as the cooling technology of choice in the tropics, more than an alternative comfort model and the attendant new technologies of cooling are needed. A reconstruction of socio-cultural perceptions of tropical heat and a reassembly of concomitant social practices of maintaining comfort are also needed.[83]

Acknowledgement

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51. Leonard Hill, *The Science of Ventilation and Open-Air Treatment, Part 1* (London, HMSO, 1919); S. Wyatt, *Reports of the Industrial Fatigue Research Board: Atmospheric Conditions in Cotton Weaving* (London, HMSO, 1923). For the difference between ASHVE's thermal comfort zone and cooling power, see, H. M. Vernon, 'Is Effective Temperature or Cooling Power the Better Index of Comfort', *The Journal of Industrial Hygiene*, 8, no. 9 (1926).
52. H. M. Vernon, T. Bedford, *A Physiological Study of the Ventilation and Heating in Certain Factories*, *op. cit*., pp. 76–78.
53. Health of Munition Workers Committee, *Final Report: Industrial Health and Efficiency* (London, HMSO, 1918), p. 85.
54. Leonard Hill, *et al*., *The Influence of the Atmosphere on Our Health and Comfort in Confined and Crowded Places* (Washington, DC, The Smithsonian Institution, 1913), pp. 2–3.

55. In fact, Leonard Hill even invented a special instrument, the kata-thermometer, to measure the cooling power of air: see, S. Wyatt, *Atmospheric Conditions in Cotton Weaving*, *op. cit.,* p. 3.
56. Anson Rabinbach, *The Human Motor: Energy, Fatigue, and the Origins of Modernity* (New York, Basic Book, 1990).
57. Warwick Anderson, *The Cultivation of Whiteness: Science, Health and Racial Destiny in Australia* (New York, Basic Books, 2003), pp. 80–86.
58. Monogenic theory of race posits a single origin of all human beings while polygenic theory posits that human beings are from different origins. See, Mark Harrison, '"The Tender Frame of Man": Disease, Climate, and Racial Difference in India and the West Indies, 1760–1860', *Bulletin of History of Medicine*, 70, no. 1 (1996).
59. See also Warwick Anderson, *Colonial Pathologies: American Tropical Medicine, Race, and Hygiene in the Philippines* (Durham, Duke University Press, 2006).
60. F. P. Ellis, 'Tolerable and Desirable Levels of Warmth in Warm Climates, with Special Reference to the Requirements of Men in the Royal Navy: Hunterian Lecture Delivered at the Royal College of Surgeons of England on 14th May, 1953', *Annals of The Royal College of Surgeons of England*, 13, no. 6 (1953), p. 369. See also, F. P. Ellis, 'Thermal Comfort in Warm, Humid Atmospheres. Observations in a Warship in the Tropics', *The Journal of Hygiene*, 50, no. 3 (1952).
61. C. G. Webb, 'An Analysis of Some Observations of Thermal Comfort in an Equatorial Climate', *op. cit*., p. 298.
62. O. H. Koenigsberger, C. T. Mahoney, M. Evans, 'Climate and House Design', *Design of Low-Cost Housing and Community Facilities*, V. 1 (New York, United Nations, 1971), p. 15. This view is very similar to that expressed in, G. P. Crowden, 'Indoor Climate and Thermal Comfort in the Tropics', in, Arthur Foyle, ed., *Conference on Tropical Architecture 1953: A Report of the Proceedings of the Conference Held at University College, London, March 1953* (London, University College London, 1953).
63. O. H. Koenigsberger, 'Introductory Lecture to Climatic Design Series', *op. cit.*; Renate Koenigsberger Private Collection. Otto Koenigsberger's lecture notes for 'Lecture on the Importance of Climate', 8th November, 1964.
64. The theme of week 4 in the course at DTS during 1965–66 was 'Heat (on parts of the world where heat is the dominant problem)': see AA Archives, Box 2003:29C, *Department of Tropical Studies: Session 1965–66*.
65. Renate Koenigsberger Private Collection. Otto Koenigsberger's lecture notes for 'Lecture on Climate and History', 12th October, 1967.
66. See Daniel J. Ryan, 'Civilising Comfort: 1914–1945', paper presented at the 7th Windsor Conference: The Changing Context of Comfort in an Unpredictable World, Windsor, UK, 2012, pp. 95–106; James Rodger Fleming, *Historical Perspectives on Climate Change* (Oxford, Oxford University Press, 2005).
67. W. Anderson, *Colonial Pathologies*, *op. cit.*, p. 139.
68. S. F. Markham, *Climate and the Energy of Nations* (London, Oxford University Press, 1947; 1942), pp. 21–31.
69. Ibid., pp. 79–80.
70. Both Ellsworth Huntington and S. F. Markham's books were featured in the reading list that Koenigsberger issued to students. See Renate Koenigsberger Private Collection. Otto Koenigsberger's lecture notes for 'Week 2 Lecture on Climate and Man',1965. For a discussion of Ellsworth Huntington's work, see, Marsha E. Ackermann, *Cool Comfort: America's Romance with Air-Conditioning* (Washington DC, Smithsonian Institution Press, 2002), pp. 8–26; S. F. Markham, *Climate and the Energy of Nations, op. cit*.
71. Koenigsberger's history was very much a summary of Chapters V, VI and VII of S. F. Markham's *Climate and the Energy of Nations*, *op. cit.*, pp. 38–105.

72. O. H. Koenigsberger, 'Lecture on Climate and History', *op. cit.*
73. S. F. Markham, *Climate and the Energy of Nations*, *op. cit.*, p. 20.
74. O. H. Koenigsberger, 'Introductory Lecture to Climatic Design Series', *op. cit*.
75. O. H. Koenigsberger, 'Lecture on the Importance of Climate', *op. cit*.
76. The other three books were: Marston Bates, *Where Winter Never Comes* (London,V. Gollancz, 1953); Clarence Mills, *Climate Makes the Man* (New York, Harpers and brothers, 1942); Pierre Gourou, *The Tropical World* (London, Longmans, 1953). See AA Archives, Box 2003:29C, *op. cit*.
77. Maxwell Fry, Jane Drew, *Tropical Architecture in the Dry and Humid Zones* (London, Batsford, 1964), pp. 23–4.
78. Victor Olgyay, Aladar Olgyay, *Design with Climate: Bioclimatic Approach to Architectural Regionalism* (Princeton, Princeton University Press,1963), p. 14.
79. For the case of Singapore, see Jiat-Hwee Chang, Tim Winter, 'Thermal Modernity and Architecture', *The Journal of Architecture*, 20, 1 (2015), pp. 92–121.
80. S. Cox, *Losing Our Cool*, *op. cit*.
81. See, for example, G. S. Brager, R. J. de Dear, 'Historical and Cultural Influences on Comfort Expectations', in, R. Lorch, R. J. Cole, eds, *Buildings, Culture and Environment: Informing Local and Global Practices* (Oxford, Blackwell, 2003); R. J. de Dear, K. G. Leow, S. C. Foo, 'Thermal Comfort in the Humid Tropics: Field Experiments in Air-Conditioned and Naturally Ventilated Buildings in Singapore', *International Journal of Biometeorology*, 34 (1991); E. Shove, *Comfort, Cleanliness and Convenience, op. cit*.
82. F. Nicol, M. Humphreys, S. Roaf, *Adaptive Thermal Comfort*, *op. cit*.
83. See also Tim Winter, 'Urban sustainability in the Arabian Gulf: Air conditioning and its alternatives', *Urban Studies* (2015).