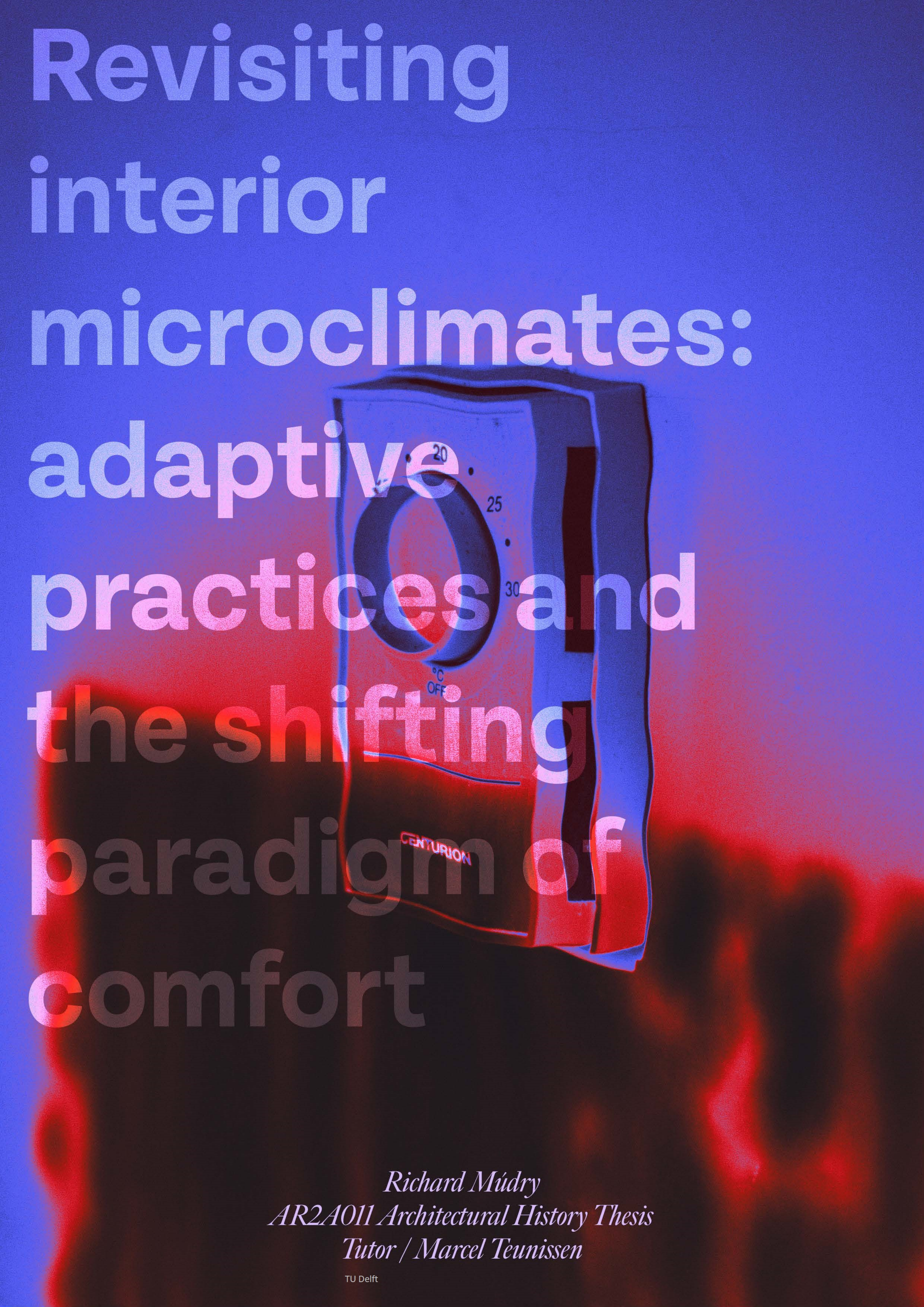
Revisiting interior microclimates: adaptive practices and the shifting paradigm of comfort



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Revisiting interior microclimates: adaptive practices and the shifting paradigm of comfort

In the context of climate change, how can we redefine the modern notion of comfort in interior microclimates, and what insights can be gained from historical vernacular practices to guide the development of adaptive and resilient living environments?

01 Introduction

“Comfort [...] is in short supply. Not because the world is running out of it but because, in the face of the climate crisis, we have to collectively adjust to its going away” (Barber, 2019, p. 44). During the last century, the Western hemisphere has grown accustomed to high standards of comfort reliably enabled by the built environment. Within the realm of thermal comfort, fossil-fueled mechanical HVAC systems are expected to mitigate heat during warmer seasons and provide warmth throughout living and working spaces in winter months. However, the understanding of and measures to achieve thermal comfort are a construct of modern societies. And they come at a price: cooling and heating accounts for approximately 20% respectively 50% of building energy (Wang et al., 2023). Facing the challenges and implications of climate change, this paper aligns with the contention of Professor Daniel A. Barber, architectural historian at the University of Technology Sydney, that the status quo on comfort needs to be revisited and it is architects who are “on the front lines”. Architects, he argues, are responsible for “exploring life after” comfort and for building noncarbon possibilities in “a world at the edge of discomfort” (Barber, 2019, p.50).

This paper delves into the historical evolution of comfort in the built environment, with a primary focus on thermal comfort and the overlooked influence of microclimates. The paper traces the historical transition from vernacular ways of shaping interior microclimates to today’s prevailing practices - and sheds light on their problematic dependency on fossil fuels. In contrast, contemporary movements to redefine the current understanding and way of achieving thermal comfort are presented. The exploration of thermal comfort has evolved throughout history, from ancient attempts of individuals who sought refuge from extreme climate conditions to sophisticated scientific models using multidisciplinary methods to answer simple questions – when do we feel comfortable and what is the amount of discomfort we can acclimatize to and embrace?

Today, construction and building technology ensuring thermal comfort have become increasingly complex, facing rising demands for stability, insulation, hygiene, and more. This complexity often results in a high error rate during planning and execution, presenting challenges for quality assurance and burdening builders and users (Ali et al., 2020). Consequently, the paper presents the potential of integrating low-tech solutions with robust design to achieve thermal comfort as an alternative to highly controlled modern building interiors.

Ultimately, this thesis aims to spark a dialogue on the evolving concept of comfort, advocating for a holistic approach that integrates vernacular wisdom, adaptive devices, sustainable practices, and a reconsideration of our reliance on fossil fuels to shape more resilient and adaptable interior microclimates.

02 Definition of thermal comfort

Thermal comfort is defined as “the condition of mind that expresses satisfaction with the thermal environment and is assessed by subjective evaluation.” (ASHRAE, 2017) In the current understanding, both individual and environmental factors are affecting the level of thermal comfort.
On the level of the individual, clothing, insulation of the body, and metabolic rate influencing heat production are considered as relevant factors to assess thermal comfort (Wang et al., 2023). Furthermore, studies show differences in the perception of indoor thermal comfort depending on social demographics such as age and gender (Asif et al., 2022)
The built environment primarily affects the second category, the environmental factors. Air temperature is defined as the crucial factor affecting thermal comfort and influenced by heating and cooling methods. Mean radiant temperature, the average temperature of room surfaces, combined with air temperature, determines the operative temperature. Air velocity measures airflow speed and direction which is crucial to avoid draughts. Vapor pressure, indicating air moisture, affects comfort levels. The primary motivation behind achieving thermal comfort in a built environment is to address our inherent biological need to maintain a constant internal temperature, known as homeostasis. The thermal conditions people encounter in their daily lives, whether at home or work, can significantly impact our physical and mental health. This, in turn, can for example influence individual productivity, economic prosperity or societal dynamics (McCartney & Nicol, 2002; Nicol & Roaf, 2022).

03 Evolution of thermal comfort in architecture

The pursuit of comfort within the built environment has been intertwined with the evolution of human civilization. Throughout history, from ancient settlements to the complexities of modern society, creating spaces where people feel safe and can prosper has remained a consistent endeavor. This pursuit has been a significant part of human culture and shows the importance of the relationship with the spaces we inhabit.

In contemporary discourse, the understanding of what makes us feel comfortable in the built environment has evolved into a complex matrix of aspects formed from various disciplines. Among those, thermal comfort emerges as a cornerstone, exerting a profound impact on our health, productivity, and overall daily well-being. However, as we delve deeper into the realm of architectural design and environmental sustainability, the significance of thermal comfort extends beyond individual satisfaction – it emerges as a critical nexus between human needs and wants and the urgent global need to conserve energy.

This chapter aims to unfold the historical development of thermal comfort within the built environment, mapping its trajectory from technical innovations to key definitions within the building codes. By critically discussing the contemporary notions of thermal comfort and reassessing the degree of comfort needed, this paper then will reveal strategies that mitigate the current reliance on fossil fuels while creating more sustainable and resilient spaces of comfort in a future shaped by climate change.

03.1 Early tempering of indoor climate

Understanding the early history of indoor climate regulation is crucial for contextualizing modern approaches and innovations. By examining the rudimentary methods employed by early humans, we gain insight into the fundamental human need for thermal comfort and the evolution of strategies to achieve it. This historical perspective not only enriches our understanding of past civilizations but also informs contemporary architectural design and sustainability efforts. By learning from the successes and failures of our predecessors, we can develop more effective and environmentally conscious solutions for indoor climate control in the present and future.

The history of human efforts to regulate indoor climate traces back to the utilization of campfires inside caves and huts. Hominis first set up a fire in the Swartkrans cave, South Africa, 1.5 million years ago (Stancampiano et al., 2023), experiencing the sensation of heat, albeit perhaps unintentionally. Early attempts at cooling and ventilation can be seen in the tent structures of tribal societies in the Middle East and Sri Lanka (Pirhayati et al., 2013). These tent structures served as inspiration to wind catchers, tower-like structures more than 1000 years old, which use wind-driven ventilation to bring fresh air into buildings and expel hot, polluted air (Nejat, 2018). Such passive cooling systems, prevalent in Iranian vernacular architecture, have garnered renewed attention from contemporary architects. They are being leveraged to reduce cooling demands and ensure adequate ventilation in modern architectural designs worldwide (Sangdeh & Nasrollahi, 2022).
In “De Architectura,” the Roman architect and architectural theorist Marcus Vitruvius Pollio who lived in the first century BC alludes to the employment of the hypocausis meaning furnace, suggesting the use of a heating system, referred to as “hypocaust,” indicative of ancient Roman practices (Black, 1985). The evolution of heating technologies progressed notably during the late Middle Ages with the advent of draft chimneys in Europe. However, the widespread adoption of more efficient heating stoves, reminiscent of those used in medieval Germany and Scandinavia, was a gradual process, taking considerable time to permeate British and American architectural traditions (Edgerton, 1961).

03.2 Before comfort there was health - emergence of the comfort era

For this research that focuses on the most prevalent contemporary building types, the relevant period of history begins in the 20th century. This period saw the emergence of modern scientific research and perspectives on indoor thermal comfort, along with the formulation of the first definitions and building laws. This era significantly shifted our understanding and approach to thermal comfort in indoor residential built environments, laying the groundwork for our comprehensive understanding today.

In the early 20th century, the pursuit of thermal comfort within architecture was enabled by two main factors: the focus of the architectural discourse turned to the human body and the role of hygiene in maintaining health was discovered.

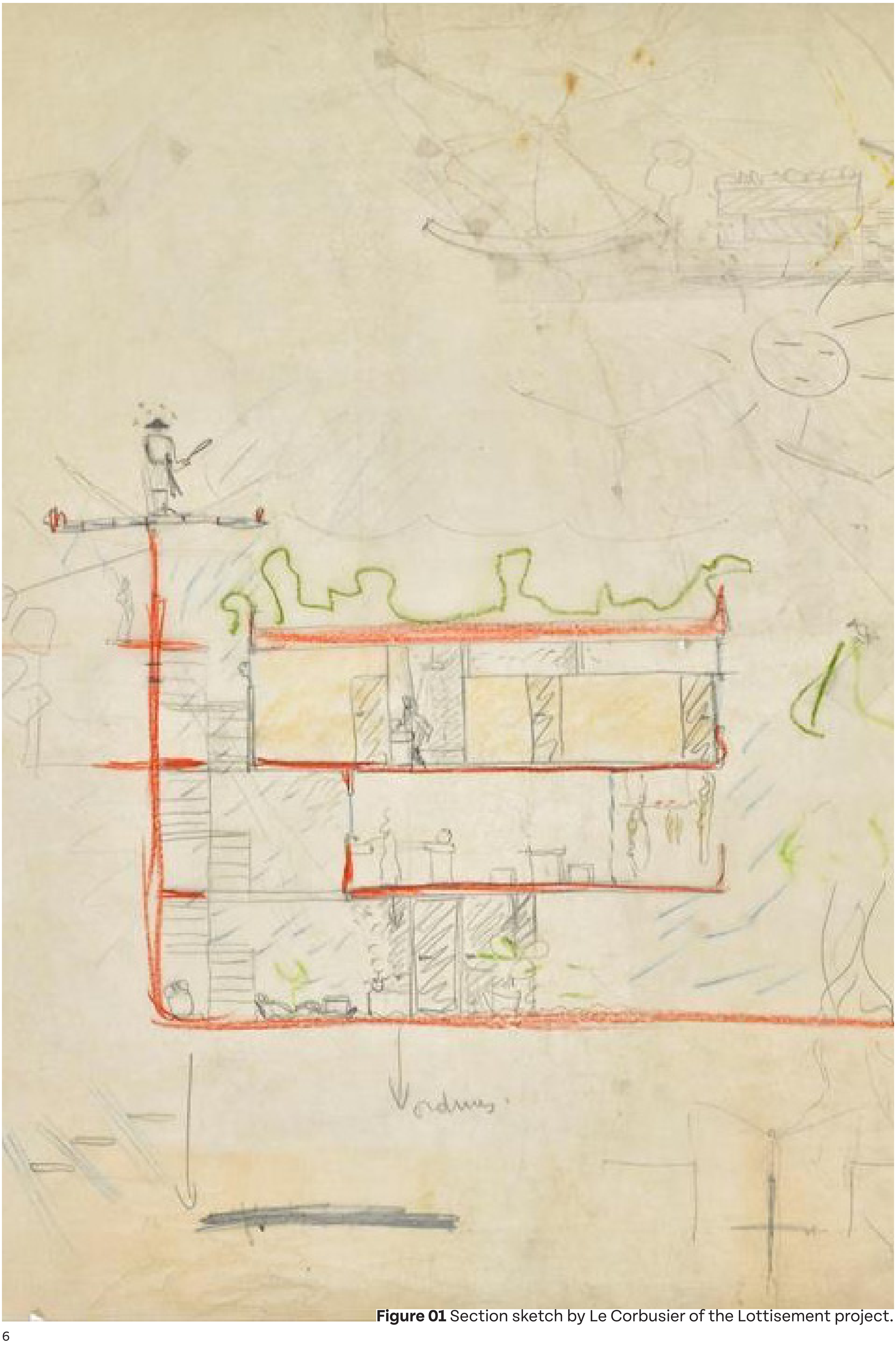


Figure 01 Section sketch by Le Corbusier of the Lottisement project.

In “A Philosophy of Discomfort”, Jacques Pezeu-Massabuau (2012) noted that “[m]ore than anything, we need to accommodate our body in a place. Where could never be a theory or use of comfort that does not begin from the body, the group of cells from which we are made and upon which our well-being rests.” (p. 22) This contemporary view of the human body as the starting point for comfort can already be found in the 20th century’s understanding of architecture. Emerging architectural styles like functionalism and influential figures such as Le Corbusier with his concept of Le Modulor emphasized the importance of analyzing and measuring the physical dimensions of individuals (Fabbri, 2024) and exploring the human body’s relationship with space. This pursuit of Le Corbusier and other modernist architects did not stop with the immediate space but started to integrate climate considerations into design practices. For example, the Barcelona Lotissement project from 1931 shows the architect’s will to reconcile aesthetic principles with climate responsiveness. The use of shading devices and passive cooling strategies highlighted a departure from conventional architectural norms, reflecting a growing awareness of the interplay between built environments and climatic conditions. Barcelona, along with other Mediterranean cities, served as testing grounds for innovative approaches to climate-sensitive design. As analyzed in Daniel A. Barber’s recent work (2023, p. 26), Le Corbusier’s vision, as exemplified by his proposal for “only one house for all countries,” aimed to create spaces that could provide consistent comfort regardless of regional variations. The Athens Charter further underscored this universality principle of modern architecture regarding comfort by suggesting that buildings should be positioned to maximize sunlight exposure. This approach aimed to foster the creation of standardized thermal interiors globally, despite diverse climatic, sociocultural, and economic contexts. However, the text also critiques modernist architecture as influenced by colonial perspectives and geopolitical contexts as it disregards existing climate-responsive vernacular strategies. In this sense, it highlights modernism’s imposition of principles on diverse climates, overlooking traditional already existing adaptations. This calls for a reassessment of colonial biases in architectural discourse and a rediscovering of diverse climatic responses across cultures.

Simultaneously, the hygienist movement emerged, spurred by advances in modern science that highlighted the relationship between environmental purity and human health. The discovery of microbes underscored the significance of maintaining clean air and access to sunlight, both of which were recognized as crucial elements in combatting prevalent health issues like rickets and tuberculosis (Requena-Ruiz, 2016). This movement gained momentum within medical environments and intersected with initiatives such as the establishment of the J.B. Pierce Laboratory (Fabbri, 2024). Led by the philanthropic vision of John B. Pierce, the laboratory aimed to advance research in heating, ventilation, and human health, recognizing the intertwined nature of environmental conditions and human well-being. Biophysicist A.P. Gagge’s pioneering work within this laboratory further explained the intricate dynamics of human thermoregulation. Gagge’s research was focused on practical applications: he studied the energy exchange between the human body and its environment to apply the findings in the fields of health, safety in the workplace, military, and the design of buildings.

Figure 02 The Tivoli, in Chicago, opened 16 February 1921 and was one of the first cinemas in the country to install air conditioning.

Figure 03 A man swelters while checking out window units in 1960. The prosperous middle class made air conditioning anecessity by the 1960s.

In the early 20th century, a crucial shift towards achieving thermal comfort in architecture began. This was driven by a greater focus on the needs of the human body and a growing awareness of the essential role of hygiene in preserving health. During this time, architectural discussions started to prioritize accommodating the human body and aimed to standardize answers to individual needs, alongside notable discoveries in related scientific fields. Together, these developments laid the foundation for the eventual mechanical control of indoor climates.

03.3 Perfect control – the rise of the use of technology within interiors

Before the 1920s, air-conditioning primarily served to maintain consistency in manufacturing, creating stable microclimates with controlled temperature and humidity (Ackermann, 2010). This ensured year-round product quality standards in factories. However, after the 1920s, air-conditioning began to integrate into urban public life. With the rise of mass media, the once scientific innovation gradually became part of the culture, with public institutions promising thermally controlled interiors (Requena-Ruiz, 2016). American cinemas embraced air-conditioning early on, promoting themselves with slogans like “Cool comfort” or “It’s cool inside.” However, widespread adoption across all social classes was not immediate. Evidence of this is the decade it took for a reputable American theatre to install a unit (Ackermann, 2010). The American Society of Heating and Ventilating Engineers (ASHVE) played a pivotal role in introducing “artificial” air into public life. In 1926, ASHVE began advocating for air-conditioning in school buildings (Ackermann, 2010), raising fundamental questions about human comfort. The first comfort charts, published in 1932 by ASHVE, emerged from experiments in heat, humidity, and ventilation conducted at Yale Medical School (Barber, 2023). Although the engineers pushed innovation and advocated for its widespread use, it wasn’t until the late 1950s that architects fully integrated mechanical cooling into their buildings.

In the post-war period, there was a notable surge in the study of climate, reflecting a growing recognition of its multifaceted impacts on human life, particularly within architecture and urban planning. The interest in climate sciences increased after the successful use of meteorological predictions for military operations by Allied forces (Barber, 2023). An influential milestone in this regard was Helmut Landsberg’s 1947 article titled “Microclimatology: Facts for Architects, Realtors, and City Planners on Climatic Conditions at the Breathing Line” which featured illustrative drawings and diagrams. Landsberg’s work aimed to integrate climate data into architectural design considerations, marking an initial step towards a more holistic approach (Barber, 2023).

Figure 04 The Olgyay brothers with the Thermoheliodon device at the Princeton Architectural Laboratory. From Collier's magazine, June 1956.

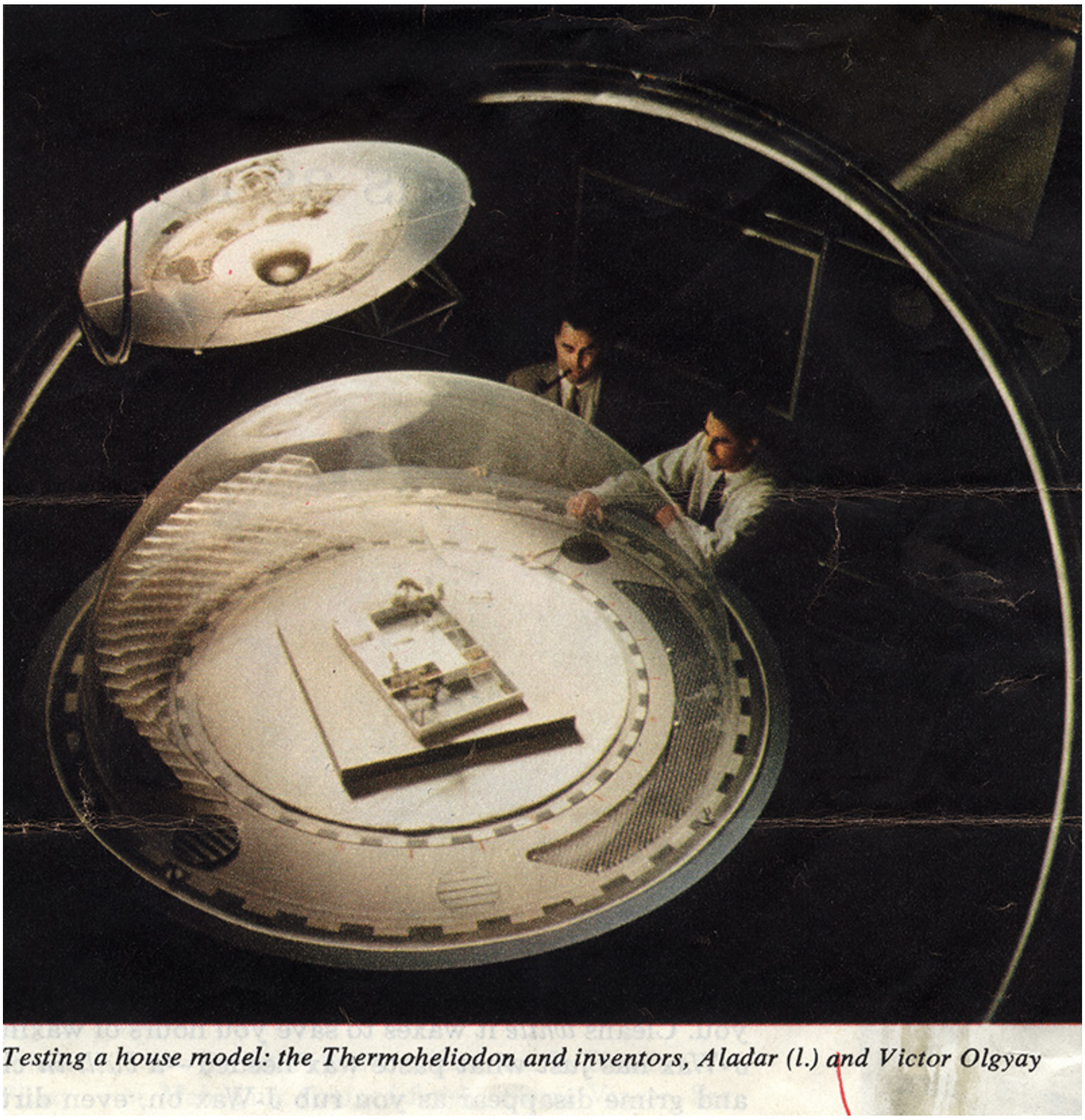


Figure 05 Uninsulated single-paned curtain wall on a typical office floor at the Segram Building In New York.

Among the pioneers in this field were Victor and Aladár Olgyay, associate professors at Princeton University's School of Architecture and Urban Planning. Their groundbreaking research in bioclimatic architecture focuses on the relationship between the architectural form and the local climate conditions to enhance comfort and energy efficiency. During the 1950s and 1960s, it laid the foundation for modern environmental building design methodologies and tools such as Autodesk's Ecotect Analysis (Leatherbarrow & Wesley, 2014). Recognizing the evolving understanding of comfort conditions in architectural design, they advocated for precise measurement techniques that considered various environmental factors like temperature, humidity, and radiation. Rather than relying solely on responsive HVAC (Heating, Ventilation and Air Conditioning) systems, the Olgyays emphasized the proactive adaptation of architectural elements to achieve optimal comfort states. However, as notions of modernity and control gained traction in the 1950s, air conditioning emerged as the preferred means of achieving thermal comfort. Architectural landmarks like Pietro Belluschi's Equitable Savings and Loan Tower in 1948 became notable for being the first fully air-conditioned building with a sealed curtain wall, pioneering a new era in architectural design (Barber, 2023). Similarly, The Seagram Building by Ludwig Mies van der Rohe and Philip Johnson, completed in 1958, exemplified this trend with its steel frame, uninsulated single-paned curtain wall, and mechanical cooling system. These iconic structures not only showcased the widespread adoption of fully air-conditioned buildings but also set a new thermal standard: driven by fossil-fuel systems and regulations set forth by organizations like The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) (Barber, 2023). This shift towards mechanized cooling was further facilitated by the affordability of air conditioning units for households in the 1960s, marking a significant milestone in the democratization of interior cooling (Ackermann, 2010).

Yet, it is crucial to acknowledge that not everyone shared this view from the 1930s to the 1960s. Some professionals aimed to harmonize artificial and natural climates rather than completely replacing one with the other. They sought to improve outdoor conditions inside buildings, creating augmented climates to contribute to society's development. The collaboration between architects and engineers such as Le Corbusier and André Missenard provides insight into how these ideas were put into practice. They took a flexible approach to creating artificial climates, using both passive strategies and mechanical devices. Their work demonstrates how architecture and artificial climates were closely intertwined, influencing each other (Requena-Ruiz, 2016).

03.4 Thermal comfort standardization

In the 1960s, with the widespread adoption of HVAC systems globally, a shift in standardization approaches emerged, particularly originating from Europe. While American scholars predominantly focused on thermal stress indexes and engineering perspectives, Povl Ole Fanger, a physiologist at the Technical University of Denmark, enriched the scientific discourse by emphasizing the subjective perception of well-being (Fabbri, 2024). In 1970, Fanger released a disruptive research paper and later a book titled “Thermal Comfort”, targeting engineers, and aiming to aid them in designing for thermal comfort by integrating insights from various disciplines such as physiology, psychology, and ergonomics (d’Ambrosio Alfano et al., 2017). This expansion of the concept of thermal comfort to encompass multidisciplinary perspectives resonated particularly well with architects who embrace a holistic design approach. Unlike engineers, architects not only consider the technical aspects of a building but also prioritize the overall human experience within it.

Fanger’s research methodology introduced a new approach by incorporating individuals’ subjective ratings of thermal sensation. This involved collecting feedback from participants doing a low-effort activity such as reading in controlled closed environments to develop an equation linking physiological environmental parameters to thermal comfort (van Hoof, 2008; Fabbri, 2024). The outcome of the study was the Predicted Mean Vote (PMV) index. This index is designed to predict the average subjective response of a group of individuals, measured on the ASHRAE seven-point scale (from cold with the value -3 to hot with the value 3). It considers four thermal factors: air temperature, radiant temperature, humidity, and air velocity, as well as two personal factors: clothing insulation and metabolic rate (Nicol, 2022). Fanger’s study acknowledged the existence of preferences in individual thermal comfort, leading to the development of the Percentage of Dissatisfied (PPD) index, related to the PMV index. PPD assigns a percentage of unsatisfied occupants to the selected value of PMV. Since its introduction, Fanger’s model of thermal comfort has been widely researched and used in building codes and standards, including ISO 7730:1984 [19] and ANSI/ASHRAE 55–1981 (Bienvenido-Huertas & Rubio-Bellido, 2021).

In the pursuit of crafting an index to make the calibration of HVAC systems easier in mechanically ventilated structures, a crucial step involved simplifying the complexities of human behavior and their interactions with their immediate surroundings. However, this endeavor inevitably brings to light the inherent limitations of such an approach. Unlike the controlled settings of a climate chamber where individuals remain passive, real-world scenarios as described by Fabri (2024) and Wang et al. (2023) witness dynamic responses to discomfort. Humans possess a wide range of adaptive actions. For example, putting on or taking off clothing, opening or closing windows, relocating their furniture to evade or enjoy direct sunlight or sealing off the window with a curtain or shutters when necessary. Some of those elements of actions are in direct influence of an architect during a design process.

Another limitation of the model is evident in naturally ventilated buildings, where the occupants' control over the environment makes them find a wider range of indoor temperatures comfortable. Additionally, Fanger's lab-based study did not withstand the challenges posed by field studies in various global environments (Humphreys & Nicol, 1998). It was discovered that people worldwide accept a broader range of thermal environments, adapting to the particular climate of their location.

In the 1970s the skepticism among scholars regarding the standardized understanding of thermal comfort began to rise. The notion of a universal solution, particularly with intensified HVAC system usage in hotter climates, faced scrutiny both publicly and academically. In 1973, "Consumers Reports", a monthly magazine representing almost a million members of the American Consumers Union, described an "air-conditioned nightmare" as the rapid increase in installed units creates a vicious cycle of cooling interior but worsening the situation by heating the exterior (Ackermann 2010). Furthermore, for the first time, the United States was confronted with the consequences of wasteful energy habits, triggered by restrictions on oil exports after the 1973 Arab-Israeli conflict and worsened by the Iranian hostage crisis of 1979 until 1980, emphasizing the nation's susceptibility to external factors due to its reliance on foreign oil.

Reacting to the skepticism, Humphreys (1978) proposed that the indoor temperature range recognized as comfortable could be indeed broader ranging from 17 °C to 30° when being related to the prevailing outdoor mean temperature. He argued that this shift would not only result in more satisfactory environments for the occupants but also lead to a more economical use of fuel. This is one of the conclusions from Humphreys' study which led to the creation of Adaptive model of thermal comfort. The main idea behind the model is that people react to discomfort with ways of trying to regain comfort (Humphreys & Nicol, 1998). The adaptive approach to thermal comfort involves, similarly to Fanger's model, gathering data by surveying occupants with a difference of surveying real users of an environment in existing buildings. Furthermore, actions the subjects take to adjust their environment to remain comfortable are observed. Simultaneously, extensive data on both physical measurements of the space and occupants' adaptive interaction with the environment, such as operating heaters, coolers or windows are collected (Humphreys & Nicol, 1998). However, the complexity of the data and variability among the individuals in the physiological and psychological aspects of their responses lead to a certain degree of scatter in the results which makes a clear interpretation of the data more difficult. The research into adaptive models has been growing since the 90s leading to the first model to be included in the 2004 ANSI/ASHRAE 55:2004 comfort standard. Since then, there has been a surge in research and new models trying to nuance more factors and cultural differences while getting included and updated in building standards all over the globe. The use of adaptive models in comfort standards allows for the design of adaptable buildings that can utilize natural ventilation, therefore liberating designers from rigid comfort zones coming from the steady state standards leading towards more efficient heating and cooling practices (Bienvenido-Huertas & Rubio-Bellido, 2021; Nicol et al., 2022).

03.5 Business-as-usual – the environmental impact of standardized thermal comfort

The 20th-century emergence of thermal comfort standards revolutionized societies, enhancing hygiene in built environments, promoting occupant health, and driving global productivity and economic growth (Fabbri, 2024). However, it was not only interiors which have been experiencing conditioning by standardization but also humans and their perception of climate and comfort. People started to expect to experience normative thermal conditions in spaces independent of their location and climate conditions around the globe (Barber, 2023). A study conducted in Maceio, Brazil, points out that a group of participants exposed to air-conditioned rooms became more sensitive to heat – their band of thermal comfort shrank while the demand for cool air increased. At the same time, progress and adapted expectations came at a steep environmental cost (Nicol & Roaf, 2022). Cooling and heating alone consume approximately 20% respectively 50% of building energy (Wang et al., 2023) with refrigeration and air-conditioning accounting for roughly 15% of global electricity usage (Prieto et al., 2018). Moreover, building construction and operations represent a major share of the total final energy consumption (35%), contributing significantly to global CO2 emissions (U.N. Environment Programme, 2024).

Despite technological advancements and evolving models, the environmental impact continues to worsen driven by the escalating adoption of air conditioning particularly in rapidly developing countries like China, India, and Brazil (Wang, 2023). Between 1990 and 2016, global sales of air conditioning units quadrupled to 135 million per year, reaching more than 1.6 billion operating units globally. In total, these units are providing 11,675 gigawatts (GW) of cooling by 2016. This surge in cooling demand has led to a threefold increase in global CO2 emissions from cooling and heating, surpassing 3000 million tons during the same period (Wang, 2023).

These ongoing trends in addressing thermal comfort underscore the prevailing business-as-usual mindset in dealing with climate change within the built environment. Environmental ethicist Philip Cafaro (2011) argues that the current strategies for addressing climate change fail to recognize the crucial connection between economic and demographic growth as well as the increase in global emissions. The widespread response to make use of technical solutions to reduce greenhouse emissions neglects the inherent link between economic growth and rising total emissions. Addressing climate change effectively requires a reevaluation of growth-centric economic models, Cafaro argues. In this context, the role of the architecture profession becomes vital.

Despite the interdisciplinary nature of thermal comfort research, architects have historically played a limited role in addressing comfort-related issues. Exemplary is the annual Windsor conference which commenced in the 1990s and emerged as a significant platform for sharing the latest discoveries in thermal comfort research. Despite its interdisciplinary nature, architects were notably absent from the debate. This research field has drawn contributions from various disciplines, including psychology, physiology, epidemiology, physics, engineering, and industrial design (Nicol et al., 2022). Architects must reclaim agency over interior environments and rediscover low-tech principles to address these challenges effectively. The early stages of building design or renovation present an opportunity for architects to advocate for innovative solutions and drive the expansion of the conventional notion of comfort.

A unique architectural perspective was already presented by Lisa Heschong (1979) in "Thermal Delight in Architecture". The work offers a compelling perspective on the significance of microclimates in architectural design and portrays them as an asset instead of a stress-inducing factor. Heschong contends that prevailing comfort norms limit sensory experiences, depriving occupants of diverse thermal sensations similar to varied culinary tastes. Architectural examples such as Italian piazzas or Japanese thermal baths demonstrate how integrating thermal elements can evoke delight and elevate the human experience. Richard de Dear (2011) in his research on human thermal perception supports the notion that diverse thermal environments compared to standardization can offer heightened comfort and pleasure (Arens et al., 2006, p. 66):

"[P]eople perceived neutral conditions as comfortable, but not as 'very comfortable'. The 'very comfortable' votes happened only in asymmetrical environments, when the local cooling / heating helps remove some level of whole body thermal stress, and/or during transients, in which comfort perception anticipates and over-shoots the coincident skin temperature. These results suggest a possible new perspective on environmental asymmetries and transients, where one might encourage them rather than avoid them as sources of discomfort. It might be feasible to achieve higher levels of thermal comfort or pleasure than are currently possible, through appropriately designed asymmetrical and transient thermal environments."

In conclusion, the evolution of thermal comfort standards highlights both progress and challenges in modern society. While these standards have enhanced built environments and represent a welcomed focus of the human body within, they have also increased energy consumption and environmental impact. Drawing from interdisciplinary insights and historical precedents architects are poised to lead a transformative effort in the face of a changing environment in climate crises that challenges our current standards and understanding of thermal comfort. Thus, architects have the potential to create sustainable environments that transcend conventional comfort standards, fostering richer sensory experiences and enhancing well-being.

04 Adaptive comfort, adaptive architecture?

The studies on adaptive thermal comfort offer engineers a significant revelation: a broader operational range for their systems. However, for architects, the seemingly banal understanding that occupants adapt and prefer having options to adjust their interior microclimates is important to design. Climate change not only brings long-term shifts in climates but also increases the frequency of extreme weather events such as hurricanes or floods. The pandemic of SARS-CoV-2 has once again highlighted the importance of fresh air and natural ventilation – a human desire and need reflected in buildings thousands of years old which has however been neglected in many modern designs.

Figure 06 Podpinka. Dzieduszycki Palace and Park Complex in Zarzecze. Photograph taken between 1918 and 1939.

The building industry today accounts for more than half of the materials used globally. While the need for housing is growing with the global population, already today the global material extraction exceeds the amount defined as sustainable by the International Resource Panel of the United Nations. Yet, it will further grow: Compared to 2015, it is expected that the material extraction from the earth's crust will have more than doubled by 2030. The building industry already faces insufficient production capacities of specific materials (e.g., of copper) or will do so in the near future (e.g., of lithium) (Sobek, 2022). Therefore, the architectural, scientific as well as recent political discourse in many European countries has shifted towards an emphasis on (re)using existing buildings. In this context, this paper will focus on the following strategies, interventions, and methods applicable to the existing building stock instead of on design principles for building new.

The presented solutions go beyond improving the technical parameters of an interior microclimate. The strategies also focus on spatial experience coming from our historical cultural understanding of space, beauty, and sensory experience. They support the notion of resilient architecture.

04.1 Threads of comfort – exploring textile traditions in architecture

In exploring future approaches to thermal comfort and microclimate adjustment, this paper will reflect on a time in architecture before thermal comfort became standardized. At this point, the pursuit of comfort could be defined as an ongoing process rather than a given product. This reflection can be connected to an ongoing study by Małgorzata Kuciewicz, Simone De Iacobis, and Aleksandra Kędziorek titled "The Clothed Home". The Warsaw-based architecture research studio therein investigates the use of textiles as an architectural material with inherent thermal comfort properties, moving beyond its role as mere interior decoration. The authors argue that architects have overlooked the potential of textiles as a tool in architectural design (Kędziorek, 2023). Despite a growing amount of literature focused on thermal comfort, the use of textiles as a tool for adjusting interior microclimates is very limited researched and documented. The majority of the research available focuses on using textiles as part of the building structure in historic and modern tents or pneumatic structures or on sustainably creating fabric for those purposes (Al-Azzawi & Al-Alwan, 2021; Scott et al., 2024)

Throughout architectural history, textiles have played a dual role, serving both functional and aesthetic purposes. Luxurious fabrics such as silk, damask, satin, and velvet, reminiscent of those found in clothing, have graced interiors in various forms, including curtains, window treatments, and wall coverings. This integration of textiles into interior design reflects a seasonal adaptation akin to attire, where heavier materials are swapped for lighter ones to accommodate changes in climate. Similar to how households transition from heavy winter clothing to lighter garments in the warmer months, oriental carpets give way to woven jute and sisal mats. Beyond their decorative appeal, textiles serve a practical function by providing insulation, offering warmth in colder seasons, and moderating microclimates within living spaces. Additionally, textiles contribute to acoustical softening, creating a quieter and more tranquil atmosphere while visually enhancing living spaces (Kędziorek, 2021).

Figure 07 Zasłony are window screens made from light fabrics, which regulate the ingress light. They inspire the daily contemplation of sunbeams wandering aroudn the room (1931).

Figure 08 Portiera reduces heat loss and prevents cold air entering the room when the doors is opened (1931).

Figure 09 Zaplecek warms the wall during cold spells in the spring so that one may lean against it without feeling a chill (1937).

A comprehensive study of historical spaces in Poland has led to the identification of a typology of domestic textiles corresponding with twelve phenological seasons. These textiles serve various functions, such as insulation (e.g., zaplecek, podpinka or chodnik), draft prevention (e.g., portiera), and gap sealing (e.g., wałek) during cold spells, while others, like muchołap and zasłony, cater to warm seasons by providing protection against insects and regulating light exposure. The strategic incorporation of textiles in architecture not only addresses concerns of thermal comfort but also reflects evolving tastes, status symbols, and the intertwining of dress and decor throughout history. This enriches the social and cultural fabric of domestic life, highlighting the intricate relationship between textiles and architectural design (Kędziorek, 2023).

A prime example of the extensive use of textiles in an interior setting is the summer house designed by architects Zofia and Oskar Hansen in Szumin, Poland, constructed in 1968. Their skillful utilization of home textiles, in collaboration with artists and architects, showcased a profound understanding of adapting living spaces to seasonal rhythms. From tulle curtains to combat heatwaves to quilted fabrics filling the attic to provide insulation during frosty weather, the Hansens transformed the house to accommodate the changing seasons, mirroring the wardrobe adjustments of its inhabitants. This practice was not unique to the Hansens but emblematic of a broader tradition across Poland, where textiles played a crucial role in insulating homes across different social classes (Kędziorek, 2023).

While the transition away from centralized heating and cooling systems may seem daunting, the revival of traditional home textiles presents a compelling avenue for reimagining sustainable architectural practices. Beyond mere historical curiosity, these textile-based solutions offer practical strategies for mitigating the environmental impact of comfort, fostering resilience in the face of climatic uncertainty. Kędziorek (2023) envisions a future where textiles would create a “soft architecture” – a changeable adaptable layer which is seamlessly integrated into the permanent structure (“hard architecture”).

To evaluate the potential of the use of textiles in architecture, I turn to Marcel Schweiker’s (2022) research on resilient thermal comfort within the context of human-building resilience and apply this method to the case study in the following chapter.
Schweiker proposes four main design recommendations. Firstly, he suggests that to ensure resilient thermal comfort in building design, professionals should prioritize long-term human resilience over conventional comfort ranges. Thus, the design should give an opportunity for adaptation and alliesthesia. According to Parkinson and de Dear (2014, p. 2) the principle of thermal alliesthesia is that „any peripheral (skin) thermal stimulus that offsets or counters a thermoregulatory load-error will be pleasantly perceived. For example, elevated air movement with the prospect of increasing net heat loss from skin tissue during exercise is likely to be pleasant.“

Figure 10 Antivilla - Front facade (2014).

Figure 11 Antivilla - Living space (2014).

Buildings should allow occupants enough time and opportunities to react and adapt to changes in temperature. Designers should also consider the urban scale impact of the tools they use; for example, while air conditioning may cool down a space locally, it can increase the heat load in the surrounding area. Finally, it is crucial to make building interactions intuitive for occupants with self-explanatory features that do not require external guidance ensuring ease of use in all situations. These four principles, according to Schweiker, enhance human-building resilience and promote lasting thermal comfort.

04.2 Redefining comfort - Antivilla's textile revolution

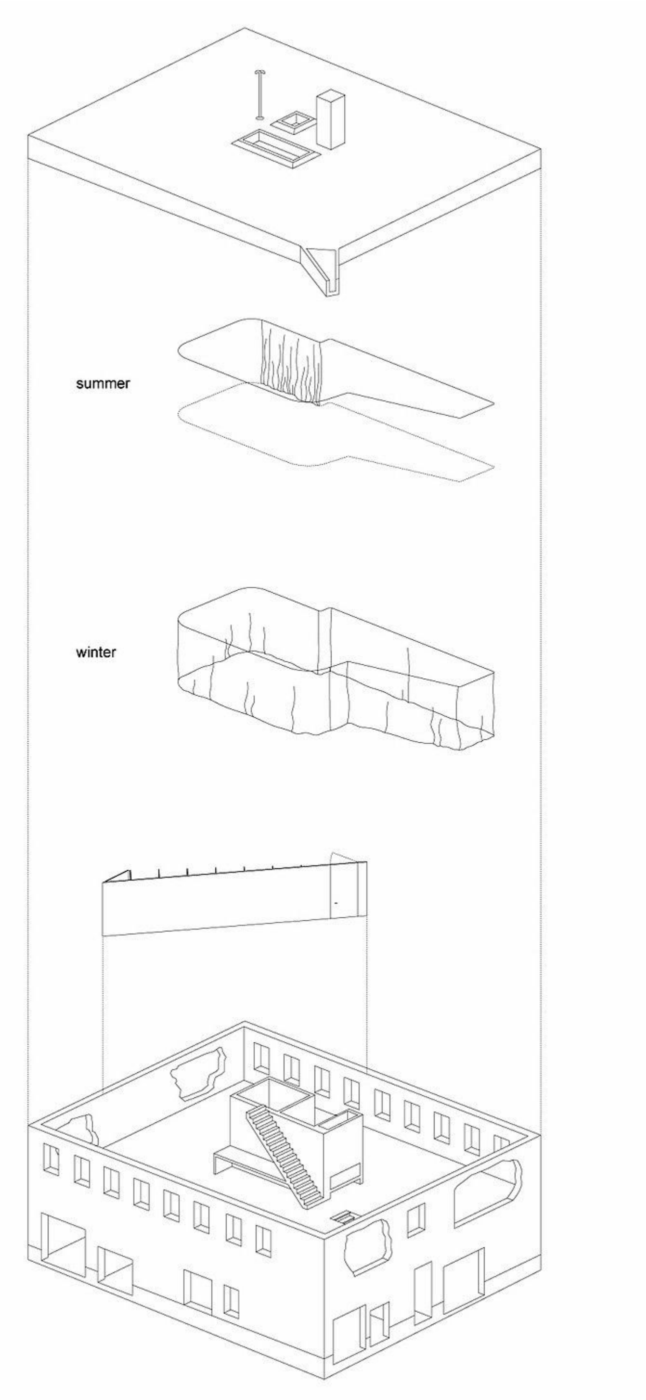
In the pursuit of redefining comfort within domestic microclimates with adaptable features, the case study of Antivilla by Brandlhuber+ comes as a provocative example of a house transformation led by textiles. German architecture practice Brandlhuber+ led by architect and professor Arno Brandlhuber, is known for challenging architectural norms, and advocating for regulatory reforms.

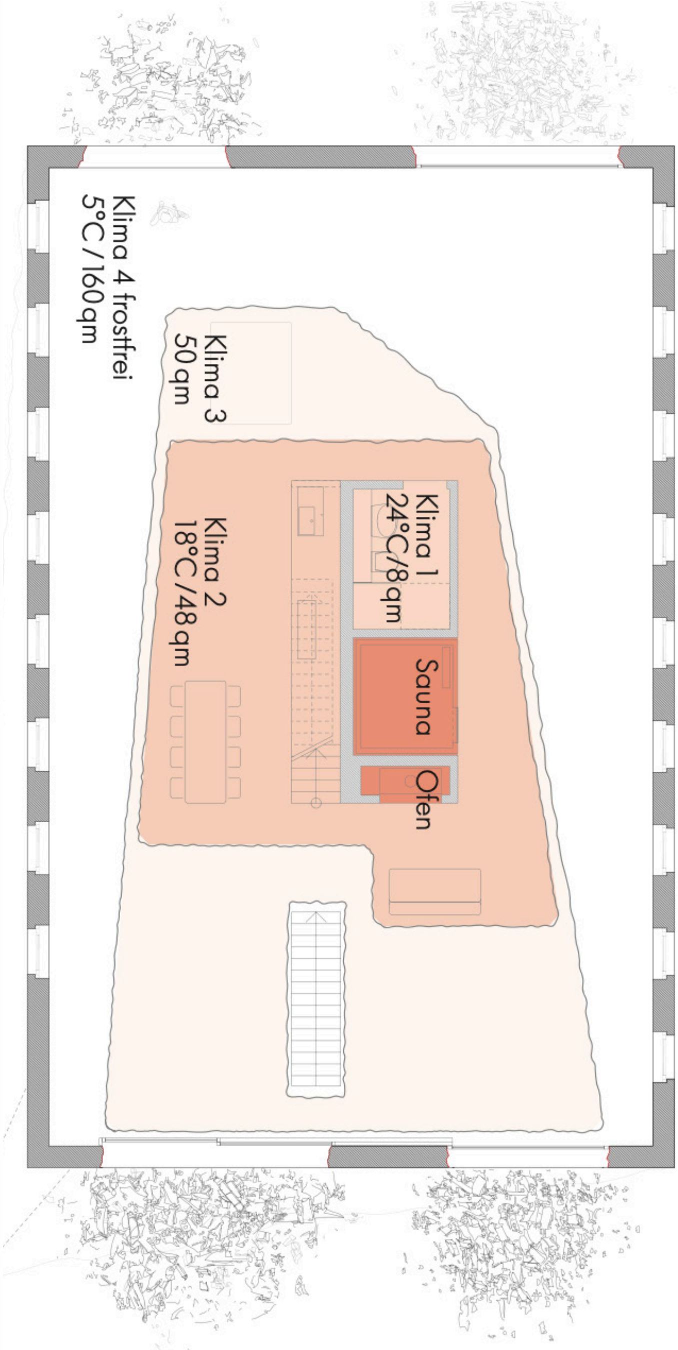
Antivilla, despite its name suggesting defiance against bourgeois norms, is a profound exploration of comfort interconnected with environmental harmony. The abandoned 500m2 factory building in Krampnitz, Germany, was at first glance not an appealing investment within the framework of standard practice. Demolition was expensive and even in case of execution, it was allowed to erect a new building with only 100m2 of living space – a size of 20% of the existing volume. Such practice would not only have taken away the quality of the former space but also mean a significant loss of energy in terms of labor and material (Sobek & Heinlein, 2022).

The project challenges the conventional practice of refurbishing buildings. In response to environmental concerns, contemporary architecture represents a tendency to focus on sealing off buildings with thick walls, small windows, and massive layers of insulation. This defensive approach aims to protect the interiors against external climatic threats, but it also isolates buildings from their surroundings, creating a sense of disconnection. Additionally, as showed in various studies and field measurements highly insulated and airtight dwellings – despite being increasingly encouraged by the general application of the Near Zero Energy Buildings (NZEB) framework in heating-dominated temperate climates – are particularly subject to overheating risks (Calì et al., 2016; Dartevelle et al., 2023; Ortiz & Bluyssen, 2022). In contrast, Brandlhuber+ chose to strip the building bare, enlarge openings, remove asbestos sheets, insulate the roof, and add a curtain. The strategic use of textiles became central to Antivilla's transformative design serving as a means to modulate thermal comfort. Thin curtain layers made of gauze or transparent soft PVC delicately partition the expansive living space, offering flexibility in temperature control. During winter, the living space acceptable for thermal comfort standards shrinks from 500 to 70m2, yet the entire space remains visually connected through a see-through curtain. The central stove used for cooking and heating warms the sauna and bathroom, creating the warm core of the house during the heating season. The heat radiates into the surrounding living area marked by the inner curtain. The bedroom area, requiring less than a constant 20°C, is situated in the third climate zone, while staircases and studio spaces which are not being occupied remain frost-free during winter. The house adapts to the seasons (Brandlhuber+, n.d.).

Figure 12 Exploded isometric drawing showing seasonal interior change.

Figure 13 Inner space, devided by transparent curtains into differentiated microclimates.





The house invites awareness of the climate, embodying what is called Chronobiological architecture heightening the sense of participation in cyclical phenomena: the rhythms of night and day, the seasons, and weather, with all their inherent consequences (Centrala, n.d.). In Reyner Banham's exploration of architectural concepts in "The architecture of the well-tempered environment" (1969), he highlights two distinct approaches: the constructive solution focusing on solid constructions to shape spaces, and the energy-supported solution utilizing energy, like fire, to delineate spatial boundaries. The Antivilla embodies a fusion of these concepts blending the existing structural framework with an energy-driven spatial organization. Banham's notion of dynamic spatial differentiation influenced by energy sources finds resonance in the Antivilla's design. By centralizing activities around a sauna stove, the Antivilla creates concentric zones of temperature and brightness, mirroring Banham's depiction of campfire-induced spatial differentiation. However, what distinguishes the Antivilla is its departure from romanticized notions of primal living instead embracing a modern synthesis of civilization's advancements and cultural experiences. This approach aims not only to create fluid, energy-driven spaces but also to ensure a minimum level of comfort through controlled energy flow (Kuhnert & Ngo, 2012).

Antivilla expands the discussion on comfort beyond financial or energy metrics and underscores the need for a holistic approach considering factors like space optimization and user behavior which could reshape legislative standards, leveraging energy certificates as a starting point (De Ferrari & Hahn, 2020). Andreas Schulz, a project consulting engineer from PICHLER Ingenieure GmbH (Kuhnert & Ngo, 2012, p. 174), critiques the German Energy Saving Ordinance (EnEV) for aiming to achieve zero-energy homes by prioritizing operational energy reduction. „[g]rey energy, such as the energy required for the production and transport of insulation and other materials, is completely ignored [...] the production energy required for low-energy houses often exceeds the operating energy saved many times over." Additionally, EnEV's fixation on standard room temperatures year-round is against innovative solutions. This regulatory bias can lead to unnecessary demolition rather than retrofitting existing structures as observed in Krampnitz (Kuhnert & Ngo, 2012).

Exploring the innovative concept of Antivilla and its creation of different microclimates provides insights for reshaping our built environment. While implementing this concept in existing apartment buildings may present challenges, the notion of a warm core and the creation of multiple microclimates offers a promising framework for retrofitting larger spaces like office buildings or parking garages into residential units. These adaptable solutions not only point towards a more sustainable future but also underscore the importance of holistic approaches to comfort and energy efficiency. Such solutions resonate with principles outlined by Schweiker (2022), emphasizing adaptable spaces operated by curtains that empower users and are intuitively self-explanatory. Importantly, these solutions minimize harm and heat stress to their surroundings and are easy to replace or maintain over their lifespan. Moreover, the open-plan design, complemented by bare concrete structures, leverages thermal capacity to harness coolness from the night for daytime interior cooling. It's worth noting that projects of this nature are rather unique, especially considering the significant 500m2 of floor space, from which they are able to sacrifice and downsize to only 70m2 during winter. Nonetheless, it is the conceptual framework and shift in thinking inspired by Reyner Banham's (1969) work that holds particular significance in shaping the trajectory of architectural innovation.

05 Conclusion – back to the future

This paper has traced the development of thermal comfort from its inception at the beginning of the 20th century to today's standards-based understanding of the term and the technology-based methods standardized in the Western world to achieve comfort. However, it has also shown that these methods cannot be sustained in the changing climate due to their energy consumption, especially as studies prove their disadvantages. Provided thermal comfort parameters often diverge from individual perceptions of thermal comfort due to inherent diversity in human physiological needs and preferences (Nicol, 2022). In certain instances, this phenomenon manifests as what is called "Thermostat wars". Alternatively, research has indicated that occupants of fully automated buildings, which leave no agency for occupants to change their environment to their liking, may resort to deliberate acts of sabotage against the building and its systems (Heschong & Day, 2022). Contemporary architects, including Studio Muoto, express significant concerns regarding the current state of architectural design, particularly in relation to thermal comfort amidst the backdrop of climate change. They argue that the concept of comfort has been oversimplified, dismissing sensory perception and reducing it to a standardized notion that only addresses basic sensations such as temperature, light, and sound. Secondly, rather than creating inspiring designs, to guarantee a state of thermal comfort modern architecture resembles thick thermoses. These structures are characterized by generic façade materials and a uniform distribution of medium-sized openings (Studio Muoto, 2023).

This paper shows that the historical example provide relevant approaches to achieve thermal comfort with context-based instead of standardized approaches. Instead, adaptive approaches such as the use of textiles in the domestic environment were presented. Those history-based approaches include external seasonal aspects of climate and geographic conditions without heavy dependency on fossil fuels. These methods help to mitigate discomfort locally and can have a positive effect on improving human resilience. A special focus was placed on approaches that can be used not only in new buildings but also in existing buildings. There is no question that traditional and historic design methods such as working with textiles cannot be simply copied in the complexity of contemporary construction. However, the example of Antivilla by the German studio Brandlhuber+ proves that approaches can certainly be made usable for the present if they are applied case- and context-based. In this sense, the present work advocates an approach based on Sou Fujimoto's (2008) concept of the primitive future and the gradual comprehension of architecture. This notion mirrors the strategy of reassessing cultural customs and transcending the dichotomy of modernity. To avoid traditionalism, traditions should be revisited with contemporary knowledge while simultaneously integrating established practices in a nuanced approach.

Research and case-based practice can and must drive forward new applications of materials or space organizations in terms of a microclimate that is perceived as comfortable. Another approach towards thermal comfort discussed in this paper that benefits the past but has been adapted to the present are the low-tech, robust, and resilient methods advocated and practiced by professors such as Thomas Auer and Florian Nagler (Niemann, 2019). Turning back on the age of supertechnization, their roots can certainly be located historically, with their further development doing justice to the contemporary complexity of building and design standards.

On the way to achieving thermal comfort more sustainably, not only design methods and adjustments within the built environment can be changed but also how people interact with it. Human behavior and expectations must change. As shown, it is important that interiors allow occupants to adapt to their surroundings and follow more flexibly the weather changes connected to seasonal shifts (Koth et al., 2022). Moreover, the studies point out that gaining control over the built environment instead of leaving it to technology, people have a broader band of thermal conditions they perceive as comfortable (Auer et al., 2020).Thus, equipping inhabitants with more control and adaptive behavioral reactions goes along with a lower energy demand for achieving comfort.

In this sense, architects must not only question how they have tried to achieve thermal comfort in the past but also how thermal comfort should be defined in the future. It is up for debate if the narrow and engineering-based understanding of thermal comfort today defined down to fixed temperature ranges, is operable for the future. As this paper points out, architects have not yet been part of this discourse. However, a shift towards a more variable, holistic, and context- and subject-dependent understanding of thermal comfort can be observed already: The integration of the adaptive model into the US ASHRAE (2017) and European CEN (2019) comfort standards marked a significant advancement in the development of adaptable buildings. This shift liberated designers from the constraints of static comfort parameters allowing for natural ventilation by simply opening windows, however, still follows temperature guidelines prescribed by previous standards. This change also paved the way for the gradual acceptance of mixed-mode buildings which utilize heating and cooling systems only when needed relying on natural ventilation for the remainder of the year (Nicol et al., 2022).

Furthermore, an understanding for the subjectivity and individual-based characteristics of thermal comfort has risen - men and women, elderly and kids all have different thermal needs (Asif et al., 2022). However, what has not been questioned so far is how far thermal comfort standards can be limited to still provide an acceptable and healthy state of comfort – in other words: how much discomfort can inhabitants bear today (Rupp et al., 2022)? Technification and standardization have created a narrowed understanding of comfort, and the question arises as to whether this can be maintained in the face of external environmental conditions that are changing towards extremes. There is a need for discourse and research on whether a certain degree of discomfort within the built environment can be allowed for as long as it does not affect mental and physical health - and to what extent the human perception of comfort is adaptive to such lowered standards. In this sense, the recent energy-saving constraints imposed by governments, which are unprecedented in the modern Western world, offer promising research potential that no experiment conducted under artificial conditions can offer in its diversity. In 2022, various European governments decided to override the usual thermal standards in light of the gas shortage triggered by the sanctions imposed by the European Union against invader Russia. Spain, for example, stipulated that in public buildings heating should not be set above 19°C and air conditioning should not be set below 27°C (Jones, 2022), and similarly in Germany heating in public buildings was limited to 19°C (Connolly, 2022). How did people perceive this deviation from their familiar thermal comfort level? What adaptive measures did they resort to? Which buildings were perceived as comfortable or uncomfortable when the heating and air conditioning were switched off? And did the perceived level of discomfort decrease after some time? Facing climate crisis, it is fundamental questions like these that architects in practice and research alongside questions of alternative and new methods to achieve thermal comfort should not shy away from when following the call raised by Barber (2019) at the beginning of this paper: to explore life after comfort. Because the end of comfort as Western world knows it today does not have to be tomorrow's discomfort.

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07 Figures

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Figure 02 The Tivoli, in Chicago, opened 16 February 1921 and was one of the first cinemas in the country to install of air conditioning. (n.d.). Retrieved 2024, from https://www.kimpton.co.uk/history-air-conditioning/.

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Figure 04 The Olgyay brothers with the Thermoheliodon device at the Princeton Architectural Laboratory. From Collier's magazine, June 1956. (n.d.). Retrieved 2024, from https://arpajournal.net/thermoheliodon/.

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Figure 07 The Casltlette of the President of the Republic of Poland. (n.d.). Zasłony are window screens made from light fabrics, which regulate the ingress light. They inspire the daily contemplation of sunbeams wandering aroudn the room (1931). Retrieved 2024, from https://centrala.net.pl/the-clothed-home/.

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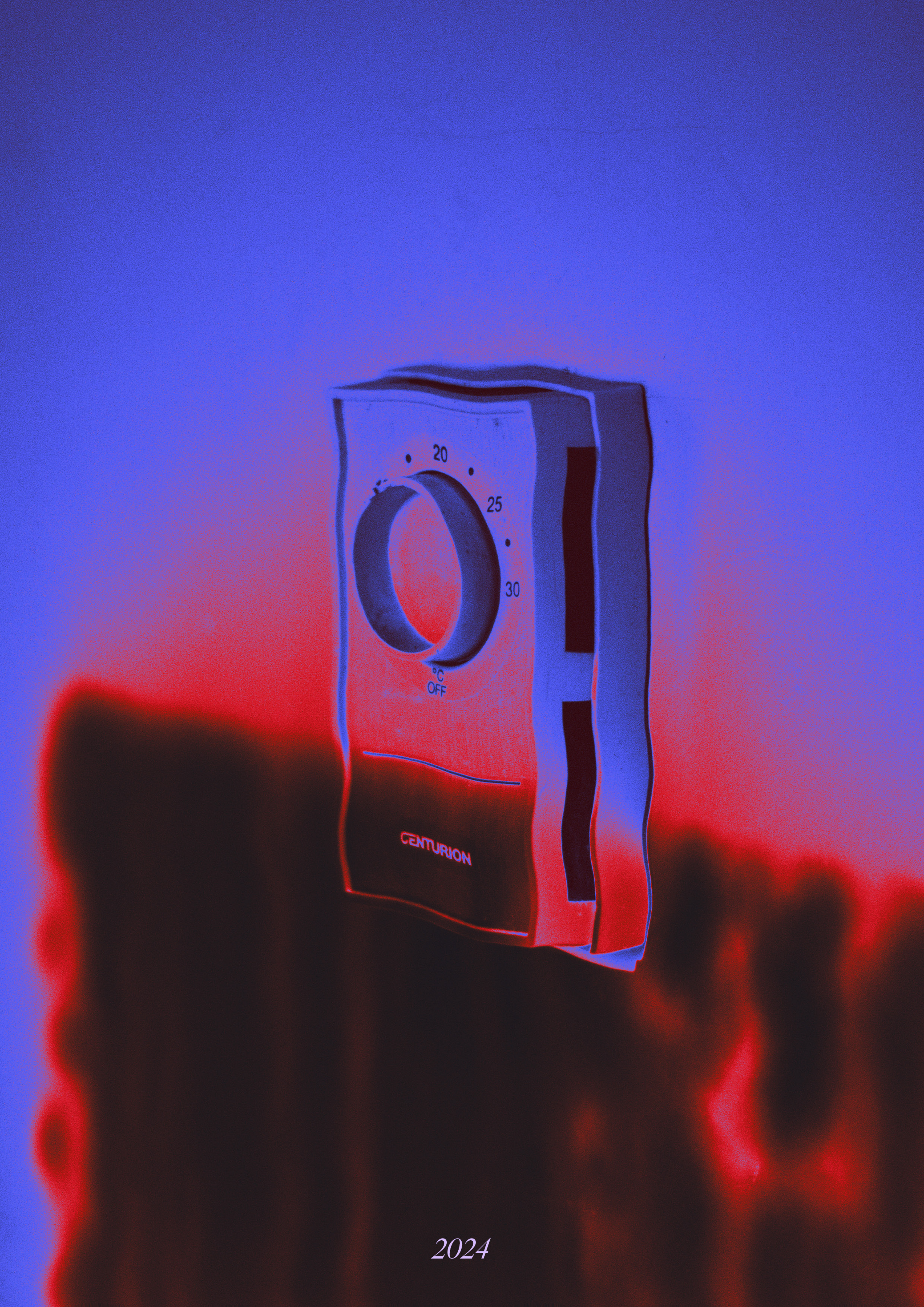

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