Today, and when reflecting upon the growing effects of heat (and its respective quantification), it has never been clearer that these concerns will remain, if not augment, for decades to come. Such decades are those that are now symbiotically associated with increasing extreme heat events, which are growing in terms of their unprecedented intensity, frequency, duration, and general consecutiveness. For this reason, the topic and vulnerability of human health have never been as salient. Man’s mental conjuring of a ‘sweltering and never-ending summer’ is proving continuously to be less of an effort, and more so one that can be increasingly associated with mere observation. It is recommended that this editorial be read while considering certain resources pertaining to thermal indices. This includes their constitution, application, and the subsequent communication to respective audiences pertaining to their usage within thermal comfort and heat stress studies [1,2].

It is well known and always present that the effect of heat or cold on humans cannot be quantified based on a single meteorological (i.e., air temperature) or other environmental factors (i.e., ozone) or thermo-physiological (i.e., skin or core temperature) parameter. As presented within this editorial, the very essence of what it means to understand an energy balance (be it of the human or that of the urban fabric) implies, by definition, embracing the crucial synergy and equilibrium of different variables within humans. Such a comprehension is what permits the effects of thermal stimuli (and their associated risk factors) to be practically connected with subsequent human biometeorological responses and/or processes. For this very reason, the necessity to quantify and describe the effect of the thermal environment on humans has led to the development of a plethora of indices based on empirical, statistical, and physical approaches [3,4]. The many existing indices show the complexity behind this issue and the necessity of a comprehensive approach to research. Just as crucial is the need to ensure the solidification of a resilient society, which will invariably need to embrace both continued urban densification patterns and, simultaneously, the augmenting effects of climate change [1–4].

There are three ways to describe the effects of the thermal environment on humans.

1. Thermo-physiological, which is based on the absence of impulses from both types of human receptors (warm and cold receptors), which give rise to change in the thermal environment.
2. Energetical, based on the heat (i.e., energetic) exchange of the human body, which must include internal heat production (be it the result of activity threads and/or physiological metabolism processes). In addition to such internal processes (from core to skin), one must also consider the exchange between adjacent surfaces and the environment, which is dictated by the levels of short- and long-wave radiation, air temperature, air humidity, and wind movement. Balanced heat conditions mean that human body temperatures are within the acceptable thermal comfort range (skin temperature $T_{sk} = 33.5 \, ^\circ C$ and core temperature $T_c = 37 \, ^\circ C$).
3. Psychological, which expresses the high variability between humans in terms of a state of mind that expresses satisfaction with the thermal environment. In addition
to this, more subjective yet influential factors such as thermal adaptability and/or acceptability (be they the result of short-term or long-term exposure) can be translated into several classes of cold or heat perception. This equally complex procedure must address the equilibrium between individuality and yet maintain its required universal application based upon human anatomical and physiological commonality.

Following this reasoning and based on these three discussed approaches, it is clear that a simple index or formula that is based on the addition of two factors (such as Heat Index or Humidex) is insufficient for this purpose. Furthermore, within such assessments, approaching both the individual and the group is of interest. Within this perspective, and according to Weihe [5], five significant levels or system views must be accounted for, these being:

1. Social behaviour, which is supraindividual and includes culture, history, religion, and moral values.
2. Intellectual behaviour, which is individual and interindividual, therefore it includes learning, invention, evaluation, communication, building, insulation, and clothing.
3. Spontaneous behaviour for changing preferences by heating, cooling, clothing justification, eating, and exercising. It also includes personal preference adaptation, expectation, experience, education, thermal sensation preferences, thermal comfort, and/or discomfort tolerances.
4. Autonomic regulation and behaviour of the human body, such as vasomotor responses, respiration, posture, shivering, and sweating instigated by the central integration of thermoreceptors, etc.
5. Atmospheric conditions, which not include only air temperature but also radiation fluxes, air humidity, and wind velocity. In addition to these, other interrelated parameters play a significant role, such as air pollution, UV-radiation, and noise. In total, more than sixty parameters and factors play a role in the quantification of the thermal environment.

The quantification is very complex and requires appropriately constructed approaches. The term ‘appropriately’ here is used with two distinct objectives. The first is interlaced again with the significance of considering an amalgamation and balance of multiple variables to correctly understand such stimuli. The second, and serving as a genre of quality control, is the correct selection of the most relevant factors to conduct the energetical, thermo-physiological, and psychological. Through the combination and standardisation of such factors, the possibility of general quantification presents itself, which in turn does not need to only be focused on the individual.

Within the last thirty years, human biometeorological studies and models have focused on the quantification of effects, which does not rely exclusively on any one of the three approaches. Instead, these three decades have rather depicted the amalgamation approaches that amalgamate the three. As a result of the comprehensive descriptions, which include thermo-physiological and energetical issues, their intrinsic complexity speaks to the meaningful and necessary stages in, respectively, resolving them. The process of solving these equations, which embrace thermo-physiological processes and deliver physical quantities (that are interlaced with energy processes) is not easy to understand by non-experts. Moreover, and again in thermo-physiological terms, which depict core temperature or sweat rates, these cannot be assumed to be sufficiently explanatory for an overall quantification of such effects.

Notwithstanding, the option of having only a single information output for a general description is not just feasible but arguably an ‘elegant’ solution as well. One could argue that such an ‘elegance’ could speak to the effectiveness of the aforementioned ‘balancing’ of variables in terms of the symbiotic relationship between environmental stimulus and that of the human being. But on the other hand, such an ‘elegance’ could be attributable to a second, often overlooked factor, which is the empowerment of interdisciplinary communication. In other words, this single information output is essentially a catalyst to instigate other audiences to understand and use such outputs and/or results. The depicted audience
here is threefold, namely: (i) for professionals (both established and emerging via the education system) that are responsible for physically shaping the spaces that host such environmental conditions; (ii) for municipalities, which are responsible for managing and/or administering decision-making and planning at local and/or regional scales; and, just as crucially, (iii) for the end-user of such spaces, which will continue to witness continued aggravations of already palpable intensifications of climate change—the human being.

Reflecting once again upon the substantial body of work over the last three decades, out of the more than 170 thermal indices, the number of those that are suitable for human biometeorological evaluation is significantly smaller. For an overall evaluation, an equivalent air temperature of an isothermal reference with minor wind velocity is needed. Furthermore, thermal indices must be traceable to complete human energy budget models consisting of both a controlled passive system (heat transfer between body and environment) and a controlling active system, which provides positive feedback on temperature deviations from neutral conditions of the body core and skin as it is the case in nature [5–7]. This shows that we have a combination of energetic and thermo-physiological approaches, in which the energy budget perpetually echoes the underlying balancing nature previously mentioned in this editorial.

With regard to this more restricted number of indices, the following five indices distinguish themselves in terms of their appropriateness to fulfil such biometereological evaluations: the Universal Thermal Climate Index (UTCI), Perceived Temperature (PT), Physiologically Equivalent Temperature (PET), modified Physiologically Equivalent Temperature (mPET), and Standard Effective Temperature (SET*) [8,9]. The advantage of all five indices is that they have a temperature unit in °C, are based upon an equivalent temperature, and require all the same input meteorological and thermo-physiological parameters [2]. Attention should be given to the accuracy of the input parameters and metadata. In addition, the thermo-physiological factors, heat production of the human body, and clothing values and behaviour require specific attention [1,2,7–9]. For individual analysis, the energy balance models, which are the backbone of the thermal indices, can provide relevant information, such as sweating or body parameters like core or skin temperatures.

Recent studies also show the relevance of thermal indices and their correlation with thermal perception for different parts and/or regions of the world [10]. For heat issues and their respective quantification, most of the thermal indices behave similarly and provide specific and relevant results. More specifically, this entails the definition of categorical or organisational thresholds (or ranges) of heat based upon defined values, in combination with epidemiological studies, including heat-related mortality or the quantification of heat stress conditions on the urban microscale (i.e., the effects of trees on thermal indices). For moderate stress (cold or heat) and general thermal comfort ranges as a result of acclimatisation and cultural and social factors, it is not possible to have a global range justification. The same can be said for cold conditions in several areas of the world. Like the calculation of the indices themselves, the determination of their associated thermal comfort range and complete full-scale modification via the appropriate methodology are required. Several studies have also shown that the existence of an agreed-upon protocol for outdoor human thermal assessment is required. Prior to this, however, and according to [10], further research is required to make a meaningful comparison of thermal adaptation to varied climatic zones and weather conditions. For this reason, and when considering action or decision protocols, these factors can never be overlooked in the interest of overly simplistic universality. This is even more the case for the development of guidelines and recommendations for urban planning and the creation of heat actions during extreme heat events. Comprehensive biometeorological research requires a focus on measurement procedures (site, season, time, and duration), appropriate questionnaire design, accurate meteorological data and calculations, careful data control, suitable methods to enable entire scale modification, and standardised assessment methods of questionnaires (physiological metrics).

More significantly, the recent thermal indices (i.e., PET, mPET, UTCI, etc.) are not simple algebraic or statistical formulas or models like wind chill and Humidex. They rely
on energy exchange between body surfaces and internal heat production by humans. In addition, and as mentioned before, the application of single energy fluxes or the results of the ‘energy balance’ is difficult to understand. Therefore, the concept of the equivalent temperature is an approach that is not only helpful but also an “elegant” solution that can, moreover, be shared more easily with non-experts as well. The combination of equivalent temperature approaches with thermal perception and behaviour approaches provides the thermal indices with additional value for a generic and applied approach for different climates and issues. The estimation of these indices may be computationally expensive. However, the previous and ongoing efforts to develop efficient computation tools (i.e., RayMan), especially for climate-related applications. The required data can be easily retrieved from station data, existing models, e.g., ERA5 Reanalysis Data, mesoscale models (WRF), or microscale models (i.e., RayMan, ENVI-met, Solweig).

As a result, there is a growing urgency not only to find or utilise the appropriate index but, moreover, to clarify whether the utilised model or thermal index meets the requirements and addresses the specific target question in the specific location or climate region. Furthermore, in addition to meeting such targets, the effectiveness of the communication method should also always consider its milieu and audience typology, including when working with non-climatic experts. It can never be forgotten that these experts share the common goal of physically shaping resilience and adaptation responses in an era of increasing climate change.

The whole aim of this editorial is to direct attention to the tools that we already possess and avoid possible misapplication and confusion of thermal indices. The application of thermal indices for short- and long-term adaptation strategies for heat and cold requires understanding and knowledge in terms of how to apply them. It is noteworthy, that calculations of thermal indices by tools and human-biometeorological models can be performed not only by measured data but also by re-analysis, climate simulation data, and sensitivity studies.

Funding: This study received no external funding.

Conflicts of Interest: The author declares no conflicts of interest.

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