Indicators to assess physiological heat strain – Part 1: Systematic review

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Indicators to assess physiological heat strain – Part 1: Systematic review

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ABSTRACT
In a series of three companion papers published in this Journal, we identify and validate the available thermal stress indicators (TSIs). In this first paper of the series, we conducted a systematic review (registration: INPLASY202090088) to identify all TSIs and provide reliable information regarding their use (funded by EU Horizon 2020; HEAT-SHIELD). Eight databases (PubMed, Agricultural and Environmental Science Collection, Web of Science, Scopus, Embase, Russian Science Citation Index, MEDLINE, and Google Scholar) were searched from database inception to 15 April 2020. No restrictions on language or study design were applied. Of the 879 publications identified, 232 records were considered for further analysis. This search identified 340 instruments and indicators developed between 200 BC and 2019 AD. Of these, 153 are nomograms, instruments, and/or require detailed non-meteorological information, while 187 can be mathematically calculated utilizing only meteorological data. Of these meteorology-based TSIs, 127 were developed for people who are physically active, and 61 of those are eligible for use in occupational settings. Information regarding the equation, operating range, interpretation categories, required input data, as well as a free software to calculate all 187 meteorology-based TSIs is provided. The information presented in this systematic review should be adopted by those interested in performing on-site monitoring and/or big data analytics for climate services to ensure appropriate use of the meteorology-based TSIs. Studies two and three in this series of companion papers present guidance on the application and validation of these TSIs, to guide end users of these indicators for more effective use.

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Introduction
Billions of people perform their daily activities in ambient conditions that exceed their bodies’ capacity for maintaining a safe body temperature [1]. This often leads to the development of severe conditions that they have to carry throughout their life [2]. Even worse, heat stress can be fatal in many cases [1,3,4]. For instance, three to four occupational heat stress fatalities are currently occurring every hour across the world [5]. While heat stress is more prevalent in working populations [2,6–11], athletes [12,13] and other civilians, especially heat-vulnerable older adults and individuals with chronic health conditions who perform intense manual tasks are also affected by hyperthermia and heat-related illnesses. Older individuals [4,14,15] and people with underlying cardiovascular diseases [4,15–17] face significant heat-related morbidity and mortality, even when sitting or resting in hot conditions. To tackle this problem, effective heat mitigation strategies should be designed and implemented. But first, it is crucial to assess the magnitude of heat stress.

The idea of having a single value characterizing the heat stress and strain experienced by
individuals was incubated in the early scientific research. The importance of this topic has inspired numerous scientists to develop sophisticated thermal stress indicators (TSI) aiming to safeguard health and well-being of humans exposed to a wide range of environments [18–21]. A total of 167 TSIs have been identified and listed in reviews published to date [18–23], but we are aware of many that have not been included in these articles. To enhance our understanding on the development and use of TSI developed throughout history, it is necessary to overview the extensive collection of TSIs so that we may build and/or expand their development.

In a series of three companion papers published in this Journal, we identified the TSIs developed since the dawn of scientific research (part 1), we conducted a Delphi exercise to understand what is important to consider when adopting a TSI to protect individuals who work in the heat (part 2) [24], and we performed field experiments across nine countries to evaluate the efficacy of each TSI for quantifying the physiological strain experienced by individuals who work in the heat (part 3) [25]. The present article is the first in this series, and our aim was to conduct a systematic review to identify the TSIs developed since the dawn of scientific research and provide reliable information regarding their computation, as well as to publish a valid and reliable software to calculate them. This information is important to ensure appropriate use of TSIs. To inform the subsequent parts of this series of companion papers, we were particularly interested in TSIs that can be calculated using only meteorological data (air temperature, relative humidity, wind speed, and solar radiation), as we aimed to enhance the quality and relevance of on-site monitoring (e.g., field evaluation) and big-data analytics (e.g., satellite data) used in climate services for the athletic, occupational, and the general populations.

**Methodology**

To reduce bias and the likelihood of duplication, as well as to maximize the validity of the procedures involved, we registered our systematic review in the international platform of registered systematic review and meta-analysis protocols (INPLASY) database (registration number: INPLASY202090088).

**Search strategy and selection criteria**

We searched eight databases from the date of their inception to 15 April 2020, for studies evaluating the capacity of TSIs to quantify the magnitude of thermal stress and strain experienced by humans. Studies published in any language were included. The following databases were searched: Pubmed, Agricultural and Environmental Science Collection, Web of Science, Scopus, Embase, Russian Science Citation Index, MEDLINE, Google Scholar. No date or other study limits (e.g., original articles, review articles, and conference papers) were applied in our search. The search algorithms used in each database are provided in the Appendix. We supplemented the electronic database searches with manual searches for published and unpublished papers, websites of international agencies (i.e., World Health Organization, World Meteorological Organization, and World Migration Organization), national bureaus of meteorology, international standards, reports (e.g., International Organization for Standardization, and American Society of Heating, Refrigerating and Air-Conditioning Engineers), and relevant books in the field. The screening was conducted independently by two investigators (LGI and KM) and any conflicts were resolved through consensus by a third researcher (ADF). We excluded studies focusing on animal-, crop-, engineering-, geology-, oil-, and clinical-related indicators. Detailed information regarding the included and excluded papers is provided in the Appendix.

**Sensitivity analysis for the search algorithm**

The term “index” is part of the name in 96 out of 340 TSIs; (Tables 1–2 e.g., Universal Thermal Climate Index, Belding-Hatch Index, Discomfort Index, Environmental Stress Index). Therefore, using “index” in a systematic search returns tens of thousands of eligible articles that adopted a TSI which happened to include “index” as part of its name. To ensure that our search is specific to the issue at hand, we opted out of using “index”
Table 1. List of 153 non-meteo-based thermal stress indicators identified in the systematic search. These are complex models requiring some or all the meteorological parameters (air temperature, relative humidity, wind speed, and solar radiation) in addition to other information. Nomograms and other instruments were also considered non-meteo based indicators. The fourth column titled “Literature” cites the eligible article that was used to extract data for the present thermal stress indicator. Precise information regarding the original article of each thermal stress indicator can be found in the supplementary material.

| ID | Thermal Stress Indicator | First Authors; Year | Literature | Reason for considered as non-meteo-based Parameter | Type |
|----|--------------------------|----------------------|------------|---------------------------------------------------|------|
| 1  | Acclimatization Thermal Strain Index | de Freitas; 2009 | [19] | ![Image](image1) | ![Image](image2) |
| 2  | Adaptation Strain Index | Blazejczyk; 2014 | [18,19] | ![Image](image3) | ![Image](image4) |
| 3  | Air Cooling Power | Mitchell; 1971 | [19] | ![Image](image5) | ![Image](image6) |
| 4  | Air Diffusion performance Index | ASHRAE; 1989 | [35] | ![Image](image7) | ![Image](image8) |
| 5  | Air Pressure Thermometer | Amonton; 1702 | [36] | ![Image](image9) | ![Image](image10) |
| 6  | Air Thermometer | Dulong; 1815 | [36] | ![Image](image11) | ![Image](image12) |
| 7  | Air Thermometer | Galileo; 1592 | [36] | ![Image](image13) | ![Image](image14) |
| 8  | Apparatus for Thermal Expansion of Gasses | Gay-Lussac; 1802 | [36] | ![Image](image15) | ![Image](image16) |
| 9  | Berkeley Comfort Model | Huizenga; 2001 | ![Image](image17) | ![Image](image18) |
| 10 | Bioclimatic Contrast Index | Blazejczyk; 2011 | [19] | ![Image](image19) | ![Image](image20) |
| 11 | Bioclimatic Distance Index | Mateeva; 2003 | [19] | ![Image](image21) | ![Image](image22) |
| 12 | Bioclimatic Index | Olgyay; 1963 | [37] | ![Image](image23) | ![Image](image24) |
| 13 | Black Sphere Actinograph | Poschmann; 1932 | [19,38] | ![Image](image25) | ![Image](image26) |
| 14 | Body Temperature Index | Dayal; 1974 | [19] | ![Image](image27) | ![Image](image28) |
| 15 | Body-atmosphere Energy Exchange Index | de Freitas; 1989 | [19] | ![Image](image29) | ![Image](image30) |
| 16 | Classification of Weather in Moments | Rusanov; 1973 | [19] | ![Image](image31) | ![Image](image32) |
| 17 | Climate Index | Becker; 2000 | [19] | ![Image](image33) | ![Image](image34) |
| 18 | Closed Air Thermometer | Amonton; 1702 | [36] | ![Image](image35) | ![Image](image36) |
| 19 | Climatic Heat | Hubac, 1989 | [39] | ![Image](image37) | ![Image](image38) |
| 20 | Clothing Insulation | Mount; 1982 | [19] | ![Image](image39) | ![Image](image40) |
| 21 | Cold Strain Index | Moran; 1999 | [19] | ![Image](image41) | ![Image](image42) |
| 22 | COMfort formulA (COMFA) | Brown; 1986 | ![Image](image43) | ![Image](image44) |
| 23 | Comfort Chart | Mochida; 1979 | ![Image](image45) | ![Image](image46) |
| 24 | Comfort Index | Terjung; 1966 | [19,23,40] | ![Image](image47) | ![Image](image48) |
| 25 | Corrected Effective Temperature (basic) | Vernon; 1932 | [19] | ![Image](image49) | ![Image](image50) |
| 26 | Corrected Effective Temperature (normal) | Vernon; 1932 | [19] | ![Image](image51) | ![Image](image52) |

(Continued)
Table 1. (Continued).

| ID | Thermal Stress Indicator                              | First Authors; Year | Literature | Reason for considered as non-meteo-based Parameter | Type |
|----|--------------------------------------------------------|---------------------|------------|---------------------------------------------------|------|
| 27 | Corrected Humid Operative Temperature                  | Horikoshi; 1985     | [41]       |                                                   |      |
| 28 | Craig Index                                            | Craig; 1950         | [42]       |                                                   |      |
| 29 | Cumulative Discomfort Index                           | Tennenbaum; 1961    | [43]       |                                                   |      |
| 30 | Cumulative Effective Temperature                       | Sohar; 1962         | [22]       |                                                   |      |
| 31 | Cumulative Heat Strain Index                           | Frank; 1996         | [19,44]    |                                                   |      |
| 32 | Cylinder                                               | Brown; 1986         | [19]       |                                                   |      |
| 33 | Daily Weather Types                                    | Lecha; 1998         | [19,23]    |                                                   |      |
| 34 | Effective Draft Temperature                            | Koestel; 1955       | [35]       |                                                   |      |
| 35 | Effective Heat Strain Index                            | Kamon; 1981         | [19]       |                                                   |      |
| 36 | Ellipsoid index                                        | Blazejczyk; 1998    | [19,23]    |                                                   |      |
| 37 | Equilibrating Columns                                  | Dulong; 1802        | [36]       |                                                   |      |
| 38 | Equilibrium Rectal Temperature                         | Givoni; 1972        | [19]       |                                                   |      |
| 39 | Equivalent Uniform Temperature                         | Wray; 1980          |            |                                                   |      |
| 40 | Eupathoscope                                           | Dufton; 1929        | [19,38]    |                                                   |      |
| 41 | Evans Scale                                            | Evans; 1980         | [18,19]    |                                                   |      |
| 42 | Exceedance                                             | Borgeson; 2011      |            |                                                   |      |
| 43 | Facial Cooling Index                                   | Tikuisis; 2002      | [45]       |                                                   |      |
| 44 | Frigorimeter                                           | Dorno; 1928         | [19,38]    |                                                   |      |
| 45 | Globe Thermometer                                      | Vernon; 1932        | [46]       |                                                   |      |
| 46 | Grade of Heat Strain                                   | Hubac; 1989         | [19]       |                                                   |      |
| 47 | Heart Rate Index                                       | Dayal; 1974         | [19]       |                                                   |      |
| 48 | Heart Rate Index                                       | Givoni; 1973        | [19]       |                                                   |      |
| 49 | Heat Budget Index                                      | de Freitas; 1985    | [19]       |                                                   |      |
| 50 | Heat Strain Decision Aid Model                         | Cadarette; 1999     | [19]       |                                                   |      |
| 51 | Heat Strain Index (corrected)                          | McKarns; 1966       | [22]       |                                                   |      |
| 52 | Heat Strain Predictive Systems                         | Lustinec; 1965      | [20]       |                                                   |      |
| 53 | Heat Stress Index                                      | Watts; 2004         | [19]       |                                                   |      |
| 54 | Heat Stress Prediction Model                           | Pandolf; 1986       | [19]       |                                                   |      |
| ID  | Thermal Stress Indicator                                      | First Authors; Year | Literature | Reason for considered as non-meteo-based Parameter Type |
|-----|--------------------------------------------------------------|---------------------|------------|----------------------------------------------------------|
| 55  | Heat Tolerance Index                                        | Hori; 1978          | [19]       |                                                          |
| 56  | Heat Tolerance Limits                                       | Vogt; 1982          | [19]       |                                                          |
| 57  | Heated Thermometer                                          | Heberden; 1826      | [47]       |                                                          |
| 58  | Heat Load                                                   | Blazejczyk; 1994    | [48]       |                                                          |
| 59  | Humid Operative Temperature                                 | Nishi; 1826         | [47]       |                                                          |
| 60  | Hybrid Thermometer                                          | Kircher; 1643       | [36]       |                                                          |
| 61  | Hypsobarometer                                               | Fahrenheit; 1724    | [36]       |                                                          |
| 62  | Increment Temperature Equivalent to Radiation Load           | Lee; 1964           | [19]       |                                                          |
| 63  | Index of Clothing Required for Comfort                      | de Freitas; 1986    | [19]       |                                                          |
| 64  | Index of Pathogenicity of Meteorological Environment         | Latsyhev; 1965      | [19]       |                                                          |
| 65  | Index of Physiological Effect                               | Robinson; 1945      | [19]       |                                                          |
| 66  | Index of Thermal Stress                                     | Givoni; 1969        | [19]       |                                                          |
| 67  | Index of Thermal Stress                                     | Kondratyev; 1957    | [19]       |                                                          |
| 68  | Integral Index of Cooling Conditions                        | Afanasiyeva; 2009   | [19, 49]   |                                                          |
| 69  | Integral Load Index                                         | Matyukhin; 1987     | [19]       |                                                          |
| 70  | Kata Thermometer                                            | Hill; 1916          | [19, 50]   |                                                          |
| 71  | Mahani Climate Index / Mahoney Scale                        | Mahoney; 1967       | [51]       |                                                          |
| 72  | Maximum Exposure Time                                       | Brauner; 1995       | [19]       |                                                          |
| 73  | Maximum Recommended Duration of Exercises                   | Young; 1979         | [19]       |                                                          |
| 74  | Mean Equivalence Lines                                      | Wenzel; 1978        | [19]       |                                                          |
| 75  | MENEX model                                                 | Blazejczyk; 1994    | [22]       |                                                          |
| 76  | Mercury Weight Thermometers                                 | Dulong; 1815        | [36]       |                                                          |
| 77  | Metal Man (thermal manikin)                                 | Pedersen; 1948      | [19]       |                                                          |
| 78  | Meteorological Health Index                                 | Bogatkin; 2006      | [19]       |                                                          |
| 79  | Modified Effective Temperature                              | Smith; 1952         | [19]       |                                                          |
| 80  | Modified Physiological Equivalent Temperature               | Lin; 2019           | [52]       |                                                          |
| 81  | Munich Energy Balance Model                                 | Hope; 1984          | [22]       |                                                          |
| 82  | New Effective Temperature                                   | Gagge; 1971         | [19]       |                                                          |
| ID | Thermal Stress Indicator                          | First Authors; Year | Literature | Reason for considered as non-meteo-based Parameter | Type |
|----|--------------------------------------------------|---------------------|------------|---------------------------------------------------|------|
| 83 | Outdoor Comfort Zone                             | Ahmed; 2003         | [53]       |                                                   |      |
| 84 | Outdoor Neutral Temperature                      | Aroztegui; 1995     | [54]       |                                                   |      |
| 85 | Outdoor Thermal Environment Index                | Nagano; 2011        | [19]       |                                                   |      |
| 86 | Optimum Summer Weather Index                     | Davis; 1968         | [55]       |                                                   |      |
| 87 | Overheating Risk                                 | Nicol; 2009         | [22]       |                                                   |      |
| 88 | Overheating Risk                                 | Robinson; 2008      | [22]       |                                                   |      |
| 89 | Perceived Temperature                            | Jendritzky; 2000    | [19]       |                                                   |      |
| 90 | Perceptual Hyperthermia Index                    | Gallagher; 2012     | [19]       |                                                   |      |
| 91 | Physiological Equivalent Temperature             | Mayer; 1987         | [19]       |                                                   |      |
| 92 | Physiological Heat Exposure Limit                | Chart; 1977         | [19]       |                                                   |      |
| 93 | Physiological Index of Strain                    | Hall; 1960          | [19]       |                                                   |      |
| 94 | Physiological Strain                             | Blazejczyk; 2005    | [19]       |                                                   |      |
| 95 | Physiological Strain Index                       | Moran; 1998         | [19]       |                                                   |      |
| 96 | Physiological Subjective Temperature             | Blazejczyk; 2007    | [19]       |                                                   |      |
| 97 | Predicted Effects of Heat Acclimatization        | Givoni; 1973        | [19]       |                                                   |      |
| 98 | Predicted Four-Hour Sweat Rate                   | McArdle; 1947       | [19]       |                                                   |      |
| 99 | Predicted Heat Strain                            | Malchaire; 2001     | [19]       |                                                   |      |
| 100| Predicted Mean Vote—Fuzzy                        | Hamdi; 1999         | [19]       |                                                   |      |
| 101| Predicted Mean Vote—Indoors                      | Fanger; 1970        | [19]       |                                                   |      |
| 102| Predicted Mean Vote—Outdoors                     | Gagge; 1986         | [19]       |                                                   |      |
| 103| Predicted Mean Vote—Outdoors                     | Jendritzky; 1981    | [19]       |                                                   |      |
| 104| Predicted Percentage Dissatisfied                | Index Fanger; 1970  | [19]       |                                                   |      |
| 105| Predicted Rectal Temperature                     | Givoni; 1972        | [21]       |                                                   |      |
| 106| Predicted Sweat Loss                             | Shapiro; 1982       | [22]       |                                                   |      |
| 107| Prescriptive Zone                                | Lind; 1970          | [22]       |                                                   |      |
| 108| Qs Index                                         | Rublack; 1981       | [19]       |                                                   |      |
| 109| Quotient of Heat Stress                          | Hubac; 1989         | [19]       |                                                   |      |
| 110| Reference Index                                  | Pulket; 1980        | [19]       |                                                   |      |
| 111| Relative Heat Strain                             | Lee; 1966           | [19]       |                                                   |      |
| 112| Required Clothing Insulation                     | Holmer; 1984        | [19]       |                                                   |      |
| 113| Required Sweat Rate                              | Vogt; 1981          | [19]       |                                                   |      |
| 114| Respiratory Heat Loss                            | Rusanov; 1989       | [19]       |                                                   |      |
| 115| Resultant Thermometer                            | Missenard; 1935     | [38]       |                                                   |      |
| ID | Thermal Stress Indicator                                      | First Authors; Year | Literature | Reason for considered as non-meteo-based |
|----|---------------------------------------------------------------|---------------------|------------|------------------------------------------|
| 116| Santorio's Thermometer                                       | Santorio; 1612     | [56]       |                                          |
| 117| Skin Temperature                                              | Mehnerdt; 2000     | [19]       |                                          |
| 118| Skin Temperature Energy Balance Index                         | de Freitas; 1985   | [19]       |                                          |
| 119| Skin Wettedness                                               | Gonzalez; 1978     | [19,23]    |                                          |
| 120| Skin Wettedness                                               | Kerslake; 1972     | [22]       |                                          |
| 121| Spatial Synoptic Classification                               | Kalkstein; 1996    | [19]       |                                          |
| 122| Standard Effective Temperature                                | Gonzalez; 1974     | [19]       |                                          |
| 123| Standard Effective Temperature                                | Pickup; 2000       | [19]       |                                          |
| 124| Standard Effective Temperature for Outdoors                  | Burton; 1955       | [19]       |                                          |
| 125| Still Shade Temperature                                       | Blazejczyk; 2005   | [19]       |                                          |
| 126| Subjective Temperature Index                                  | McLaughlin; 1977   | [19]       |                                          |
| 127| Summer Severity Index                                         | Gonzalez; 1978     | [19,23]    |                                          |
| 128| Survival Time Outdoors in Extreme Cold                       | de Freitas; 1987   | [19,23]    |                                          |
| 129| Temperature Load                                              | cited by Kioka; 2006| [57]       |                                          |
| 130| Thermal Acceptance Ratio                                      | Ionides; 1945      | [19,23]    |                                          |
| 131| Thermal Balance                                               | Rusanov; 1981      | [19]       |                                          |
| 132| Thermal Discomfort                                            | Gagge; 1986        | [19]       |                                          |
| 133| Thermal Insulation of Clothing                                | Aizenshtat; 1964   | [18,19]    |                                          |
| 134| Thermal Insulation of Clothing                                | Budko; 1960        | [19]       |                                          |
| 135| Thermal Insulation of Clothing                                | Rusanov; 1981      | [19]       |                                          |
| 136| Thermal Insulation of Protective Clothing                     | Afanasieva; 1977   | [19]       |                                          |
| 137| Thermal Sensation                                              | Fountain; 1995     | [54]       |                                          |
| 138| Thermal Sensation                                              | Givoni; 2003       | [19,23]    |                                          |
| 139| Thermal Sensation Index                                        | Kiuichi; 2001      | [57]       |                                          |
| 140| Thermal Strain Index                                          | Lee; 1958          | [19,23]    |                                          |
| 141| Thermal Work Limit                                            | Brake; 2002        | [19]       |                                          |
| 142| Thermo-Integration Characteristics of Clothing                | Kondrata; 1957     | [19]       |                                          |
| 143| Thermo-Integrator                                              | Winslow; 1935      | [19,23]    |                                          |
| 144| Thermoscope                                                    | Hero; 40 AD        | [36]       |                                          |
| 145| Thermoscope                                                    | Philo; 200 BC      | [36]       |                                          |
| 146| Total Heat                                                     | Hubac, 1989        | [39]       |                                          |
| 147| Total Thermal Stress                                           | Auliciems; 1981    | [19]       |                                          |
| 148| Tourism Climate Index                                         | Mieczkowski; 1985  | [55]       |                                          |

(Continued)
| ID  | Thermal Stress Indicator                          | First Authors; Year | Literature | Reason for considered as non-meteo-based |
|-----|--------------------------------------------------|---------------------|------------|------------------------------------------|
| 149 | Weather Stress Index                             | Kalkstein; 1986     | [19]       |                                          |
| 150 | Weather–Climate Contrasts                        | Rusanov; 1987       | [19]       |                                          |
| 151 | Wet Bulb Thermometer                             | Haldane; 1905       | [58]       |                                          |
| 152 | Wet Globe Thermometer                            | Botsford; 1971      | [59]       |                                          |
| 153 | Wind Effect Index                                | Terjung; 1966       | [19,23,40] |                                          |

- Metabolic Rate
- Elevation / Barometric Pressure
- Skin Temperature
- Clothing Insulation
- Cloud Level
- Duration of Effort
- Long-wave Radiation
- Acclimatization status
- Heart Rate
- Precipitation
- No Environmental Data
- Water Intake
- Core Temperature
- Covered Distance
- Specialized Equipment
- Sweat Rate / Water loss / Vapor Pressure at Skin Surface
- Evaporative Heat Loss from Skin
- Questionnaire
- Delta Data (fluctuation throughout the time)
- No Fitted Equation / Nomogram
- average temperature over multiple measures
Table 2. The environmental parameters used by the 187 meteo-based thermal stress indicators. Meteo-based indicators were defined as those that can be calculated using only meteorological data (air temperature, relative humidity, wind speed, and solar radiation).

| ID | Thermal Stress Indicator                                      | First Author    | Year | Unit   | Temperature | Humidity | Radiation | Wind |
|----|--------------------------------------------------------------|-----------------|------|--------|-------------|----------|-----------|------|
| 1  | Accepted Level of Physical Activity [60]                   | Blazejczyk      | 2010 | W/m²   | ✓           | ✓        | ✓         | ✓    |
| 2  | Actual Sensation Vote [61]                                 | Nikopolopoulou  | 2003 | [-]    | ✓           | ✓        | ✓         | ✓    |
| 3  | Actual Sensation Vote [62]                                 | Nikopolopoulou  | 2004 | [-]    | ✓           | ✓        | ✓         | ✓    |
| 4  | Actual Sensation Vote (Europe) [62]                        | Nikopolopoulou  | 2004 | [-]    | ✓           | ✓        | ✓         | ✓    |
| 5  | Air Enthalpy [63]                                          | Boer            | 1964 | Kcal/kg| ✓           | ✓        | ✓         | ✓    |
| 6  | Apparent Temperature [64]                                  | Almeida         | 2010 | °C     | ✓           | ✓        | ✓         | ✓    |
| 7  | Apparent Temperature [65]                                  | Arnoldy         | 1962 | °C     | ✓           | ✓        | ✓         | ✓    |
| 8  | Apparent Temperature [66]                                  | Fischer         | 2010 | °C     | ✓           | ✓        | ✓         | ✓    |
| 9  | Apparent Temperature [67]                                  | Kalkstein       | 1986 |        | ✓           | ✓        | ✓         | ✓    |
| 10 | Apparent Temperature [68]                                  | Smoyer-Tomic    | 2001 | °C     | ✓           | ✓        | ✓         | ✓    |
| 11 | Apparent Temperature (indoor) [69]                         | Steadman        | 1994 | °C     | ✓           | ✓        | ✓         | ✓    |
| 12 | Apparent Temperature (indoors) [70]                        | Steadman        | 1984 | °C     | ✓           | ✓        | ✓         | ✓    |
| 13 | Apparent Temperature (shade) [70]                          | Steadman        | 1984 | °C     | ✓           | ✓        | ✓         | ✓    |
| 14 | Apparent Temperature (shade) [69]                          | Steadman        | 1994 | °C     | ✓           | ✓        | ✓         | ✓    |
| 15 | Apparent Temperature (sun) [70]                            | Steadman        | 1984 | °C     | ✓           | ✓        | ✓         | ✓    |
| 16 | Apparent Temperature (sun) [69]                            | Steadman        | 1994 | °C     | ✓           | ✓        | ✓         | ✓    |
| 17 | Approximated Subjective Temperature                        | Auliciems       | 2007 | °C     | ✓           | ✓        | ✓         | ✓    |
|    | [71]                                                         |                 |      |        |             |          |           |      |
| 18 | Belding-Hatch Index [72]                                   | Belding         | 1955 | [-]    | ✓           | ✓        | ✓         | ✓    |
| 19 | Belgian Effective Temperature [38]                         | Bidlot          | 1947 | °C     | ✓           | ✓        | ✓         | ✓    |
| 20 | Bioclimatic Index of Severity [73]                         | Belkin          | 1992 | [-]    | ✓           | ✓        | ✓         | ✓    |
| 21 | Biologically Active Temperature [74]                       | Tsitsenko       | 1971 | °C     | ✓           | ✓        | ✓         | ✓    |
| 22 | Biometeorological Comfort Index [75]                       | Rodriguez       | 1985 | °C     | ✓           | ✓        | ✓         | ✓    |
| 23 | Bodman’s Weather Severity Index [76]                        | Bodman          | 1908 | [-]    | ✓           | ✓        | ✓         | ✓    |
| 24 | Clothing Thickness                                         | Steadman        | 1971 | mm     | ✓           | ✓        | ✓         | ✓    |
| 25 | Comfort Vote [77]                                          | Bedford         | 1936 | [-]    | ✓           | ✓        | ✓         | ✓    |
| 26 | Cooling Power [78]                                         | Becker          | 1972 | mcal/cm²/s | ✓       | ✓        | ✓         | ✓    |
| 27 | Cooling Power (79,80)                                      | Becker          | 1933 | mcal/cm²/s | ✓       | ✓        | ✓         | ✓    |
| 28 | Cooling Power (79,80)                                      | Bider           | 1931 | mcal/cm²/s | ✓       | ✓        | ✓         | ✓    |
| 29 | Cooling Power (79,80)                                      | Bradtke         | 1926 | mcal/cm²/s | ✓       | ✓        | ✓         | ✓    |
| 30 | Cooling Power (79,80)                                      | Buttner         | 1934 | mcal/cm²/s | ✓       | ✓        | ✓         | ✓    |
| 31 | Cooling Power (79,80)                                      | Cena            | 1966 | mcal/cm²/s | ✓       | ✓        | ✓         | ✓    |
| 32 | Cooling Power (79,80)                                      | Dorno           | 1925 | mcal/cm²/s | ✓       | ✓        | ✓         | ✓    |
| 33 | Cooling Power (79,80)                                      | Dorno           | 1934 | mcal/cm²/s | ✓       | ✓        | ✓         | ✓    |
| 34 | Cooling Power (eq. 1) [79,80]                              | Goldschmidt     | 1952 | mcal/cm²/s | ✓       | ✓        | ✓         | ✓    |
| 35 | Cooling Power (eq. 2) [79,80]                              | Goldschmidt     | 1952 | mcal/cm²/s | ✓       | ✓        | ✓         | ✓    |
| 36 | Cooling Power [79]                                         | Henneberger     | 1948 | mcal/cm²/s | ✓       | ✓        | ✓         | ✓    |
| 37 | Cooling Power [76,81]                                      | Hill            | 1916 | W/m²   | ✓           | ✓        | ✓         | ✓    |
| 38 | Cooling Power (eq. 1) [79]                                 | Hill            | 1937 | mcal/cm²/s | ✓       | ✓        | ✓         | ✓    |
| 39 | Cooling Power (eq. 2) [79]                                 | Hill            | 1937 | mcal/cm²/s | ✓       | ✓        | ✓         | ✓    |
| 40 | Cooling Power [79]                                         | Lahmayer        | 1932 | mcal/cm²/s | ✓       | ✓        | ✓         | ✓    |
| 41 | Cooling Power (eq. 1) [79]                                 | Matzke          | 1954 | mcal/cm²/s | ✓       | ✓        | ✓         | ✓    |
| 42 | Cooling Power (eq. 2) [79]                                 | Matzke          | 1954 | mcal/cm²/s | ✓       | ✓        | ✓         | ✓    |
| 43 | Cooling Power [79]                                         | Meissner        | 1932 | mcal/cm²/s | ✓       | ✓        | ✓         | ✓    |
| 44 | Cooling Power [82]                                         | Vinje           | 1962 | mcal²/h | ✓       | ✓        | ✓         | ✓    |
| 45 | Cooling Power [79]                                         | Weiss           | 1926 | mcal²/h | ✓       | ✓        | ✓         | ✓    |
| 46 | Cooling Power [82]                                         | Angus           | 1930 | mcal²/h | ✓       | ✓        | ✓         | ✓    |
| 47 | Cooling Power [82]                                         | Lehmann         | 1936 | mcal²/h | ✓       | ✓        | ✓         | ✓    |
| 48 | Cooling Power [82]                                         | Joranger        | 1955 | mcal²/h | ✓       | ✓        | ✓         | ✓    |
| 49 | Cooling Power (Wet Air Temperature) [76,81]                | Hill            | 1916 | W/m²   | ✓           | ✓        | ✓         | ✓    |
| 50 | Corrected Effective Temperature (Basic) [71]               | Auliciems       | 2007 | °C     | ✓           | ✓        | ✓         | ✓    |
| 51 | Corrected Effective Temperature (Normal) [71]              | Auliciems       | 2007 | °C     | ✓           | ✓        | ✓         | ✓    |
| 52 | Dew Point [83]                                             | Bruce           | 1916 | °C     | ✓           | ✓        | ✓         | ✓    |
| 53 | Discomfort Index [84]                                      | Giles           | 1990 | °C     | ✓           | ✓        | ✓         | ✓    |
| 54 | Discomfort Index [79]                                      | Kawamura        | 1965 | [-]    | ✓           | ✓        | ✓         | ✓    |
| 55 | Discomfort Index [79]                                      | Tennenbaum      | 1961 | °C     | ✓           | ✓        | ✓         | ✓    |
| 56 | Discomfort Index (eq. 1) [85]                              | Thom            | 1959 | [-]    | ✓           | ✓        | ✓         | ✓    |
| 57 | Discomfort Index (eq. 2) [54,86]                           | Thom            | 1959 | [-]    | ✓           | ✓        | ✓         | ✓    |

(Continued)
| ID  | Thermal Stress Indicator                          | First Author | Year | Unit          | Temperature | Humidity | Radiation | Wind |
|-----|--------------------------------------------------|--------------|------|---------------|-------------|----------|-----------|------|
| 58  | Discomfort Index [87]                            | Weather Services of South Africa | 2018 | [ ] | ✓       | ✓       |           |      |
| 59  | Draught Risk Index [88]                          | Fanger       | 1987 | % of people dissatisfied | ✓                  | ✓                  |           |      |
| 60  | Dry Kata Cooling [89]                            | Maloney      | 2011 | W/m²          | ✓                  | ✓                  |           |      |
| 61  | Effective Radiant Field [90]                     | Gagge        | 1967 | W/m²          | ✓                  | ✓                  | ✓                  | ✓    |
| 62  | Effective Radiant Field [90]                     | Nishi        | 1981 | W/m²          | ✓                  | ✓                  | ✓                  | ✓    |
| 63  | Effective Temperature [71]                       | Houghten     | 1923 | °C            | ✓                  | ✓                  |           | ✓    |
| 64  | Effective Temperature [91]                       | Missenard    | 1933 | °C            | ✓                  | ✓                  |           | ✓    |
| 65  | Environmental Stress Index [86]                  | Moran        | 2001 | °C            | ✓                  | ✓                  | ✓                  |      |
| 66  | Equatorial Comfort Index [79]                    | Webb         | 1960 | °C            | ✓                  | ✓                  | ✓                  | ✓    |
| 67  | Equivalent Effective Temperature [23]            | Aizenshtat   | 1974 | °C            | ✓                  | ✓                  |           | ✓    |
| 68  | Equivalent Effective Temperature [92]            | Aizenshtat   | 1982 | °C            | ✓                  | ✓                  |           | ✓    |
| 69  | Equivalent Temperature [77]                      | Bedford      | 1936 | °C            | ✓                  | ✓                  |           | ✓    |
| 70  | Equivalent Temperature [93]                      | Brundl       | 1984 | °C            | ✓                  | ✓                  |           | ✓    |
| 71  | Equivalent Warmth [77]                           | Bedford      | 1936 | °C            | ✓                  | ✓                  |           | ✓    |
| 72  | Exposed Skin Temperature [94]                    | Brauner      | 1995 | °C            | ✓                  | ✓                  |           | ✓    |
| 73  | Facial Skin Temperature (Cheek) [95]             | Adamenko     | 1972 | °C            | ✓                  | ✓                  |           | ✓    |
| 74  | Facial Skin Temperature (Ear Lobe) [95]          | Adamenko     | 1972 | °C            | ✓                  | ✓                  |           | ✓    |
| 75  | Facial Skin Temperature (Nose) [95]              | Adamenko     | 1972 | °C            | ✓                  | ✓                  |           | ✓    |
| 76  | Fighter Index of Thermal Stress (Direct Sunlight) [96] | Stribley     | 1978 | °C            | ✓                  | ✓                  | ✓                  | ✓    |
| 77  | Fighter Index of Thermal Stress (Moderate Overcast) [96] | Stribley     | 1978 | °C            | ✓                  | ✓                  | ✓                  | ✓    |
| 78  | Globe Temperature [97]                           | Liljegren    | 2008 | °C            | ✓                  | ✓                  |           | ✓    |
| 79  | Heart Rate [98]                                  | Fuller       | 1966 | beats/min     | ✓                  | ✓                  |           | ✓    |
| 80  | Heart Rate Safe limit [98]                       | Lafleur      | 1971 | beats/min     | ✓                  | ✓                  |           | ✓    |
| 81  | Heat Index [91]                                  | Blazejczyk   | 2012 | °C            | ✓                  | ✓                  |           | ✓    |
| 82  | Heat Index [99,100]                              | Stull        | 2000 | °C            | ✓                  | ✓                  |           | ✓    |
| 83  | Heat Index [101]                                 | National Oceanic and Atmospheric Administration | 2014 | °C            | ✓                  | ✓                  |           | ✓    |
| 84  | Heat Index [102]                                 | Patricola    | 2010 | °C            | ✓                  | ✓                  |           | ✓    |
| 85  | Heat Index [103]                                 | Rothfusz     | 1990 | °C            | ✓                  | ✓                  |           | ✓    |
| 86  | Humidex [91]                                     | Masterson    | 1979 | °C            | ✓                  | ✓                  |           | ✓    |
| 87  | Humisery [104]                                   | Weiss        | 1982 | °C            | ✓                  | ✓                  |           | ✓    |
| 88  | Humiture [105]                                   | Lally        | 1960 | °C            | ✓                  | ✓                  |           | ✓    |
| 89  | Humiture [104]                                   | Weiss        | 1982 | °C            | ✓                  | ✓                  |           | ✓    |
| 90  | Humiture [106]                                   | Hevener      | 1959 | °C            | ✓                  | ✓                  |           | ✓    |
| 91  | Humiture revised                                | Wintering    | 1979 | °F            | ✓                  | ✓                  |           | ✓    |
| 92  | Insulation Predicted Index [107]                 | Blazejczyk   | 2011 | °C            | ✓                  | ✓                  |           | ✓    |
| 93  | Integrated Index (indoor) [108]                  | Junge        | 2016 | [ ] | ✓                  | ✓                  |           | ✓    |
| 94  | Integrated Index (outdoor) [108]                 | Junge        | 2016 | [ ] | ✓                  | ✓                  |           | ✓    |
| 95  | Internal Comfort Temperature [109]               | Xavier       | 2000 | °C            | ✓                  | ✓                  |           | ✓    |
| 96  | Kata Index [110]                                 | Zhongpeng    | 2012 | [ ] | ✓                  | ✓                  |           | ✓    |
| 97  | Mean Radiant Temperature (approximated) [111]    | Ramsey       | 2001 | °C            | ✓                  | ✓                  |           | ✓    |
| 98  | Mean Skin Temperature [112]                      | McPherson    | 1993 | °C            | ✓                  | ✓                  |           | ✓    |
| 99  | Mediterranean Outdoor Comfort Index [113]        | Salata       | 2016 | [ ] | ✓                  | ✓                  |           | ✓    |
| 100 | Missenard’s Index [114]                          | Missenard    | 1969 | °C            | ✓                  | ✓                  |           | ✓    |
| 101 | Modified Discomfort Index [115]                  | Moran        | 1998 | °C            | ✓                  | ✓                  |           | ✓    |
| 102 | Modified Environmental Stress Index [116]        | Moran        | 2003 | °C            | ✓                  | ✓                  |           | ✓    |
| 103 | Natural Wet Bulb Temperature [89]                | Maloney      | 2011 | °C            | ✓                  | ✓                  |           | ✓    |
| 104 | Nett Radiation [117]                             | Cena         | 1984 | W/m²          | ✓                  | ✓                  |           | ✓    |
| 105 | New Wind Chill [118]                             | NOAA         | 2001 | [ ] | ✓                  | ✓                  |           | ✓    |
| 106 | Normal Equivalent Effective Temperature [74]     | Boksha       | 1980 | °C            | ✓                  | ✓                  |           | ✓    |
| 107 | Operative Temperature [119]                      | ASHRAE       | 2004 | °C            | ✓                  | ✓                  |           | ✓    |
| 108 | Operative Temperature [120]                      | ISO 7726:1998 | 1998 | °C            | ✓                  | ✓                  |           | ✓    |
| 109 | Operative Temperature [121]                      | ISO 7730:1994 | 1994 | °C            | ✓                  | ✓                  |           | ✓    |
| 110 | Operative Temperature [122]                      | Winslow      | 1937 | °C            | ✓                  | ✓                  |           | ✓    |
Table 2. (Continued).

| ID  | Thermal Stress Indicator                                      | First Author        | Year  | Unit  | Temperature | Humidity | Radiation | Wind |
|-----|----------------------------------------------------------------|---------------------|-------|-------|-------------|----------|-----------|------|
| 111 | Outdoor Standard Effective Temperature [123]                 | Skinner             | 2001  | °C    | ✓           | ✓        | ✓         | ✓    |
| 112 | Oxford Index [124]                                           | Lind                | 1957  | []    | ✓           | ✓        | ✓         | ✓    |
| 113 | Perceived Equivalent Temperature [125]                       | Monteiro            | 2010  | °C    | ✓           | ✓        | ✓         | ✓    |
| 114 | Perceived Temperature [38]                                   | Linke               | 1926  | °C    | ✓           | ✓        | ✓         | ✓    |
| 115 | Predicted Percentage Dissatisfied [109]                      | Xavier              | 2000  | % dissatisfied people | ✓ | ✓ | ✓ | ✓ |
|     | Predicted Thermal Sensation Vote [126]                       | Cheng               | 2008  | [.]   | ✓           | ✓        | ✓         | ✓    |
| 117 | Psychrometric Wet Bulb Temperature [127]                     | Malchair            | 1976  | °C    | ✓           | ✓        | ✓         | ✓    |
| 118 | Psychrometric Wet Bulb Temperature [30]                      | McPherson           | 2008  | °C    | ✓           | ✓        | ✓         | ✓    |
| 119 | Radiative Effective Temperature [128]                        | Blaziejczyk         | 2004  | °C    | ✓           | ✓        | ✓         | ✓    |
| 120 | Radiation Equivalent Effective Temperature (Non-Pigmented) [129] | Sheleihovskiy      | 1948  | °C    | ✓           | ✓        | ✓         | ✓    |
| 121 | Radiation Equivalent Effective Temperature (Pigmented) [129]  | Sheleihovskiy       | 1948  | °C    | ✓           | ✓        | ✓         | ✓    |
| 122 | Relative Humidity Dry Temperature [130]                      | Wallace             | 2005  | °C    | ✓           | ✓        | ✓         | ✓    |
| 123 | Relative Strain Index [54]                                   | Kyle                | 1992  | [ ]   | ✓           | ✓        | ✓         | ✓    |
| 124 | Relative Strain Index [131]                                  | Lee                 | 1966  | [ ]   | ✓           | ✓        | ✓         | ✓    |
| 125 | Revised Wind Chill Index [132]                               | Court               | 1948  | kcal/m²/hr | ✓ | ✓ | ✓ | ✓ |
| 126 | Robaia’s Index [114]                                         | Robaia              | 2003  | [ ]   | ✓           | ✓        | ✓         | ✓    |
| 127 | Saturation Deficit [38]                                      | Flugge              | 1912  | kPa   | ✓           | ✓        | ✓         | ✓    |
| 128 | Severity Index [129]                                         | Osokin              | 1968  | [ ]   | ✓           | ✓        | ✓         | ✓    |
| 129 | Simple Index [86]                                            | Moran               | 2001  | [ ]   | ✓           | ✓        | ✓         | ✓    |
| 130 | Simplified Radiation Equivalent Effective Temperature [74]   | Boksha              | 1980  | °C    | ✓           | ✓        | ✓         | ✓    |
| 131 | Simplified Tropical Summer Index [71]                        | Auliciems           | 2007  | °C    | ✓           | ✓        | ✓         | ✓    |
| 132 | Simplified Universal Thermal Climate Index [133]             | Blaziejczyk         | 2011  | °C    | ✓           | ✓        | ✓         | ✓    |
| 133 | Simplified Wet Bulb Globe Temperature [134]                  | American College of Sports Medicine | 1984 | °C | ✓ | ✓ | ✓ | ✓ |
| 134 | Simplified Wet Bulb Globe Temperature [30]                   | Gagge               | 1976  | °C    | ✓           | ✓        | ✓         | ✓    |
| 135 | Skin Temperature [135]                                       | Blaziejczyk         | 2005  | °C    | ✓           | ✓        | ✓         | ✓    |
| 136 | Skin Wettedness [135]                                        | Blaziejczyk         | 2005  | [ ]   | ✓           | ✓        | ✓         | ✓    |
| 137 | Standard Operative Temperature [136]                         | Gagge               | 1940  | °C    | ✓           | ✓        | ✓         | ✓    |
| 138 | Subjective Temperature [137]                                 | McIntyre            | 1973  | °C    | ✓           | ✓        | ✓         | ✓    |
| 139 | Sultriness Index [138]                                       | Scharlau            | 1943  | Torr  | ✓           | ✓        | ✓         | ✓    |
| 140 | Sultriness Intensity [139]                                   | Akimovich           | 1971  | [ ]   | ✓           | ✓        | ✓         | ✓    |
| 141 | Summer Scharlau Index [140]                                  | Scharlau            | 1950  | [ ]   | ✓           | ✓        | ✓         | ✓    |
| 142 | Summer Simmer Index [141]                                   | Pepi                | 1987  | °C    | ✓           | ✓        | ✓         | ✓    |
| 143 | Swedish Wet Bulb Globe Temperature [142]                     | Eriksson            | 1974  | °C    | ✓           | ✓        | ✓         | ✓    |
| 144 | Temperature Humidity Index [99]                              | Schoen              | 2005  | °C    | ✓           | ✓        | ✓         | ✓    |
| 145 | Temperature Humidity Index [143]                             | Costanzo            | 2006  | °C    | ✓           | ✓        | ✓         | ✓    |
| 146 | Temperature Humidity Index [144]                             | INMH                | 2000  | [ ]   | ✓           | ✓        | ✓         | ✓    |
| 147 | Temperature Humidity Index [144]                             | Kyle                | 1994  | °C    | ✓           | ✓        | ✓         | ✓    |
| 148 | Temperature Humidity Index [145]                             | Nieuwolt            | 1977  | °C    | ✓           | ✓        | ✓         | ✓    |
| 149 | Temperature Humidity Index (eq. 1) [145]                     | Pepi                | 1987  | °C    | ✓           | ✓        | ✓         | ✓    |
| 150 | Temperature Humidity Index (eq. 2) [141]                     | Pepi                | 1987  | °C    | ✓           | ✓        | ✓         | ✓    |
| 151 | Temperature of the Exhaled air [112]                         | McPherson           | 1993  | °C    | ✓           | ✓        | ✓         | ✓    |
| 152 | Temperature Resultante Miniere [38]                          | Vogt                | 1978  | °C    | ✓           | ✓        | ✓         | ✓    |
| 153 | Temperature Wind Speed Humidity Index [146]                  | Zaninovic           | 1992  | KJ/kg | ✓           | ✓        | ✓         | ✓    |
| 154 | Thermal Comfort [147]                                        | Givoni              | 2000  | [ ]   | ✓           | ✓        | ✓         | ✓    |
| 155 | Thermal Comfort (Humid-Tropical environments) [148]          | Sangkertadi         | 2014  | [ ]   | ✓           | ✓        | ✓         | ✓    |
| 156 | Thermal Resistance of Clothing (1 Clothing Layer) [149]      | Jokl                | 1982  | W/m [2]/K | ✓ | ✓ | ✓ | ✓ |
| 157 | Thermal Sensation [125]                                      | Monteiro            | 2010  | [ ]   | ✓           | ✓        | ✓         | ✓    |
**Table 2. (Continued).**

| ID  | Thermal Stress Indicator | First Author | Year | Unit | Temperature | Humidity | Radiation | Wind |
|-----|--------------------------|--------------|------|------|-------------|----------|-----------|------|
| 158 | Thermal Sensation (eq 1) [150] | Rohles       | 1971 | []   | ✓           | ✓        | ✓         | ✓    |
| 159 | Thermal Sensation (eq. 2) [151] | Rohles       | 1971 | []   | ✓           | ✓        | ✓         | ✓    |
| 160 | Thermal Sensation [152] | Givoni       | 2004 | [ ]  | ✓           | ✓        | ✓         | ✓    |
| 161 | Thermal Sensation Index [109] | Xavier       | 2000 | [ ]  | ✓           | ✓        | ✓         | ✓    |
| 162 | Thermal Sensation Vote (Summer) [153] | Yahia       | 2013 | [ ]  | ✓           | ✓        | ✓         | ✓    |
| 163 | Thermal Sensation Vote (Winter) [153] | Yahia       | 2013 | [ ]  | ✓           | ✓        | ✓         | ✓    |
| 164 | TPV index (Baghdad) [72] | Nicol        | 1975 | [ ]  | ✓           | ✓        | ✓         | ✓    |
| 165 | TPV index (Roorkee) [72] | Nicol        | 1975 | [ ]  | ✓           | ✓        | ✓         | ✓    |
| 166 | Tropical Summer Index [154] | Sharma       | 1986 | °C   | ✓           | ✓        | ✓         | ✓    |
| 167 | Universal Thermal Climate Index [155] | Jendritzky | 2012 | °C   | ✓           | ✓        | ✓         | ✓    |
| 168 | Wet Bulb Globe Temperature (eq. 1) [156] | Ono         | 2014 | °C   | ✓           | ✓        | ✓         | ✓    |
| 169 | Wet Bulb Globe Temperature (eq. 2) [156] | Ono         | 2014 | °C   | ✓           | ✓        | ✓         | ✓    |
| 170 | Wet Bulb Globe Temperature (indoors) [156] | Yaglou      | 1956 | °C   | ✓           | ✓        | ✓         | ✓    |
| 171 | Wet Bulb Globe Temperature (outdoors) [156] | Yaglou      | 1956 | °C   | ✓           | ✓        | ✓         | ✓    |
| 172 | Wet Bulb Temperature [97] | Liljegren    | 2008 | °C   | ✓           | ✓        | ✓         | ✓    |
| 173 | Wet Bulb Temperature [127] | Malchaire    | 1976 | °C   | ✓           | ✓        | ✓         | ✓    |
| 174 | Wet Bulb Temperature [157] | Stull        | 2011 | °C   | ✓           | ✓        | ✓         | ✓    |
| 175 | Wet Cooling Power [79] | Landsberg    | 1972 | mcal/cm²/s | ✓       | ✓        | ✓         | ✓    |
| 176 | Wet Globe Temperature (Botsball) [158] | Botsford   | 1971 | °C   | ✓           | ✓        | ✓         | ✓    |
| 177 | Wet Kata Cooling [89] | Maloney      | 2011 | W/m² | ✓           | ✓        | ✓         | ✓    |
| 178 | Wet Kata Cooling Power [112] | Chamber of Mines of South Africa | 1972 | mcal/cm²/s | ✓       | ✓        | ✓         | ✓    |
| 179 | Wet Kata Cooling Power [159] | Krisha       | 1996 | W/m² | ✓           | ✓        | ✓         | ✓    |
| 180 | Wet Kata Cooling Power [160] | Hill         | 1919 | mcal/cm²/s | ✓       | ✓        | ✓         | ✓    |
| 181 | Wet-Bulb Dry Temperature [130] | Wallace     | 2005 | °C   | ✓           | ✓        | ✓         | ✓    |
| 182 | Wind Chill [161] | OFCM/NOAA   | 2003 | °C   | ✓           | ✓        | ✓         | ✓    |
| 183 | Wind Chill [162] | Siple        | 1945 | kg cal/m²/hr | ✓      | ✓        | ✓         | ✓    |
| 184 | Wind Chill [163] | Steadman    | 1971 | cal/m²/s | ✓         | ✓        | ✓         | ✓    |
| 185 | Wind Chill Equivalent [164] | Quayle     | 1998 | °C   | ✓           | ✓        | ✓         | ✓    |
| 186 | Wind Chill Equivalent Temperature (wind of 1.34 m/s) [165] | Falconer | 1968 | °C   | ✓           | ✓        | ✓         | ✓    |
| 187 | Winter Scharlau Index [140] | Sharlau     | 1950 | [ ]  | ✓           | ✓        | ✓         | ✓    |

**Notes:**
- [ ] no unit available for this thermal index
- ✓ environmental parameter required for the calculation of this thermal index
- [cit] no original article found; the equation for the identified thermal index was found in the cited publication
- [appr:] the current index requires specialized equipment; an equation found in the cited publication was used for its approximation

**Information on complex parameters used for the computation of some thermal indices.**

In case where the calculation of a thermal index requires any of the following parameter, that parameter was translated as follows:

| Parameter | Temperature | Humidity | Radiation | Wind |
|-----------|-------------|----------|-----------|------|
| Mean Radiant Temperature (approximated). Proper measurement considers short- and long-wave radiation. | ✓         | ✓        | ✓       | ✓    |
| Dew point | ✓          | ✓        | ✓         | ✓    |
| Wet Bulb Temperature | ✓          | ✓        | ✓         | ✓    |
| Globe Temperature | ✓          | ✓        | ✓         | ✓    |
| Vapor Pressure | ✓          | ✓        | ✓         | ✓    |
| Saturated Vapor Pressure | ✓           | ✓        | ✓         | ✓    |
| Wet Bulb Globe Temperature | ✓           | ✓        | ✓         | ✓    |
| Psychrometric Wet Bulb Temperature | ✓           | ✓        | ✓         | ✓    |

*indirect use of a parameter incorporating that factor

within the search algorithm. To confirm that this did not limit the sensitivity of our search, we performed a sensitivity analysis as follows:

1. The reference lists of all eligible articles were extracted.
2. Duplicates were removed.
(3) The titles and abstracts of all unique citations were screened for eligibility.
(4) Sensitivity was defined as the percent of eligible articles resulting from the search algorithm out of all the known eligible articles that were included in the systematic review (articles from the search algorithm + articles added from detailed reference list search + articles added manually).

**Risk of bias assessment**

There is no tool to assess the risk of bias in modelling studies (i.e., studies that use mathematics to describe the effect of physical phenomena on humans, on the absence of human participants). Therefore, we assessed the sources of funding for the eligible studies, as an indicator of bias. Also, we assessed the strength of the evidence presented in each study using the Evidence for Policy and Practice Information (EPPP) approach [26], which is a recommended methodology for assessing methodological quality [27]. This tool employs four criteria to evaluate each study: (1) trustworthiness (assessed as the percent of TSIs cited and described appropriately in each study; scores: 0 = 0%, 1 = 20%, 2 = 40%, 3 = 60%, 4 = 80%, and 5 = 100%), (2) appropriateness (assessed as the appropriateness of the study’s research design in addressing the current review question; scores: 0 = conference abstract, 1 = book/report, 2 = meteorology/modelling article, 3 = human study, 4 = narrative review, and 5 = systematic review), (3) relevance (assessed as the relevance of each study to the current review question; all articles were given the highest score [5 in this criterion]), and (4) the overall weight of each study (assessed as the average score of the previous three criteria). For instance, a study receiving a relevance score of 5 (as it has been screened for eligibility), an appropriateness score of 4 (because it is a narrative review), and a trustworthiness score of 3 (because it provides appropriate citation and description for 60% of the TSIs mentioned in its text), will have an overall weight of 4 = (5 +4 +3)/3.

**Data extraction and analysis**

As described in the Introduction, we present a comprehensive list of different types of TSIs in the current systematic review, yet our analysis focused primarily on indicators requiring only meteorological data (air temperature, relative humidity, wind speed, and solar radiation), as we aimed to enhance the quality and relevance of big-data analytics used in climate services for the occupational and the general populations. Independent data extraction was performed by two investigators (LGI and KM) and conflicts were resolved through consensus and supervision by a third researcher (ADF). When necessary, additional information was requested from the journals and/or the study authors via email. For all studies, we extracted the author name(s), year of publication, country of the first author, as well as all the relevant information regarding the TSIs used to describe the heat stress/strain experienced by humans. The equations describing each TSI were retrieved from the original publication or, in case where the original manuscript was not available, the equations were cross-referenced with multiple sources in scientific literature. Formulas having the same name but considering different environmental factors and/or using different equations for their computation were considered unique TSIs and were treated as such in the present systematic review. Data for non-English articles were extracted based on the provided English abstracts and the mathematical equations presented in the original manuscript. No professional English translation of these articles was performed. When deemed necessary, Google Translator was used to improve understanding and provide context.

**Development of a software to calculate all meteo-based thermal stress indicators**

A software titled “Thermal Stress Indicators calculator” was developed to calculate all the meteo-based TSIs using the Visual Basic programming language (Microsoft; USA). In its core, the software incorporates the assumptions and equations required for each TSI. The user can edit the assumed default
values in each case by clicking “options”. In addition, the software includes a number of features to optimize practicality and user-friendliness, including a method to estimate solar radiation using geographical and chronological data [28], as well as to adjust it for cloud cover [29].

The “Thermal Stress Indicators calculator” software can be freely downloaded using the following link: [www.famelab.gr/meteo-TSI.html](http://www.famelab.gr/meteo-TSI.html). It runs on Microsoft Windows operating systems (XP/Vista/Win7/Win10/Win11). With the use of Windows emulators, the software can also run on Linux and Apple Macintosh platforms. The calculated data are provided in numeric format and can be exported in *.csv format.

We assessed the criterion-related validity, construct validity, and reliability of the “Thermal Stress Indicators calculator” to compute all the identified meteo-based TSIs. Criterion-related validity refers to comparing a measurement against some known quantity, while construct validity refers to the property of a measurement being associated with variables assessing the same (or similar) characteristics. Reliability in this case assessed the degree to which the calculated TSIs were consistent from one test to the next.

**Qualitative assessment of meteo-based TSIs for work in hot environments**

Part of our analysis focused on TSIs targeting working environments and different population groups to support research on this front and the development of effective heat mitigation measures. We used the following criteria to determine whether a TSI can assess the heat stress/strain in working people:

1. **Evaluation of the activity level** (i.e., whether a TSI was developed for “active” or “passive” metabolic state) [19]. Indicators developed only for passive conditions were considered non-eligible for assessing the heat stress/strain experienced by workers in occupational settings.

2. **Evaluation of environmental conditions** to ensure that a TSI applies to environments typically found in outdoor and indoor occupational settings.

a. **Evaluation of the operating temperature range** [parameters used: air temperature, globe temperature, operative temperature, wet bulb temperature, and Wet-Bulb Globe Temperature (WBGT)] identified for each TSI: A recent systematic review identified that 62 out of 88 studies that examined health-related outcomes due to occupational heat strain reported WBGT ranges of 19.3 to 52.0°C [2]. This WBGT range was translated to air temperature by using a published method to calculate WBGT from meteorological data [30]. The environmental data we utilized were 600 W/m² solar radiation, 50 % relative humidity, and 0.5 m/s wind speed, while keeping constant WBGT values (i.e., 19.3 and 52.0°C) and solving for air temperature. It is important to note that an infinite range of environmental conditions lead to the same WBGT value. Here we chose to use environmental data which characterize the heat stress experienced by outdoor workers. The computed air temperature range was 18.2 to 56.5°C. The same environmental data were employed for the computation of the remaining parameters used to describe the operating temperature range of some thermal indices [globe temperature (32.5 to 72.0°C), operative temperature (34.8 to 72.0°C), and wet bulb temperature (15.7 to 45.7°C)]. Thereafter, these data were used to calculate the percentage of overlap between the identified operating temperature range of each TSI and the temperature ranges used in the literature for examining health-related outcomes in occupational settings. Indicators covering less than two-thirds (66.6%) of the temperature range found in the literature were considered non-eligible for assessing the heat stress and strain experienced by workers in occupational settings.

b. **Evaluation of the operating wind speed range** identified for each TSI: Indicators with an operative wind speed range lower
than half (50%) of the wind speed range that the United States of America Occupational Safety and Health Administration (OSHA) considers safe for work and it is not immediately dangerous for life or health. Specifically, we assumed that typical wind speed in occupational settings ranges between negligible (0 m/s) and high (17.9 m/s) air flow conditions also defined as “high wind” according to OSHA [31]. It is important to note that the majority of outdoor workplaces are characterized by much lower wind speed than the extreme value of 17.9 m/s, while working indoors involves wind speeds ranging between negligible to very low air flows (i.e., 0 to 1 m/s) [32].

(3) Evaluation of the environmental parameters used by each TSI: Indicators incorporating less than two (2) environmental parameters were considered non-eligible for assessing the heat stress/strain experienced by workers in occupational settings.

Results

A total of 228 publications from the search algorithms met the eligibility criteria and were considered in the analysis (Table S1), while 664 publications were excluded as non-eligible (Table S2). Full manuscripts written in 11 languages (English: 178; Iranian: 7; Chinese: 6; French: 3; Spanish: 3; Russian: 2; Korean: 2; Japanese: 1; Polish: 1; Italian: 1; and Czech: 1) were retrieved for 89.9% (205/228; Table S1) of the identified eligible publications. An additional set of 18 publications found in the reference lists of the eligible articles as well as 14 publications (e.g., standards, reports from reputable organizations, books) were manually included in the analysis (Table S3). Overall, 237 unique publications were included in the current systematic review as shown in the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flowchart (Figure 1). The associated PRISMA checklist is presented in the Appendix.

The sensitivity analysis conducted demonstrated that the search algorithm captured 87.7% of all the known eligible articles that were included in the systematic review (i.e., articles from the search algorithm + articles added from detailed reference list search + articles added manually; Figure 1).

In the following subsections, we adopt established recommendations [27] to ensure a high quality of evidence synthesis in this systematic review, in a way that brings together research evidence to give an overall picture of the existing knowledge that can be used to inform policy and decisions.

Overview of thermal stress indicator literature

The majority of the analysed studies aimed to compare the technical characteristics of different TSIs – for instance, the response of different TSIs as one or more environmental, physiological, clothing, or behavioural parameters changes. In most cases, the technical characteristics for each TSI were retrieved from the original publication cited in the eligible articles (Table S4). Analysis of the sources of funding for the eligible studies, as an indicator of bias, demonstrated that 65.4% of studies received no funding, 29.1% of studies were funded by government/public organizations, 4.2% of studies were funded by private/industry stakeholders, and 1.3% of studies received funding from governmental organizations and the industry.

In total, the average score in the EPPI tool across all studies was $3.8 \pm 0.6$ (mean $\pm$ sd), indicating high strength of evidence (0–1: low; 2: medium; 3–5: high). Of the 237 unique studies included in the current systematic review, 222 received a “high” score, eight studies were classified as “medium” and seven were given an overall score of “low”. More specifically, 221 studies scored “high” in the “trustworthiness” item, while five studies were classified as “medium” and 11 studies were classified as “low” in this item. With regards to the “appropriateness” item, 22 studies scored “high”, 133 studies were classified as “medium” and 57 were classified as “low”. Finally, all 237 studies were classified as “high” in the “relevance” item of the EPPI tool.
In total, our search identified 340 unique TSIs developed between 200 BC and 2019 AD. Of these, 153 TSIs required data for some or all the meteorological parameters in addition to other detailed information (Table 1), while 187 utilize only meteorological data (Table 2). The majority (123) of these meteo-based TSIs were identified through the algorithmic database search, while 64 were identified through publications found in the reference lists of the eligible studies and the manually added articles (Table S4).

The meteo-based TSIs identified in the current systematic review are widely applicable because their calculation requires freely-available weather data and their development considered the characteristics of the local populations across 35 countries in all six geographical regions (Africa, eastern Mediterranean, Europe, America, south-east Asia, and western Pacific; Figure 2). 75.4% percent of these TSIs assess heat and/or physiological strain using air temperature and humidity, while 41.2% utilize all four...
Figure 2. Countries (Alpha-3 code) in which the 187 meteo-based thermal stress indicators originated from, based on the affiliation of the first author. Bars represent the number of indicators developed in each country. Detailed information regarding the number of thermal stress indicators developed by each country can be found in www.famelab.gr/meteo-TSI.html.

Figure 3. Development of the 187 thermal stress indicators (TSIs) that use only meteorological data. Bars represent the number of indices developed in chronological groups of 20 years. The black line indicates the cumulative number of TSIs developed during the last 120 years.
meteorological parameters (Figure 2). The first meteo-based TSI identified in our search was developed in 1905 while the last one was published in 2018 (Figure 3).

**Preliminary synthesis**

While tabulating the data, it became apparent that there were some discrepancies between the information presented in the eligible articles and those in the cited original papers. Specifically, our analysis identified nine common misconceptions regarding the use of meteo-based TSIs which are listed below with references to Table S4:

1. More than one equation, providing different results, has been reported under the same TSI name (e.g., TSI #6-16, #26-49, #81-85, #88-90, #107-110, #133-135).
2. Location-specific equations, providing different results, are given for the same TSI (e.g., TSIs #164-165).
3. Original papers provide more than one equation to calculate the same TSI (e.g., TSIs #158-159, #168-169).
4. The same equation, providing identical results, has been reported under different TSI names (e.g., TSI #176).
5. Nomograms have been partially converted to equations under the same TSI name (e.g., TSI #50-51).
6. TSIs were developed to predict the reading of specialized instruments (e.g., the Wet Bulb Thermometer) under the same TSI name based on meteorological data (e.g., TSIs #172-174).
7. Mistakes in a TSI equation are carried over in subsequent publications (e.g., TSI #56-57).
8. Reference to TSIs that do not appear in the original article (e.g., #73-75).
9. Erroneous citation of the original paper introducing a TSI (e.g., #112, #133).

All the above discrepancies were addressed upon reviewing the original article, and/or contacting the eligible article authors. To harmonize knowledge for each individual TSI identified in our search, we provide the equation, operating range, interpretation categories, as well as the physical activity mode (active or passive) that it has been designed for in Tables 5 & S5.

We found that almost all meteo-based TSIs incorporate air temperature (98.4%), about three quarters of them incorporate humidity.

![Figure 4](image-url)  
*Figure 4. Usage of different meteorological parameters in the 187 meteorology-based thermal stress indicators (TSIs) (bars) and complexity (pie chart; i.e., number of meteorological parameters utilized by these TSIs).*
Table 3. Recommended assumptions in the calculation the meteo-based 187 TSIs for practicality or when no data are available.

| ID | Assumption                                                                 | Value                  | Assumption                  |
|----|---------------------------------------------------------------------------|------------------------|-----------------------------|
| 1  | We calculated wind at altitude using a friction coefficient for “high crops, hedges and shrubs”. [166] | $\alpha = 0.20$       |                             |
| 2  | We set a standard value for workers’ body stature. [167]                  | Height = 1.80 m        |                             |
| 3  | We set a standard value for workers’ body mass. [168]                   | Weight = 75 kg         |                             |
| 4  | We assume a comfortable barometric pressure (sea level). [169]          | $P = 1016$ hPa         |                             |
| 5  | Mean skin temperature was estimated as a function of air temperature. [112] | $T_{sk} = f(Ta)$       |                             |
| 6  | We set a constant emissivity of the body / clothing. [167]              | $\varepsilon = 0.97$  |                             |
| 7  | We set a constant effective radiating area of the body (standing posture). [167] | $A_r = 0.77$          |                             |
| 8  | We assume a constant core temperature. This can be modified as needed.  | $T_{cr} = 37.3$        |                             |
| 9  | Clothing insulation was estimated as a function of air temperature.      | $I_{cl} = f(Ta)$       |                             |

Note: Assumptions were not adopted for the computation of all TSIs

(76.8 %) and wind (71.9 %), while less than half incorporate sunlight (44.9 %) (Table 2; Figure 4). Even fewer TSIs incorporate all four environmental parameters (Table 2). The lists of the assumptions (Table 3), abbreviations (Table 4), equations (Table 5), as well as the limits and categories (Table S5) required for the calculation of each of the 187 meteo-based indicators are presented below.

For our sub-analysis regarding occupational settings, each meteo-based TSI was scored based on whether it satisfied or not each of the qualitative criteria described in the Methodology section. The results showed that 33.0 % (61/187) of the identified TSIs fulfilled all qualitative criteria for assessing the heat stress and strain experienced by workers in occupational settings (Table S6).

Validity and reliability of the thermal stress indicators calculator

The criterion-related validity of the “Thermal Stress Indicators calculator” to compute the meteo-based TSIs was assessed for all 187 TSIs by comparing the calculated values from the developed software against the identified limits and categories for each TSI. Specifically, we tested whether a TSI value can be considered cold, neutral, or hot after testing cold, neutral, and hot environments, respectively.

The above analyses returned perfect (i.e., null differences between our software and the 13 available calculators) criterion-related validity, construct validity, and reliability for the “Thermal Stress Indicators calculator” under environmental consistent conditions. Moreover, we confirmed that the software returns null value for a TSI when the provided meteorological data fall outside its operating range.

It is important to note that this criterion-related validation does not examine the predictive (the extent to which TSIs predict the physiological strain experienced during heat stress by someone) and concurrent (the extent to which TSIs correlate with the physiological strain experienced during heat stress by someone) validities of the identified TSIs, but, instead, it was performed to ensure that the developed software provides valid and reliable output.

Discussion

Our systematic search identified 340 unique TSIs that have been developed between 200 BC and 2019 AD to assess the heat stress and physiological strain experienced by people performing various activities over a wide operating range and conditions. Of these TSIs, 153 represent nomograms,
Table 4 | List of abbreviations used for the computation of the 187 meteo-based thermal stress indicators.

| ID | Variable | Abbreviation | Formula / Value | Assumption/s |
|----|----------|--------------|----------------|-------------|
| 1  | Air Temperature (undefined unit) | Ta | Input value |  |
| 2  | Relative Humidity (%) | RH | Input Value |  |
| 3  | Air Velocity (undefined unit) | WS | Input Value |  |
| 4  | Solar Radiation (undefined unit) | SR | Input Value |  |
| 5  | Wet Bulb Globe Temperature (undefined unit) [30] | WBGT | TSI # 171 |  |
| 6  | Vapor Pressure (undefined unit) [168] | VP | \(= 6.11 \times \left(10 \times \left(7.5 \times Td^{0.6} / (237.3 + Td^{0.6})\right)\right)\) \(\Rightarrow Td = TSI \# 52\) |  |
| 7  | Barometric Pressure (hPa) | P | \(= 1016\) |  |
| 8  | Mean Radiant Temperature (undefined unit) | Tmrt | TSI # 97 |  |
| 9  | Absolute Humidity (g/kg) [169], [170] | h | \(= (6.112 \times \exp(17.56 \times Ta^{0.6}) / (Ta^{0.6} + 243.5)) \times RH \times 2.1674 / ((273.15 + Ta^{0.6}) \times 1.204 \times 10^6)\) |  |
| 10 | Wet Bulb Temperature [97] (undefined unit) | Tw | TSI # 172 |  |
| 11 | Radiant heat exchange coefficient (w/m²) | Hr | \(= 4 \times \varepsilon \times \sigma \times A / ADu \times \left(2.723 + \left(Tsk^{0.6} + Tmrt^{0.6}\right) / 2\right) \wedge 3)\) |  |
| 12 | Mean Skin Temperature [112] | Tsk | TSI # 98 |  |
| 13 | Friction coefficient (unitless) | \(\alpha\) | \(= 0.20\) |  |
| 14 | Emissivity of skin (unitless) | \(\varepsilon\) | \(= 0.97\) |  |
| 15 | Universal radiation constant (w/m²K⁰) [171] | \(\sigma\) | \(= (5.67 \times 10^{-8})\) |  |
| 16 | Fraction of the body affected by radiation | \(Ar\) | \(= 0.77\) |  |
| 17 | Globe Temperature (undefined unit) [97] | Tg | TSI # 78 |  |
| 18 | Latent heat released by water vaporization (cal/g) [172] | r | \(= 585\) |  |
| 19 | Real mixture ratio (g/kg) [172] | w | \(= RH \times \left(6.112 \times 10 \times \left(7.5 \times Ta^{0.6} / (237.7 + Ta^{0.6})\right)\right) / P \times 100\) |  |
| 20 | Specific heat of air at constant pressure (cal/Kg/C⁰) [172] | \(Cp\) | \(= 0.24\) |  |
| 21 | Specific heat of water (cal/C⁰/g) [172] | \(Cw\) | \(= 1\) |  |
| 22 | Body tissue thermal resistance (kcal/h/°C/m²) | \(Rb\) | \(= 0.08\) |  |
| 23 | Convection heat transfer coefficient (w/m²) | \(Hc\) | \(\Rightarrow if WS < 1 Then = 8.7 \times WS^{0.6} \times 0.6\) \(\Rightarrow if WS >= 1 Then = 3.5 \times WS^{0.6}\) |  |
| 24 | Psychrometric wet bulb (undefined unit) | Tpw | TSI # 118 |  |
| 25 | Metabolic rate (w/m²) | Met | low intensity = 100; moderate intensity = 165; and high intensity = 230 |  |
| 26 | Body surface area (m²) [173] | ADu | \(= 0.202 \times \text{height}^{0.725} \times \text{weight}^{0.425}\) |  |
| 27 | Clothing insulation (clo) | \(IcI\) | \(IcI = 1.691 - 0.0436 \times Ta^{0.6}\) \(\Rightarrow if Ta^{0.6} < -30 Then = 3\) \(\Rightarrow if Ta^{0.6} > 25 Then = 0.6\) |  |
| 28 | Saturated vapor pressure (undefined unit) | SVP | \(= \left(2.7153005 \times \log(Ta^{0.6}) - 2836.5744 \times Ta^{0.6} - (2 - 6028.076559 / Ta^{0.6} + 19.54263612 - 0.02737830188 \times Ta^{0.6} + 0.000016261698 \times Ta^{0.6} + 2 \times 7.0229056E-10 \times Ta^{0.6} - 3 \times 1.868009E-13 \times Ta^{0.6} + 4 \right) \times 0.01\) |  |
| 29 | Core temperature (°C) | Tcr | \(= 37.3\) |  |

Notes: “undefined unit” indicates that the variable is not characterized by the same unit for all TSI-<sub>subscript</sub> condition which characterizes the variable (e.g., \(V_{10m}\) = air velocity at a height of 10 m), [superscript] unit of the variable:

- °C = degrees Celsius
- °F = degrees Fahrenheit
- hPa = hectopascal
- kPa = kilopascal
- mmHg = millimeter of mercury

(Continued)
specific instruments, and complex models, while the remaining 187 TSIs are formulas that can be mathematically calculated utilizing only meteorological data (air temperature, relative humidity, wind speed, and solar radiation). We focused primarily on the TSIs requiring only meteorological data, as we aimed to enhance the quality and relevance of big-data analytics used in climate services to inform the public of possible health risks during physical activity in warm – hot conditions. To foster popularization of the meteo-based TSIs, we developed a valid and reliable software to calculate them, which can be freely downloaded.

The identified TSIs included unique and sometimes abbreviated names in multiple languages across multiple sources. For instance, TSIs such as the Actual Sensation Vote (#2), Belding-Hatch Index (#18), Dry Kata Cooling (#60), Humisery (#87), Humiture (#88), Robaa’s Index (#126), Universal Thermal Climate Index (#167), and Wet-Bulb Globe Temperature (#170), are some of the unique names that we had to identify. It is nearly impossible for a search algorithm to include all the possible unique names and abbreviations, especially since these are unknown at the time of the search. This may be the reason why the only systematic review [23] on this topic identified just 32 eligible articles. Together with the available narrative reviews on TSIs [18–22], a total of 165 TSIs had been identified in previous searches. We were able to expand this and identify 340 unique TSIs by searching for articles introducing individual TSIs as well as those incorporating and comparing multiple TSIs. For instance, our searches included the term “indices”, targeting papers involving multiple TSIs, as well as the previous systematic reviews [23] on the topic that used the term “index”. We performed an exhaustive search in the reference lists of the articles identified through our search algorithm. Our analysis revealed that this search algorithm was 87.7% sensitive, indicating that our search has likely missed many TSIs that have been developed across the centuries in different languages and publication modalities. We did not place language or publication year limits, yet our searchers were done mostly in databases including English literature. Also, we only searched journal publications, but grey literature likely presents with many additional TSIs.

We did not detect significant evidence for bias. Nearly all (94.5%) of the analysed studies either received no funding or were supported by government/public funding. Also, 94% of the studies were classified as “high” in the EPPI tool which assessed the strength of the evidence presented. Nevertheless, as indicated in the Results section, our analysis identified nine common misconceptions regarding the use of meteo-based TSIs. We made every effort to harmonize knowledge regarding the adoption and use of each individual TSI identified in our search, providing the equation (Table 5), operating range, interpretation categories, as well as the physical activity mode (active or passive) that it has been designed for (Table S5). Critical evaluation of these operational characteristics of the 187 meteo-based TSIs showed that 127 TSIs were developed for people who are physically active and 61 those are eligible for use in occupational settings. The classification of occupational TSIs was compiled after
Table 5 Computation of the 187 meteo-based thermal stress indicators in BASIC programming language ($^\wedge$ = power notation and $\text{sqr}$ = square root).

| ID | Thermal Stress Indicator | Formula/s | Assumption/s |
|----|--------------------------|-----------|--------------|
| 1  | Accepted Level of Physical Activity (Blazejczyk; 2010) | $(90 - 22.4 - 0.25 \times ((5 \times Ta^{(C)}) + (2.66 \times VP^{(mH)}))) / 0.18$ | $\Rightarrow$ |
| 2  | Actual Sensation Vote (Nikolopoulou; 2003) | $0.061 \times Ta^{(C)} + 0.091 \times TGA - 0.324 \times WS^{[m]} + 0.003 \times RH - 1.455$ | $\Rightarrow$ $\text{TGA} = Ta^{(C)} - Ta^{(C)}$ |
| 3  | Actual Sensation Vote (Nikolopoulou; 2004) | $0.034 \times Ta^{(C)} + 0.0001 \times SR^{[m;2]} - 0.086 \times WS^{[m;2]} - 0.001 \times RH - 0.412$ | $\Rightarrow$ |
| 4  | Actual Sensation Vote (Europe) (Nikolopoulou; 2004) | $0.049 \times Ta^{(C)} + 0.001 \times SR^{[m;2]} - 0.051 \times WS^{[m;2]} - 0.014 \times RH - 2.079$ | $\Rightarrow$ |
| 5  | Air Enthalpy (Boer; 1964) | $0.24 \times (Tw^{(C)} + (1555 / P^{[Pa]}) + SPF^{[Pa]})$ | $\Rightarrow$ |
| 6  | Apparent Temperature (Almeida; 2010) | $-2.653 + (0.994 \times Ta^{(C)}) + (0.0153 \times Td^{(C)}) \times 2$ | $\Rightarrow$ |
| 7  | Apparent Temperature (Arnoldy; 1962) | $= Ta^{(C)} - (2 \times WS^{[m;2]})$ | $\Rightarrow$ |
| 8  | Apparent Temperature (Fischer; 2010) | $= c1 + (c2 \times Ta^{(C)}) + (c3 \times (Ta^{(C)}) \times 2)) + (RH \times (c4 + (c5 \times Ta^{(C)}) + (c6 \times (Ta^{(C)} \times 2)))$ | $c1 = -8.7847; c2 = 1.6114; c3 = -0.012308; c4 = 2.3385; c5 = -0.14612; c6 = 2.2117 \times (10 \times -3); c7 = -0.016425; c8 = 7.2546 \times (10 \times -4); \text{and} \ c9 = 3.582 \times (10 \times -6)$ |
| 9  | Apparent Temperature (Kalkstein; 1986) | $= -2.653 + (0.994 \times Ta^{(C)}) + (0.368 \times Td^{(C)}) \times 2$ | $\Rightarrow$ Errorneous reported by Kwon;1990:74 |
| 10 | Apparent Temperature (Smoyer-Tomic; 2001) | $= -2.719 + 0.994 \times Ta^{(C)} + 0.016 \times Td^{(C)} \times 2$ | $\Rightarrow$ If $Ta^{(C)} < 25$ Then $= Ta^{(C)}$ |
| 11 | Apparent Temperature (indoor) (Steadman; 1994) | $(0.89 \times Ta^{(C)}) + (3.82 \times VP^{[Pa]}) - 2.56$ | $\Rightarrow$ |
| 12 | Apparent Temperature (indoor) (Steadman; 1984) | $= -1.3 + 0.92 \times Ta^{(C)} + 2.2 \times VP^{[Pa]}$ | $\Rightarrow$ |
| 13 | Apparent Temperature (shade) (Steadman; 1984) | $= -2.7 + 1.04 \times Ta^{(C)} + 2 \times VP^{[Pa]} - 0.65 \times WS_{10m}^{[m/s]}$ | $\Rightarrow$ |
| 14 | Apparent Temperature (shade) (Steadman; 1994) | $= Ta^{(C)} + (3.3 \times VP^{[Pa]}) - (0.7 \times WS_{10m}^{[m/s]}) - 4$ | $\Rightarrow$ |
| 15 | Apparent Temperature (sun) (Steadman; 1984) | $= -1.8 + 1.07 \times Ta^{(C)} + 2.4 \times VP - 0.92 \times WS + 0.044 \times Qg$ | $\Rightarrow$ $Qg = Hr \times (Tmrt^{(C)} - Ta^{(C)})$ |
| 16 | Apparent Temperature (sun) (Steadman; 1994) | $= Ta^{(C)} + (3.48 \times VP^{[Pa]}) - (0.7 \times WS_{10m}^{[m/s]}) + (0.7 \times Qg / (WS_{10m}^{[m/s]} + 10)) - 4.25 | $\Rightarrow$ $Qg = Hr \times (Tmrt^{(C)} - Ta^{(C)})$ |
| 17 | Approximated Subjective Temperature (Auliciems; 2007) | $= Tg^{(C)} + (2.8 \times (1 - Sqr(10 \times WS^{[m/s]}))) / (0.44 + 0.56 \times Sqr(10 \times WS^{[m/s]}))$ | $\Rightarrow$ |
| 18 | Belding-Hatch Index (Belding; 1955) | $= E / \text{Emax}$ | $\Rightarrow$ $E = 110 + 11.6 \times (1 + 1.3 \times (WS^{[m/s]} \times 0.5)) \times (Tg^{(C)} - 35)$ |
| 19 | Belgian Effective Temperature (Bidlot; 1947) | $= 0.9 \times Tw^{(C)} + 0.1 \times Ta^{(C)}$ | $\Rightarrow$ $\text{Emax} = 25 \times (WS^{[m/s]} \times 0.4) \times (42 - VP^{[mmHg]})$ |
| 20 | Bioclimatic Index of Severity (Belkin; 1992) | $= (Ti \times (P - 266)) \times (1 - (0.02 \times WS)) / (Ri \times S \times 75)$ | $\Rightarrow$ $\text{Temperature coefficient (Ti)}: \Rightarrow$ If $Ta^{(C)} < -90 \text{ Or } Ta^{(C)} > 60 \text{ Then } Ti = 0$ |
| 21 | Biologically Active Temperature (Tsitsenkov; 1971) | $= 0.8 \times EET + 9$ | $\Rightarrow$ $\text{EET} = Ta^{(C)} \times (1 - 0.0003 \times (100 - RH)) - (0.385 \times WS_{2m}^{[m/s]} \times 0.59 \times ((36.6 - Ta^{(C)}) + 0.622 \times WS_{2m}^{[m/s]} \times 0.0008) + 0.0008) \times (36.6 - Ta^{(C)})$ |}
Table 5 (Continued).

| ID | Thermal Stress Indicator (Rodriguez; 1985) | Formula/s | Assumption/s |
|----|------------------------------------------|-----------|--------------|
| 22 | Biometeorological Comfort Index (Rodriguez; 1985) | \[ (T_a + Tw^{\text{CC}}) / 2 \] \[ V_{\text{km/day}} = 150 \text{ km } / \text{ day} \text{ (air speed relative to a person while walking in calm air)} \] \[ T_{c_r}^{\text{CC}} = 37.3 \] \[ n = 0.6 * \exp(-0.01 * T_a^{\text{CC}}) \text{ (cited by Garcia;1994 [175])} \] \[ n = 0.6 * \exp(-0.01 * T_a^{\text{CC}}) \] \[ V_{\text{km/day}} > W_{\text{km/day}} \text{ Then } T_a = T_{c_r}^{\text{CC}} \] \[ V_{\text{km/day}} < W_{\text{km/day}} \text{ Then } T_a = T_{c_r}^{\text{CC}} \] \[ ((0.9311 + 0.0295 * (W_s \wedge n)) / (0.0411 + 0.0295 * (V_{\text{km/day}} \wedge n))) \] | (Continued) |

(Continued)
| ID | Thermal Stress Indicator | Formula/s | Assumption/s |
|----|--------------------------|-----------|--------------|
| 59 | Draught Risk Index (Fanger; 1987) | \( (3.143 \times (34 - Ta^{(TC)}) + (WS^{(m/s)} - 0.05) \times 0.6233) + (0.3696 \times WS^{(m/s)} \times Tu \times (34 - Ta^{(TC)}) \times WS^{(m/s)} - 0.05) \times 0.6233 \) | The parameter Tu can simply be defined as the ratio between standard deviation of instantaneous air speeds (Vsd) and the mean air speed (V), both of which are derived from anemometry, having time-constants of 1/10 S or faster [176] |
| 60 | Dry Kata Cooling (Maloney; 2011) | If \( WS^{(m/s)} = 0 \) Then \( Tu = 0.27 \times (36.5 - Ta^{(TC)}) \times 1.06 \) If \( WS^{(m/s)} > 0 \) And \( WS^{(m/s)} < 1 \) Then \( Tu = 0.2 + 0.4 \times (WS^{(m/s)} - 0.5) \times (36.5 - Ta^{(TC)}) \times 1.06 \) If \( WS^{(m/s)} \geq 1 \) Then \( Tu = 0.13 + 0.47 \times (WS^{(m/s)} - 0.5) \times (36.5 - Ta^{(TC)}) \times 1.06 \) | |
| 61 | Effective Radiant Field (Gagge; 1967) | \( Hr^{(TC)} = (1.97483 \times Ta^{(TC)} - 0.75) \times (100 - RH) \) | |
| 62 | Effective Radiant Field (Nishi; 1981) | \( 0.76 \times (6.1 + 13.6 \times Sqr(SWS^{(m/s)})) \times (T_{g}^{(TC)} - Ta^{(TC)}) \) | |
| 63 | Effective Temperature (Houghton; 1923) | \( Ta^{(TC)} = 0.4 \times (Ta_{n}^{(TC)} - 10) \times (1 - (RH / 100)) \) | |
| 64 | Effective Temperature (Missenard; 1933) | \( Ta^{(TC)} = (37 - (33 - Ta^{(TC)}) / (0.68 - 0.0014) \times RH + (1 / (1.76 + (1.4 \times (WS^{(m/s)} - 0.75)))) - 0.29 \times Ta^{(TC)} + (1 - (0.01 \times RH)) \) | |
| 65 | Environmental Stress Index (Moran; 2001) | \( (0.63 \times Ta^{(TC)} - 0.03 \times RH) + (0.002 \times SR^{(m/m2)}) + (0.0054 \times (Ta^{(TC)} - RH)) - (0.073 \times (0.1 \times SR^{(m/m2)}) \times -1) \) | |
| 66 | Equatorial Comfort Index (Webb; 1969) | \( T_{w}^{(TC)} = 0.447 \times (T_{a}^{(TC)} - T_{w}^{(TC)}) - 0.231 \times (WS^{(m/min)}) \times 0.5 \) | |
| 67 | Equivalent Effective Temperature (Aizenshtat; 1974) | \( Ta^{(TC)} = (1 - 0.003 \times (100 - RH)) \times 0.385 \times (WS^{(m/s)} - 0.59) \times (36.6 - Ta^{(TC)}) + 0.662 \times (WS^{(m/s}) - 1) \times (0.0015 \times WS^{(m/s)} + 0.0008 \times (36.6 - Ta^{(TC)}) - 0.0167) \times (100 - RH) \) | |
| 68 | Equivalent Effective Temperature (Aizenshtat; 1982) | \( Ta^{(TC)} = (1 - 0.003 \times (100 - RH)) \times 0.385 \times WS^{(m/s)} \times 0.59 \times (36.6 - Ta^{(TC)}) + 0.662 \times (WS^{(m/s)} - 1) \times (0.0015 \times WS^{(m/s)} + 0.0008 \times (36.6 - Ta^{(TC)}) - 0.0167) \times (100 - RH) \) | |
| 69 | Equivalent Temperature (Bedford; 1936) | \( (0.522 \times Ta^{(TC)} + 0.478 \times T_{mrt}^{(TC)} - 0.0147 \times Sqr(SWS^{(m/min)}) \times (100 - Ta^{(TC)}) \) | |
| 70 | Equivalent Temperature (Brundl; 1984) | \( Ta^{(TC)} = w \times (r - 2.326 \times Ta^{(TC)}) / (cp + w \times cw) \) | |
| 71 | Equivalent Warmth (Bedford; 1936) | \( 9.979 \times x - 0.1495 \times (x - 2) - 2.89 \) | |
| 72 | Exposed Skin Temperature (Brauner; 1995) | \( T_{c}^{(TC)} = (T_{c}^{(TC)} - Q_{s} \times Rh) \) | |
| 73 | Facial Skin Temperature (Cheek) (Adamenko; 1972) | \( Q_{s} = (T_{c}^{(TC)} - Ta^{(TC)}) / (Rh + (1 / Hc)) \) | |
| 74 | Facial Skin Temperature (Ear Lobe) (Adamenko; 1972) | \( 0.4 \times Ta^{(TC)} - 3.3 \times Sqr(SWS^{(m/s)}) + 19 \) | |
| 75 | Facial Skin Temperature (Nose) (Adamenko; 1972) | \( 0.4 \times Ta^{(TC)} - 3.3 \times Sqr(SWS^{(m/s)}) + 17 \) | |
| 76 | Fighter Index of Thermal Stress (Direct Sunlight) (Stribyle; 1978) | \( (0.8281 \times T_{p}^{(TC)} + 0.3549 \times Ta^{(TC)}) + 5.08 \) | |
| 77 | Fighter Index of Thermal Stress (Moderate Overcast) (Stribyle; 1978) | \( (0.8281 \times T_{p}^{(TC)} + 0.3549 \times Ta^{(TC)}) + 2.23 \) | |
| 78 | Globe Temperature (Liljegren; 2008) | Solve by iteration method: \( f(Ta, RH, SR, WS) \) | |
| 79 | Heart Rate (Fuller; 1966) | \( 0.029 \times Met(BUhr) + 0.7 \times (Ta^{(TC)} + Vol(m/min)) \) | |
| 80 | Heart Rate Safe limit (LaFleur; 1971) | \( 0.2064 - 0.63 \times (Ta^{(TC)} + Vol(m/min)) \times 10 \) | |
| 81 | Heat Index (Blazejczyk; 2012) | \( -8.784695 + 1.61139411 \times Ta^{(TC)} + 2.338549 \times RH - 0.14611605 \times Ta^{(TC)} \times RH - (1.2308094 \times (10 \times -2)) \times (Ta^{(TC)} \times 2) - (1.6424828 \times (10 \times -1)) \times (RH \times 2) + (2.211732 \times (10 \times -3)) \times (Ta^{(TC)} \times 2) \times RH + (7.2546 \times (10 \times -4) \times Ta^{(TC)} \times RH ^{2} - (3.582 \times (10 \times -6)) \times (Ta^{(TC)} \times 2) \times (RH \times 2) \) | |
| 82 | Heat Index (Stull; 2000) | \( 16.923 + (1.85212 \times 10 \times -1) \times Ta^{(TC)} + (5.739411 \times RH) - (1.00254 \times 10 \times -1) \times Ta^{(TC)} \times RH + (9.41695 \times 10 \times -3) \times Ta^{(TC)} \times 2) + (7.28898 \times 10 \times -3) \times RH \times 2) + (3.45372 \times 10 \times -4) \times Ta^{(TC)} \times 2 \times RH - (1.84971 \times 10 \times -4) \times Ta^{(TC)} \times RH ^{2} + (1.02102 \times 10 \times -5) \times Ta^{(TC)} \times 2 \times RH ^{2}) - (3.8466 \times 10 \times -5) \times Ta^{(TC)} \times RH ^{3} + (2.91583 \times 10 \times -5) \times RH ^{3} + (1.42721 \times 10 \times -6) \times Ta^{(TC)} \times 3 \times RH ^{3} + (1.97483 \times 10 \times -7) \times Ta^{(TC)} \times RH ^{3} \times 2.2 \times (1.84299 \times 10 \times -8) \times Ta^{(TC)} \times 3 \times RH ^{3} \times 3 \times RH ^{3} \times 3 \times RH ^{3} \) | | (Continued) |
| ID | Thermal Stress Indicator | Formula/s | Assumption/s |
|----|--------------------------|-----------|--------------|
| 83 | Heat Index (National Oceanic and Atmospheric Administration; 2014) | If Ta[°F] <= 40 Then = Ta[°F] ElseIf Ta[°F] < 80 Then = A ElseIf (RH <= 13) = True And (80 <= Ta[°F] And Ta[°F] <= 112) = True Then = B + ((13 - RH) / 4) * Sqr((17 - Abs(Ta[°F] - 95)) / 17) ElseIf (RH > 85) = True And (80 <= Ta[°F] And Ta[°F] <= 87) = True Then = B + ((RH - 85) / 10) * ((87 - Ta[°F]) / 5) Else = B EndIf ⇒ A = 0.5 * (Ta[°F] + 61 + (Ta[°F] - 68) * 1.2) + (RH * 0.994) ⇒ B = -42.379 + 2.04901523 * Ta[°F] + 10.14333127 * RH - 0.22475541 * Ta[°F] + RH * 0.00683783 * Ta[°F] + 0.05481717 * RH * RH + 0.00085282 * Ta[°F] + RH * RH - 0.00000199 * Ta[°F] + Ta[°F] + RH * RH * RH
| 84 | Heat Index (Patricola; 2010) | = -42.4 + 2.05 * Ta[°F] + 10.1 * RH - 0.225 * (Ta[°F] + RH) - 6.74 * (10 - 3) * (Ta[°F] + 2) - 5.48 * (10 - 2) * (RH + 2) + 1.23 * (10 - 3) * (Ta[°F] + 2) * RH + 8.53 * (10 - 4) * (Ta[°F] + RH - 2) - 1.99 * (10 - 6) * (Ta[°F] + 2) * RH * 2 * RH + 2 + RH <= 80 Or RH <= 40 Then = Ta[°F]
| 85 | Heat Index (Rothfusz; 1990) | = -42.379 + 2.04901523 * Ta[°F] + 10.14333127 * RH - 0.22475541 * Ta[°F] + RH - 0.00683783 * Ta[°F] + 0.05481717 * RH * RH + 0.00085282 * Ta[°F] + RH * RH - 0.00000199 * Ta[°F] + Ta[°F] + RH * RH
| 86 | Humidex (Masterson; 1979) | = Ta[°C] + 0.5555 * (6.11 * Exp(5417.7353 * (1 / 273.15) - (1 / (Ta[°C] + 273.15))) - 10)
| 87 | Humisery (Weiss; 1982) | = Ta[°C] + Tda + WSa + Ea

Dew point adjustment (Tda): If Td[°C] <= 20 Then Tda = 0 If Round(Td[°C], 0) = 21 Then Tda = 1 If Round(Td[°C], 0) = 22 Then Tda = 3 If Round(Td[°C], 0) = 23 Then Tda = 4 If Round(Td[°C], 0) = 24 Then Tda = 6 If Round(Td[°C], 0) = 25 Then Tda = 7 If Round(Td[°C], 0) = 26 Then Tda = 9 If Round(Td[°C], 0) = 27 Then Tda = 11 If Round(Td[°C], 0) = 28 Then Tda = 13 If Round(Td[°C], 0) = 29 Then Tda = 14 If Round(Td[°C], 0) = 30 Then Tda = 16 If Round(Td[°C], 0) = 31 Then Tda = 18

Wind Speed adjustment (WSa): If WS[°C] = 0 Then WSa = 0 If Round(Ws[°C], 0) = 1 Then WSa = 0 If Round(Ws[°C], 0) = 2 Then WSa = 0 If Round(Ws[°C], 0) = 3 Then WSa = -2 If Round(Ws[°C], 0) = 4 Then WSa = -3 If Round(Ws[°C], 0) >= 5 Then WSa = -4

Elevation adjustment (Ea): If Elevation = 0 Then Ea = 0 (in the current study we assume no elevation) If Elevation = 300 Then Ea = -1 If Elevation = 600 Then Ea = -1 If Elevation = 900 Then Ea = -2 If Elevation = 1200 Then Ea = -2 If Elevation = 1500 Then Ea = -3

88 | Humiture (Lally; 1960) | = Ta[°F] + humits

humits = Vp[°C] - 10

89 | Humiture (Weiss; 1982) | = Ta[°C] + Tda[°C] - 18

90 | Humiture (Hevener; 1959) | = (Ta[°C] + Tw[°C]) / 2

91 | Humiture (Wintering, 1979) | = Ta[°F] + Wp[°C] - 21

92 | Insulation Predicted Index (Blazejczyk; 2011) | = Iltot - Ia

Iltot = 0.082 * (91.4 - (1.8 * Ta[°C] + 32)) / 2.3274 ⇒ Insulation of clothing and surrounding air layer Ia = 1 / (0.61 + 1.9 * (Wp[°C] ^ 0.5)) ⇒ Insulation of air layer

93 | Integrated Index (indoor) (Junge; 2016) | = (Ta[°C] * RH) / Sqr(Ws[°C])

(Continued)
### Table 5 (Continued).

| ID  | Thermal Stress Indicator                                      | Formula/s                                                                 | Assumption/s                  |
|-----|---------------------------------------------------------------|----------------------------------------------------------------------------|--------------------------------|
| 94  | Integrated Index (outdoor) (Junge; 2016)                    | $= \frac{(0.7 \ast Ta_C^{°C} + 0.3 \ast Ta_D^{°C} + RH)}{Sqrt(Ws_m^{m2})}$ |                                |
| 95  | Internal Comfort Temperature (Xavier; 2000)                  | $= (S + 4.8689) / 0.2107$                                                   |                                |
|     |                                                               | $\Rightarrow S = 0.219 \ast OT + 0.012 \ast RH - 0.547 \ast Ws^{m2} \cdot 5.83$ |                                |
|     |                                                               | $\Rightarrow OT = (Ta^{°C} + Tmrt^{°C}) / 2$                                |                                |
| 96  | Kata Index (Zhongpeng; 2012)                                 | If $WS < 1$ Then = $(0.35 + 0.85 \ast 3 \ast (Ws^{m2} / (1/3)) + (36.5 - Tw^{°C}))$ |                                |
|     |                                                               | If $WS > 1$ Then = $(0.1 + 1.1 \ast 3 \ast (Ws^{m2} / (1/3)) + (36.5 - Tw^{°C}))$ |                                |
| 97  | Mean Radiant Temperature (approximated) (Ramsey; 2001)       | $= ((Ta^{°C} + 273.15) \ast 4 + 1.335 \ast Ws^{m2} \ast 0.71 \ast (Ta^{°C} - Ta^{°C} / (0.95 \ast 0.15) \ast (0.4 \ast 10000000) \ast 0.25 - 273.15$ |                                |
| 98  | Mean Skin Temperature (McPherson; 1993)                      | $= 24.85 + 0.322 \ast Ta^{°C} - 0.00165 \ast (Ta^{°C} - 2)$                  |                                |
| 99  | Mediterranean Outdoor Comfort Index (Salata; 2016)           | $= -4.068 + 0.272 \ast Ws^{m2} + Ws^{m2} + 0.005 \ast RH + 0.083 \ast Tmrt^{°C} + 0.058 \ast Ta^{°C} + 0.264 \ast Ic$ |                                |
| 100 | Missenard’s Index (Missenard; 1969)                         | $= Ta^{°C} - 0.4 \ast (Ta^{°C} - 10) \ast (RH / 100)$                        |                                |
| 101 | Modified Discomfort Index (Moran; 1998)                     | $= (0.75 \ast Tw^{°C} + (0.3 \ast Ta^{°C})$                                 |                                |
| 102 | Modified Environmental Stress Index (Moran; 2003)            | $= 0.62 \ast Ta^{°C} - 0.007 \ast RH + 0.002 \ast Sr^{w/m2} + 0.0043 \ast (Ta^{°C} - RH) - 0.078 \ast (0.1 + Sr^{w/m2})$ |                                |
| 103 | Natural Wet Bulb Temperature (Maloney; 2011)                | $= 0.85 \ast Ta^{°C} + 0.17 \ast RH - 0.61 \ast Ws^{m2} + 0.5 \ast 0.016 \ast Sr^{w/m2} - 11.62$ |                                |
| 104 | Nett Radiation (Cena; 1984)                                 | $= Hu \ast (Tmrt^{°C} - Tsk^{°C})$                                           |                                |
| 105 | New Wind Chill (NOAA; 2001)                                 | $= 35.74 + 0.6215 \ast Ta^{°F} - 35.75 + (WS^{mph}) \ast 0.16 + 0.4275 \ast Ta^{°F} \ast (WS^{mph}) \ast 0.16$ |                                |
| 106 | Normal Equivalent Effective Temperature (Boksha; 1980)      | $= 0.8 \ast EET + 7$                                                         |                                |
|     |                                                               | $\Rightarrow EET = Ta^{°C} + ((0.1 - 0.003 \ast (100 - RH)) - (0.385 \ast Ws^{m2}) \ast 0.59 \ast ((36.6 - Ta^{°C}) + 0.622 \ast (Ws^{m2} - 1)) + ((0.0015 \ast Ws^{m2} + 0.0008) \ast (36.6 - Ta^{°C})$ |                                |
| 107 | Operative Temperature (ASHRAE; 2004)                        | $= (Tmrt^{°C} + Ta^{°C}) / 2$                                                |                                |
| 108 | Operative Temperature (ISO 7726:1998; 1998)                 | $= (Ta^{°C} \ast Sqrt(10 \ast Ws^{m2} + Tmrt^{°C}) / (1 + Sqrt(10 \ast Ws^{m2}))$ |                                |
| 109 | Operative Temperature (ISO 7730:1994; 1994)                 | $= A \ast Ta^{°C} + (1 - A) \ast Tmrt^{°C}$                                |                                |
|     |                                                               | $\Rightarrow A = 0.73 \ast (Ws^{m2} \sqrt{2}) \ast 0.2$                    |                                |
| 110 | Operative Temperature (Winslow; 1937)                       | $= ((Hr \ast Tmrt^{°C}) + (Hc \ast Ta^{°C})) / (Hr + Hc)$                   |                                |
| 111 | Outdoor Standard Effective Temperature (Skinner; 2001)      | $= (WBGT - 11.76) / 0.405$                                                  |                                |
| 112 | Oxford Index (Lind; 1957)                                   | $= 0.85 \ast Ta^{°C} + 0.15 \ast Ta^{°C}$                                   |                                |
| 113 | Perceived Equivalent Temperature (Monteiro; 2010)           | $= -3.777 + 0.4828 \ast Ta^{°C} + 0.5172 \ast Tmrt^{°C} + 0.0080 \ast RH - 2.3222 \ast Ws^{m2}$ |                                |
| 114 | Perceived Temperature (Linke; 1926)                        | $= Ta^{°C} - (4 \ast WS) + (12 \ast SrTa^{m2} / WS)$                        |                                |
| 115 | Predicted Percentage Dissatisfied (Xavier; 2000)            | $= 18.94 \ast (S \ast 2) - 0.24 \ast S + 24.41$                            |                                |
|     |                                                               | $\Rightarrow S = 0.219 \ast OT + 0.012 \ast RH - 0.547 \ast Ws^{m2} \cdot 5.83$ |                                |
|     |                                                               | $\Rightarrow OT = (Ta^{°C} + Tmrt^{°C}) / 2$                                |                                |
|     |                                                               | $\Rightarrow$ If $S > 2 \ OR \ S < -2$ then $= 100$                         |                                |
| 116 | Predicted Thermal Sensation Vote (Cheng; 2008)              | $= 0.1859 \ast Ta^{°C} - 0.7754 \ast Ws^{m2} + 0.0028 \ast Sr^{w/m2} + 0.1953 \ast h - 8.23$ |                                |
| 117 | Psychrometric Wet Bulb Temperature (Malchaire; 1976)        | $= ((0.16 \ast (Ta^{°C} - Ta^{°C}) + 0.8) / 200) \ast (560 - 2 \ast RH - 5 \ast Ta^{°C} - 0.8 + Tw^{°C}$ |                                |
| 118 | Psychrometric Wet Bulb Temperature (McPherson; 2008)        | Solve by iteration method: $[30] = f(Ta, RH, WS)$                            |                                |
| 119 | Radiative Effective Temperature (Blazewicz; 2004)           | $= TE^{°C} + (1 - 0.01 \ast abedlo) \ast Sr^{w/m2} \ast (0.015 - 0.00025 \ast TE^{°C}) - (0.0043 - 0.0.0011 \ast TE^{°C})$ |                                |
|     |                                                               | $\Rightarrow$ If $WS < 0.2$ Then $TE = Ta^{°C} - 0.4 \ast (Ta^{°C} - 10) \ast (1 - 0.01 \ast RH)$ |                                |
|     |                                                               | $\Rightarrow$ If $WS > 0.2$ Then $TE = 37 - (37 - Ta^{°C}) / (0.68 - 0.0014 \ast RH + (1 / (1.76 + 1.4 \ast (WS \ast 0.75)))) - 0.29 \ast Ta^{°C} \ast (1 - 0.01 \ast RH)$ |                                |
|     |                                                               | $\Rightarrow$ We assume skin abedlo for pigmented individuals = 0.11, based on index $#120$ below |                                |
| 120 | Radiation Equivalent Effective Temperature (Non-Pigmented)   | $= 125 \ast Log(1 + 0.02 \ast Ta^{°C} + 0.001 \ast (Ta^{°C} - 8) \ast (RH - 60) - 0.045 \ast (33 - Ta^{°C}) \ast Sqrt(Ws^{m2}) + 0.185 \ast X)$ |                                |
|     |                                                               | $\Rightarrow X = SrTa^{m2} \ast (1 - abedlo)$                                |                                |
|     |                                                               | $\Rightarrow$ Skin abedlo for pigmented individuals = 0.11                  |                                |

(Continued)
| ID          | Thermal Stress Indicator                                            | Formula/s                                                                 | Assumption/s                                                                 |
|------------|---------------------------------------------------------------------|---------------------------------------------------------------------------|-------------------------------------------------------------------------------|
| 121        | Radiation Equivalent Temperature (Pigmented) (Sheleihovskyi; 1948)  | $\text{X} = \frac{\text{SR}}{\text{R}_{\text{calc} + \text{con} 2\text{min}}} \times \{(1 - \text{albedo}) \text{ Skin albedo for non-pigmented individuals} = 0.28}$ |                                                                              |
| 122        | Relative Humidity Dry Temperature (Wallace; 2005)                   | $= (0.1 \times \text{RH}) + (0.9 \times \text{Ta}_C^C)$                   |                                                                              |
| 123        | Relative Strain Index (Kyle; 1992)                                  | $= (\text{Ta}_C^C - 21) / (58 - \text{VP}^{B[\text{H}_2]\text{O}})$          |                                                                              |
| 124        | Relative Strain Index (Lee; 1966)                                   | $= (10.7 + 0.74 \times (\text{Ta}_C^C - 35)) / (44 - \text{VP}^{B[\text{H}_2]\text{O}})$ |                                                                              |
| 125        | Revised Wind Chill Index (Court; 1948)                             | $= (10.9 \times \text{S} \times \text{W}^{B[\text{H}_2]\text{O}}) + 9 - \text{W}^{B[\text{H}_2]\text{O}} \times \{(33 - \text{Ta}_C^C)$ |                                                                              |
| 126        | Roba’s Index (Robaa; 2003)                                         | $= (1.53 \times \text{Ta}_C^C - 0.32 \times \text{Twf}^C) - (1.38 \times \text{W}^{B[\text{H}_2]\text{O}} + 44.65$ |                                                                              |
| 127        | Saturation Deficit (Flugge; 1912)                                  | $= \text{SV}^{B[\text{H}_2]\text{O}} - \text{VP}^{B[\text{H}_2]\text{O}}$      |                                                                              |
| 128        | Severity Index (Osokin; 1968)                                      | $= (1 - 0.06 \times \text{Ta}_C^C) \times (1 + 0.2 \times \text{W}^{B[\text{H}_2]\text{O}} \times (1 + 0.0006 \times \text{Elevation}) \times \text{Kb} \times \text{AC}$ | Elevation = 0 m (we assume sea level altitude)                                |

Relative humidity:
- if RH <= 60 Then Kb = 0.9
- if RH > 60 And RH <= 70 Then Kb = 0.95
- if RH > 70 And RH <= 80 Then Kb = 1
- if RH > 80 And RH <= 90 Then Kb = 1.05
- if RH > 90 And RH <= 100 Then Kb = 1.1

Diurnal temperature (DTR): (e.g., the variation between a high temperature and a low temperature that occurs during the same day).
- if DTR <= 4 °C then AC = 0.85
- if DTR > 4 °C And DTR <= 6 °C Then AC = 0.90
- if DTR > 6 °C And DTR <= 8 °C Then AC = 0.95
- if DTR > 8 °C And DTR <= 10 °C Then AC = 1.00
- if DTR > 10 °C And DTR <= 12 °C Then AC = 1.05
- if DTR > 12 °C And DTR <= 14 °C Then AC = 1.10
- if DTR > 14 °C And DTR <= 16 °C Then AC = 1.15
- if DTR > 18 °C And DTR <= 20 °C Then AC = 1.20
- if DTR > 18 °C Then AC = 1.25

129 Simple Index (Moran; 2001) $= 0.66 \times \text{Ta}_C^C + 0.09 \times \text{RH} + 0.0035 \times \text{SR}_{\text{H}[2]\text{O}}$ 

130 Simplified Radiation Equivalent Effective Temperature (Boksha; 1980) $= 0.8 \times \text{EET} + 12$

131 Simplified Tropical Summer Index (Auliciems; 2007) $= (1 / 3) \times \text{Tw}_{f}^C + (3 / 4) \times \text{Tg}^C - (2 \times \text{SR}_{\text{H}[2]\text{O}})$

132 Simplified Universal Thermal Climate Index (Blazejczyk; 2011) $= 3.21 + 0.872 \times \text{Ta}_C^C + 0.2459 \times \text{Tw}_{f}^C - 2.5078 \times \text{W}^{B[\text{H}_2]\text{O}} - 0.0176 \times \text{RH}$

133 Simplified Wet Bulb Globe Temperature (American College of Sports Medicine; 1984) $= 0.567 \times \text{Ta}_C^C + 0.393 \times \text{W}^{B[\text{H}_2]\text{O}} + 3.94$

134 Simplified Wet Bulb Globe Temperature (Gagge; 1976) $= 0.567 \times \text{Ta}_C^C + 0.216 \times \text{W}^{B[\text{H}_2]\text{O}} + 3.38$

135 Skin Temperature (Blazejczyk; 2005) $= (26.4 + 0.02138 \times \text{Trmt}^C + 0.2095 \times \text{Ta}_C^C - 0.0185 \times \text{RH} - 0.009 \times \text{W} + 0.6 \times (\text{IC} - 1) + 0.00128 \times \text{Met}$

136 Skin Wettedness (Blazejczyk; 2005) $= 1.031 \times (37.5 - \text{Tk}^C) - 0.065$

137 Standard Operative Temperature (Gagge; 1940) $= \text{Tk}^C - \text{Heat}_{\text{Loss}} / 5.2$

138 Subjective Temperature (McIntyre; 1973) $= \text{WS}^{B[\text{H}_2]\text{O}} - 0.1 \times \text{Tsk}^C + 0.44 \times \text{Ta}_C^C$

139 Sultness Index (Scharlau; 1943) $= \text{vp}^{[\text{H}_2]\text{O}} - 10.67 \times \text{Sultness}$
| ID  | Thermal Stress Indicator                                                                 | Formula/s                                                                 | Assumption/s                      |
|-----|------------------------------------------------------------------------------------------|---------------------------------------------------------------------------|-----------------------------------|
| 140 | Sultriness Intensity (Akimovich; 1971)                                                   | ⇒ if VP < 18.8 Then = 0                                                 |                                   |
|     |                                                                                         | ⇒ if VP = 18.8 Then = 1                                                  |                                   |
| 141 | Summer Scharlau Index (Scharlau; 1950)                                                    | TC = Ta[C]                                                              |                                   |
|     |                                                                                         | ⇒ TC = (-17.089 * Log(RH)) + 94.979 ⇒ critical temperature              |                                   |
| 142 | Summer Simmer Index (Pepi; 1987)                                                         | 1.98 * (Ta[T] - (0.55 - 0.55 * (RH / 100)) * (Ta[T] - 58)) - 56.83     |                                   |
| 143 | Swedish Wet Bulb Globe Temperature (Eriksson; 1974)                                       | if WS(mix) >= 0.5 Then = 0.7 * Tpw[C] + 0.3 * Ta[C]                     |                                   |
|     |                                                                                         | if WS(mix) < 0.5 Then = 0.7 * Tpw[C] + 0.3 * Ta[C] + 2                  |                                   |
| 144 | Temperature Humidity Index (Schoen; 2005)                                                 | Ta[C] = 1.7099 * Exp(0.03755 * Ta[C]) - (1 - Exp(0.0801 * (VP[Pa])) - 14)) |                                   |
| 145 | Temperature Humidity Index (Costanzo; 2006)                                               | Ta[C] = 0.55 * (1 - 0.001 * RH) * (Ta[C] - 14.5)                        |                                   |
| 146 | Temperature Humidity Index (INMH; 2000)                                                   | (Ta[C] * 1.8 + 32) - (0.55 - 0.0055 * RH) * (Ta[C] - 1.8 + 32) - 58     |                                   |
| 147 | Temperature Humidity Index (Kyle; 1994)                                                   | Ta[C] = 0.55 - 0.0055 * (Rh) * (Ta[C] - 14.5)                           |                                   |
| 148 | Temperature Humidity Index (Nieuwolt; 1977)                                               | Ta[C] = 0.8 * Tt[C] + (RH * (Ta[C] / 500))                              |                                   |
| 149 | Temperature Humidity Index (eq. 1) (Pepi; 1987)                                           | Ta[T] = (0.55 - 0.55 * (RH / 100)) * (Ta[T] - 58)                      |                                   |
| 150 | Temperature Humidity Index (eq. 2) (Pepi; 1987)                                           | Ta[T] = 0.55 * Ta[T] + 0.2 * Td[T] + 17.5                               |                                   |
| 151 | Temperature of the exhaled air (McPherson; 1993)                                          | Ta[C] = 0.0002 * Ta[C] * (32 + 0 / 66) + 0.0055 * Ta[C]                |                                   |
| 152 | Temperature Resultante Miniere (Vogt; 1978)                                              | (0.7 * Tw[C]) + (0.3 * Ta[C] - WS[mix])                                |                                   |
| 153 | Temperature Wind Speed Humidity Index (Zaninovic; 1992)                                    | Th1 = 36.5 - (0.902 + 0.063 * (WS[mix] / 1.072)) * (36.5 - Tw[C]) / 0.902 |                                   |
|     |                                                                                         | Th2 = 36.5 - ((0.902 + 0.063 * (WS[mix] / 1.072)) * (36.5 - Ta[C]) / 0.902 |                                   |
|     |                                                                                         | ETH[Pa] = saturated vapour pressure at temperature Th2.                 |                                   |
|     |                                                                                         | = 1.2 + 0.1115 * Ta[C] + 0.0019 * SR[mix] - 0.3158 * WS[mix]            |                                   |
| 154 | Thermal comfort (Givoni; 2000)                                                           | = -7.91 - 0.52 * WS[mix] + 0.05 * Ta[C] + 0.17 * Tg[C] - 0.0007 * RH + 1.43 * ADu |                                   |
| 155 | Thermal Comfort (Humid-Tropical environments) (Sangkertad; 2014)                         | = (0.0053 + 0.035 * Layers) + 0.61 * Exp(-0.147 * WS[mix]) + 0.054 * Exp(-0.23 * Layers) - 0.1076 + 0.0677 * Tmrt[C] + 0.0105 * RH - 0.304 * WS[mix] |                                   |
| 156 | Thermal Resistance of Clothing (Jokl; 1982)                                              | VTd = saturated vapor pressure at dew point temperature                  |                                   |
|     |                                                                                         | = (0.245 * Ta[C]) + (0.033 * Vtd[Pa]) - 6.471                          |                                   |
| 157 | Thermal Sensation (Monteiro; 2010)                                                        | (1.83 - 0.05 * GTa[C] - (0.135 * Ta[C] + (0.00155 * SR[mix] - 0.6)) - 0.4915 * Log(WS[mix])) |                                   |
| 158 | Thermal Sensation (eq. 1) (Rohles; 1971)                                                  | ⇒ GTa[C] = average temperature of season                                 |                                   |
| 159 | Thermal Sensation (eq. 2) (Rohles; 1971)                                                  | = 0.219 * OT + 0.012 * RH - 0.547 * WS[mix] + 0.58                      |                                   |
| 160 | Thermal Sensation (Givoni; 2004)                                                          | OT = (Ta[C] + 1mrt[C]) / 2                                               |                                   |
| 161 | Thermal Sensation Index (Xavier; 2000)                                                     | = 0.134 * SET - 3.208                                                  |                                   |
| 162 | Thermal Sensation Vote (Summer) (Yahia; 2013)                                             | ⇒ SET = (WBGT - 11.76) / 0.405 ⇒ Outdoor Standard Effective temperature based on a formula (e.g., TSI #111) found in literature [123]. |                                   |
| 163 | Thermal Sensation Vote (Winter) (Yahia; 2013)                                             | = 0.082 * SET - 2.928                                                  |                                   |
| 164 | TVP index (Baghdad) (Nicol; 1975)                                                         | = 0.214 * Tg[C] + 0.031 * Vp[mix][Pa] + 0.545 * (WS[mix] / 0.5) - 2.85 |                                   |
| 165 | TVP index (Roorkee) (Nicol; 1975)                                                         | = 0.186 * Tg[C] + 0.032 * Vp[mix][Pa] - 0.366 * (WS[mix] / 0.5) - 0.82 |                                   |
| 166 | Tropical Summer Index (Sharma; 1986)                                                      | = (0.308 * Tw[C]) + (0.745 * Ta[C]) - (2.06 * Sqrt[WS[mix]] + 0.841 |                                   |
| 167 | Universal Thermal Climate Index (Jendritzky; 2012)                                        | = f(Ta[C], Tmrt[C], WS[mix], Vp[Pa])                                    |                                   |
| 168 | Wet Bulb Globe Temperature (eq. 1) (Ono; 2014)                                            | = 0.718 * Ta[C] + 0.0316 * RH + 0.00321 * Ta[C] + 4.363 * SR[mix][m2] / 0.5020 * WS[mix] + 3.623 |                                   |
| 169 | Wet Bulb Globe Temperature (eq. 2) (Ono; 2014)                                            | = 0.735 * Ta[C] + 0.0374 * RH + 0.00292 * Ta[C] + 7.619 * SR[mix][m2] / 4.557 * (SR[mix][m2] / 2) - 0.0572 * WS[mix] + 4.064 |                                   |
| 170 | Wet Bulb Globe Temperature (indoors) (Yaglou; 1956)                                       | = 0.67 * Tpw[C] + 0.33 * Ta[C] - 0.048 * Log(WS) / Log(10) * (Ta[C] - Tpw[C]) | Calculation based on meteorological data according to the literature. [30] |
| 171 | Wet Bulb Globe Temperature (outdoors) (Yaglou; 1956)                                      | = 0.214 * Tg[C] + 0.031 * Vp[mix][Pa] + 0.545 * (WS[mix] / 0.5) - 2.85 | Calculation based on meteorological data according to the literature. [30] |
| 172 | Wet Bulb Temperature (Liljegren; 2008)                                                     | = 0.0052 * WS[mix] + 3.623                                              |                                   |
| 173 | Wet Bulb Temperature (Malchaire; 1976)                                                    | = (0.151977 * (RIH + 8.313659) - 0.5) + Atm(Ta[C] - RH) - Atm(RH - 1.676331) + 0.00391838 * (RH ^ (3 / 2)) |                                   |
| 174 | Wet Bulb Temperature (Stull; 2011)                                                        | = 0.151977 * (RIH + 8.313659) + 0.00391838 * (RH ^ (3 / 2)) + Atm(0.023101 * RH) - 4.686035 |                                   |

(Continued)
Table 5 (Continued).

| ID  | Thermal Stress Indicator                          | Formula/s                                                                 | Assumption/s |
|-----|--------------------------------------------------|---------------------------------------------------------------------------|--------------|
| 175 | Wet Cooling Power (Landsberg; 1972)              | = (0.37 + 0.51 \times (WS^{[\text{m/s}]}) \wedge 0.63) \times (36.5 - Tw^{[\text{°C}]}) |              |
| 176 | Wet Globe Temperature (Botsford; 1971)           | = \text{WBGT} + 2.64 / 1.044                                            |              |
| 177 | Wet Kata Cooling (Maloney; 2011)                 | = (0.648 \times (36.4 - Tw) + 0.833 \times (36.4 - Tw) \times (WS^{[\text{m/s}]}) \wedge 0.5) \times 41.84 | \text{Tw} = 0.85 \times Ta^{[\text{°C}]} + 0.17 \times RH - 0.61 \times (WS^{[\text{m/s}]}) \wedge 0.5 + 0.0016 \times SR^{[\text{m/s}]}) \wedge 11.62 \Rightarrow \text{Tw} = \text{natural wet bulb temperature as described in the paper [89].} |
| 178 | Wet Kata Cooling Power (Chamber of Mines of South Africa; 1972) | = (0.7 + (RH \wedge 0.5)) \times (36.5 - Tw^{[\text{°C}]}) |              |
| 179 | Wet Kata Cooling Power (Krisha; 1996)            | \Rightarrow \text{if } WS^{[\text{m/s}] < 1 \text{ Then } \text{ WS}^{[\text{m/s}]}} \times (16.65 + (35.59 \times (WS^{[\text{m/s}]}) \wedge (1 / 3))) \times (309.65 - Ta^{[\text{°C}]}) |              |
| 180 | Wet Kata Cooling Power (Hill; 1919)              | \Rightarrow \text{if } WS^{[\text{m/s}] \geq 1 \text{ Then } \text{ WS}^{[\text{m/s}]}} \times (4.19 + (46.05 \times (WS^{[\text{m/s}]}) \wedge (1 / 3))) \times (309.65 - Ta^{[\text{°C}]}) |              |
| 181 | Wet-Bulb Dry Temperature (Wallace; 2005)        | \Rightarrow \text{if } WS^{[\text{m/s}] < 1 \text{ Then } \text{ WS}^{[\text{m/s}]}} \times (36.5 - Ta^{[\text{°C}]}) \times (0.2 + 0.4 \times Sqr(WS^{[\text{m/s}]}) \times 41.868 | \Rightarrow \text{if } WS^{[\text{m/s}] > 1 \text{ Then } \text{ WS}^{[\text{m/s}]}} \times (36.5 - Ta^{[\text{°C}]}) \times (0.13 + 0.47 \times Sqr(WS^{[\text{m/s}]}) \times 41.868 | |
| 182 | Wind Chill (OFCM/NOAA; 2003)                    | = 13.12 + 0.6215 \times Ta^{[\text{°C}]} - 11.37 \times (WS_{10m}^{[\text{km/h}]} \wedge 0.16) + 0.3965 \times Ta^{[\text{°C}]} \times (WS_{10m}^{[\text{km/h}]} \wedge 0.16) | \Rightarrow \text{RS} = 1 / (HR + Hc). \Rightarrow \text{Surface resistance} |
| 183 | Wind Chill (Siple; 1945)                        | = (Sqr(WS^{[\text{m/s}]}) \times 100)) + 10.45 - WS^{[\text{m/s}]}) \times (33 - Ta^{[\text{°C}]}) | \Rightarrow \text{RS} = 1 / (HR + Hc). \Rightarrow \text{Surface resistance} |
| 184 | Wind Chill (Steadman; 1971)                     | = (30 - Ta^{[\text{°C}]}) / RS                                           | \Rightarrow \text{RS} = 1 / (HR + Hc). \Rightarrow \text{Surface resistance} |
| 185 | Wind Chill Equivalent (Quayle; 1998)            | = 1.41 - 1.162 \times WS^{[\text{m/s}]}) + 0.98 \times Ta^{[\text{°C}]} + 0.0124 \times (WS^{[\text{m/s}]}) \times 2) + 0.0185 \times (WS^{[\text{m/s}]}) \times Ta^{[\text{°C}]} | \Rightarrow \text{WC} = (((Sqr(WS^{[\text{m/s}]}) \times 100)) + 10.45 - WS^{[\text{m/s}]}) \times (33 - Ta^{[\text{°C}]}) \Rightarrow \text{Wind Chill} |
| 186 | Wind Chill Equivalent Temperature (wind of 1.34 m/s) (Falconer; 1968) | = \text{Solve by iteration method: } f(Ta, WS) = \text{WC} = (((Sqr(WS^{[\text{m/s}]}) \times 100)) + 10.45 - WS^{[\text{m/s}]}) \times (33 - Ta^{[\text{°C}]}) \Rightarrow \text{Wind Chill} According to the authors the Wind Chill Equivalent Temperature is “the equivalent temperature that would be felt on exposed flesh in a 3 mph wind – the amount of ventilation one might experience in walking in an otherwise calm wind condition” [165]. | \Rightarrow \text{WC} = (((Sqr(WS^{[\text{m/s}]}) \times 100)) + 10.45 - WS^{[\text{m/s}]}) \times (33 - Ta^{[\text{°C}]}) \Rightarrow \text{Wind Chill} According to the authors the Wind Chill Equivalent Temperature is “the equivalent temperature that would be felt on exposed flesh in a 3 mph wind – the amount of ventilation one might experience in walking in an otherwise calm wind condition” [165]. |
| 187 | Winter Scharlau Index (Scharlau; 1950)           | = Ta^{[\text{°C}]} - Tc                                                 | \Rightarrow \text{WC} = (((Sqr(WS^{[\text{m/s}]}) \times 100)) + 10.45 - WS^{[\text{m/s}]}) \times (33 - Ta^{[\text{°C}]}) \Rightarrow \text{Wind Chill} According to the authors the Wind Chill Equivalent Temperature is “the equivalent temperature that would be felt on exposed flesh in a 3 mph wind – the amount of ventilation one might experience in walking in an otherwise calm wind condition” [165]. |

Critical evaluation of all 187 meteo-based TSIs against their operational characteristics, including grading whether a TSI (1) was developed for “active” metabolic state, (2) operates to environments typically found in occupational settings, and (3) incorporates more than one environmental factor.

It is important for future studies to assess the validity of the 153 complex models identified in the present search for describing the heat stress and strain experienced by non-occupational populations performing various activities over a wide operating range of ecologically valid conditions. In this exercise, it is important to consider the impact of interindividual and intraindividual factors that modify the heat strain response and the associated health outcomes [14,176,177].

In conclusion, the information presented in this systematic review should be adopted by those interested to perform on-site monitoring and/or big data analytics for climate services to ensure valid use of the meteo-based TSIs. The present systematic search identified 340 unique TSIs that have been designed to assess the heat stress experienced by people performing various activities over a wide range of ambient conditions. Of these, 187 TSIs can be calculated utilizing only meteorological data and, therefore, are relevant for big-data analytics used in climate services. These TSIs are the most important component for heat-health guidelines, and as such, they should be included in future legislation and climate change policy.

This study is led by the FAME Laboratory, which stands for (F)unctional (A)rchitecture of (M)ammals in their (E)nvironment. It is part of the University of Thessaly and is situated in Trikala, Greece. It was founded in 2008 and currently employs 18 researchers with backgrounds in physiology, molecular biology, epidemiology, medicine, and data science. Together, they publish widely on the effects of different environmental factors on human health and performance, with particular focus on the effects of heat. The lab is also contributing to efforts aiming to translate
scientific evidence to environmental, climate, and health policies for international organizations, including the World Health Organization, the International Labour Organization, the Greek Ministry of Labour, and the Qatari Ministry of Administrative Development, Labour and Social Affairs.

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AUTHOR CONTRIBUTIONS

Conceptualization: LGI, ADF, LN, GH, GPK; Data curation: LGI, ADF; Formal Analysis: LGI, ADF; Funding acquisition: ADF; Investigation: LGI, KM, LT, ADF; Methodology: LGI, GH, GPK, LN, ADF; Project administration: LGI, ADF; Software: LGI, KM, ADF; Supervision: ADF; Validation: ADF; Visualization: LGI, ADF; Writing – original draft: LGI, ADF; Writing – review & editing: LGI, KM, LT, SRN, PCD, MB, YE, GH, MS, PB, IM, GPK, TEB, LN, ADF.

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