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Review on Koppen-Geiger System for Indoor Thermal Comfort

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***Abstract* – Several research studies were carried out in recent years for monitoring climate change and heat island effect in the world. Many authors addressed the effect of climate on thermal comfort by referring to Koppen-Geiger climate classification. However, little information is available on the effect of climate types on thermal comfort. A review of four climate classification systems are described and discussed in this study. Additionally, the Koppen-Geiger climate system in terms of its classification criteria and impact on thermal comfort are portrayed in the present publication. The shifts in climate types did not necessary affect the predicted indoor neutral temperatures. Given that the identified climate types in some cases are different when using the Kottek and the Peel methods, this study recommends reporting the employed Koppen-Geiger classification method. The year (s) or the time period of climate identification is also required. This study also recommends investigating in the near future thermal comfort requirements for climate type A for generalization of the conclusions.**

***Keywords* – Thermal Comfort, Climate Classification Approaches, Koppen-Geiger Climate.**

I. Introduction

Weather is defined as the atmospheric conditions that occur within a short period. It is always changing from hour to hour, from day to day and from season to season [39]. Weather includes instantaneous data of air temperature, precipitation, to list a few [1]. Climate is defined as the statistics of weather over a long-term period, generally of thirty years [2]. It has been reported that climate shows the way an atmosphere behaves within a period of time under a specific area.

Examples of climate elements are mean air temperature, mean precipitation, and mean relative humidity [3]. Hence, the main difference between weather and climate is in terms of measurement of time. The actual observed temperatures on any given day are weather, whereas long-term averages based on observed temperatures are considered climate. Climate data provide useful information and observation on climate variation and change. Previous studies have pointed out the global concerns on climate issues in the twentieth century, notably the global warming and heat island effect [4]. Detailed information relevant to climate change is important in building energy demand prediction [5]. Climate change is predicted from the effects of variations in temperature and precipitation.

II. Climate Classification Methods

Climate classification is established to identify the similarities and differences of climatic patterns in different parts of the earth [6].

The climatic classification method summarizes the climatic data of a part or region. Such classification provides a brief description of climate of the location. It also acts as an initial point to analyze the reasons of climate variations. The empirical and the genetic methods are widely known for climate classification.

A summary of the climate classification approaches is shown in Fig. 1. The distinctive aspects are based on the nature of the data used for the classification.

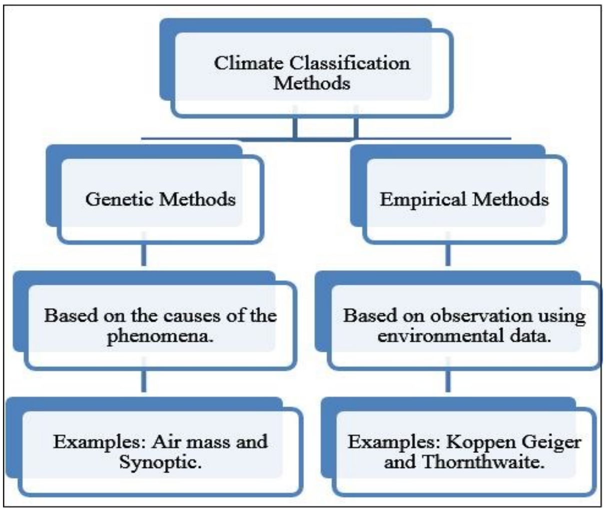

Fig. 1. Summary of the climate classification approaches.

A genetic method classifies climate on the basis of its causal elements, the activity, and the characteristics of all factors that give rise to the spatial and temporal patterns of climatic data. The factors include air masses, circulation systems, fronts, jet streams, solar radiation and topographic effects, to list a few. In contrast, empirical methods make use of observed environmental data, such as temperature, humidity, and precipitation.

Empirical classifications use predetermined class boundaries to classify the climate types. These require climatic data. Thus, similar climatic conditions in two locations will be categorized in one group.

According to Khlebnikova [6], locations that have abundant high-quality climate data, they are more ideal to be classified in empirical way than with the genetic classification methods. This is because the genetic approach is more tedious than the empirical approach as the former requires more meteorological variables. Both methods are explained further in the following subsections.

A. *Genetic Methods*

Genetic classification attempts to organize climates while considering various factors relevant to the atmospheric circulation of major winds and air masses [6].

The genetic method requires climatic data such as solar radiation, air masses, and pressure systems. This method has been deemed not user-friendly as it requires many variables [7]. Examples of systems under this method are the air mass frequency model and the synoptic classification.

The air mass frequency model differentiates climate groups with Venn diagrams. Actual station surface data are used for the identification of monthly air mass dominance [8]. The model then constructs monthly air mass identification chart for classification. The results are in the form of three basic climatic regimes: dominant, seasonal, and compound [9].

This genetic classification method requires considerable number of meteorological variables such as temperature, humidity, cloud cover, and wind speed [10]. However, these many weather variables are the main weakness of this method.

The synoptic classification method is also well-known for assessing the climate impacts of environmental problems, including air quality [11]. A temporal synoptic index (TSI) is an automated and objective synoptic classification procedure. It classifies individual days into homogenous air mass categories based on the similarity of weather elements indicative of regional-scale climate.

TSI has been utilized to estimate the influence of climate on numerous environmental variables, such as cloud cover, temperature, dew point temperature, sea level pressure, wind speed, and wind direction [12]. TSI relies on air mass differentiation by assigning the data of daily climate to a particular synoptic category. The synoptic categories have no specific names but it can be determined from the frequencies and meteorological characteristics after analysis. However, the requirement to collect many meteorological variables for analysis has been a disadvantage of this technique [13].

B. *Empirical Methods*

Empirical method is a classification system based on observation of temperature and precipitation. These two parameters are the easiest measured climate characteristics and most likely the ones having the longest historical record [14]. For example, Koppen-Geiger and Thornthwaite are under the empiric classification method.

In 1918, Wladimir Koppen introduced the Koppen - Geiger climate classification [15]. The concept underlying this classification is climate zone boundaries which are selected according to vegetation limits [16]. The annual and monthly averages of air temperature and precipitation determine their categories [15]. Various methods were suggested as improved versions from Wladimir Koppen work. Thornthwaite is another known classification. It was suggested by the climatologist Thornthwaite in 1931 who later revised the method in 1948 [17]. This method classifies climate types according to vegetation characteristics. Precipitation effectiveness (P/E, where P is the total monthly precipitation, and E is the total monthly evaporation) is used to determine the classification (Allaby, 2004). Thornthwaite climate classification categorizes climate types according to the relationship of temperature-evaporation and precipitation-evaporation. Because the Thornthwaite classification considers evapotranspiration, it was considered an improvement method for agricultural applications.

From Thornthwaite classification, the soil is considered as wet condition if precipitation is more than evaporation. The soil is considered as dry condition if precipitation is less than evaporation. However, the Thornthwaite classification has been used infrequently because it tended to be too complex for use in everyday settings. In fact, the world maps of this classification were never produced [18]. In a nutshell, the genetic approach is tedious because it requires more meteorological variables compared to the empirical approach.

The Koppen-Geiger climate classification in the empirical approach is easier and more user-friendly compared to the Thornthwaite classification. The Koppen-Geiger classification is widely used in many studies [19]. It is considered an effective way to gain better understanding about climate variations and it also imposes lesser data requirements [20]. It has been reported that this method is frequently used compared to other methods. It is relatively simple and more adaptable [21, 22]. Hence, this review also opted for Koppen-Geiger climate classification system.

III. Description of Koppen-Geiger Climate Classification

Different parts of the world have different climates. Average temperature and precipitation are the important features of a climate. These two parameters are used in Koppen-Geiger climate classification. Daily and seasonal variations also depend on temperature and precipitation.

For example, San Francisco, California, and Beijing have similar yearly temperatures and precipitation but different daily and seasonal changes. San Francisco's winters are not much cooler than its summers, whereas Beijing is hot in the summer and cold in the winter [23].

The Koppen classification consists of five primary types: tropical moist climates (climate type A), dry climates (climate type B), moist subtropical mid-latitude climates (climate type C), moist continental mid-latitude climates (climate type D), and polar climates (climate type E) [15, 22, 24]. The main types are known as primary classifications. Those are further divided into secondary classification which considers precipitation. The third letter represents air temperature [25].

Koppen classification has thirty-one climate types [26]. The tropical climates (climate type A) under the Koppen classification are mostly located near the tropics. This region mostly experiences a warm climate with lots of rain all the years [27]. The sub-types are determined by the annual and mean precipitation. The arid climates (climate type B) are climates with very less rainfall which is inadequate for plant growth [28]. These climates are classified according to annual average precipitation and temperature as well as annual precipitation [24]. The moist subtropical mid-latitude climates (climate type C) are climates that have warm and humid summers with mild winters. Different seasonal precipitations decide its four sub-types, which are Cfb, Cfc, Cwb and Cwc [29]. The snow climates (climate type D) commonly have evergreen coniferous forest [22]. Finally the polar climates (climate type E) are subdivided into tundra and ice-sheet climates [15, 28].

IV. Criteria for Identification of Koppen-Geiger Main Climate Classification

A description of the symbols and the criteria used to define the Koppen-Geiger climate types is well outlined in references [15, 19]. All the precipitation variables are in units of millimeters (mm) and all the temperature variables are in units of degree Celsius (°C). The A, C, D, and E main climate types are classified according to temperature criteria, whereas the main climate type B is classified according to precipitation and temperature criteria as depicted in [15, 19].

The Kottek et. al. [15] procedure used in the development of their climate world map was made by referring to two investigators work [30, 31] works. There is also an updated world map developed by Peel et. al. [19]. Both methods are listed in Table 1.

According to Peel et. al. [19], the climate type B must be identified first, because all the locations that satisfy the climate type B criteria will also satisfy one of the other's (A, C, D or E) climate criteria. The difference between the Kottek method and the Peel method is clearly shown when classifying climate type C and D. For the Kottek method, the location is classified as climate type C when it meets the criteria of minimum temperature which must be greater than -3 °C.

Table 1. Criteria for Sub-type C Climates.

Climatic Type	Criteria for sub type C climate of Kottek et. al. (2006)	Criteria for sub type C climate of Peel et. al. (2007)
Csa	$P_{s,\,min} < P_{w,\,min}$, $P_{w,\,max} > 3 P_{s,\,min}$ and $P_{s,\,min} < 40$ mm and $T_{max} \geq 22°C$	$P_{w,\,max} > 3 P_{s,\,min}$ and $P_{s,\,min} < 40$ mm and $T_{max} \geq 22°C$
Csb	$P_{s,\,min} < P_{w,\,min}$, $P_{w,\,max} > 3 P_{s,\,min}$ and $P_{s,\,min} < 40$ mm and $T_{max} < 22°C$ and $T_{mon\ 10} \geq 4$	$P_{w,\,max} > 3 P_{s,\,min}$ and $P_{s,\,min} < 40$ mm and $T_{max} < 22°C$ and $T_{mon\ 10} \geq 4$
Cwa	$P_{w,\,min} < P_{s,\,min}$ and $P_{s,\,max} > 10 P_{w,\,min}$ and $T_{max} \geq 22°C$	$P_{s,\,max} > 10 P_{w,\,min}$ and $T_{max} \geq 22°C$
Cwb	$P_{w,\,min} < P_{s,\,min}$ and $P_{s,\,max} > 10 P_{w,\,min}$ and $T_{max} < 22°C$ and $T_{mon\ 10} \geq 4$	$P_{s,\,max} > 10 P_{w,\,min}$ and $T_{max} < 22°C$ and $T_{mon\ 10} \geq 4$
Cfa	Neither Cs nor Cw; and $T_{max} \geq 22°C$	Neither Cs nor Cw; and $T_{max} \geq 22°C$
Cfb	Neither Cs nor Cw; and $T_{max} < 22°C$ and $T_{mon\ 10} \geq 4$	Neither Cs nor Cw; and $T_{max} < 22°C$ and $T_{mon\ 10} \geq 4$

Notes: $P_{s,\,min}$: the lowest monthly precipitation values for summer half years on the hemisphere considered; $P_{s,\,max}$: the highest monthly precipitation values for summer half years on the hemisphere considered; $P_{w,\,min}$: the lowest monthly precipitation values for winter half years on the hemisphere considered; $P_{w,\,max}$: the highest monthly precipitation values for winter half years on the hemisphere considered; $T_{mon\ 10}$: the number of months where the mean temperature is above 10°C.

The location is under climate type D when minimum temperature equals to or smaller than -3 °C.

For the Peel method, the minimum temperature must be greater than 0 °C for the climate type C. The maximum temperature must be greater than 10 °C when using the Peel method. In addition, the minimum temperature must be equal to or smaller than 0 °C for the criteria of climate type D in Peel method. Other differences are described by Peel et. al [19]. The reader may refer to their publication for other relevant information. Additional information is available in [32].

V. Thermal Comfort Models

Several thermal comfort models have been used to predict people thermal comfort requirements. The two widely used models recognised by the ASHRAE 55 standard [33] are the predicted mean vote and the adaptive model.

A. *Predicted Mean Vote Model*

The predicted mean vote (PMV) model is considered a static model, though it requires various variables. It can be applied to air-conditioned buildings [34]. Fanger developed the PMV model by using principles of heat balance and experimental data collected in a controlled climate chamber under steady state conditions.

PMV is calculated on the basis of four measurable quantities. Those are air velocity, air temperature, mean radiant temperature, and relative humidity. There are also two additional parameters; these are clothing and metabolism rate. The vote generated from PMV is considered as an index in the assessment of the thermal sensation of the subject such when feeling hot, warm, cold.

B. *Adaptive Model*

The adaptive model considers human being interacts with the environment. People modify their own behaviour due to various factors. For instance past thermal history may change their expectations and thermal preferences.

The adaptive model has been widely used in predicting indoor comfort conditions for naturally-ventilated buildings. The model proposes that occupants dynamically interact with their environment. This is because building occupants will change clothes, operate windows, operate fans, drink water, and use several strategies to establish their thermal comfort [35].

The adaptive comfort model in the ASHRAE 55 [33] was intended to determine acceptable thermal conditions in naturally-ventilated buildings.

The adaptive model in EN 15251 specifies comfort temperatures for free-running buildings. ANSI/ASHRAE Standard 55 has incorporated a model of adaptive thermal comfort called Adaptive Comfort Standard (ACS) for occupant-controlled, naturally-ventilated buildings [36].

European standard EN 15251 also includes an adaptive comfort temperature model that applies to all buildings that are neither heated nor cooled mechanically. This model relates the neutral temperatures indoors to outdoor temperatures. An advantage of EN 15251 is that it relies on actual weather data and thus displays more variability than do the historic monthly means [37]. However, the model was developed only for Europe. The models in both ANSI/ASHRAE Standard 55 and EN 15251 have few differences but similar concept [38]. The adaptive model is useful when addressing the impact of climate on thermal comfort.

VI. Impact of Climate on Thermal Comfort

Weather and climate affects many aspects of the planet Earth. Climate influences the development of cultures and civilizations [39]. People try their own way to adapt themselves in various climates in order to live comfortably.

Climate is also important in building design [40]. The design of buildings has been based on the climate of a particular location since the ancient. This can be observed for example, in roof shape of Malay traditional houses and the height of a building as well.

It is widely accepted that field thermal comfort studies are important for constructing a comfortable shelter [41]. Moreover, it is also important to know the climate during the surveyed period. This is because unusually warm day during a cold season might lead to an overestimation of the warmth [42]. This could be detected if the long-term climate (thirty-year period) for the measurement period is reported. The reporting should preferably include the long-term climate as measured at the nearest meteorological station immediately before and during the survey year [43].

Human health is also affected by weather and climate [44]. Human physiological factors (metabolic rate, clothing, age, degree of acclimatisation) are also responsible for the human thermal comfort [45]. For example, clothing is influenced by climate. The warm clothing developed by human beings is necessary for survival in a cold, windy climate. Human beings keep internal body temperature constant at 37 °C under different inner and outer conditions in order to stay healthy. This measure serves to maintain a balance between the produced and received heat by the body [46, 47].

Comfort temperatures in naturally ventilated buildings are related to the climate variable, such as mean monthly outdoor air temperature. This is due to the powerful influence of climate on several aspects of living, such as clothing, life pace, daily cycle of activity, building furnishing type, and building construction design.

VII. Koppen-Geiger Climate Classification for Thermal Comfort Studies

According to Healey [48], climate is an important factor for comfort building design. Every building should firstly provide, climatically appropriate passive design strategies which take advantage of external conditions. Thus reflecting the comfort preferences and functional needs of the occupants. However, thermal comfort is subjected to change over time. Therefore, it is important to observe the variation of climate variable over time and over years on people thermal comfort.

The Koppen-Geiger climate classification system is widely used model in the world from various disciplines. The situation is not an exception in thermal comfort studies.

In recent years, several authors considered the Koppen-Geiger climate classification in their articles just to cite few references [49, 50, 22, 27] and many others. Most thermal comfort researchers refereed in their publications to the developed climate world map of Koppen-Geiger by Kotteck et al. [15]. In fact, many researchers ignored the updated version developed by Peel et. al. [19]. Further little is known about the implications in using the Peel et. al. [19] climatic world map in addressing the impact of climate types on neutral temperatures [32].

For the purpose to investigate the effect of climate on thermal comfort, a research study used Melbourne thermal comfort data and identified the climate type during the year of the survey. The identified climate was Cwa based on Kottek et al. method [15]. It was Csa based on Peel et al method [19]. The authors observed that the climate type is also subjected to yearly variation. It means, the dominant climate may not necessary be the average climate type [32]. Average climate type refers to climate type estimated from average air temperature and precipitation over for instance 30 Years. Such procedure is used in the development for instance of Kottek et al. and Peel et. al. maps [15, 19]. This shows the lack of relevance of Koppen-Geiger method in investigating the impact of climate on thermal comfort.

In another study conducted by Mishra and Ramgopal [22], the authors investigated the adaptive comfort equations from various climate types. Their analysis revealed that except for climate main type A; other climate types have wide ranges of neutral temperatures. Unfortunately, their study only considered the Kottek et. al. [15] world map.

The authors investigated the main climate types but omitted climate subtypes. Further, the Kottek and Peel maps as stated above are only developed from average air temperature and precipitation data over the selected period of time. An average long-term climate type may not be necessary the dominant climate type. In fact, it did not necessary reflect the yearly climate type when the thermal comfort survey was conducted.

In another study, Toe and Kubota [50] classified the climate types of several places into three climate groups according to survey location and season. The selected climate types are hot-humid, hot-dry, and moderate.

The main purpose of their study was to develop an adaptive model equation for hot-humid climate. This time, the investigators selected Peel et. al. method [19]. However, the authors made some assumptions in categorizing various locations under hot-humid. It was made by just referring to the description of the climate types according to Koppen-Geiger approach. For instance, they considered climate of locations classified as climate type A and climate type Cfa during summer season as hot-humid climate. Such classification had yet to be validated.

The Koppen procedure for climate type was made by referring to variability of plants. This is because food was the major issue in human settlements. This method reflects the effect of climate on plants and cold-blooded animals.

This is because humans may survive at extreme temperatures as explained by the Harimi [51]. It has been reported that Koppen-Geiger is not probably an appropriate method for predicting neutral temperature according to climate types [51].

In a study carried out by Harimi and Tay [52] using Koppen-Geiger system and thermal comfort data for Melbourne case study, the climate of the location was categorized under Cfb. However, the authors also reported that the average indoor relative humidity was 39.2%. This is relatively dry. Their results showed that the description of the outdoor climate according to Koppen-Geiger method did not reflect the indoor relative humidity. Similar observation was also made with air temperature. Cfb refers to warm temperate, fully humid, warm summer.

Harimi [51] developed a simple procedure for identification of climate types according to indoor temperature classification. This was made by considering the air temperature range within 20 to 25 ^{0}C as temperate climate. Other descriptions were also made by range. The first range was set for the calibration of the classification. By referring to this approach the comparison of finding among thermal comfort studies will be meaningful. Such procedure can be used for outdoor temperature as well. For each air temperature range, a description of air temperature was also suggested by range. This can be further calibrated by investigating various studies all over the world.

VIII. Conclusions

The present publication reviewed the Koppen-Geiger system for indoor thermal comfort investigations. Several climate classification systems were addressed in this article, the Koppen-Geiger system was found to be widely-used from various disciplines. The criteria for identifying each main climate types are prescribed in the present publication. Climate will influence human thermal comfort.

Two widely known methods for predicting neutral temperatures were also introduced in this article. These are the PMV and the adaptive approach. The adaptive approach is widely used for predicting neutral temperatures in naturally ventilated buildings. In the present review, only adaptive model is considered when referring to Koppen-Geiger system. This is because PMV is generally used for a controlled indoor thermal environment. The present review indicated that temperature prediction cannot be made by referring to Koppen-Geiger method. This is regardless of the version used. Probably the exception for climate type Af. This requires further investigations. Koppen method is more relevant to plants and cold bloods animal.

The design of a building in any location in the world should not be limited to historical climatic data. It should also consider the expected changes during the planned life of the building. This is important in designing an adaptive building for adaptive people subjected to short and long-term climate variation and change. Currently, this is attracted the European interest in recent years. This procedure is highly recommended to be investigated in various places in the world. This is for mitigating the effect of climate change on human thermal comfort.

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