International Journal of Recent Technology and Engineering (IJRTE)
ISSN: 2277-3878 (Online), Volume-7, Issue-6, March 2019

Exploring Köppen-Geiger Climate Classification of the ASHRAE RP-884 Database

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Abstract*: The Köppen-Geiger climate classification system is the most widely used and refereed model in the world from various disciplines. This is also the case of thermal comfort studies. In recent years, several thermal comfort authors considered the Köppen-Geiger climate map introduced by Kottek research group in their investigations; however, most of the studies ignored the updated version made by Peel group. This investigation addressed the climate types of the reported site locations from ASHRAE RP-884 for naturally ventilated buildings. The analysis was made based on the Köppen-Geiger climate maps from various sources and the new LocClim 1.10 software. The climate type of each location was identified. Some contradicting results were reported. Those were further investigated and discussed in this study. It is recommended to report the exact geographic coordinates of the location under investigation. Further, the Köppen-Geiger map or method used in identifying the location under consideration is recommended to be clearly specified to avoid contradicting information. This is because the climate type of some locations is subjected to yearly variation.

***Index Terms*: Köppen-Geiger; ASHRAE RP-884; Thermal Comfort; Climate types..**

I. INTRODUCTION

Buildings provide a comfortable living environment for their occupants [1]. This includes, among others, thermal, visual and acoustic comfort as well as indoor air quality. It is widely accepted fact that buildings are not isolated but are generally placed in an urban context, influenced by the urban heat island and global warming. Urban warming has serious consequences on the energy, environmental, and social balance of cities as well as on human comfort and health [2]. The associated effects of urban heat island and global warming increase the near-surface temperature in cities [3]. Although there has been obvious progress in monitoring and understanding climate change, there remain many scientific, technical, and institutional impediments to precisely planning for, adapting to, and mitigating the effects of climate change [4]. In this regard, the Köppen-Geiger climate classification system is the most widely used and refereed model in the world from various disciplines in predicting and evaluating climate change [5]. The situation is not an exception in thermal comfort studies. In recent years, several authors considered the Köppen-Geiger climate classification in their articles just to cite few references [6, 7, 8, 9, 10] and many others. Mishra and Ramgopal [11] investigated the reliability of the adaptive comfort equations from various climate types. However, they concluded that except for climate main type A; other climate types have wide ranges of neutral temperatures. Their study only considered climate world map which was developed by Kottek, Grieser, Beck, Rudolf, Rubel. according to Köppen-Geiger procedure [5]. The updated version developed by Peel, McMahon, Finlayson [12] was not considered in their study. Given the above points, it is necessary to reanalyze the ASHRAE RP-884 database by identifying climate types using various methods. Only naturally ventilated buildings locations were considered in this study.

Revised Manuscript Received on 30 March 2019.
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II. THE MATERIAL AND METHODS

This section describes the chronological sequences of the designed methodology of this study. Firstly, the main climate type of each location as provided in the ASHRAE RP-8884 database was identified by using the updated versions of the Köppen-Geiger world map by Kottek, Grieser, Beck, Rudolf, Rubel [5], Peel, McMahon, Finlayson [12], and the new LocClim 1.10 software. Figure 1 shows the methodology adopted in identifying the survey locations.

The Kottek climate world map used mean monthly air temperature and monthly total precipitation data for the period 1951 to 2000 on a regular 0.5 degree latitude or longitude grid [5]. This is similar to the Peel world map [12]. Therefore, this study required the identification of the geographic coordinates of each survey location.

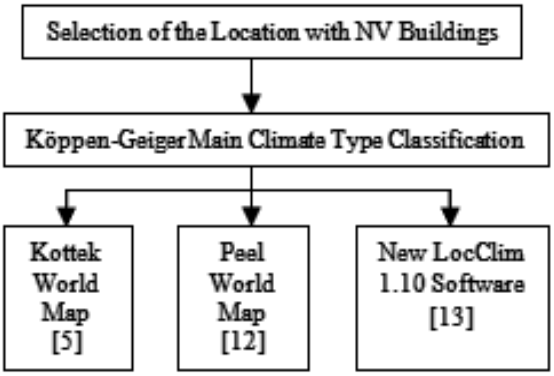

Fig. 1: Sequences for identification of the survey locations

The climate main types of these locations were then identified by referring to Kottek and Peel versions of the Köppen-Geiger world maps, and thus the main climate classification for each survey location was determined.

In this research, New LocClim 1.10 software [13] was used as an alternative tool for Köppen-Geiger climate classification. The climatic data in the New LocClim 1.10 software is within the period from 1971 to 2000. However, it was reported that in this software, the data within the period from 1961 to 1990 were the more often collected data [14,15]. The climatic data used by the New LocClim software was maintained by the Environment and Natural Resources Service (SDRN) in the sustainable development department of Food and Agriculture Organization (FAO).

Figure 2 illustrates the main steps for running the New LocClim 1.10 software. The first step is about the selection of the type of modes; the second step requires the identification of the survey location, and the last step is about the selection of the interpolation method. For the first step, three modes are also available in the New LocClim 1.10 software, namely, Automatic Mode, Single Point Mode, and Workbench Mode. In this study, Single Point Mode was selected. This is because the analysis required displaying the climate type at specific survey geographic coordinates. Additionally, the advantage of this mode is this; warnings will be given for this mode in case of extrapolation, strange data, or lacking of neighbouring stations [16]. This is certainly important in the present research. For the second step, three input types were provided in this software for the selection of the survey location. This is by making the selection from the world map, or by providing the survey location coordinates, or by selecting the location from the provided name lists. In the present investigation, the location by coordinates was the selected option. It was the preferred option for the purpose of comparison of all results from various tools. For the third step, the Shepard's method was the selected interpolation method. This method is specifically designed for climate interpolation. In fact, It is considered the most suitable approach for climate classification [17].

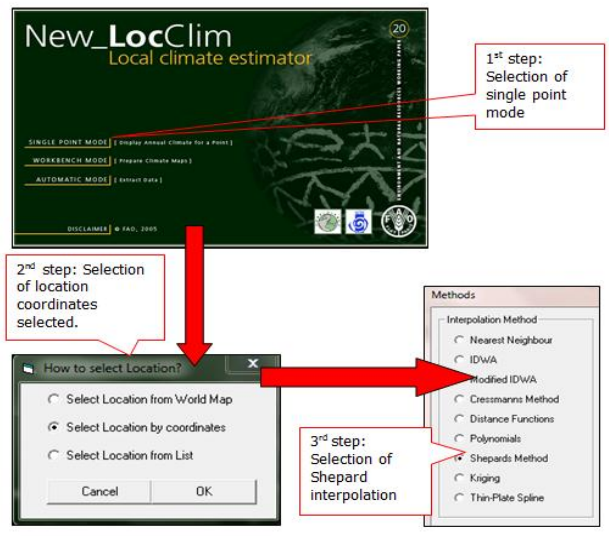

Fig. 2: The main steps for climate identification using the New LocClim 1.10 software

III. RESULTS AND DISCUSSION

A. Identification of Survey Locations for naturally-Ventilated Buildings

There are 52 Excel files in ASHRAE RP-884 database. Those files are categorized into three main types; naturally-ventilated buildings (NV), mixed mode buildings, and HVAC buildings. HVAC refers to buildings subjected to heating, ventilation, and air conditioning control system. This study focused on the analysis of NV buildings; therefore details pertaining to NV buildings were extracted as listed in Table 1. In the ASHRAE database, there were 22 studies conducted within the years from 1983 to 1996. Additionally, 15 Excel files were categorized under summer season and 7 Excel files were categorized under winter season. The building types are offices, residences, and schools.

After screening the information obtained from the RP-884 database, a total of 17 locations out of 22 Excel files were chosen. The selected locations are Berkeley, San Francisco, St. Helen, Liverpool, Oxford, Peshawar, Chester, Athens, Quetta, Saidu Sharif, Multan, Karachi, Bangkok, Singapore, Jakarta, Brisbane, and Melbourne. In this study, the Honolulu location was excluded (Study ID 21 and ID 22). This is because the respondents to thermal comfort study were school children [18]. This means that the validity of the thermal comfort prediction for adult is questionable. It is probably important to report that the data for the conducted survey in Liverpool and its surrounding areas (Study ID 18 and ID 19) were recorded at three places in the UK, namely; Liverpool, St. Helens, and Chester. Those locations belong to the west coast marine climate [19]. The surveyed buildings are naturally ventilated. Those were grouped under one location. It was named Liverpool. San Francisco and Berkeley are situated in the San Francisco Bay area (study ID 16, 17). In fact, the San Francisco Bay Area is a region in Northern California. The Geographic coordinates of San Francisco and Berkeley were determined separately. Similar procedure was followed for the case of Liverpool, St. Helen, and Chester.

ASHRAE RP-884 did not provide the geographic coordinates of the 17 survey locations; therefore, the identification of the coordinates of each location was made. Initially, an extensive research online was performed for the identification of each location. This is by referring to the original authors' publications. Most of those publications were accessible for free download in the web. There are few exceptions such as the case of Liverpool (Studies ID 18 and ID 19). Additionally only abstracts were accessible for articles pertaining to Brisbane (Study ID 3) and Melbourne (Study ID 4). Table 2 shows the location of survey sites. By referring to the survey locations, the geographic coordinates of the seventeen locations were identified as listed in Table 3 and plotted in Figure 3.

Table 1: Extraction and compilation of the data from RP-884 database

Study ID	Database ID	Locations	Survey Year	Season	B.T.
1	4	Bangkok, Thailand	1988	Summer	O
2	7	Jakarta, Indonesia	1993	Summer	O
3	12	Brisbane, Australia	1984	Summer	O
4	16	Melbourne, Australia	1983	Summer	O
5	18	Karachi, Pakistan	1993	Summer	R & O
6	19	Karachi, Pakistan	1994	Winter	R & O
7	20	Multan, Pakistan	1993	Summer	R & O
8	21	Peshawar, Pakistan	1993	Summer	R & O
9	22	Peshawar, Pakistan	1994	Winter	R & O
10	23	Quetta, Pakistan	1993	Summer	R & O
11	24	Quetta, Pakistan	1993, 1994	Winter	R & O
12	25	Saidu Sharif, Pakistan	1993	Summer	R & O
13	26	Saidu Sharif, Pakistan	1993, 1994	Winter	R & O
14	27	Athens, Greece	1993, 1994	Summer	R
15	28	Oxford, UK	1994	Summer	O
16	33	San Francisco Bay area, USA	1987	Summer	O
17	35	San Francisco Bay area, United States	1986, 1987	Winter	O
18	38	Liverpool and surrounding areas, UK	1994	Summer	O
19	39	Liverpool and surrounding areas, UK	1994, 1995	Winter	O
20	42	Singapore	1987	Summer	R
21	49	Honolulu, USA	1995	Summer	S
22	51	Honolulu, USA	1996	Winter	S

R stands for Residences, O stands for Office, S stands for School. Database ID refers to the Microsoft Excel file ID as in RP-884 database; B.T. refers to Building Type.

Table 2: Location of survey sites

SOP	RP-884	Original Authors		
Study ID	Location	Location	Ref.	Publication Accessibility
1	Bangkok, Thailand	Downtown, Bangkok	[20]	Accessible
2	Jakarta, Indonesia	Capital city of Jakarta	[21]	Accessible
3	Brisbane, Australia	Brisbane	[22]	Abstract accessible
			[23]	Thesis inaccessible
4	Melbourne, Australia	Melbourne	[22]	Abstract accessible
			[23]	Thesis inaccessible
5	Karachi, Pakistan	Karachi	[24]	Accessible
6	Karachi, Pakistan	Karachi	[24]	Accessible
7	Multan, Pakistan	Multan	[24]	Accessible
8	Peshawar, Pakistan	Peshawar	[24]	Accessible
9	Peshawar, Pakistan	Peshawar	[24]	Accessible
10	Quetta, Pakistan	Quetta	[24]	Accessible
11	Quetta, Pakistan	Quetta	[24]	Accessible
12	Saidu Sharif, Pakistan	Saidu Sharif	[24]	Accessible
13	Saidu Sharif, Pakistan	Saidu Sharif	[24]	Accessible
14	Athens, Greece	Athens	[25]	Accessible
15	Oxford, UK	Oxford University	[26]	Accessible
16	San Francisco and Berkeley, USA	San Francisco Bay	[27]	Accessible
17	San Francisco and Berkeley, USA	San Francisco Bay	[27]	Accessible
18	Liverpool, St. Helen and hester, UK	Not Available	[28, 29]	Article inaccessible
19	Liverpool, St. Helen and hester, UK	Not Available	[28, 29]	Article inaccessible
20	Singapore	Central business district of Singapore	[30]	Accessible

Accessibility refers to free accessibility in the Web via UMS during the investigation period; SOP refers to Source of Publication.

Table 3: Geographic coordinates of the surveyed locations

Study ID	Location of the Study	Latitude	Longitude
1	Bangkok, Thailand	13.75° N	100.47° E
2	Jakarta, Indonesia	6.20° S	106.80° E
3	Brisbane, Australia	27.47° S	152.03° E
4	Melbourne, Australia	37.82° S	144.96° E
5,6	Karachi, Pakistan	24.86° N	67.01° E
7	Multan, Pakistan	30.20° N	71.47° E
8,9	Peshawar, Pakistan	34.02° N	71.58° E
10,11	Quetta, Pakistan	30.21° N	67.02° E
12,13	Saidu Sharif, Pakistan	34.81° N	72.35° E
14	Athens, Greece	37.97° N	23.72° E
15	Oxford, United Kingdom	51.75° N	1.25° W
16,17	San Francisco, USA	37.78° N	122.42° W
16,17	Berkeley, USA	37.87° N	122.27° W
18,19	Liverpool, UK	53.40° N	3.00° W
18,19	St. Helen, UK	53.46° N	2.74° W
18,19	Chester, UK	53.19° N	2.89° W
20	Singapore	1.30° N	103.80° E

Fig. 3: Geographic locations of the survey sites

B. Climate Types in The ASHRAE RP-884 Database

The ASHRAE RP-884 classified the NV building locations into eight climate types. Those are cool semi desert, semi desert, dessert, hot humid, humid subtropical, Mediterranean, west coast marine, and wet equatorial. The climate types with the corresponding sites are listed in Table 4.

C. Identification of Climate Main Type of the Investigated Locations

In this section the main climate type of the selected study locations were identified through the Köppen-Geiger approach. Three procedures were used. Those are the Kottek world map [5], the Peel world map [12] and the New LocClim 1.10 software [13]. Kottek and Peel generated the climate world map by using the climatic data from 1951 to 2000. The situation is different with the New LocClim 1.10. It used the climatic data from 1961 to 1990. The discrepancy in the period year might lead to different climate classification.

Table 4: Climate types in the ASHRAE RP-884

Study ID	Survey Location	Climate Type
1	Bangkok, Thailand	Hot humid
2	Jakarta, Indonesia	Wet equatorial
20	Singapore	
3	Brisbane, Australia	Humid subtropical
4	Melbourne, Australia	West coast marine
15	Oxford, UK	
18, 19	Liverpool, St. Helen, Chester, UK	
5, 6	Karachi, Pakistan	Desert
7	Multan, Pakistan	
8, 9	Peshawar, Pakistan	Semi desert
12, 13	Saidu Sharif, Pakistan	
10, 11	Quetta, Pakistan	Cool semi desert
14	Athens, Greece	Mediterranean
16, 17	San Francisco, Berkeley, USA	

D. Identification of Climate Main Type from Kottek Climate World Map

The climate types of the locations under investigation were firstly identified via the Kottek world map. The identified climate main type for each location is listed in Table 5. The results showed that Jakarta, Bangkok and Singapore were subjected to climate type A. Those sites are situated within less than 15° of latitude above the equator. Generally, climate type A extends below and above the equator to about 15 to 25° of latitude.

Climate type A requires that all months have average temperatures above 18 °C. It is usually considered as tropical moist climates. According to ASHRAE RP-884 report, the climate of Bangkok is hot-humid. Jakarta and Singapore are subjected to wet equatorial climate. The present identification is in agreement with the investigation made by Mishra and Ramgopal [31] for those three locations.

Table 5: Climate classification from Kottek world map

Study ID	Location	Main Climate Type
1	Bangkok, Thailand	A
2	Jakarta, Indonesia	
20	Singapore	
5,6	Karachi, Pakistan	B
7	Multan, Pakistan	
8,9	Peshawar, Pakistan	
10,11	Quetta, Pakistan	
3	Brisbane, Australia	C
4	Melbourne, Australia	
12,13	Saidu Sharif, Pakistan	
14	Athens, Greece	
15	Oxford, United Kingdom	
16,17	San Francisco, USA	
16,17	Berkeley, USA	
18,19	Liverpool, United Kingdom	
18,19	St. Helen, United Kingdom	
18,19	Chester, United Kingdom	

Karachi, Multan, Peshawar, Quetta are four locations situated in Pakistan. In the Kottek world map, Karachi, Multan, Peshawar, and Quetta were classified under B climate. Climate type B is arid climate. Saidu Sharif was classified under climate type C. it is warm temperate climate. When referring to Sarfaraz, Arsalan, Fatima [32] in regionalizing the climate of Pakistan using the Köppen classification system, the authors identified Karachi, Multan and Peshawar under B climate, Quetta and Saidu Sharif under C climates. Their analysis was made by using the climatic data obtained from the Pakistan meteorological department. They reported that it was a quality controlled data from 1981 to 2010. So, the only difference between the present classification and their classifications is for the case of Quetta. By referring to the ASHRAE report, Karachi and Multan were categorized under desert climate. The climate of Peshawar was classified as semi desert, whereas the Quetta climate was classified as cool semi desert. Any desert climate is climate type B under the Köppen-Geiger classification [33].

Saidu Sharif was classified as semi desert in the ASHRAE RP-884. This means, that this location was categorized under climate type B. This is not in agreement with the Kottek classification.

The discrepancy could be attributed to several reasons. For instance, the Köppen world map cannot ensure precisely the survey locations at the map by the length scale estimation. The time period also can affect the classification. It has been reported that Pakistan is the only country in the world to have various range of altitudes. This gives it considerable variation in climate across its different areas. This is because there are considerable differences in air temperature due to large spread of latitude and diversity of relief with large spatial rainfall distribution [32]. This means that the climate classification of such region require very precise geographic coordinates and several meteorological stations to overcome any contradicting information. Unfortunately, this is not the case for Saidu Sharif. Therefore, the identification of climate type should be analyzed with precaution. Interestingly, the classification approach made by Sarfaraz, Arsalan, Fatima [32] for the Pakistan case was based on the Peel method. This probably explains the different outcomes for the case of Saidu Sharif.

Liverpool, Melbourne, Saidu Sharif, Athens, Oxford, San Francisco, and Berkeley were all identified under climate type C. ASHRAE RP-884 reported that Brisbane climate is humid subtropical; whereas Athens and San Francisco Bay areas is Mediterranean climate. For Melbourne, Oxford, Liverpool, the climate was classified under west coast marine climate. These three climates were grouped under climate type C in the Köppen-Geiger classification [34].

E. Identification of Climate Main Type from Peel Climate World Map

The main climate types of the investigated locations were also identified by using the Peel world map. Google Earth Pro for the Peel climate classification was considered. The analysis revealed that the results are similar to the Kottek results with the exception for Saidu Sharif. This location was classified under climate type B. The discrepancy in the classification of this location was discussed in the previous section.

F. Identification of Climate Main Type according to New LocClim 1.10 Classification

The climate types of the surveyed locations were also identified by using the New LocClim 1.10 software as listed in Table 6.

Table 6: Climate classification from the New LocClim 1.10 software

Study ID	Location	Main Climate Type
1	Bangkok, Thailand	A
20	Singapore	
2	Jakarta, Indonesia	B
5,6	Karachi, Pakistan	
7	Multan, Pakistan	
8,9	Peshawar, Pakistan	
10,11	Quetta, Pakistan	
14	Athens, Greece	
16,17	San Francisco, USA	
16,17	Berkeley, USA	
3	Brisbane, Australia	C
4	Melbourne, Australia	
12,13	Saidu Sharif, Pakistan	
15	Oxford, United Kingdom	
18,19	Liverpool, United Kingdom	
18,19	St. Helen, United Kingdom	
18,19	Chester, United Kingdom	

The analysed results from the New LocClim 1.10 software revealed that the climate types for Jakarta, Athens, San Francisco and Berkeley were different from the Kottek and Peel classifications. Further discussion of Saidu Sharif, Pakistan was not made as it was addressed in the previous section. Athens, San Francisco and Berkeley were classified as climate type B in the New LocClim 1.10 software. However, those were classified as climate type C in the Kottek and Peel world maps. This occurred probably due to the discrepancy in the climatic data used in the New LocClim 1.10.

The New LocClim 1.10 software classified Jakarta under climate type B. However, it was classified under climate type A in the Kottek and Peel world maps. It is not clear why the software classified Jakarta as climate type B. It is widely known that Jakarta city is subjected to warm and humid tropical climate [35]. It is located near the equator. In fact, the land condition of Jakarta is subjected to yearly flooding. The discrepancy of the results could be attributed to the climatic data used by the New LocClim 1.10 software or for other factors. The New LocClim 1.10 software uses an interpolation method for the prediction of the climate type of any location. This is by referring to the nearest meteorological stations [36, 37]. This probably will lead to erroneous classification for any location with limited meteorological stations. It depends on the topography of the location. The erroneous classification may also occur due to the lack of quality controlled climatic data. Further, the spatial interpolation method used by the New LocClim of temperature data has shown some limitations in a case study conducted in Pakistan [38].

G. Comparison of the Results from Various Methods

The results from Kottek, Peel and the New LocClim 1.10 software are summarized in this section. Table 7 lists the identified survey locations from various methods. It was observed that the climate classifications when considering all the applied procedures were mostly similar. However, the new LocClim 1.10 software provided different results in few locations. Those were discussed in the previous section.

Table 7: Survey locations under C climates

Study ID	Location	Kottek and Peel classification	New LocClim 1.10 software
3	Brisbane, Australia	C	C
4	Melbourne, Australia	C	C
12,13	Saidu Sharif, Pakistan	C (Kottek), B (Peel)	C
14	Athens, Greece	C	B
15	Oxford, United Kingdom	C	C
16,17	San Francisco, USA	C	B
16,17	Berkeley, USA	C	B
18,19	Liverpool, United Kingdom	C	C
18,19	St. Helen, United Kingdom	C	C
18,19	Chester, United Kingdom	C	C
2	Jakarta, Indonesia	A	B
1	Bangkok, Thailand	A	A
5,6	Karachi, Pakistan	B	B
7	Multan, Pakistan	B	B
8,9	Peshawar, Pakistan	B	B
10,11	Quetta, Pakistan	B	B
20	Singapore	A	A

IV. CONCLUSIONS

This investigation addressed Climate Types of ASHRAE RP-884 Database for Naturally Ventilated Buildings by using three tools. Those are Kottek and Peel updated maps of Köppen-Geiger and the New LocClim 1.10 software. Each site location was identified. Similar results were obtained when considering Kottek and Peel updated maps except for the case of Saidu Sharif, Pakistan. This was traced back to the various ranges of altitudes in this location. The climate classification of such region probably requires very precise geographic coordinates and several meteorological stations. Few contradicting results were also noted when using the New LocClim 1.10 software as opposed to Kottek and Peel updated maps. The erroneous classification probably occurred due to the lack of quality controlled climatic data in this software. Therefore, it should be used with caution.

ACKNOWLEDGMENT

This research was supported by the Fundamental Research Grant Scheme, FRG0363-TK-2014, Ministry of Higher Education, Malaysia, FRG0363-TK-1/2014.

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