Five Locations to Represent World Climates

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ABSTRACT: In the pioneering book of Victor Olgyay "Design with Climate", 1963, he selected four American cities to represent four distinct climatic regions. Since then, the same four American cities have been used in other publications to represent the four distinct climatic regions: hot-humid, hot-arid, temperate, and cold. This paper presents a model to select international cities to represent the world's distinct climatic regions. Indeed, the two major climatic influences on buildings' environmental performance are solar radiation and outside temperature. Consequently, a meaningful representation of world climates should equally consider the geographic location (latitude) and global distribution of ambient temperatures. In the suggested model, three locations were selected within each of the five world climatic zones. Then, a set of criteria is used to narrow the selection by eliminating locations that do not meet certain conditions. In accordance with the published climatic data and in reference to ASHRAE classification of world climates, the five representative locations were found to be: Singapore (tropical), Cairo (hot-arid), Milan (temperate), Ft. Smith (cold), and Resolute (polar). The paper suggests that these five cities be used as reference to world climates and to establish distinct sets of regional bioclimatic recommendations for the design of buildings.

Keywords: climate, bio-climatic analysis, bio-climatic design, design strategies

1. INTRODUCTION

In the field of bioclimatic design, comparisons are often made between strategies that are appropriate for different climates. Being focused on North America, early bioclimatic research made a reference to climatic regions that exist within the North American continent. In his pioneering book "Design with Climate", 1963, Victor Olgyay selected four American cities to represent four distinct climatic regions, which are: City of Minneapolis, MN (cold), New York, NY – New Jersey, NJ area (temperate), City of Phoenix, AZ (hot-arid), and City of Miami, FL (hot-humid) [1]. This paper presents a model to select international cities to represent the world's distinct climatic regions.

2. WORLD CLIMATES

According to the meteorological data and studies, the world's distinct climatic regions are five (and not four), which are: (1) tropical, (2) sub-tropical, (3) temperate, (4) sub-polar, and (5) polar. These five climatic regions cover the two hemispheres, north and south, respectively from the equator to the pole. However, in most bioclimatic literature, the polar region is usually ignored or excluded. Because the polar region is almost uninhibited, it receives much less attention than other regions.

In order to select international cities to serve as representative locations for the five World's distinct climates, an initial selection is made based on the two major factors that make local climate, i.e., outdoor temperature and solar radiation. Then, the selection process excluded locations that are affected by non-typical characteristics that may significantly modify the macro-climatic conditions of the encompassing region. This selection process is explained in the following sections.

3. INITIAL SELECTION

3.1 Envelope load as a criterion

In bioclimatic comparisons (between different locations), envelope load is the load component that makes a difference in the environmental performance of buildings. Envelope load occurs mainly due to two climatic factors, which are: (1) outdoor temperature and (2) solar radiation. That is why in this initial selection phase, the objective is to pick candidate locations that cover a full range of distribution of these two factors from the Equator to the Pole.

3.2 Candidate Locations

The candidate locations were selected to exhibit an even geographic distribution of the recorded weather data in the Northern Hemisphere. These locations are selected on 15 degrees increments in latitude angles starting from the equator, i.e., 0^o, 15^o, 30^o, 45^o, 60^o, and 75^o NL. These intervals do also coincide with mid latitudes of climate belts that run parallel to the equator [2]. At each latitude circle, the atmosphere has a certain thickness that gradually decreases from equator to pole, which is a fact that significantly affects local solar intensities at sea level due to the filtration effect of the atmosphere.

All chosen cities lie in the Northern Hemisphere. Locations close to latitude 15^o NL are excluded since they are still within the tropical belt. Three candidate locations are selected for each climatic region thereof,

with the exception of the polar region where recorded data is rarely available. Candidate locations are listed in Table 1.

All data in Table 1 is obtained from published climatic data in ASHRAE Standard 90.1, 2001. [3]

Table 1: Candidate locations to represent the five climatic regions of the World.

Region & Location	Continent	LAT*	ELEV*
Tropical			
Singapore	Asia	1.37	15
Belem	S. America	1.43	24
Nairobi	Africa	1.32	1,625
Sub-Tropical			
Cairo	Africa	30.13	74
Phoenix	N. America	33.43	339
Tucson	N. America	32.13	788
Temperate			
Burlington	N. America	44.47	101
Milan	Europe	45.43	107
Lyon	Europe	45.73	248
Sub-Polar			
Ft. Smith	N. America	60.02	203
Oslo	Europe	59.90	16
Stockholm	Europe	59.65	61
Polar			
Resolute	N. America	74.72	67

* Latitudes are all North latitudes, and Elevation is given in meters above see level.

3.3 Climatic regions

Hypothetically, each group of cities in Table 1 share the same macroclimate of the climatic region. That is why buildings, in the same region, are initially expected to perform in a similar manner.

In the tropical region, all cities lie within the tropical belt between the equator and 23.5^{o} NL. The climate in this region is mainly hot-humid because of the large bodies of water around the equator. Very high precipitation levels are due to humid air ascending to higher and colder latitudes. Solar radiation is very intense and does alternate from north to south. Solar altitudes are always higher than 60 degrees at noon all year round. That is why in this region, sol-air temperature on roofs is much higher than on vertical walls.

In the sub-tropical region, all cities lie within the sub-tropical belt just outside of the tropics. The climate is hot-arid. Solar radiation comes mainly from the equator side. Solar altitudes reach high angles (more than 45 degrees) at noontime during summer, fall and spring months.

In the temperate region, all cities lie between the subtropical belt and the polar circle. Solar radiation comes mainly from the equator side. Solar latitudes at noontime are high (higher than 45 degrees) during summer months, 45 degrees in the two equinoxes, and low (lower than 45 degrees) during winter months. Solar radiation alternates from roofs to walls depending on the season.

In the sub-polar region, all cities lie close to, but outside of, the polar circle. The climate is cool. Solar latitudes are low (lower than 45 degrees) year round. Solar radiation comes from the equator side.

In the polar region, The City of Resolute lies inside the Polar Circle. The climate is extremely cold with very low solar altitudes when the sun is visible.

4. ELIMINATION OF NON-REPRESENTATIVE LOCATIONS

Second step is to eliminate cities at locations where the macroclimate is significantly modified by geographic factors that may affect the typical temperature fluctuation and/or the intensity of solar radiation in the region. This elimination process ended with the confirmation of only one city to represent each climatic region.

4.1 Elimination based on elevation

As seen in Table 1, some cities are located on high altitudes that create a unique meso-climate for the location that is not native to the region. Based on this criterion, the following cities were eliminated from the candidates list: Nairobi (Kenya, Africa), Phoenix (Arizona, USA, N. America), Tucson (Arizona, USA, N. America), and Lyon (France, Europe).

4.2 Elimination based on proximity to large bodies of water or mountains

According to the World's Atlas, some cities in Table 1 lie close to large bodies of water or close to mountainous areas. Proximity to large bodies of water modifies the temperature fluctuation profiles and wind patterns. Proximity to mountainous areas affects wind patterns and directions.

Based on this criterion, the following costal cities were eliminated from the list: Belem (Brazil, S. America), Burlington (Vermont, USA, N. America), Oslo (Norway, Europe), and Stockholm (Sweden, Europe).

Table 2: Selected locations to represent the five climatic regions of the World.

Region & Location		Continent	LAT*	ELEV*
Hot-Humid				
	Singapore	Asia	1.37	15
Hot-Arid				
	Cairo	Africa	30.13	74
Temperate				
	Milan	Europe	45.43	107
Cold				
	Ft. Smith	N. America	60.02	203
Polar				
	Resolute	N. America	74.72	67

* Latitudes are all North latitudes, and Elevation is given in meters above see level.

The tropical belt is a humid region and most of the large cities within the belt are costal cities or close to large bodies of water. That is why Singapore is not eliminated from the list and considered an appropriate representative location for the hot humid climate.

Figure 1 shows locations of the selected five representative locations.

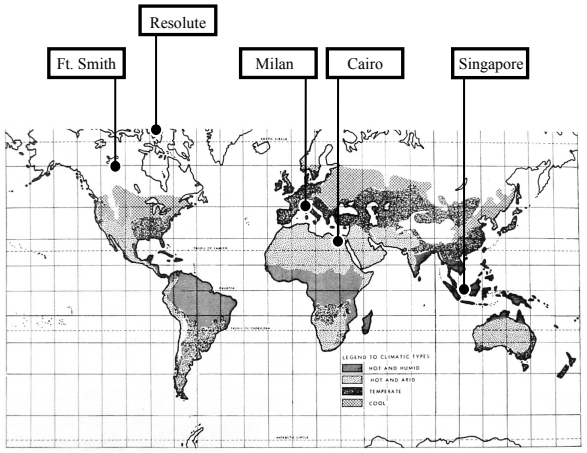

Figure 1: World climatic zones according to Koppen. Source: Olgyay, 1963, p. 6

5. OTHER CLIMATE CLASSIFICATIONS

The five selected locations fit relatively well with other climate classifications and the distribution of measured solar irradiance.

5.1 Koppen map

Figure 1 shows the distribution of the world's climate zones according to Koppen. Using the relationship between climate and vegetation as a criterion, Koppen determined five basic climate zones, which are: (1) tropical-rainy, (2) dry, (3) warm-temperate, (4) cool-snow-forest, and (5) polar.

According to Koppen, Singapore lies in the tropical-rainy region; Cairo lies in the dry region; Milan lies in the warm-temperate region; and both Ft. Smith and Resolute lie in the polar region.

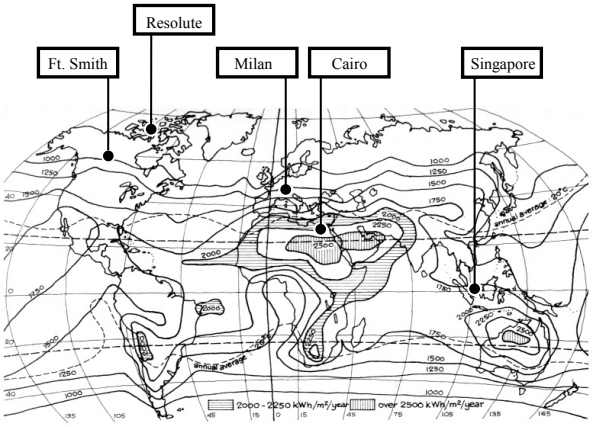

Figure 2: World distribution of mean annual solar radiation in kWh/m^2.yr on a horizontal surface at ground level. Source: Konya, 1980, p. 13

5.2 Annual solar radiation

Figure 2 shows the world distribution of mean annual solar radiation on a horizontal surface at the ground level [4].

The five suggested cities depict a gradual drop in the intensity of solar radiation from the Equator to the North Pole. The highest solar irradiance occurs in the African Sahara and in the Arabian Desert where there is no suggested representative locations.

5.3 ASHRAE climate classification

The five selected locations cover the full range of the need for heating and cooling. Table 3 shows that these cities cover the full range from no need for heating (Singapore) to no need for cooling (Resolute). However, the data shows a dramatic change in the need for heating and cooling within the boundaries of the temperate climate zone, since there is a significant difference in HDD & CDD between the Hot-Arid region (Cairo) and the Cold region (Ft. Smith).

Table 3: HDD18 & CDD10 for the five selected locations.

Location	ASHRAE table*	HDD18	CDD10
Singapore	B-1	0	6,664
Cairo	B-3	463	4,440
Milan	B-14	2,504	1,853
Ft. Smith	B-24	7,884	518
Resolute	B-26	12,702	0

* Table numbers refer to the building envelope requirements tables in ASHRAE Standard 90.1.
Base temperatures for HDD & CDD are in ^{o}C.

6. CONCLUSION

The five suggested cities can be used in the bioclimatic studies as reference locations for the five world climates. Because these locations are well distributed between the continents and longitudes, they represent very well the world climate and not only climates within the North American continent.

Comparative studies, which compare building performance in a variety of climates, may use these five locations to demonstrate the wide range of diversity in world climates.

However, these five locations do not cover the extreme hot arid areas in the world that are mainly concentrated in Africa and southwest Asia, with some pockets in Australia and South America.

Further research is needed to detect the internal variations within each climatic region, especially the temperate region, which is the most populated climate region in the world.

The need for heating and cooling changes dramatically within the temperate climate zone, that is why it would be a good idea to establish two more climate zones, which are: temperate-cool and temperate-hot. If so, then world climate would be represented in gradual increments of change.

REFERENCES

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