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〈Research Article〉

A Tourism Climate Index for Tokyo Summer:
Modifying the HCI:urban to Hot and Humid Conditions

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Abstract

Climate comfort is an essential component of destination attractiveness and a key driver of a destination's tourism economy. The measurement of tourism climate via indices such as the Holiday Climate Index (HCI:urban) is thus of great importance to urban locations like Tokyo that, before the Covid-19 pandemic, had burgeoning international tourism profiles. This importance has been amplified by global heating which has caused the already thermally severe Tokyo summertime climate to deteriorate and increase tourism's vulnerability to heat stress. Employing a confidence interval analysis technique, the current research proposes a modification to the HCI:urban such that Tokyo's inherent summertime heat is internalized into the index resulting in a more representative estimate of the city's tourism climate. Calibration of a new rating scale for conditions equal to, or greater than, Humidex 39 has produced a derivative tourism climate index, the HCI:urban Tokyo Summer (HCI:$urban_{TS}$), which may be better suited to evaluate Tokyo's tourism climate. Longitudinal data analysis using the derivative index suggests the city's summertime tourism climate should be downrated from the current 'tolerable' to 'intolerable'. Possible means to validate the new index are discussed.

Key words: Tourism Climate Index, Urban Tourism, Global Warming/Heating, Tokyo Summer Climate

1. Introduction

Tourism is one of the world's leading economic activities contributing a 10.4% share to global GDP while supporting 334 million jobs worldwide (WTTC, 2020). In the 10 years prior to the Covid-19 pandemic international tourist arrivals grew by 4-5% per annum to reach 1.5 billion globally, but in some destinations such as Tokyo the growth rate has been even greater. Between 2012 and 2019 inbound visitor numbers to Tokyo grew 3-fold to 15.2 million to make the Japanese capital one of the world's most visited urban destinations (Tokyo Metropolitan Government, 2020). Tokyo offers a vast array of cultural and urban attractions, but for many travelers it is the city's distinct four seasons that are the biggest draw (Xu and Tavitiyaman, 2016). In recent years however as “global heating” advances (United Nations, 2019) the likelihood of more extreme summertime conditions increases (Robine, Cheung, LeRoy et al., 2008; WMO 2019) and the Japanese capital, already considered too hot for most visitors in summer (MLIT, 2019; Watts, 2021), may find conditions worsen further.

As a key attribute of destination attractiveness (Hu and Ritchie, 1993) climate is an important natural resource for tourism (Scott, Rutty, Amelung et al., 2016) and acts to ‘pull’ visitors to a destination (Dann, 1981). Equally, climate can also limit tourism activities temporally and spatially and is a known cause of seasonality of tourism demand (Butler, 1994). Tourist activities can thus be considered as “highly dependent” on the prevailing weather and climate of a destination (Grillakis, Koutroulis, Seiradakis et al., 2016). As the scientific consensus on global heating has become “unequivocal” (IPCC, 2021), evidence from tourism studies indicates that more extreme thermal conditions are already starting to limit the temporal and spatial distribution of outdoor activities in locations around the world (Rutty and Scott, 2010; Orosa, Costa et al, 2014; Lukic, Pecelj, Protic et al., 2019; Matthews, 2018; Demiroglu, Saygili, Pacal et al., 2020; Rutty, Scott, Matthews et al., 2020). If tourism is to be an economically sustainable and safe activity there is thus an urgent need to better understand climate as a tourism resource by measuring its impact with greater accuracy. This is particularly true for cities like Tokyo which have invested heavily in tourism (JETRO, 2021) and already experience summertime conditions which research considers as “unacceptably hot” (Rutty et al., 2010).

Global heating has already led to an increase in summertime heat-related health risks in Tokyo (Shimpo, Takemura, Wakamatsu et al., 2019) and heat stress indices such as the Wet Bulb Globe Temperature (WBGT) and Humidex (Hu) indicate there is inherent danger in the city’s summertime climate (Japan, NIES, 2021). This is reflected in heatstroke-induced hospital admissions (Kasai, Okaze, Yamamoto et al., 2017) which have increased by an average 4000 persons per year nationwide since 2014 (FDMA, 2021). Heat and humidity concerns also affected preparations and events of the Tokyo 2020 Olympics (BBC, 2021; Wu, Graw and Matzarakis, 2020), and have cast doubts on the viability of future global megaevents in heat stressed urban locations (Matzarakis and Frohlich, 2014; Smith, Woodward, Lemke et al., 2016). Despite clear public health messaging (Sanchez-Martinez, Imai and Masumo, 2011; FDMA, 2021), public space adaptation (Ohashi, Ihara, Kikegawa et al., 2014), and visitor-focused information on extreme summertime conditions (MLIT, 2017), the role of climate on Tokyo tourism has received relatively limited scholarly attention.

Studies that have examined the tourist climate in Japan include those of Ichinose, Matuschek, and Jing (2008) who provide a historical overview of previous climate biometeorological in Japan, and Matzarakis (2008), who produced physiological equivalent temperature (PET) maps for the country as whole. Though these studies provide valuable insights for the current research neither are specific to Tokyo and as global heating progresses so their findings become increasingly outdated. Other studies such as Kubokawa, Inoue and Satoh (2014) focused on likely future climate scenarios nationwide rather than on contemporary climate in the country's most visited urban centre. The staging of the 2020 Tokyo Olympics heralded new interest in the city's climate particularly in relation to the negative effects of summer heat on athletes and spectators (Kakamu, Wada, Smith et al., 2017; Honjo, Yuhwan, Yamasaki et al., 2018; Garrett, Kingman, Sluijter et al., 2019; Matzarakis, Frohlich, Bermon et al., 2019) but did not address tourist activity directly nor employ a tourism climate index such as the Holiday Climate Index (Scott, Rutty, Amelung et al., 2016) in their assessments.

The aim of the current study is thus to fill some of the paucity of knowledge in Tokyo's tourism climate and, by using the Humidex heat index and the Holiday Climate Index (HCI:urban) examine the thermal characteristics of Tokyo's summertime tourism climate with a view to developing a new index that is more relevant to the city. In doing so it is hoped that a tool can be produced which can more accurately inform tourists and tourism practitioners of Tokyo's summertime tourism climate and, by extension, the tourism climate of climatically synonymous urban tourism centers.

2. Tourism Climate Indices

Over the past 40 years a range of tourism climate indices have been developed to determine the suitability of a destination's climate for tourism. These indices combine the climate parameters (generally air temperature, relative humidity, precipitation, cloud cover/sunshine and wind speed) considered the most significant to tourist comfort into a simple to compute, and easy to interpret numerical figure. The best-known indices include the Tourist Climate Index (Mieczkowski, 1985), the Beach Climate Index (Morgan et al., 2000), the Climate Index for Tourism (de Freitas, Scott and McBoyle, 2009), the Holiday Climate Index (Scott et al., 2016), and the Relative Climate Index (Li, Goh et al., 2017). Although the Tourism Climate Index (TCI) remains popular with researchers, in recent years the Holiday Climate Index (HCI) is being increasingly employed in tourism climate studies worldwide (Scott et al., 2016; Mahtabi and Taran, 2018; Hejazizadeh, Karbalaee, Hosseini et al., 2019; Demiroglu et al., 2020; Rutty et al., 2020; Yu, Rutty, Scott et al., 2020) and is the index of choice for the current study.

Most tourism climate indices employ a variable weighting scale and a component rating system to ascribe values to each climate parameter (HCI:urban shown in Tables 1 and 2) with the index value for each period of time being calculated via an additive equation (HCI is given in (1)). The resultant index value corresponds to a descriptive rating such as shown for the HCI:urban (Table 3) for which a score of 90 or more denotes "ideal" tourism conditions and a score of less than 20 indicates "dangerous" ones.

Other indices, particularly in the field of thermal comfort, such as the Standard Effective Temperature (SET), Physiologically Equivalent Temperature (PET) and PMV (Predicted Mean Vote) have also been successfully employed in tourism biometeorological studies (Matzarakis, 2008; Lin and Matzarakis, 2011; Makaremi et al., 2012; Matzarakis et al., 2019; Wu et al., 2020). However, as these indices fail to internalize the specific preferences of travelers, such as the effect of aesthetic factors (de Freitas, 2003; Rutty et al., 2020), and utilize less easily accessible meteorological parameters such as the mean radiant temperature, or require the adjustment of weather data (Zare, Hasheminejad, Shirvan, et al., 2018) they are not considered here. A further index, the Wet Bulb Globe Temperature (WBGT), combines air temperature, humidity, wind velocity and solar insolation and is used extensively as a metric for outdoor summertime heat stress in Japan (Kakamu et al., 2017; Kasai et al., 2017). The WBGT has been shown to have excellent concordance with Humidex under hot and humid urban conditions (Zare et al., 2018: Heo and Bell, 2018) and is employed in the current study to calibrate the HCI:urban thermal scale with respect to Humidex (see 7).

3. The Holiday Climate Index (HCI) and Humidex

3.1 The Holiday Climate Index (HCI)

The Holiday Climate Index (HCI) is a tourism climate index developed from critical research into Mieczkowski's 1985 Tourism Climate Index (TCI) for which key design flaws were discovered. These included an arbitrary weighting system of climate variables, poor temporal resolution and an overweighting of the thermal component (Scott et al., 2016). The TCI is also unable to take account of aesthetic facets of climate (cloud cover), and the over-riding effect of physical parameters such as heavy rain on tourism climate conditions (de Freitas, 2003). The HCI is the result of research to resolve these issues (Scott et al., 2016; Matthews et al., 2019; Rutty et al., 2020) and since an urban tourism version of the index was developed (HCI:urban) it is perhaps the most relevant index to measure Tokyo's tourism climate.

Table 1. Holiday Climate Index Variable Weighting System

Index Component	Weather Variable	HCI:Urban
Thermal comfort (TC)	Temp & relative humidity	40%
Aesthetic (A)	Cloud cover (%)	20%
Precipitation (P)	Total precipitation (mm)	30%
Wind (W)	Mean wind speed (m/s)	10%
Overall index score range		0 to 100

$$\text{HCI:urban} = 4*TC + 2*A + 3(\text{precipitation}) + \text{wind} \quad (1)$$

Table 2. Holiday Climate Index Components Rating System

Rating	**Humidex Value (C)**	**Mean Daily Precipitation (mm)**	**Mean Cloud Cover (%)**	**Mean Wind Speed (km/hr)**
10	23.0-25.9	0	11-20.9	0.1-9.9
9	20-22.9 / 26.0-26.9	0.01-2.99	1.0-10.9	10.0-19.9
8	27.0-28.9	3.00-5.99	0-0.9 and 31-40.9	0.0 and 20.0-29.9
7	18-19.9 / 29.0-30.9	-	41-50.9	-
6	15-17.9 / 31.0-32.9	-	51-60.9	30.0-39.9
5	33.0-34.9	6.00-8.99	61-70.9	-
4	35.0-36.9	-	71-80.9	-
3	-	-	81-90.9	40.0-49.9
2	37.0-38.9	9.00-11.99	91-99.9	-
1	-	-	100	-
0	≥39.0	12.00-24.99	-	50.0-69.9
-1	X	≥25	-	≥70

Source: Scott, Rutty, Amelung and Tang (2016)

Table 3. Holiday Climate Index (HCI:urban) Rating System

Score	**Descriptive Rating**
90 - 100	Ideal
80 - 89	Excellent
70 - 79	Very good
60 - 69	Good
50 - 59	Acceptable
40 - 49	Marginal
30 - 39	Unacceptable
20 - 29	
10 - 19	Dangerous
0 - 9	

3.2 Humidex

Developed by Masterton and Richardson (1979), Humidex (*Hu*) is a summertime heat index which combines air temperature (T) and relative humidity (R_H) to describe thermal conditions. Being based on dew point temperature, Humidex indicates how thermal conditions actually feel. It is represented by equation (2) where Humidex = T + 5/9(e-10) with vapor pressure (e) being calculated using e_{sat} (hPa) based on Tetens formula (see Infusino, Caloiero, Fusto et al, 2021).

$$\text{Humidex } (Hu) = T + \frac{5}{9} \times \left(\left(6.112 \times 10^{\frac{7.5 \times T}{237.7+T}} \times \frac{R_H}{100} \right) - 10 \right) \quad (2)$$

Humidex is a dimensionless scale but corresponds with ºC which can make it easier to interpret over other indices such as WBGT. The Canadian Meteorological Service uses Humidex to describe levels of comfort with *Hu*<30 considered as offering "little or no discomfort" and *Hu*>=55 as a threshold for "probable heatstroke" (Table 4). Demiroglu et al. (2020) defined "Humidex-Dangerous" conditions as *Hu*>=45 which the current study adopts together with *Hu*>=50 ("Humidex-Very Dangerous") as two critical thermal datum. It is known that thermal comfort varies across cultures and levels of acclimation (Mansfield et al., 2007; Ichinose et al., 2008; Lin and Matzarakis, 2011; Marekami et al., 2012; Hidayati and Banja, 2018) and as Masterton and Richardson (1979) propose two parallel Humidex scales - for non-acclimated and acclimated individuals - the index can help evaluate the comfort level of tourists from different climatic origins. Humidex has been employed to assess tourism climate in locations as diverse as the Caribbean (Rutty et al., 2020), N. America (Matthews et al., 2019), mainland Europe (Orosa et al., 2014; Scott et al., 2016; Lukic et al., 2019), the Eastern Mediterranean (Demiroglu et al., 2020) and Asia (Mahtabi and Taran, 2018; Yu et al., 2020).

Table 4: Humidex Comfort Levels (after Masterton and Richardson, 1979)

Hu	***Level of comfort***		***Outcome***
	Non-acclimated persons	**Acclimated persons**	
>=55	Heatstroke probable	Heatstroke possible/probable	Heatstroke unavoidable if activity continues
50-54	Heatstroke possible	Dangerous discomfort (stop activity)	Prolonged physical activity can lead to heat stroke
45-49	Dangerous discomfort (stop activity)	Intense discomfort (avoid exertion)	
40-44	Intense discomfort (avoid exertion)	Evident discomfort	Avoid strenuous physical activity
35-39	Evident discomfort	Noticeable discomfort	Heat exhaustion possible if physical activity prolonged
30-34	Noticeable discomfort	Little/No discomfort	
<30	Little/No discomfort	Little/No discomfort	Fatigue with prolonged physical activity possible

4. Tokyo's Summertime Climate

Tokyo is located on the eastern side of Japan's main island Honshu at approximately 35° 41'N and 139° 45'E. The city's climate is classified as Cfa "humid subtropical" by the Koppen classification, but with a one-month seasonal lag making August the warmest month (as a result, 'summertime' in the current study is classified as July, August and September (JAS) rather than the WMO standard of June, July and August (JJA)). Based on the 1991-2020 average, mean JAS air temperature is 26°C, with a mean maximum of 29.7°C (Aug=31.5°C). Thermal discomfort is accentuated throughout JAS by high relative humidity (mean=73%) and mean maximum *Hu*=41 (Aug=44). Daily *Hu* values in excess of 50 are commonly recorded in all three JAS months. Cloud cover is generally in the range 74-80% and even though mean precipitation is 535mm for the three-month period, wet days (>10mm/day) occur on less than 20% of JAS days. The city experiences 5-6 (mostly) weak typhoons each year.

5. Method

The current study employed meteorological data (daily air temperature (*Ta*), relative humidity (*RH*), rainfall (*R*), cloud cover (*C*) and wind speed (*W*)) from the publicly available online records of the Japan Meteorological Organization (JMO) Otemachi, Tokyo for 1991-2020 (*Ta* records from 1961 were included in part). Otemachi weather station (35° 41.5", 139° 45") was selected due to the comprehensiveness of its climate record and its geographical proximity to places tourists frequent in Tokyo. Holiday Climate Index (HCI:urban) values at a temporal scale of 24 hours were calculated via equation (1) and thermal comfort by Humidex (2). The data was processed using the excel application. The key research aims were:

1) Examine the thermal profile of, and any changes in, Tokyo's JAS climate 1991-2020.
2) Use the HCI:urban to describe changes in Tokyo's JAS tourism climate.
3) Use WBGT and Humidex to recalibrate the HCI:urban's thermal rating system.
4) Present and discuss the modified HCI:urban for Tokyo JAS.

First, to assess current thermal conditions in Tokyo, and any longitudinal changes, the daily maximum, mean and minimum air temperatures for 1961-1990 and 1991-2020 were compared, and the frequency of *moushobi* "extremely hot days" (*Ta* max >35°C) and *nettaiya* "tropical nights" (*Ta* min >25°C) charted. Daily Humidex values (*Hu*) were calculated for JAS between 1991 and 2020 (N=2760) and a ratio plot of thermal conditions constructed to indicate the longitudinal distribution of "Humidex-Dangerous" (*Hu*>=45) and "Humidex Very Dangerous" (*Hu*>=50) days. In order to compare HCI:urban-defined "dangerous" conditions with Humidex dangerous days, daily HCI:urban values for the 30-year period were calculated using (1) and a year-by year distribution of “dangerous” HCI:urban days (HCI<20) established. Finally, to modify the HCI:urban thermal component rating scheme, known maximum daily WBGT values were plotted against calculated Humidex values and based on Frost (2020) confidence interval analysis performed to recalibrate the index’s thermal component for Humidex>=39. Parametric and post hoc tests were carried out to help validate the modified rating scale.

6. Results

6.1 Tokyo JAS Air Temperature

The JMO air temperature (*Ta*) record indicates Tokyo JAS climate is changing. This is shown by the increase in mean *Ta* for all three months (July, +1.1ºC; Aug +0.5ºC; Sep +0.9ºC) when comparing 1961-90 with 1991-2020. A similar trend towards higher temperatures is repeated for mean daily *Ta maxima* (July +0.2ºC (28.8-30ºC), Aug +0.6ºC (30.9-31.5ºC) and Sept +1ºC (26.7-27.7ºC)), and mean daily *minima Ta* (July +1.1ºC (22.3-23.4ºC), Aug +0.6ºC (24-24.6ºC) and Sept +1ºC (20.2-21.2ºC)) between the two 30-year periods (Table 5).

Table 5: Tokyo Mean Air Temperatures (*Ta*) (1961-1990 and 1991-2020)

	July		August		Sept	
	1961/90	1991/2020	1961/90	1991/2020	1961/90	1991/2020
Max Ta	28.8	30	30.9	31.5	26.7	27.7
Min Ta	22.3	23.4	24	24.6	20.2	21.2
Mean Ta	25.2	26.3	27.1	27.6	23.2	24.1
	Mean increase +1.1ºC		**Mean increase +0.5ºC**		**Mean increase +0.9ºC**	

In tandem with changes in *Ta,* the frequency of *moushobi* (Tmax>=35ºC*)* and *nettaiya* (Tmin>=25ºC) has also increased between the two 30-year periods. Between 1961 and 1990, 46 *moushobi* (mean=1.5 days/year) and 540 *nettaiya* (18 nights/year) were recorded but between 1991-2020 these grew significantly to 161 days (+350%, 5.4 days/year) and 898 nights (+66%, 30 nights/year) respectively (Figure 1).

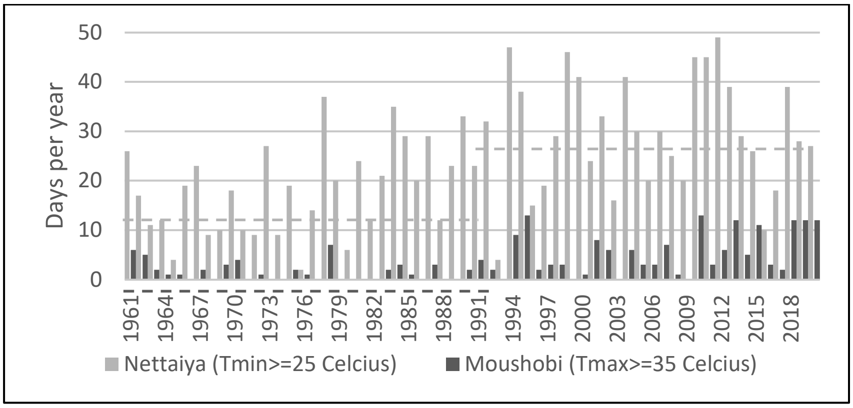

Figure 1: Frequency of *Nettaiya* and *Moushobi* in Tokyo (1961-2020)

6.2 Tokyo JAS Humidex

Although changes in *Ta* described in 6.1 are significant, the role of relative humidity (*RH*) in determining thermal comfort also needs to be considered (Makaremi et al., 2012; Villadiego and Velay-Dabat, 2014; Lukic et al., 2019). This is shown in Figure 2 and Table 6 which describe the 30-year Humidex record calculated using (2).

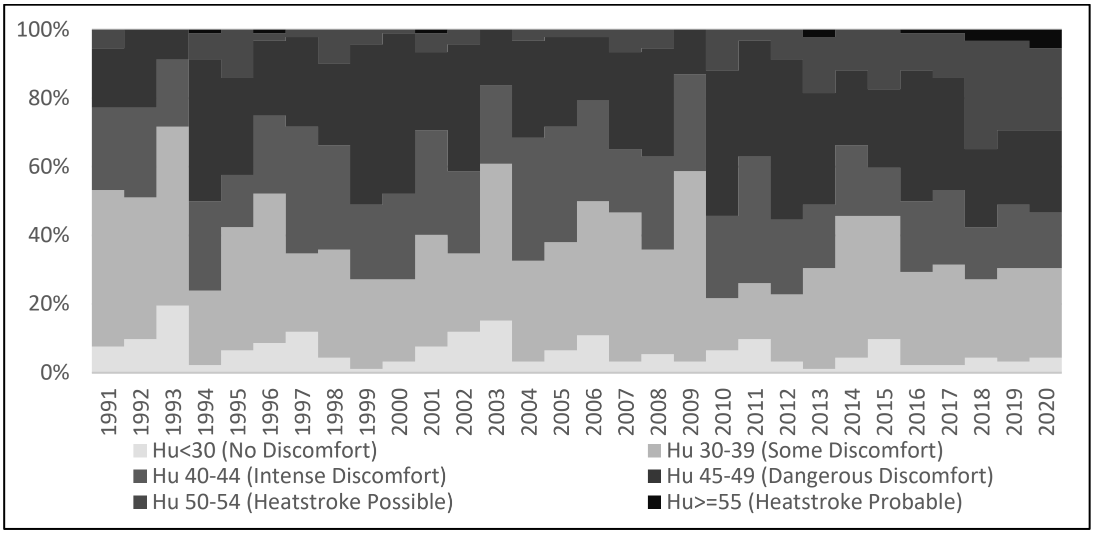

Figure 2: Tokyo JAS Daily Maximum Humidex 1991-2020 (N=2760)

Figure 2 shows the ratio plot of 6 Humidex categories from *Hu*<=30 ('No Discomfort') to *Hu*>=55 ('Heatstroke Probable') for Tokyo JAS 1991-2020. The majority of days are described as having 'Intense Discomfort' or worse (*Hu*>=40), with an increase in the ratio of Humidex-Dangerous days (*Hu*>=45) from around 20% of days in the early 1990s to 50% today, and in Humidex-Very Dangerous days (*Hu*>=50) from less than 5% to around 30% today. In the most recent decade (2011-2020) mean

JAS Humidex has reached *Hu*43 (July=43; Aug=47; Sep=39) 2C above the 1991-2020 average (Table 6). Mirroring these changes, Humidex Non-Dangerous Days, or days of 'No discomfort' (*Hu*<30) or 'Noticeable /evident discomfort' (*Hu*=30-39) have *decreased* from about 50% of days (1990s) to around 30% today.

Table 6: Tokyo JAS Humidex-Dangerous days (1991-2020 and 2011-2020)

	JAS mean		July		Aug		Sep	
	1991-2020	2011-2020	1991-2020	2011-2020	1991-2020	2011-2020	1991-2020	2011-2020
Mean Humidex	41	43	42	43	44	47	37	39
1. Humidex Non-Dangerous (Hu <= 39) Total days/year	35.5	29.4	10.7	8.5	5.9	4.1	18.9	16.8
2. Humidex Dangerous (Hu = 45-49) days/year	25.9	27.3	9.4	9.9	12.4	12.0	4.1	5.0
3. Humidex Very Dangerous (Hu >= 50) days/year	8.3	16.5	2.7	5.2	5.1	10.2	0.5	1.1
4. Total (2 + 3) (Hu >= 45) Total days/year	**34.2**	**43.8**	**12.1**	**15.1**	**17.5**	**22.2**	**4.6**	**6.1**

Table 6 shows the frequency of four different Humidex ranges (*Hu*<=39; *Hu*=45-49; *Hu*>=45; *Hu*>=50) for 1991-2020 and the most recent decade (2011-2020). As described in Figure 2 there is an overall increase in Humidex values for the JAS period as a whole and for each month individually. The recent deterioration in thermal conditions is however perhaps best characterized by the average 43.8 days per year on which Humidex-Dangerous conditions prevailed in 2011-2020 (a 28% increase on the 30-year mean). Of these days 16.5 days were Humidex-Very Dangerous (*Hu*>=50) a +99% increase on 1991-2020. Deterioration of conditions is apparent in all three JAS months with August recording the highest frequency of Humidex-Dangerous and Humidex-Very Dangerous days (22.2 and 10.2 days respectively). Just 29.4 days (32%) in 2011-2020 were 'Non Dangerous' (*Hu*<=39) indicating more than 2/3 (68%) of Tokyo JAS days produce a zero (0) HCI:urban thermal rating. Chi^2 independence testing of the incidence of 'Humidex-Dangerous' (*Hu*>45) and 'Humidex-Non-Dangerous' days (*Hu*<39) across the two periods (1, N=2760) = 28.829, *p*=0.00000079 indicates the difference is statistically significant.

6.3 Tokyo JAS Holiday Climate Index (HCI:urban)

As a means to understand how the HCI:urban describes the Tokyo JAS climate a longitudinal ratio plot for Tokyo JAS 1991-2020 (N=2760 days) was constructed (Figure 3). From this we can see the majority of Tokyo JAS days are classified as 'acceptable' (HCI=50-59) or 'marginal' (40-49) with 50-70% of days in one of these two categories. By contrast, in most years less than 10% of days are rated as 'very good' (70-79) or 'excellent' (80-89); no days are rated as 'ideal' (90-100). In the five most recent years while 'marginal' and 'unacceptable' days (20-39) have increased in frequency to cumulatively account for approximately 60% of JAS days, there is no significant increase in the frequency of 'dangerous' days (HCI <20). These findings are confirmed in Table 7 which compares the mean incidence of HCI:urban 'dangerous' JAS days for 1991-2020 and 2011-2020.

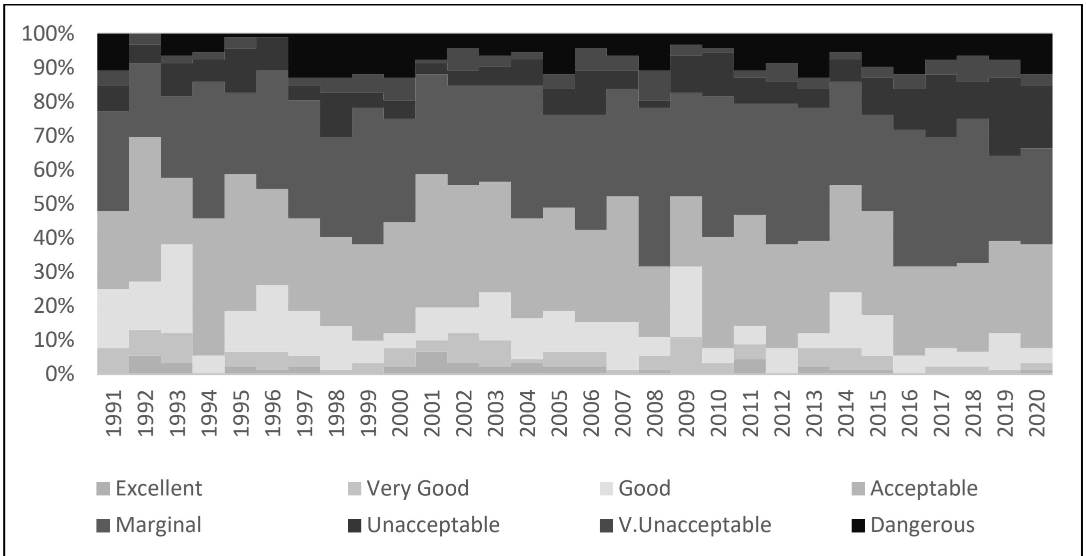

Figure 3: Tokyo JAS HCI:urban 1991-2020 (daily)

In contrast to Humidex, HCI:urban exhibits limited change in the mean tourism climate between the 30-year periods, this is indicated by similar 'marginal' scores for both 1991-2020 (HCI=47) and 2011-2020 (45) although there is a trend towards worsening conditions with the least favorable climate conditions for each month occurring in the most recent decade and the most favorable conditions in the two prior decades (e.g. July 2020=35; July 1993=51) (Figure 3). The frequency of HCI:urban-defined 'dangerous' days however shows only a limited increase from 7.3 to 9 days per year between the two periods. Closer inspection shows that just 4 of these 9 'dangerous' days are thermally dangerous (*Hu*>=45) signaling that HCI:urban ascribes a 'danger' rating to 1/10th of the number of days that Humidex (43.8 days) does.

Table 7: HCI:uban-defined Dangerous days 1991-2020 and 2011-2020

	JAS		July		Aug		Sep	
	1991-2020	2011-2020	1991-2020	2011-2020	1991-2020	2011-2020	1991-2020	2011-2020
Mean HCI^{max}_{min}	$\mathbf{47^{65}_{35}}$	$\mathbf{45^{59}_{35}}$	45^{51}_{35}	44^{49}_{35}	45^{53}_{37}	44^{49}_{37}	52^{65}_{40}	48^{59}_{40}
HCI<20 (days/yr)	**7.3**	**9**	2.2	2.9	2.8	2.9	2.3	3.2
HCI<20 & Hu =>45 (days/yr)	**2.7**	**4**	0.7	1.3	1.4	1.6	0.6	1.1

That Humidex and HCI:urban evaluate climate 'danger' differently is not a surprise since the former index measures thermal conditions only, and the latter is a composite measure of the total tourism climate. Nevertheless, the discrepancy showing that Tokyo's climate is *thermally* dangerous (*Hu*>=45) on 43.8 of 92 JAS days (48%) but *touristically* dangerous for just 9 days (10%) is a significant anomaly when we consider that *Hu*>45 is the threshold for non-acclimated individuals such as tourists to 'stop all activity'. Research carried out in conditions similar to Tokyo summer indicates that a comfortable walking distance is just 320 meters (Koerniawan and Gao, 2015) and supports the notion that the HCI:urban may be misrepresenting Tokyo's summertime climate.

This misrepresentation is perhaps best illustrated by considering the HCI:urban for three climatic conditions typical of Tokyo JAS which are beyond the index's thermal rating upper threshold (*Hu*>39). Keeping rain (R), cloud cover (C) and wind (W) constant (R=0mm, C=35%, W=3m/s), but adjusting thermal conditions to *Hu*=39, 45, & 50 we find the HCI:urban delivers a score of 55 ("acceptable") in all three cases (Table 8). Given that 'activity should cease' at *Hu*>=45, and that 'heatstroke is possible' beyond *Hu*>=50 (Table 4) this result seems incongruous and suggests a modification to the HCI:urban thermal rating system to internalize the over-riding effects of severe thermal conditions should be considered.

Table 8: HCI:urban Thermal Weighting (Humidex 39, 45, 50)

	Ta (°C)	RH (%)	Hu (C)	Rain (mm)	Cloud (%)	Wind (m/s)	HCI (Rating)	Humidex (Comfort Level)
Case a	28.5	75	**39**	0	35	3.0	55 (Acceptable)	Evident Discomfort
HCI weighting			0*4	10*3	8*2	9*1		
Case b	30	85	**45**	0	35	3.0	55 (Acceptable)	Dangerous Discomfort
HCI weighting			0*4	10*3	8*2	9*1		
Case c	34	75	**50**	0	35	3.0	55 (Acceptable)	Heatstroke Possible
HCI weighting			0*4	10*3	8*2	9*1		

7. Recalibrating the HCI Thermal Rating

7.1 A New Rating System

Redesigning and modifying tourism climate indices is a well-established practice (de Freitas, 2003) and highly desirable as it can enable destination-specific indices to be developed and lead to more accurate ways to measure tourism climate (Scott et al., 2016; Mahtabi and Taran, 2018; Matthews et al., 2019; Demiroglu et al., 2020; Rutty et al., 2020; Yu et al., 2020). As an index that is already proven to be robust (Scott et al., 2016; Matthews et al., 2019; 2020; Rutty et al., 2020) the current research did not aim to alter the theoretical underpinnings of the HCI:urban instead the aim was to develop an overriding thermal rating scheme for severe summer heat and internalize more Tokyo JAS days into the index score.

First, HCI:urban thermal component values (Humidex) were calibrated against daily maximum WBGT values (Japan Ministry of Environment) for the years 2016-2020 (N=460) to confirm the correlation between the two indices (Figure 4). Research by Zare et al (2018) has shown that Humidex and WBGT exhibit strong positive correlation and the scatter plot and regression analysis confirmed this for Tokyo JAS ($R^2 = 0.94$ (r (458) = 0.97, $p < 0.001$)).

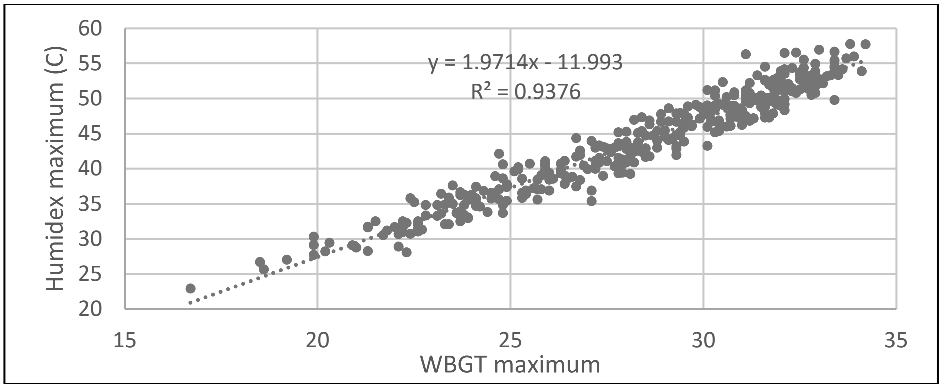

Figure 4: Tokyo JAS WBGT / Humidex Regression (2016-2020)

Next, using confidence interval analysis the upper and lower confidence interval (CI, 95%) of mean daily maximum WBGT values were plotted against whole integer Humidex values (*Hu*=29-58) on a histogram (Figure 5). To develop thermal component ratings (TC) for the Humidex values a visual technique based on Cumming and Finch (2005) was used to pair the upper confidence interval (UCI) of a lower Humidex value with the lower confidence interval (LCI) of overlapping higher Humidex value(s). To test the null hypothesis there is no difference between two overlapping Humidex samples, *t*-tests (for two samples) and ANOVA (for three or more samples) were carried out to validate this visual technique (Table 10). Post hoc confidence interval testing *between* paired Humidex values was conducted to confirm the significance of *t*-test pairings. Tukey analysis was used to validate the ANOVA results.

The resultant calibration shows the HCI:urban thermal ratings for *Hu*29 to *Hu*58 inclusive (Figure 5). The pairings for the existing HCI:urban thermal ratings 7 to 0 (i.e. *Hu* 29-39 inclusive) showed excellent concordance with those of Scott, Rutty, Amelung, et al (2016) giving support to the method employed in the current research. Sample similarity for Humidex integer pairings was confirmed by *t*-test and Anova which exhibited $p>0.05$ for all pairings. These tests confirmed the *lack* of statistical difference between grouped Humidex values validating the visual pairings technique with the only exception being the triple pairing *Hu*43, *Hu*44, *Hu*45 ($p=0.015$, $F=4.65$, *df* within =42, *df* between =2) which produced a Tukey’s value 3.44 indicating days at *Hu*45 are statistically different to those at *Hu*43 and *Hu*44. This argument notwithstanding, by cross referencing the resultant pairings with the WBGT guidelines and the Humidex rating scale (Table 10) a thermal components rating system was devised for the derivative HCI:urban index, the HCI:urban Tokyo Summer (HCI:$urban_{TS}$): *Hu*=39-40 (0 rating); *Hu*=41-42 (-1); *Hu*=43-45 (-2); *Hu*=46-48 (-3); *Hu*=49-51 (-4); *Hu*=52+ (-5) (Table 9).

The new scale differentiates varying degrees of WBGT ‘Warning’ represented by *Hu*39 at the lower end and *Hu*42 at the upper by ascribing thermal component ratings 0 and -1 respectively. For ‘Danger’ (*Hu*>49) less severe conditions (*Hu*49-51) are differentiated from more severe ones (*Hu*>=52) by component ratings -4 and -5. Thermal ratings -2 and -3 represent lesser and greater interpretations of 'severe warning'. As a result of this process the new progressively regressive thermal component ratings scheme corresponds well with other established thermal stress guidelines such as the Japan Sports Association (JSA, 2013), and can allow the index to account for different levels of acclimation by visitors according to their climate of origin, or level of vulnerability (Heo and Bell, 2018; Infusino et al., 2021).

Table 9: HCI:urban and HCI:urban$_{TS}$ Thermal Rating Scale

Rating	**HCI:urban Humidex Value**	**HCI:urban$_{TS}$ Humidex Value**
10	23.0-25.9	23.0-25.9
9	20-22.9 / 26.0-26.9	20-22.9 / 26.0-26.9
8	27.0-28.9	27.0-28.9
7	18-19.9 / 29.0-30.9	18-19.9 / 29.0-30.9
6	15-17.9 / 31.0-32.9	15-17.9 / 31.0-32.9
5	33.0-34.9	33.0-34.9
4	35.0-36.9	35.0-36.9
2	37.0-38.9	37.0-38.9
0	≥39.0	39.0-40.9
-1	x	41.0-42.9
-2	x	43.0-45.9
-3	x	46.0-48.9
-4	x	49.0-51.9
-5	x	≥52

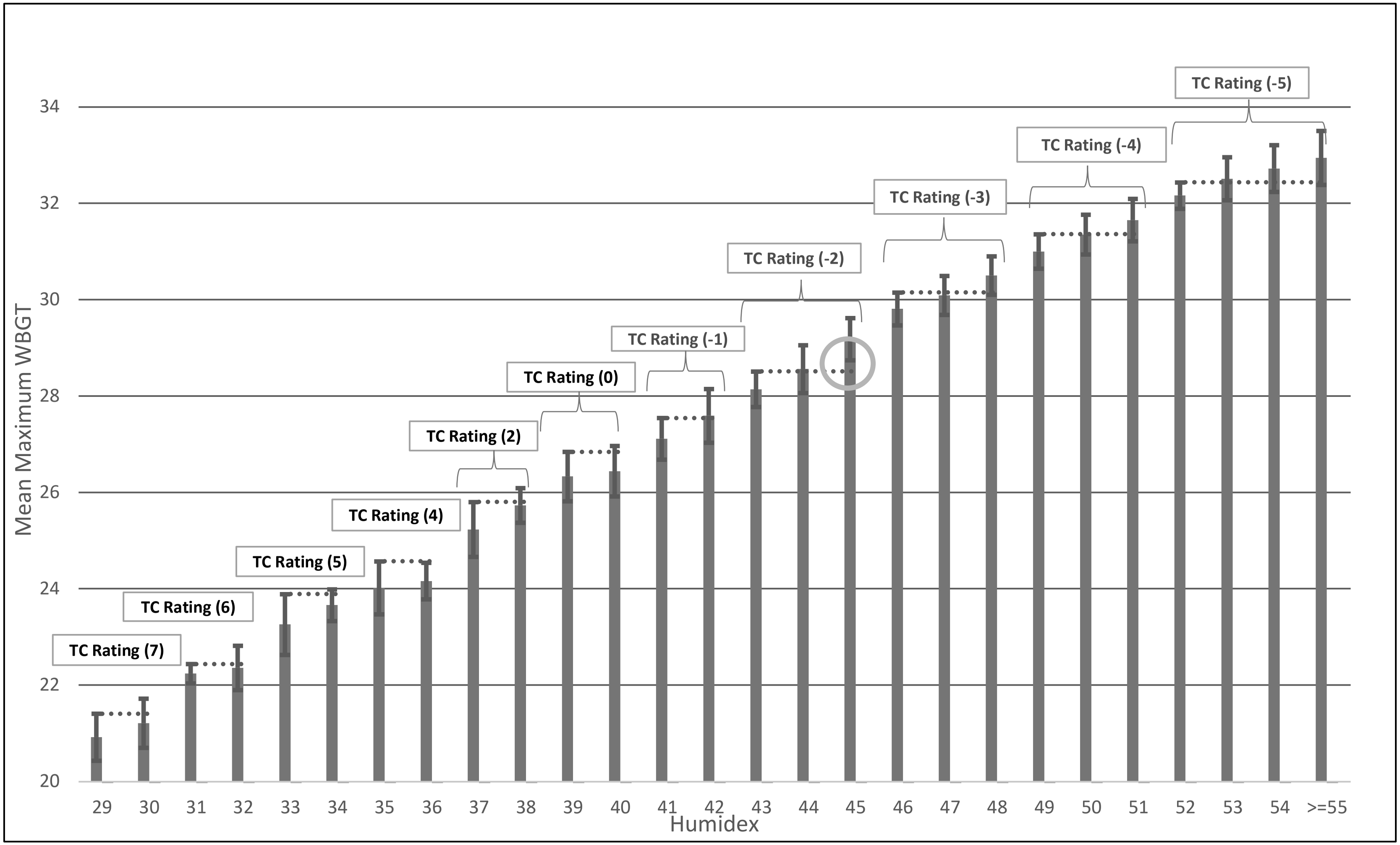

Figure 5: Confidence Interval Analysis WBGT vs Humidex (Humidex>=29)

*Note: *Hu*<29 not plotted due to small sample size

Table 10: Confidence Interval Analysis and Thermal Rating Scheme

Humidex (N)	Mean WBGT	LCI (95%)	UCI (95%)	Std Dev	Point Est.	T Stat *F* value	*p* value (Tukey q)	HCI:urban$_{TS}$ Thermal Rating	WBGT Guideline**
Hu29 (10)	20.9	20.4	21.4	0.69	0.29	1.04	0.31	7*	Safe
Hu30 (10)	21.2	20.7	21.7	0.62					
Hu31 (13)	22.2	22	22.4	0.33	0.12	0.53	0.62	6*	Caution (water should be taken)
Hu32 (13)	22.4	21.9	22.8	0.77					
Hu33 (10)	23.3	22.6	23.9	0.75	0.64	1.52	0.15	5*	
Hu34 (17)	23.7	23.4	24	0.47					
Hu35 (19)	24	23.5	24.6	1.21	0.12	0.36	0.73	4*	
Hu36 (19)	24.2	23.8	24.5	0.79					
Hu37 (16)	25.2	24.7	25.8	1.07	0.5	1.58	0.13	2*	Warning (rest needed every 30 minutes)
Hu38 (16)	25.7	25.4	26.1	0.67					
Hu39 (17)	26.3	25.8	26.8	1.0	0.09	1.58	0.75	0	
Hu40 (15)	26.4	25.9	27	0.95					
Hu41 (17)	27.1	26.7	27.5	0.84	0.48	1.45	0.16	-1	
Hu42 (17)	27.6	27	28.1	1.08					
Hu43 (15)	28.1	27.8	28.5	0.81	n/a	4.65	0.015 (3.44)	-2	Severe Warning (all hard exercise should cease)
Hu44 (15)	28.6	28.1	29.1	0.89					
Hu45 (15)	29.2	28.7	29.6	0.96					
Hu46 (21)	29.8	29.5	30.1	0.75	n/a	2.96	0.06 (3.4)	-3	
Hu47 (21)	30.1	29.7	30.5	1.02					
Hu48 (21)	30.5	30.1	30.9	0.83					
Hu49 (23)	31	30.6	31.4	0.81	n/a	2.92	0.06 (3.4)	-4	Danger (all physical activity should cease)
Hu50 (23)	31.3	30.9	31.8	0.88					
Hu51 (23)	31.7	31.2	32.1	0.99					
Hu52 (15)	32.2	31.9	32.4	0.59	n/a	1.93	0.14 (3.74)	-5	
Hu53 (14)	32.5	32.1	33	0.77					
Hu54 (15)	32.7	32.2	33.2	0.69					
Hu55+(13)	32.9	32.4	33.5	0.93					

*Note: Existing thermal rating pairings (Hu<39) accord with Rutty et al. (2016)
**Japan Sports Association: A Guidebook for the prevention of heat disorder during sporting activities (2013)

7.2 Application of the HCI:urban$_{TS}$

The performance of the HCI:urban$_{TS}$ derivative index in describing Tokyo's summertime tourism climate is outlined in Table 11 which compares the new index with the HCI:urban for the meteorological conditions in 6.3 above (R=0mm, C=35%, W=3m/s) for thermal conditions *Hu*=39, *Hu*=45 and *Hu*=50. At *Hu*39 the HCI:urban$_{TS}$ evaluates climate conditions as 'acceptable' (HCI=55) which is equal to the

HCI:urban. This is due to the unchanged zero thermal rating of the HCI:urban$_{TS}$. At *Hu*=45 (rating= -2) and *Hu*=50 (rating= -4) however conditions are assessed as 'marginal' (HCI=47), and 'unacceptable' (HCI=39) respectively due to the progressively limiting rating scale. In this way the HCI:urban$_{TS}$ responds to extreme thermal conditions and downrates the tourism climate overall. Since there is a maximum limiting thermal components rating of -5 (*Hu*>=52), the lowest possible rating for the conditions described here is 'unacceptable' (HCI=34).

Table 11: Comparative Performance of the HCI:urban and HCI:urban$_{TS}$

Humidex	HCI:urban$_{TS}$ Thermal Value	Rain (0mm) + Cloud (35%) + Wind (3m/s)	HCI:urban (Rating)	HCI:urban$_{TS}$ (Rating)	Humidex Comfort Rating	WBGT (Rating)
Hu=39	0*4 = 0	10*3 + 8*2 +9 =55	55 (Acceptable)	0 + 55 = 55 (Acceptable)	Evident Discomfort	25.9 (Warning)
Hu=45	-2*4 = -8		55 (Acceptable)	-8+55 = 47 (Marginal)	Dangerous Discomfort	28.9 (Severe Warning)
Hu=50	-4*4 = -16		55 (Acceptable)	-16+55 = 39 (Unacceptable)	Heatstroke Possible	31.5 (Danger)

This limit to downrating is reasonable since at *Hu*>=52 it is likely visitors will proactively seek alternatives to outdoor tourism activities, and as a result any further increases in discomfort in outdoor heat will have been mitigated against. This is especially true for heat stressed urban destinations that in many cases have alternative in-door, air-conditioned, or otherwise heat mitigated attractions for visitors (Demiroglu, 2020). The limiting is also justified in that it mirrors scales such as Humidex and WBGT which have upper thermal ratings ('Heatstroke Probable' and 'Danger' respectively) to internalize extreme heat. At the same time depending on other weather parameters the HCI:urban$_{TS}$ doesn't necessarily rerate days with extreme Humidex values as 'dangerous' (HCI<20). In this sense while the robusticity of the HCI:urban is retained in the HCI:urban$_{TS}$ by relating conditions it is able to raise awareness of the dangers of tourist activity during extreme heat.

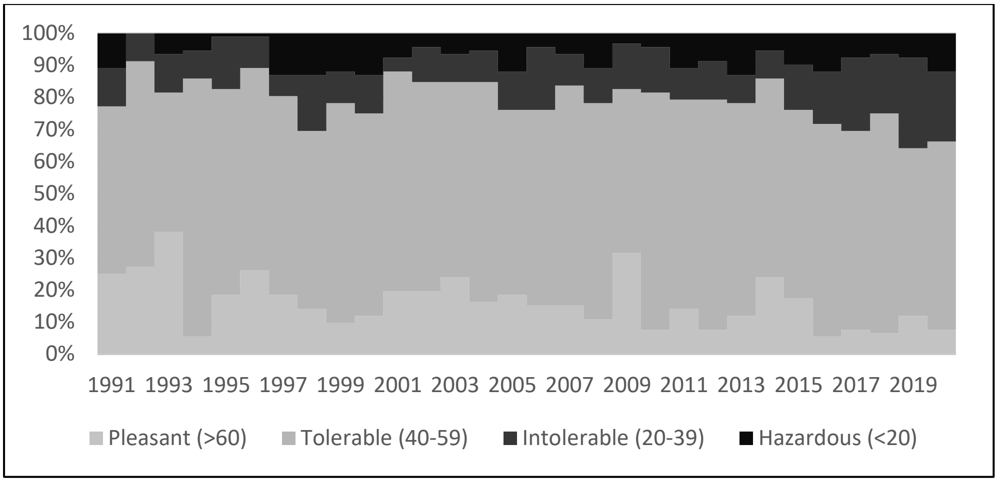

Figure 6a: Tokyo JAS HCI:urban (1991-2020) 4-Category Frequency Plot

To illustrate how the HCI:urban$_{TS}$ compares to the HCI:urban over 1991-2020, frequency plots of both indices were produced (Figure 6a, 6b) using a simplified 4-category rating scale where HCI:urban$_{TS}$>=60 was classified as 'Pleasant', 40-59 as 'Tolerable', and 20-39 as 'Intolerable'. Values below 20 were classified as 'Hazardous'.

Over the 30-year period both indices show an almost identical decline in the ratio of 'Pleasant' days from 20% in the 1990s to around 10% today. This can be explained by understanding that the maximum possible HCI:urban score for days with a thermal rating of zero (*Hu*>=39) is 60 (R=0mm + C=11-20% + wind <2.8m/s), consequently days with HCI scores of 60 or more have thermal values less than Humidex 39. Meanwhile, although 'Tolerable' conditions (HCI=40-59) are the most common category under the HCI:urban (around 50-60% of JAS days throughout the 30-year record), such days are both less common and - as a result of global heating - in decline under the HCI:urban$_{TS}$ which indicates 40-50% of JAS days in the 1990s (similar to the HCI:urban), but only 20-30% in the 2010s in this category. A similar disparity is seen in the incidence of 'Intolerable' days (HCI=20-39) between the two indices with the HCI:urban indicating a slight increase in frequency from 10% to 20% of days over the 30-year record while the HCI:urban$_{TS}$ indicates an increase from 30% of days (1990s) to around 60% (2010s). As for 'Hazardous' days, although the two indices indicate very similar profiles, in the most recent decade the former index categorizes more days at HCI<20. These findings show the HCI:urban$_{TS}$ internalizes not only the inherent thermal conditions of Tokyo JAS beyond the upper threshold of the HCI:urban, but can also represent increases in thermal conditions due to global heating or urban heat island effects (Wang, Berardi and Akbari, 2015).

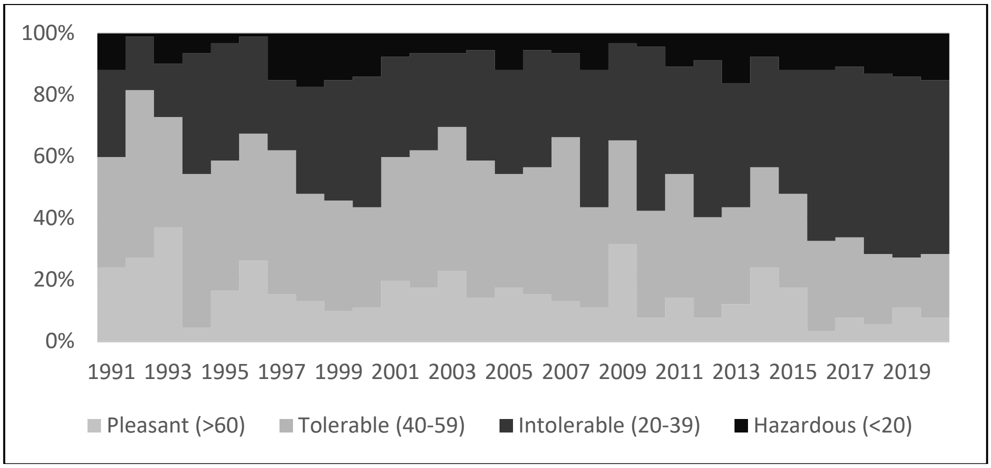

Figure 6b: Tokyo JAS HCI:urban$_{TS}$ (1991-2020) 4-Category Frequency Plot

8. Discussion

This research has shown that tourism climate conditions during Tokyo summertime are thermally challenging and that worsening conditions over the last 30 years are in line with IPCC AR6 predictions (Imada, Watanabe, Kawase et al., 2019). Average JAS air temperature increases of around 1°C between 1991 and 2020, more frequent *nettaiya* and *moushobi*, and the high incidence of summer days classified as Humidex-Dangerous (*Hu*>=45) and Humidex-Very Dangerous (*Hu*>50) testify to this. These climatic facts present a problem for employing the HCI:urban in settings such as Tokyo since the index evaluates a much smaller proportion of days as 'dangerous' and could lead index end users to misinterpret the city's climate and consequently make poorly informed choices (BBC, 2021; Naughton 2021). In the summer of 2018 almost 1500 deaths across Japan were attributable to extreme heat (Shimpo, Takemura, Wakamatsu et al., 2019) and although no specific data is available of cases among visitors in Tokyo, global heating and the city's popularity will make the inclusion of foreign visitors in future statistics much more likely.

The derivative HCI:urban index developed here (the HCI:urban$_{TS}$) is an attempt to modify an existing tourism climate tool to help reduce any such misinterpretation by internalizing the thermal factors of Tokyo's inherently severe summer months, but without compromising the index's original robust framework. Other international urban tourism destinations such as Bangkok, Kuala Lumpur and Ho Chi Minh City, where conditions similar to Tokyo summer prevail throughout the year may also find the HCI:urban$_{TS}$ an appropriate index to better assess their own tourism climate resources.

The question of whether the climate will be too hot for tourism is an important one for destinations facing changes to their climate due to global heating (Rutty and Scott, 2010; Kang, Pal and Eltahir, 2019; Demirgolu et al., 2020). However, since all aspects of tourism are "weather sensitive" (Becken and Hay, 2012), the more important question is how can tourism climate, and any changes it experiences due to global heating, be more accurately measured so that tourists and tourism industry stakeholders are better informed and can respond to threats caused by climate. For tourism-invested urban destinations like Tokyo with inherently challenging and gradually deteriorating summer conditions finding an answer to this question is even more acute. Since it is expected that tourists will prioritize health and risk more actively in the new tourism normal after the Covid-19 pandemic (Matiza, 2020) more accurate means to measure threats to health - including presumably those from climatically-induced heat - will become a consideration for all tourist destinations.

At the same time it has been claimed that, urban tourists have a greater tolerance to severe heat than is conventionally thought, possibly to as much as Humidex-Dangerous conditions (*Hu*>=45) (Demiroglu et al., 2020); tourists in the future may even be better acclimated to more severe heat (Scott et al., 2016; Hewer and Gough, 2016). However, since there are physiological thermal limits beyond which it seems fair to assume even the hardiest of tourists will view such conditions unfavorably. Thus without significant increases in institutional mitigation measures tourists will need to adopt spatial or temporal coping strategies to avoid destinations of extreme heat. These all serve to emphasize the need for a tool that can assess meteorological conditions and unambiguously describe the features important to visitors, while at the same time assist tourism stakeholders to make informed decisions to ensure visitor safety and tourism sustainability.

Prior to the adoption of new thermal indices validation is an important step in the development process. It is therefore highly desirable that such validation can be made in respect of the HCI:urban$_{TS}$ for Tokyo and other urban destinations. The conventional method to validate tourism climate indices has been to assess tourism arrival figures against climate index scores (Scott et al., 2016, Demiroglu et al., 2020; Yu et al., 2020; Rutty et al., 2020), and although this is a widespread and proven approach, the high correlation coefficients obtained can be a result of institutional seasonality and sociological factors rather than satisfaction with the climate *per se* (Demiroglu, 2020; Matthews et al., 2019). Instead, it is recommended that validation of the HCI:urban$_{TS}$ may be better served by exploring the stated climate preferences of visitors (Scott et al., 2016).

One such stated preference research was carried out by Japan’s Ministry of Land Infrastructure, Tourism and Transport in 2019 (MLIT, 2019) and gives an insight into the merit of downrating Tokyo’s tourism climate due to thermal severity as proposed by the HCI:urban$_{TS}$. The questionnaire research found that despite a high level of pre-visit awareness among respondents of Tokyo’s summertime climate, 93% of visitors considered the city “too hot and humid” to walk outside (this rose to 100% among European visitors). Significantly during the period of the study (August 2019) the daily mean maximum Humidex in Tokyo was *Hu*44 which corresponds to the median value for the most recent decade of meteorological data. Hence, although the air temperature and humidity could be considered as no more than ‘average’, visitors’ perceptions of conditions in Tokyo were unequivocally negative. If global heating progresses at the rate and intensity as AR6 (IPCC, 2021) suggests future tourists to Tokyo and tourism practitioners in the city will need improved tourism climate information to prepare for summertime visits. It thus seems appropriate to propose that the HCI:urban, which indicates around 60% of Tokyo JAS days are ‘Tolerable’ is not an accurate measure of what real tourists actually think. Instead by concluding that 60-70% of Tokyo’s summer days are ‘Intolerable’ or ‘Hazardous’ it is the HCI:urban$_{TS}$ which provides a more accurate measure of the city’s summertime tourism climate.

9. Conclusion

Climate comfort is an essential component of destination attractiveness and can be a key driver of a destination’s tourism economy. Understanding the measurement of climate as it is experienced by tourists and tourism stakeholders is thus of great importance to locations like Tokyo that have burgeoning international tourism profiles. This understanding however has been complicated in recent decades by global heating which is causing tourism climate to deteriorate, potentially to the detriment of both tourists and tourism. In the current research a method based on confidence interval analysis was proposed as a means to modify the thermal component of the HCI:urban tourism climate index so that it can better reflect the severe heat conditions typical of Tokyo’s summertime climate and, at the same time, respond to any future global heating-induced changes. With reference to Humidex and WBGT a new thermal scale beyond the current index threshold of Humidex 39 was calibrated and a new derivative index produced (HCI:urban$_{TS}$). The new index suggests Tokyo’s summertime tourism climate conditions should be downrated from ‘Tolerable’ to ‘Intolerable’; contemporary stated preference surveys of tourists carried out in Tokyo support this assertion.

As a work in progress the conclusions reached in the current research can be viewed as only the initial steps to developing a tourism climate index for Tokyo (Kubokawa et al., 2014). Moreover, since the methodology adopts a statistical data-driven approach to calibrate the index rather than a revealed or stated preference survey approach, the findings should not be seen as definitive. Instead, it is hoped the current research invites further investigation through *in situ* and *ex situ* stated preference surveys of visitors to Tokyo and other climatically similar urban tourism destinations to uncover the important metric of optimal thermal range among urban tourists (Scott et al., 2016). This can encourage a wholistic “thermal environment management” (Kakamu et al., 2017) of tourism and in doing so satisfy the needs of visitors, and facilitate better long-term tourism climate-focused strategic planning. In this way it hoped the HCI:urban$_{TS}$ can help to underpin a better understanding of urban tourism climate conditions so that a new tourism can emerge that is safer for its participants and more sustainable for its practitioners.

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東京における夏の観光気候指数
―HCI:urban の高温多湿条件の加味―

David Williams

【要旨】

快適な気候は、観光地が観光客を引きつけるためには不可欠であり、また観光経済を推進させるための重要な要素でもある。Covid-19 パンデミック以前は観光産業が急成長を遂げていた東京などの都市部にとって、HCI:urban などの指数を利用した観光気候の測定は非常に重要なものであった。地球温暖化の影響で、東京の暑い夏がさらに過酷化し、その暑さにより同都市の観光産業がより脆弱になっていることも、この指数の重要性を高めている。この論文では信頼区間の分析により、東京に固有の夏の暑さを予め指数に盛り込むことでより典型的な観光気候の予測が可能なよう、HCI:urban 観光気候指数の改良を提案する。Humidex39 と同等もしくはそれ以上の条件を評価するための新基準を設けることにより派生する指数 HCI:urban Tokyo Summer ($HCI{:}urban_{TS}$) が、東京の観光気候を評価するにはより適しているかもしれない。また、この指数を利用した時系列データ分析からは、同都市の夏の観光気候は現在「tolerable」であるが、「intolerable」に引き下げられるべきだということが分かる。現在、この新しい指数の有効性を確認するための手段が議論されている。

キーワード：観光気候指数、都市観光、気候変動、東京夏季の気候