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A study regarding thermal environment and thermal comfort during 2021 National Intercollegiate Athletic Games related activities in Taiwan

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Abstract: Due by the impact regarding global warming and extreme weather events, outdoor thermal condition become tougher and harder to mitigate especially for pedestrian movement and exercises. In order to better understand the thermal environment and thermal comfort especially for outdoor sports, 2021 National Intercollegiate Athletic Games held at Tainan, southern Taiwan, in May has been selected as the research target. Both on site real-time environmental monitoring data, and Taiwan Climate Change Projection Information and Adaptation Knowledge Platform (TCCIP) Taiwan ReAnalysis Downscaling data (TReAD) were applied in estimating mPET (modified Physiologically Equivalent Temperature) Tmrt (Mean Radiant Temperature) and WBGT (Wet-bulb Globe Temperature) for members participating in the relevant activities. This study interests in trying to analyze the thermal performance among 1) the torch relay around Taiwan from April 20th to May 8th, and 2) the scheduled planning games held in track and field stadium, National Cheng Kung University (NCKU), Taiwan from May 15th to May 18th.

Keywords: Hot-Humid Climate; 2021 Taiwan National Intercollegiate Athletic Games; Torch Relay around Taiwan; Thermal Comfort; mPET; Tmrt; WBGT; Thermal Risk Assessment

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1. Introduction

With the unavoidable fact of global warming and the increasing tendency of having high-temperature days, causing outdoor thermal stress to rise, this might frequently lead us to feel sultry and uncomfortable. The high-temperature outdoor environment may also cause thermal hazards, which not only affects the quality of life, but also affects health and public safety. While athletic games or activities taking place, volunteers and staff participating in athletic games in the venue need to continue their work and stay in the fixed area for hours. Thermal hazards and thermal comfort issues in the outdoor environment are important concerns for human quality of life. Therefore it is certainly essential to find ways in better adjusting and quantifying the influence of thermal comfort and risk for important athletic activities.

Affected by the COVID-19 global epidemic, most of the international athletic games and activities cannot be held recently. Taiwan has been quite benefited from quick reaction in prevention and the fully commitment among the central government and all nationals, we are lucky that we could have 2021 National Intercollegiate Athletic Games and related activities, such as the torch relay around Taiwan, and preliminaries, held from middle April to early May. With comprehensively consideration in epidemic prevention and public health concern, the decision of postponing the track field race during

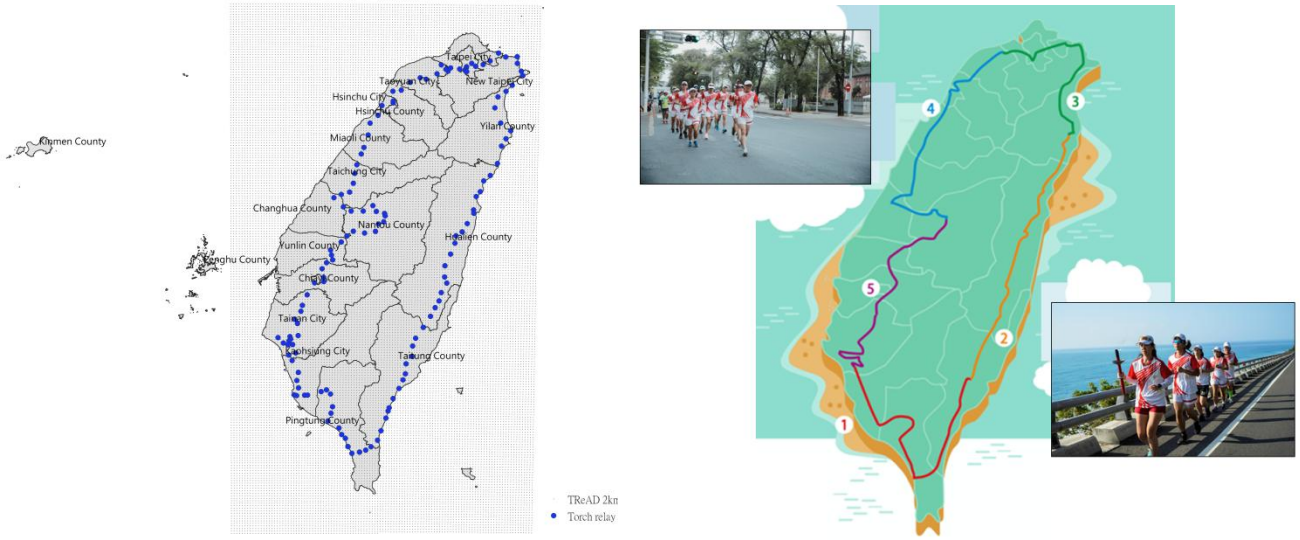
May 15th - 18th to this September has made on May 13th. And the track and field stadium has been closed for avoiding people gathering ever since then, on-site environmental monitoring and questionnaires obtaining will not be able to initiate until September.

To discuss the issue of outdoor thermal comfort, there are many factors involved to [1-3], and it is also strongly relevant to individuals' places of residence and preferences in approaching of sunlight or shading. Shade and lower Sky View Factor would be the most concerns in promoting comfort thermal adaptation especially for sub-tropical/ tropical climates [4-11]. The aims of this study are to apply the real time monitoring data along with Taiwan Climate Change Projection Information and Adaptation Knowledge Platform (TCCIP) Taiwan ReAnalysis Downscaling data (TReAD) of 2 km grid resolution at different locations among Taiwan, and this is a preliminary research of viewing the implementation of simulating the thermal performance before scheduled events or activities in the future.

2. Methods

2.1. Study Area and Settings

In this study, research areas and periods are 1) the torch relay around Taiwan from April 20th to May 8th, and 2) the scheduled planning games held in track and field stadium, NCKU, Taiwan from May 15th to May 18th. As for the former one, 142 sites among 16 cities/ counties, and including 32 universities around Taiwan were selected connecting as the torch relay route shown in Figure 1 (a). The scheduled 5 turns for this total 1,164 km tour were shown in Figure 1 (b).



(**a**) (**b**)

Figure 1. The torch relay around Taiwan from April 19th to May 9th, the sites and the turns shown as: (**a**) Entire torch relay 142 sites and TReAD 2km grids among Taiwan; (**b**) The scheduled 5 turns: ①Tainan City-Taitung County, 280 km, April 20th–23rd., ②Taitung County-Yilan County, 229 km, April 23rd–27th., ③Yilan County-Taoyuan City, 196 km, April 27th–May 1st., ④Taoyuan City-Nantou County, 276 km, May 1st-5th., and ⑤Nantou County-Tainan City, 183 km, May 5th-8th.

As for the second research area and period, the scheduled planning games held in track and field stadium, NCKU, Taiwan from May 15th to May 18th, the track and field stadium has been closed since the postponing announcement made on May 13th, 3 sites nearby the venue, shown in Figure 2 were selected as relatively open and shade examination monitoring sites to estimate the outdoor thermal condition if the track and field games held in time.

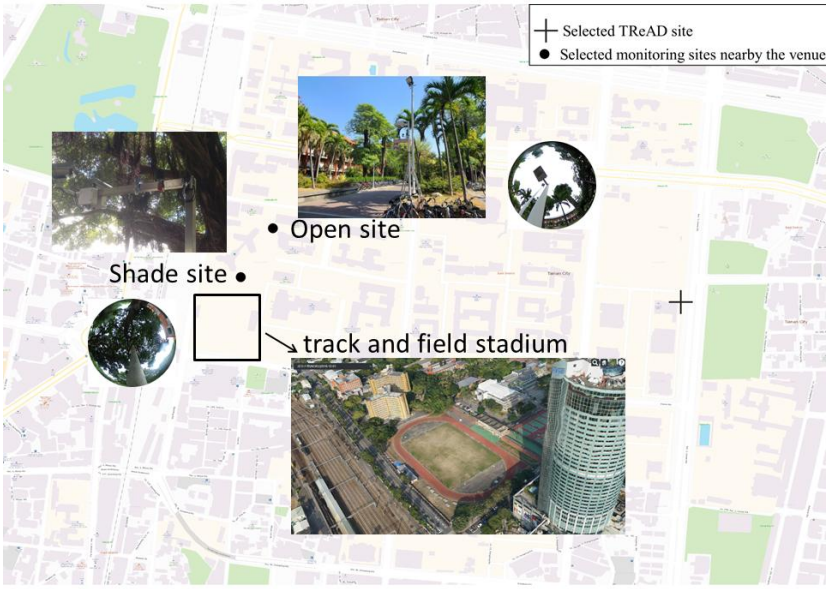
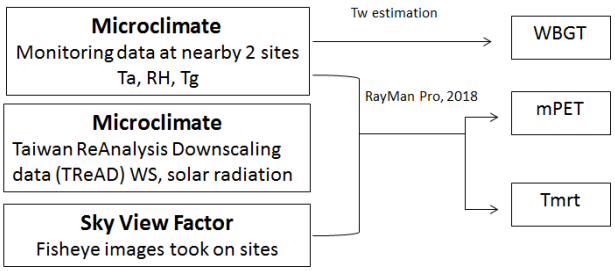


Figure 2. Open & shade monitoring sites and the TReAD 2km grid point nearby the Game venue.

The data applied and the process phases were summarized at Flow Chart 1. And more details regarding the real time monitoring data, Sky View Factor, and the definition of thermal indices would be described in section *2.2-2.4*.

Flow Chart 1. Data Application and Analysis Phase for Tainan sites



In this study, the modified Physiologically Equivalent Temperature (mPET) instead of PET was applied for better co-relationship between human biometeorological factors on thermal environments [12]. Nevertheless, Mean Radiant Temperature (Tmrt, the mean temperature of the surrounding surface from the environment radiation to the human body), and Wet-Bulb Globe Temperature (WBGT, a parameter to evaluate the environment thermal load of human body) were also applied here as thermal indicators for getting a more comprehensive perspective.

As mentioned before, places of residence and preferences play quite important roles in indicating the thermal feelings. Hence, people from different regions would have different thermal sensations and tolerance. The warm temperature for people in Taiwan is "PET 34-38℃" while PET > 38℃ people would feel hot and obviously uncomfortable[13]. Assuming the condition of exposing under the direct solar radiation might cause Tmrt rising to 60℃ [14]; and it was approved that once the body temperature forced to increase to over 40℃, higher possibility in getting heat stroke and confusion [15]. Japan Ministry of the Environment and Japan Sports Association had announced the guideline of WBGT standard of prevention in causing heat disorder [16-18], when WBGT > 25℃,

the heat stress risk would increase, and shall be viewed as reaching "warning" level, while WBGT > 31℃, reaching the "danger" level of exercise prohibited threshold.

Therefore, mPET≧34℃ and WBGT > 25℃ were viewed as thresholds leading to thermal discomfort; mPET > 38℃, Tmrt ≧ 40℃, and WBGT > 31℃ were identified as the thresholds leading to thermal danger risk for people in this study.

2.2. Environmental Data Applied

For the scheduled planning games held in track and field stadium from May 15th to May 18th, UnaSense, sensors from UnaBiz SigFox, were applied to monitor the air temperature (detection range -20 ~ 70℃, with ± 1℃ accuracy) and relative humidity (detection range 0 ~ 100 %, with ± 2% RH accuracy) and Temphawk sensors (detection temperature range -40 to 125℃, with ± 0.2℃ accuracy; detection relative humidity range 0 ~ 100 %, with ± 3% RH accuracy) covered with small copper balls dyed black to monitor the Globe Temperature (Tg) shown as Figure 3.

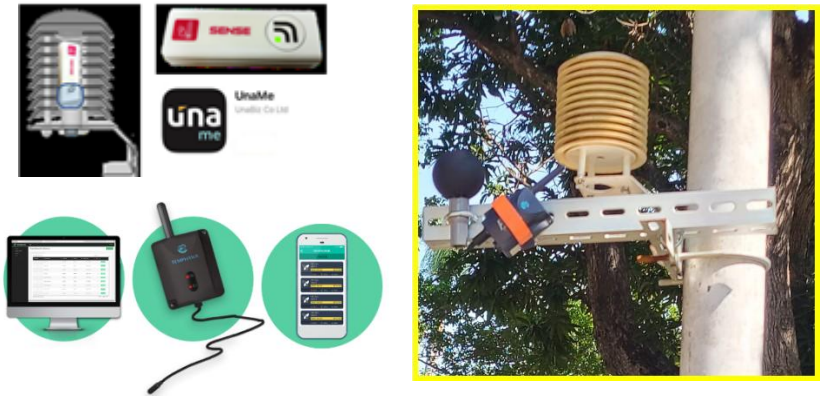
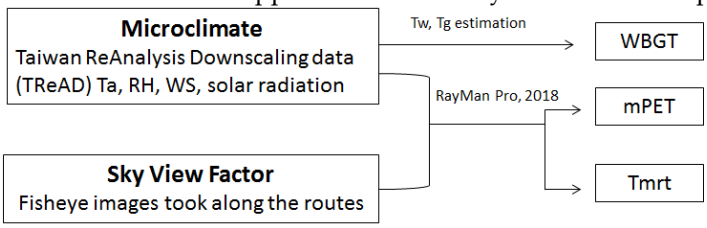


Figure 3. UnaSense (left up)and Temphawk (left down) sensors and the installation.

For the torch relay around Taiwan from April 20th to May 8th, the coverage area was the whole island, and there are inevitable problems of lacking of sites providing sufficient data set with the similar quality assurance/ quality control process. Therefore, Taiwan Climate Change Projection Information and Adaptation Knowledge Platform (TCCIP) Taiwan ReAnalysis Downscaling data (TReAD) were applied in this study for estimating the thermal performance among the torch relay route.

TReAD was made via dynamic downscaling for obtaining high-resolution data by enhancing the resolution of the model. Through applying terrain data near to the ground, it can produce more accurate and realistic estimated data. Which better presents geographical and climatic characteristics within small scales, and also allows the model to simulate larger extreme values, and it could enlarge the model capacity to simulate extreme events. This data is a reanalysis of the ERA5 data produced by the European Centre for Medium-Range Weather Forecasts (ECMWF) using the WRF model. The original resolution is reduced to 30 km through dynamic downscaling, and then the ERA5 reanalysis data is gradually downscaled to 2 kilometers grid [19-21]. And there are total approximately 15,000 dots all over the island.

Flow Chart 2. Data Application and Analysis Phase for Taipei sites



In this study, TReAD 2011-2018 hourly mean reanalyzed and downscaled 2 km resolution data of near the ground Air Temperature (Ta), Relative Humidity (RH), Wind Speed (WS), and Solar Radiation (Sol) were applied. As an example implied in this study, 5 torch relay sites in Taipei, along with 4 nearby TReAD sites were selected and shown in Figure 4. And the arrival time from site A to site E would be 1st May 8:00, 9:00, 10:00, 11:00, and 12:00 in the morning respectively. And the Sky View Factor (SVF) estimated at 142 sites via GSV2SVF - an interactive GIS tool, which transformed Google Street View (GSV) images into fisheye images. With fisheye images, we could estimate sky/tree/building view factor [22, 23]. The SVF, TVF, and BVF among the torch relay route around Taiwan were shown in Figure 5. And the data application and analysis phase for Taipei sites thermal indicators estimation showed as Flow Chart 2.

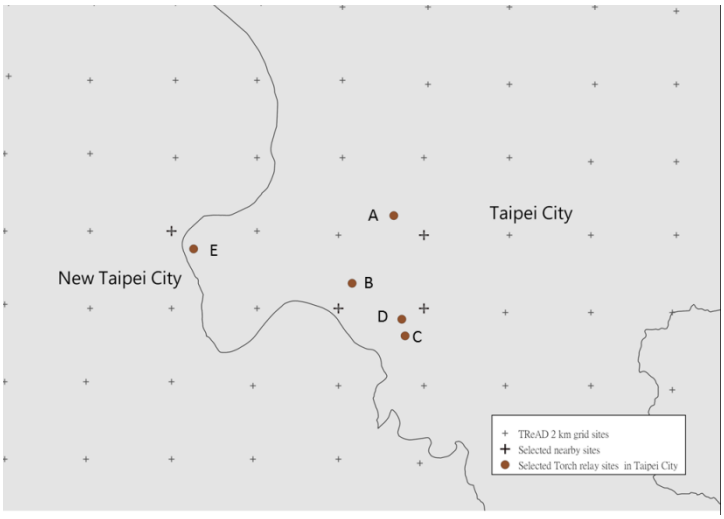
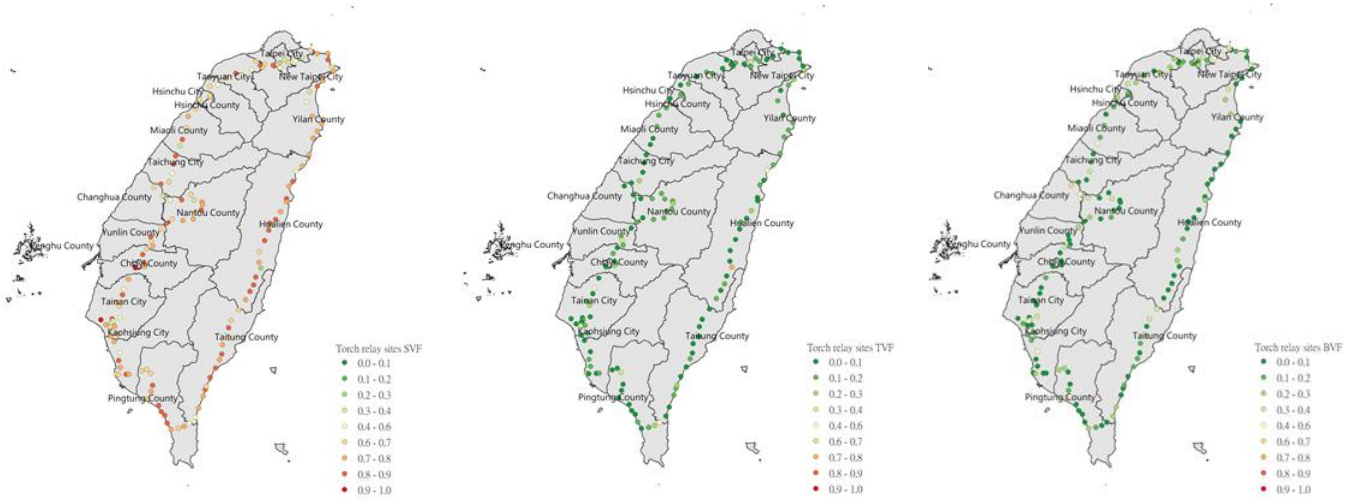


Figure 4. Selected torch relay sites in Taipei and the TReAD 2km grid points nearby.



(**a**) (**b**) (**c**)

Figure 5. (a) SVF, **(b)** TVF, and **(c)** BVF among the torch relay route around Taiwan.

2.3. Wet Bulb Globe Temp (WBGT) Estimation

WBGT is an estimation to quantify the heat stress under direct sunlight environment constantly, by ISO 7243 [24], in outdoor with solar exposure condition,

$$WBGT = 0.7Tw + 0.2Tg + 0.1Td \quad (1)$$

Tw: Wet Bulb Temperature Tg: Globe Temperature
Td: Dry Bulb Temperature, here shown as Air Temperature (Ta)

The method and function in estimating Tg for southern Taiwan was developed [11, 25], and this has been applied for WBGT estimating in this study:

$$Tg = Ta + (sol-14.91974) / (0.07796*sol + 12.83756*wind + 16.89265) \quad (2)$$

Tg: Globe Temperature Ta: Air Temperature
sol: Solar Radiation wind: Wind Velocity

2.4. mPET and Tmrt Estimation

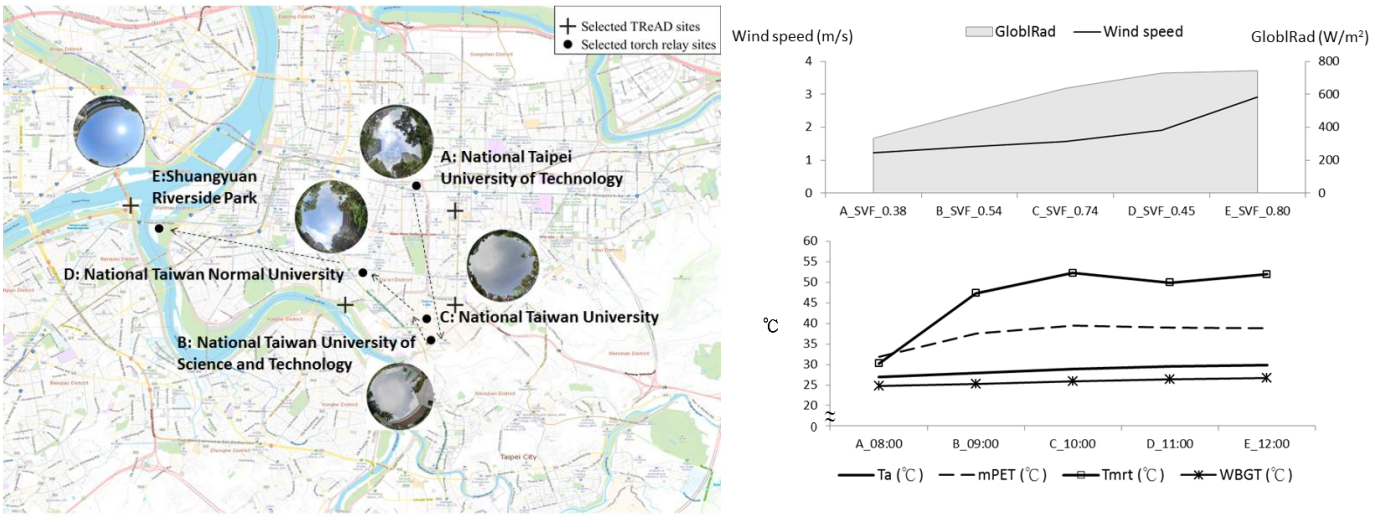
For the scheduled planning games held in track and field stadium, NCKU, Tainan from May 15th to May 18th, by providing the real time air temperature, relative humidity, the SVF taken at the 2 sites; and the TReAD reanalyzed wind speed, global radiation data from the nearest point less than 1 km away from the venue. RayMan pro model has been applied in this study for estimate mPET and Tmrt [26, 27].

According to the Annex B- Metabolic rates of different activities in ISO 7730 [28], in the study, the initial condition settings for 1) torch relay participants as "Runners" were defined slow runners who would complete 10 km route within 2 hours by rate 5 km/h, of metabolic rate 200 W/m^2, and 2) volunteers and staff participating in athletic game as "standing or slow walkers" were defined to stay longer at the venue with relatively slower pedestrian movements of moving rate 2-2.5 km/h, of metabolic rate 110 W/m^2.As for clothing, in order to focus to the thermal environment primarily in this study, a daily wear clothing option of underwear, shirt, trousers, socks, and shoes of Clothing Insulation (Icl) clo 0.7 was generally applied in this study for both tow settings [29,30]

3. Results and Discussion

3.1. The selected 5 torch relay sites in Taipei on 8 AM to 12 PM on May 1st

For the examination implied in this study, 5 torch relay sites in Taipei, along with 4 nearby TReAD sites were selected. The fisheye photos and the map of the 5 torch relay sites in Taipei, and the thermal performance on 8 AM to 12 PM on May 1st shown in Figure 6 and Table 1.



(**a**) (**b**)

Figure 6. (a) The fisheye photos and the map of the 5 torch relay sites in Taipei, and **(b)** The torch relay thermal performance on 8 AM to 12 PM on May 1st

In Figure 6(b), the solar radiation gradually increased from 330 W/m² at 8 AM to 740 W/m² at noon. And the SVF among the 5 sites were estimated between 0.38 and 0.80. Ta, mPET and WBGT were quite steady, and the rise tendency along with the increasing of solar radiation reach to the ground by time was not obvious. While Tmrt addressed relatively clear increasing trend by time, Tmrt highest point of 52.2℃. With higher solar radiation heat gain by noon, mPET and Tmrt value at 12 PM were even lower than the previous ones. This might be related to the better ventilation condition (higher wind speed).

Table 1. The torch relay risk in causing thermal discomfort on 8 AM to 12 PM on May 1st .

Thermal thresholds	Risk percentage	Standards
mPET>34 ℃	80.0 %	Warm standard for Taiwan[a]
mPET>38 ℃	80.0 %	Hot standard for Taiwan[a]
Tmrt>40℃	80.0 %	
WBGT>25℃	80.0 %	Warning standard[b]
WBGT>31℃	0	Danger standard[b]

[a] Lin and Mazarakis [13]
[b] Ministry of the Environment, Japan [16]

In Table 1, the risk in causing thermal discomfort was 80% for mPET>34 ℃(Warm standard for Taiwan), mPET>38 ℃(Hot standard for Taiwan), Tmrt>40℃, WBGT>25℃ (Warning standard for outdoor exercises), and WBGT>31℃ (Danger standard for exercise prohibited), which indicated that all sites at the route in the morning were defined very likely to have thermal discomfort feelings or heat stress hazards after 9 AM.

3.2.The scheduled planning games held in track and field stadium, from May 15th - 18th

The track and field stadium has been closed since the postponing announcement made on May 13th, 2 sites nearby the venue, representing the open area and the tree shaded area were selected as a replacement for on-site monitoring site within the track and field stadium to estimate the outdoor thermal condition if the Game held in time.

The thermal performances of the selected open site and the shade site nearby the venue during the scheduled Game period are shown in Figure 7, and Figure 8.

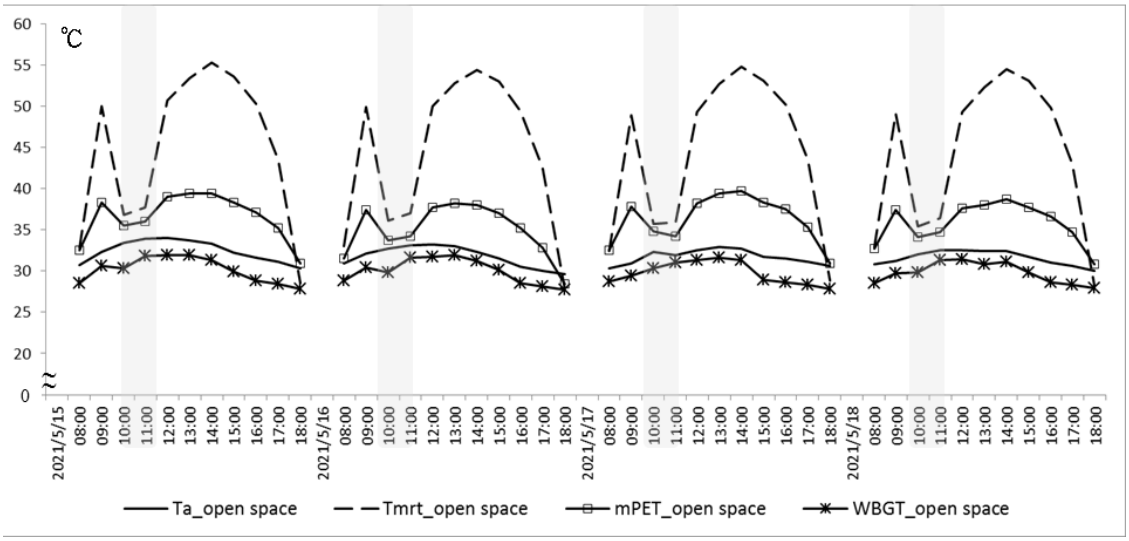


Figure 7. The open site thermal performance nearby track and field stadium, NCKU, from May 15th - 18th

In Figure 7, we have first noticed the repeat low values for Tmrt and mPET during 10 AM to 11 AM. After comparing the solar track in the sky and the fisheye photo, we found the reason is that the structure of the LED street light causing sufficient shade as the shield at 10-11AM to affect the sensors installed beneath it. The peak occurred at 2 PM for thermal indices, and the value seems to be higher in the afternoon for Tmrt /mPET, and around noon for WBGT. Tmrt, mPET, and WBGT could reach to > 50℃, > 39 ℃, and > 31℃ during 11 AM to 3 PM.

Table 2. The open site risk in causing thermal discomfort from May 15th - 18th

Thermal thresholds	Risk percentage	Standards
mPET>34 ℃	77.3 %	Warm standard for Taiwan[a]
mPET>38 ℃	31.8 %	Hot standard for Taiwan[a]
Tmrt>40℃	63.6 %	
WBGT>25℃	100.0 %	Warning standard[b]
WBGT>31℃	34.1 %	Danger standard[b]

[a] Lin and Mazarakis [13]
[b] Ministry of the Environment, Japan [16]

In Table 2, the risk in causing thermal discomfort were 77.3%, 31.8%, 63.6%, 100.0%, and 34.1% for mPET>34 ℃(Warm standard for Taiwan), mPET>38 ℃(Hot standard for Taiwan), Tmrt>40 ℃, WBGT>25 ℃(Warning standard for outdoor exercises), and WBGT>31℃ (Danger standard for exercise prohibited), which indicated that if you stay at open area without proper shading, you were exposed under heat stress warning for all the time, and around one third of the time even under too hot and danger situations.

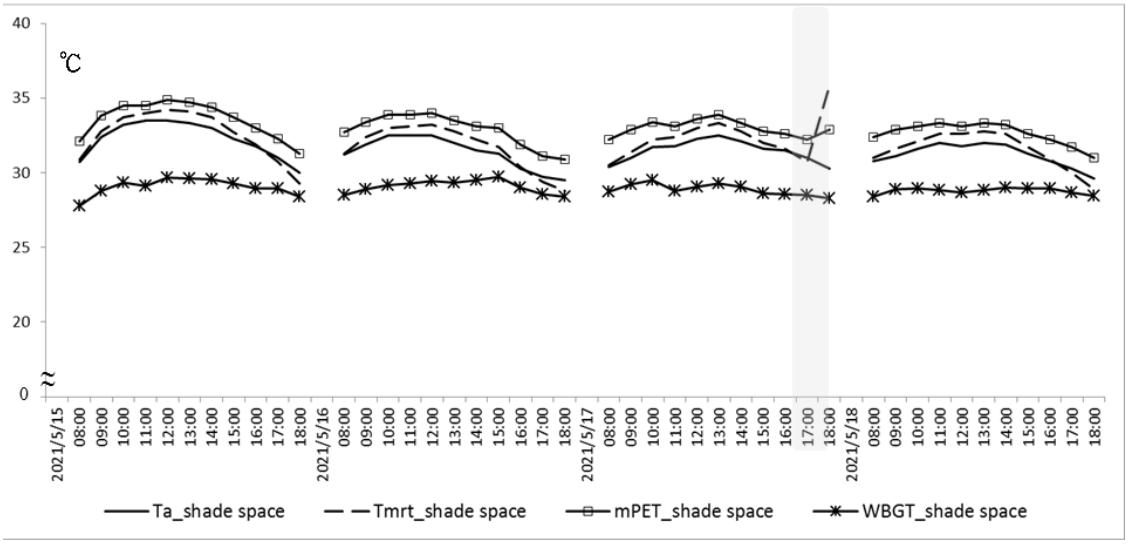


Figure 8. The shade site thermal performance nearby track and field stadium, NCKU, from May 15th - 18th

In Figure 8, it was indicated that the peak values under tree shade located at 12 PM for Tmrt, mPET, and Ta on May 15th and 16th, and shifted to 1 PM for the following two days. The trend of WBGT did not present the similar distribution characteristics as the rest tow thermal indices nor the air temperature. WBGT value was quite steady during the monitoring period of time, instead of sometime near noon, the peaks located at 3 PM and 10 AM on May 16th and 17th. mPET and Tmrt decline after 2 PM, and Tmrt tends to be lower than air temperature after 4 PM, but the mPET and Tmrt value suddenly rising to 32.9℃ and 35.8℃ on May 17th 6 PM.

Table 3. The shade site risk in causing thermal discomfort from May 15th - 18th

Thermal thresholds	Risk percentage	Standards
mPET>34 ℃	13.6 %	Warm standard for Taiwan[a]
mPET>38 ℃	0.0	Hot standard for Taiwan[a]
Tmrt > 40℃	0.0	
WBGT>25℃	100.0 %	Warning standard[b]
WBGT>31℃	0.0	Danger standard[b]

[a] Lin and Mazarakis [13]
[b] Ministry of the Environment, Japan [16]

In Table 3, the shade site risk in causing thermal discomfort were 13.6%, 100.0%, for mPET>34 ℃(Warm standard for Taiwan), and WBGT>25℃(Warning standard for outdoor exercises), which indicated that if you stay under the tree shade area, you still need to be aware of the slight chance in having discomfort feeling for all the time during the event, but it shall be not too hot or too uncomfortable for the most of time.

Table 4. The temperature difference between open site and shade site (T_{open} - T_{shade})

2021/5/15	△Ta	△Tmrt	△mPET	△WBGT	2021/5/17	△Ta	△Tmrt	△mPET	△WBGT
08:00	0.0	**1.9**	**0.4**	**0.7**	08:00	-0.1	**1.9**	**0.3**	0.0
09:00	-0.1	**17.2**	**4.5**	**1.8**	09:00	-0.1	**17.5**	**4.9**	**0.2**
10:00	**0.2**	**3.1**	**1.0**	**1.0**	10:00	**0.6**	**3.5**	**1.4**	**0.8**
11:00	**0.4**	**3.7**	**1.5**	**2.7**	11:00	**0.1**	**3.5**	**1.1**	**2.2**
12:00	**0.5**	**16.5**	**4.1**	**2.3**	12:00	**0.2**	**16.3**	**4.6**	**2.3**
13:00	**0.4**	**19.3**	**4.7**	**2.3**	13:00	**0.4**	**19.4**	**5.5**	**2.3**
14:00	**0.3**	**21.6**	**5.0**	**1.8**	14:00	**0.6**	**22.0**	**6.4**	**2.3**
15:00	-0.1	**20.9**	**4.6**	**0.7**	15:00	**0.1**	**21.1**	**5.5**	**0.4**
16:00	-0.2	**18.4**	**4.1**	-0.1	16:00	**0.0**	**18.6**	**4.9**	**0.1**
17:00	**0.1**	**12.8**	**2.9**	-0.6	17:00	**0.1**	**12.8**	**3.1**	-0.1
18:00	**0.3**	-0.8	-0.4	-0.5	18:00	**0.3**	-7.0	-2.0	-0.4
2021/5/16	△Ta	△Tmrt	△mPET	△WBGT	2021/5/18	△Ta	△Tmrt	△mPET	△WBGT
08:00	-0.3	**1.7**	-1.2	**0.3**	08:00	0.0	**1.9**	**0.3**	**0.1**
09:00	**0.2**	**17.5**	**4.0**	**1.5**	09:00	**0.1**	**17.5**	**4.5**	**0.8**
10:00	**0.2**	**3.1**	-0.2	**0.7**	10:00	**0.4**	**3.3**	**1.0**	**0.9**
11:00	**0.6**	**3.9**	**0.3**	**2.4**	11:00	**0.5**	**3.8**	**1.4**	**2.5**
12:00	**0.7**	**16.8**	**3.7**	**2.3**	12:00	**0.7**	**16.7**	**4.5**	**2.7**
13:00	**1.0**	**20.0**	**4.7**	**2.5**	13:00	**0.4**	**19.5**	**4.7**	**2.0**
14:00	**0.8**	**22.2**	**4.9**	**1.7**	14:00	**0.5**	**21.9**	**5.5**	**2.2**
15:00	**0.2**	**21.3**	**4.0**	**0.4**	15:00	**0.4**	**21.4**	**5.1**	**0.9**
16:00	**0.2**	**19.0**	**3.3**	-0.5	16:00	**0.2**	**18.9**	**4.4**	-0.3
17:00	**0.3**	**13.1**	**1.7**	-0.4	17:00	**0.3**	**13.0**	**3.0**	-0.3
18:00	**0.1**	-1.0	-2.5	-0.7	18:00	**0.4**	-0.7	-0.2	-0.5

The temperature difference between open site and shade site (T_{open} - T_{shade}) shown in Table 4, which indicated how much cooler could shade keep. By checking the temperature difference among thermal indices and air temperature, it addressed that the shade could really effectively lower the heat especially from 11 AM to 2 PM. The shade could keep Tmrt lower 22.2℃, mPET lower 6.4℃, WBGT lower 2.7℃, and even Ta lower 1.0℃ than the condition without proper shading.

4. Conclusions

Even though 2021 National Intercollegiate Athletic Games track field race scheduled on May 15th to 18th would have to be postponed to September due by the consideration in epidemic prevention and public health concern regarding COVID-19. By analyzing the thermal condition nearby the venue, it addressed a relatively high risk in having heat stress and thermal discomfort feelings for staying outdoors without shading during the previous scheduled Game period. The outdoors condition shall be tender this September, so maybe it could also beneficial for all of the Game participants to have a safer and more comfortable experience. And on-site environmental monitoring and questionnaires project will be carried on this September.

For analyzing area that is wide or lacking of sites providing sufficient data set with the similar quality assurance/ quality control process, reanalysis downscaling data could be quite helpful. But it is still needed to understand how to adjust the simulated data accuracy to close to the real condition near the surface, such as the wind speed and solar radiation data. Since they could be affected by various factors detected only in street scale, and the value could rapidly change in short periods of time. In this study, only 5 sites in Taipei among all 142 sites with the torch relay route around Taiwan were selected to analyze the thermal condition for examination the implementation of applying TReAD relanalysis downscaling simulation data, GSV2SVF tool, and RayMan pro. And it is quite certain that the analysis of all 142 sites will be continued in the near future, and the study of the variation among SVF, TVF, and BVF at different urban stereotypes in Taiwan will be also continued.

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