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# A Simple Method to Evaluate Adaptation Measures for Urban Heat Island

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Received: 16 May 2018; Accepted: 14 June 2018; Published: 16 June 2018

**Abstract:** In recent years, adaptation measures such as awnings, louvers, directional reflective materials, mist sprays, and evaporative materials, have been developed with the expectation that they will serve as effective solutions to outdoor human thermal environments that are under the influence of urban heat island. A simple method to evaluate the aforementioned adaptation measures is examined in this study, focusing on their appropriate introduction on urban space. The influence of the solar transmittance of adaptation measures such as shading, on mean radiant temperature (MRT) is approximately 1.5 °C per 0.10. If a shielding device that reflects a large amount of solar radiation and facilitates high levels of evaporation is developed, MRT and standard new effective temperature (SET*) will both decrease.

**Keywords:** adaptation measures; urban heat island; simple evaluation method; countermeasures against heat; SET*; MRT

## 1. Introduction

Mitigation measures such as green roof, cool roof (with a high reflectance material), and water-retentive materials, have been developed with the expectation that they will serve as countermeasures to the urban heat island [1–4]. In recent years, in order to serve as effective solutions to outdoor human thermal environments under the influence of urban heat islands, adaptation measures such as awnings, louvers, directional reflective materials, mist sprays, and evaporative materials have been developed. A simple method to evaluate these adaptation measures focusing on their appropriate introduction into urban space has been here investigated.

The Japanese Ministry of the Environment developed the 'Heat countermeasure guideline in the city' [5], which includes basic, specific adaptation measures, and technical sections. The guideline states that 'by understanding the factors that make it hot and implementing appropriate adaptation measures for places we have to wait for or places we want to spend comfortably such as bus stops and plazas, we can promote a healthy and comfortable environment in the urban area' (p. 11 of [5]). In the basic section, the adaptation measures against heat are explained in an accessible manner for the Japanese administration and the general public. In the specific adaptation measures section, the type and effect of adaptation measure technologies and precautions to be considered upon introducing them are explained for the general public and practitioners involved in town development. In the technical section, technical information on adaptation measure technologies is explained for building and external construction design practitioners.

Several studies focused on effective measures against heat waves have been implemented in various countries [6,7]. Evaporative cooling effects such as irrigation [6,7], vegetation and pavement watering [7] have been studied by the numerical simulation. Some of those scenarios assumed the future climate affected by climate change [7,8]. Discussions including the improvement of thermal environments in the street canyon or in the plaza were not sufficiently conducted based on the evaluation of the human thermal comfort in previous examinations [9–11].

In Germany, several cities are considering adaptation measures. According to a report from Karlsruhe City [12], it is recommended that appropriate adaptation measures be introduced in 'hot spots' where temperatures are high. Several typical urban districts in cities that may undergo adaptation in the future are also discussed. Within the Osaka Heat Island Countermeasure Technology Consortium [13], adaptation technologies developed by various companies were presented and evaluation methods were discussed so that they may be properly implemented in society. In this study, a specific method to evaluate adaptation measures is discussed, considering these efforts in Japan.

## 2. Adaptation Measures

The adaptation measures for urban heat islands listed in the heat countermeasure guidelines established by the Japanese Ministry of Environment [5], the report by the Japanese Ministry of Environment [14], and the town planning idea competition considering the urban heat island presented at the Osaka Heat Island Countermeasure Technology Consortium [15] are shown in Table 1. The mechanisms by which these methods work and the evaluation indices governing their effects are also presented. Heat is mainly mitigated by solar shading, solar reflection, and evaporation. Therefore, solar transmittance, solar reflectance, and evaporative efficiency (evaporative rate) are the primary evaluation indices. The increase in the convection heat transfer coefficient is the cause of cooling by fractal-shaped sunshades, and the artificial cooling is the cause of cooling by ceiling cooling systems and water cooling benches. Examples of adaptation measures developed by Japanese companies are shown in Figures 1–3 [14]. Experiments demonstrating these measures are currently proceeding throughout Japan [5,14–28].

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

**Figure 1.** Automatically opening and closing awning installed at a bus stop, which are provided by Prof. Misaka. (**a**) whole view; (**b**) internal view; (**c**) closed state.

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

**Figure 2.** Fractal-shaped sunshade, which is provided by Prof. Misaka. (**a**) in a park; (**b**) at a tram stop.

**Table 1.** Adaptation measures for urban heat islands and their effects and associated evaluation indices.

| Menu | Evaluation Index | Main Effect Mechanism |
|---|---|---|
| From the heat countermeasure guidelines by the Japanese Ministry of Environment [5] | | |
| Green shade [16] | Solar transmittance, Evaporative efficiency | Sun shade, Evaporative cooling |
| Solar radiation shade [17] | Solar transmittance, Convection heat transfer coefficient | Sun shade, Convection heat transfer |
| Retroreflective surface [18,19] | Downward solar reflectance | Solar reflection |
| Water retentive pavement [20,21] | Evaporative efficiency | Evaporative cooling |
| Cool pavement [21] | Solar reflectance | Solar reflection |
| Green pavement [22] | Evaporative efficiency | Evaporative cooling |
| Green wall [23] | Evaporative efficiency | Evaporative cooling |
| Water-retentive wall [24] | Evaporative efficiency | Evaporative cooling |
| Fine mist spray [25,26] | Evaporation rate | Evaporative cooling |
| from the report by the Japanese Ministry of Environment [14] | | |
| Awning [27] | Solar transmittance | Sun shade |
| Fractal-shaped sunshade [17] | Solar transmittance, Convection heat transfer coefficient | Sun shade, Convection heat transfer |
| Mesh shade and water supply [14] | Solar transmittance, Evaporative efficiency | Sun shade, Evaporative cooling |
| Evaporative cooling louver [24] | Evaporative efficiency | Evaporative cooling |
| Greening cooling louver [14] | Evaporative efficiency | Evaporative cooling |
| Tree pot [14] | Solar transmittance, Evaporative efficiency | Sun shade, Evaporative cooling |
| Water-retentive block [20] | Evaporative efficiency | Evaporative cooling |
| Water surface [28] | Evaporative efficiency | Evaporative cooling |
| Fine mist spray with blower [25,26] | Evaporation rate | Evaporative cooling |
| Ceiling cooling system [14] | Surface temperature | Artificial cooling |
| Water cooling bench [14] | Surface temperature | Artificial cooling |
| from town planning idea competition by Osaka Heat Island Countermeasure Technology Consortium [15] | | |
| Water surface [28] | Evaporative efficiency | Evaporative cooling |
| Watering [28] | Evaporative efficiency | Evaporative cooling |
| Fine mist spray [25,26] | Evaporation rate | Evaporative cooling |
| Shading [27] | Solar transmittance | Sun shade |
| Tree planting | Solar transmittance, Evaporative efficiency | Sun shade, Evaporative cooling |
| Roof and ground greening [22] | Evaporative efficiency | Evaporative cooling |
| Wind use | Convection heat transfer coefficient | Convection heat transfer |
| Traffic mode control | Anthropogenic heat release | Reduction of anthropogenic heat release |
| Unused energy use, natural energy use | Anthropogenic heat release | Reduction of anthropogenic heat release |
| ICT use | Human body physiological amount | Reduction of human thermal load |

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

**Figure 3.** Evaporative cooling louver, which is provided by Prof. Misaka. (**a**) in a park; (**b**) at a tram stop.

## 3. Simple Evaluation Method of Adaptation Measures

### 3.1. Methods

The effect of the studied adaptation measures is evaluated by outdoor human thermal comfort, which is strongly correlated to the outdoor thermal environment. As Nouri et al. [29] pointed out, the selection of the index for the assessment of outdoor thermal comfort conditions is still a debated matter [30]. They stated that, "So far, within the international community various indices have been developed and disseminated, including the (i) Standard Effective Temperature (SET*) [31]; (ii) Outdoor Standard Effective Temperature (OUT_SET*) [32,33]; (iii) Perceived Temperature (PT) [34]; (iv) Predicted Mean Vote (PMV) [35,36]; (v) Index of Thermal Stress (ITS) [37]; (vi) Predicted Percentage of Dissatisfied (PPD) [35]; (vii) COMFA outdoor thermal comfort model [38]; (viii) Universal Thermal Climate Index (UTCI) [39–41]; (ix) Wet Bulb Globe Temperature (WBGT) [42,43]; and (x) Predicted Heat Strain (PHS) [44–46]." They also demonstrated the necessity of standardizing a thermal comfort index for specific regions. Currently, different indices are widely used by each academic community. Physiologically Equivalent Temperature (PET) is widely used in Europe; it has been defined as the air temperature at which, in a typical indoor setting, the human energy budget is maintained by the skin temperature, core temperature, and perspiration rate, which are equivalent to those under the conditions to be assessed [47,48]. In Japan, SET* and WBGT are mainly used. WBGT, which is a stress index worldwide accepted as a preliminary tool for the assessment of hot thermal environments [49–51], is often used under more severe conditions to warn of the risk of heat stroke. SET* is defined as the equivalent dry bulb temperature of an isothermal environment at 50% RH in which a subject, while wearing clothing standardized for the activity concerned, would have the same heat stress and thermo-regulatory strain as in the actual test environment [31], is used to evaluate the thermal environment [5]. The relationship between SET* and thermal comfort, which is based on the results of a declaration test for the outdoor comfort of Japanese people, is shown in Table 2 [52]. SET* is desirable as an index from the viewpoint of appropriately introducing adaptation measures in urban areas and developing a more comfortable outdoor space as it exhibits a good relationship with outdoor thermal comfort [53].

**Table 2.** Relationship between Standard Effective Temperature (SET*) and thermal comfort.

| SET* (°C) | Thermal Comfort |
|---|---|
| | extremely uncomfortable |
| 33.3 | |
| | Uncomfortable |
| 32.1 | |
| | slightly uncomfortable |
| 30.8 | |
| | Neither |
| 28.4 | |
| | slightly comfortable |
| 27.0 | |
| | Comfortable |

#### 3.1.1. Sensitivity Analysis

Assuming a typical summer day as a standard condition; under which the air temperature is 34 °C, relative humidity is 50%, wind speed is 1 m/s, mean radiant temperature (MRT) in a sunny place is 50 °C or 37 °C in a shaded place, clothing insulation is 0.6 clo, and metabolic rate is 2 Met; a SET* sensitivity analysis was conducted with a variation range of 20 °C to 40 °C for air temperature, 30% to 80% for relative humidity, 0.5 m/s to 3 m/s for wind speed, and 20 °C to 60 °C for MRT [54,55].

#### 3.1.2. MRT and Surface Temperature Reduction Evaluation

The decrease in MRT caused by solar radiation shielding was dominant over the improvement in SET*. Assuming the implementation of adaptation measures such as shading, MRT was evaluated using the following indices: solar transmittance $\tau$, evaporation rate $E$, solar absorptance $a$, and convective heat transfer coefficient $h$. Assuming that the human body is spherical with a solar absorptance $a_h$ which is assumed to be 0.5, MRT can be calculated from Equation (1) [55–57]:

$$MRT = \left( a_h Q/\sigma + \sum_{i=1} \Phi_i T_i^4 \right)^{\frac{1}{4}} \quad (1)$$

With reference to previous studies in Japan [54,55], the weather conditions during a typical summer day were assumed as follows; solar radiation $J$ was 1000 W/m$^2$ (direct solar radiation was 900 W/m$^2$ and diffuse solar radiation was 100 W/m$^2$), each surface temperature $T_i$ was the same as the air temperature $T_a$ ($T_i$ = $T_a$ = 34 °C), the MRT under clear sky conditions was 56.2 °C. While the relationship between the human body and the surrounding objects is varied actually, in order to simplify the discussion, it is supposed to be a human body on a green area that has been thoroughly irrigated. The incident solar radiation on the human body was calculated by $Q$ = 900/4 + 100 W/m$^2$, as the human body was assumed to be a sphere. $\sigma$ is the Stefan–Boltzmann constant (=5.67 × 10$^{-8}$ W/(m$^2$K$^4$)), and $\Phi_i$ is the shape factor between the human body and each surface.

Surface temperature $T_s$ of the adaptation measures is calculated from Equation (2):

$$T_s = \frac{1}{h}(aJ + \varepsilon q - lE) + T_a \quad (2)$$

where, ε is emissivity, q is net infrared radiation and l is the latent heat of vaporization of water (=2500 kJ/kg).

### *3.2. Results*

#### 3.2.1. Sensitivity Analysis

Sensitivity analysis results are shown in Figure 4. The sensitivities by air temperature, relative humidity, wind speed, and MRT were 0.63 °C/°C, 0.13 °C/%, 1.4 °C/(m/s), and 0.21 °C/°C, respectively. The sensitivities by MRT and wind speed were larger than those by air temperature and relative humidity, however, they were within the expected variation range of each element. The relationship between air temperature, MRT, and SET* is shown in Figure 5. SET* is indicated by a contour line. Above-standard conditions were set for the other elements. If the evaluation point moved from a sunny to a shaded place, the MRT decreased by 13 °C and SET* decreased by 2.8 °C. To obtain the same decrease in SET* due to air temperature reduction by mist spraying, it must be lowered by 4.2 °C. Similarly, it is difficult to considerably reduce MRT using cool walls and pavements. Examples of the effects of adaptation measures obtained by demonstrative experiments are shown in Figure 6. As MRT was measured by a globe thermometer, the solar absorptance was set to 1.0, which was much larger than that of the human body. The measurements were taken at various places and times under typical summer weather condition, therefore, a simple mutual comparison was not appropriate. It was, however, possible to qualitatively recognize the characteristics of each adaptation measure [14]. Shielding of solar radiation to pedestrians was a more effective method of lowering MRT and SET*.

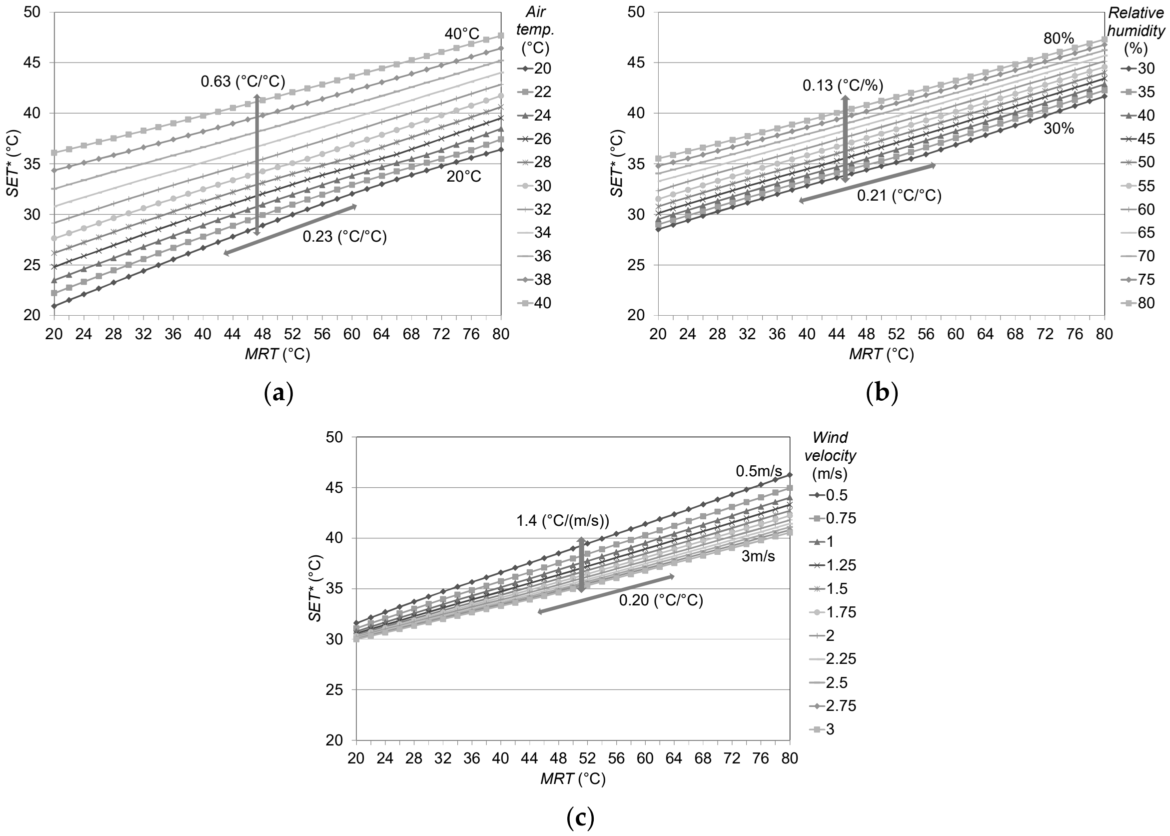



**Figure 4.** Sensitivity analysis results conducted with a variation range of (**a**) 20 to 40 °C for air temperature, (**b**) 30 to 80% for relative humidity, (**c**) 0.5 to 3 m/s for wind speed, and 20 to 60 °C for mean radiant temperature (MRT), when clothing insulation is 0.6 clo and metabolic rate is 2 Met.

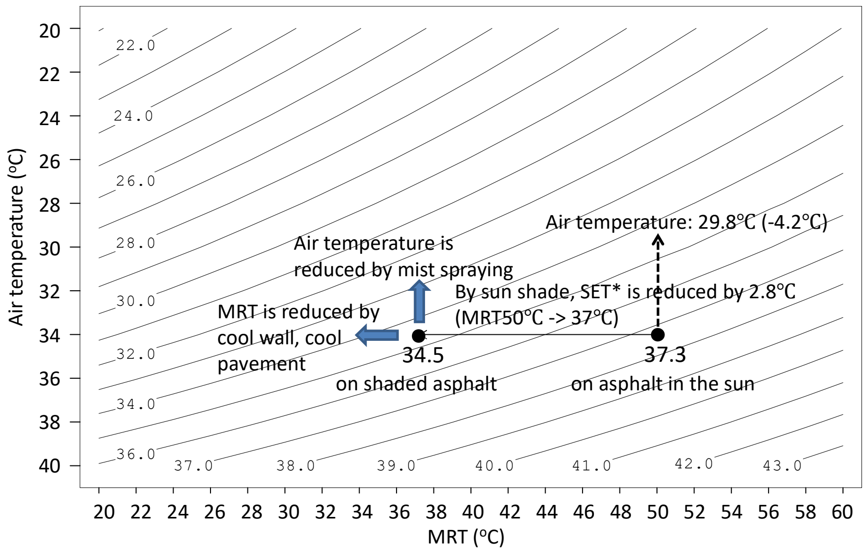



**Figure 5.** Relationships between air temperature, MRT, and SET*. SET* is indicated by a contour line. The relative humidity is 50%, wind speed is 1 m/s, clothing insulation is 0.6 clo, and metabolic rate is 2 Met.

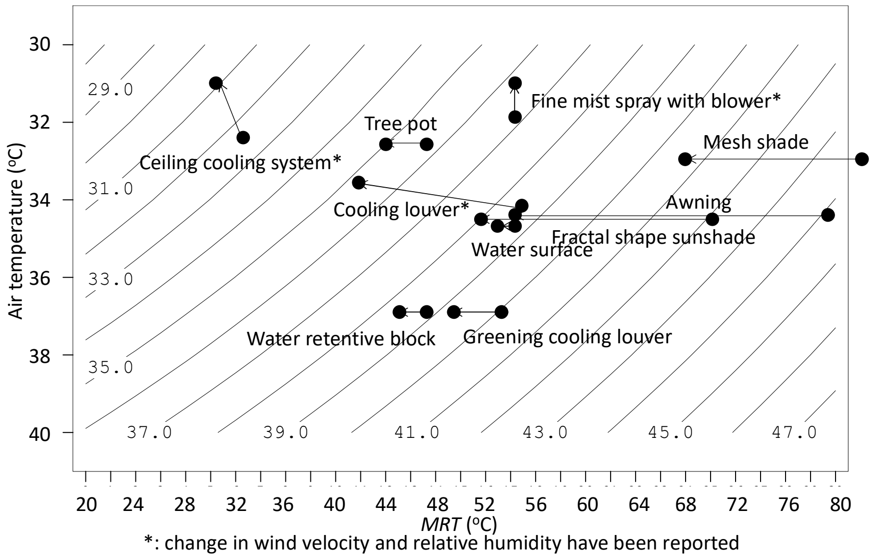



**Figure 6.** Examples of the effects of adaptation measures obtained through demonstrative experiments. The background SET* is the same as that in Figure 5.

### 3.2.2. MRT and Surface Temperature Reduction Evaluation

The relationship between solar transmittance $\tau$ and MRT reduction by adaptation measures such as an awning, is shown in Figure 7. If the influence of long-wave radiation was ignored, complete shielding of solar radiation decreased the MRT by 15 °C.

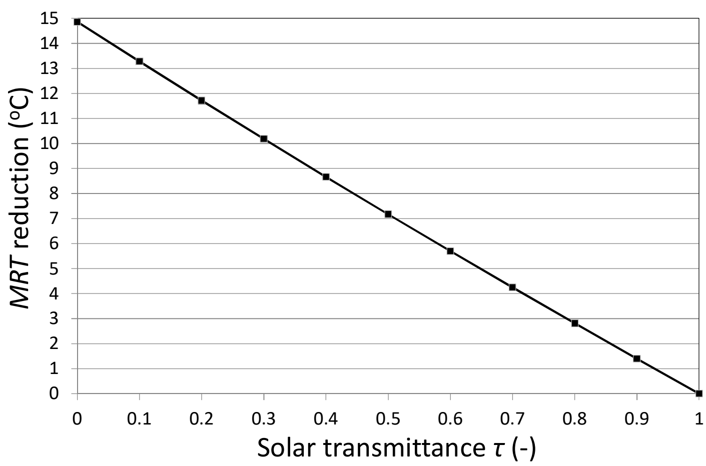



**Figure 7.** Relationship between solar transmittance $\tau$ and MRT reduction by adaptation measures.

The relationship between the surface temperature $T_s$ of the adaptation measures and the solar absorptance $a$ when the heat transfer coefficient $h$ is 23 W/(m$^2$K), emissivity $\varepsilon$ is 0.97, and net infrared radiation $q$ is −93 W/m$^2$ for different values of the evaporation rate $E$ is shown in Figure 8. Although net infrared radiation $q$ and the evaporation rate $E$ varied depending on weather conditions such as surface temperature, air temperature, and wind velocity, they were set to specific values to allow simple evaluation. Even if the evaporation rate $E$ was 0 L/(m$^2$h), when the solar radiation absorptance $a$ was 0.1, the surface temperature $T_s$ was almost the same as the air temperature. The surface temperature $T_s$ when the heat transfer coefficient $h$ is 46 or 92 W/(m$^2$K) is shown in Figure 9. A fractal-shaped sunshade was developed focusing on the utilization of the effect caused by increasing the heat transfer coefficient [17]. As the heat transfer coefficient $h$ increased, the surface temperature $T_s$ approached the air temperature value regardless of the solar absorptance $a$ and evaporation rate $E$.

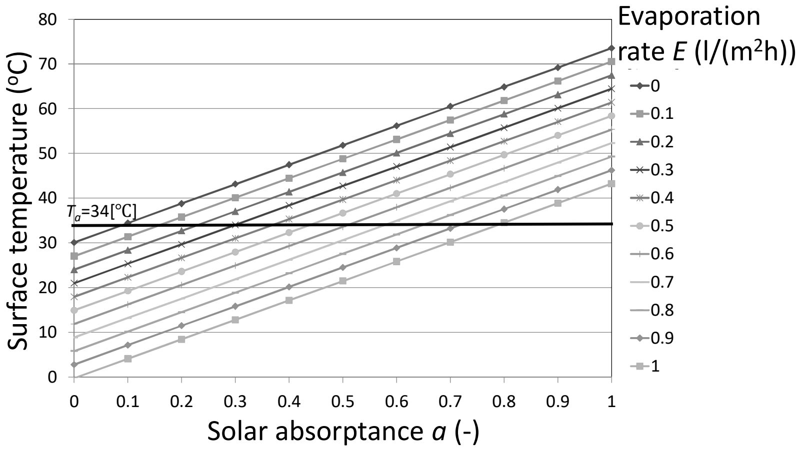
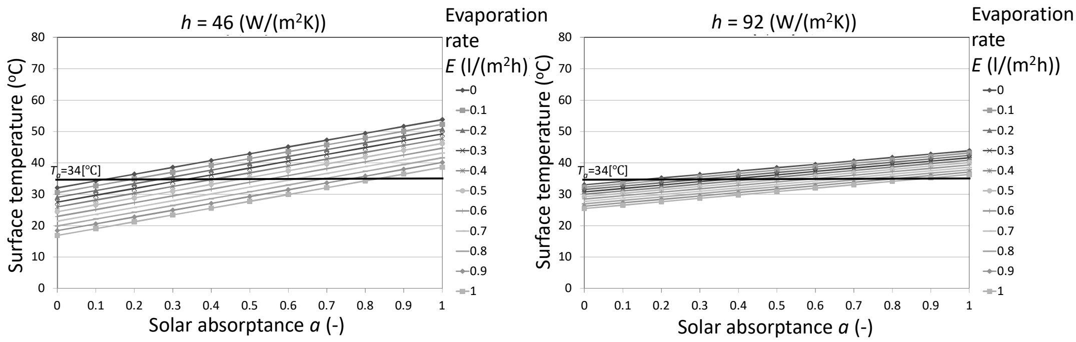



**Figure 8.** Relationship between the surface temperature $T_s$ of the adaptation measures and the solar absorptance $a$ when the heat transfer coefficient $h$ is 23 W/(m$^2$K), emissivity $\varepsilon$ is 0.97, and net infrared radiation $q$ is $-93$ W/m$^2$ for different values of the evaporation rate $E$.




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

**Figure 9.** Surface temperature $T_s$ when the heat transfer coefficient (**a**) $h$ is 46, (**b**) $h$ is 92 W/(m$^2$K).

The relationship between the MRT reduction and the solar absorptance $a$ when the evaporation rate $E$ is 0 L/(m$^2$h) for different values of the shape factor $\Phi$ of the human body is shown in Figure 10. When the shape factor $\Phi$ and solar absorptance $a$ were large, the MRT increased due to the effect of long-wave radiation from the adaptation measures.

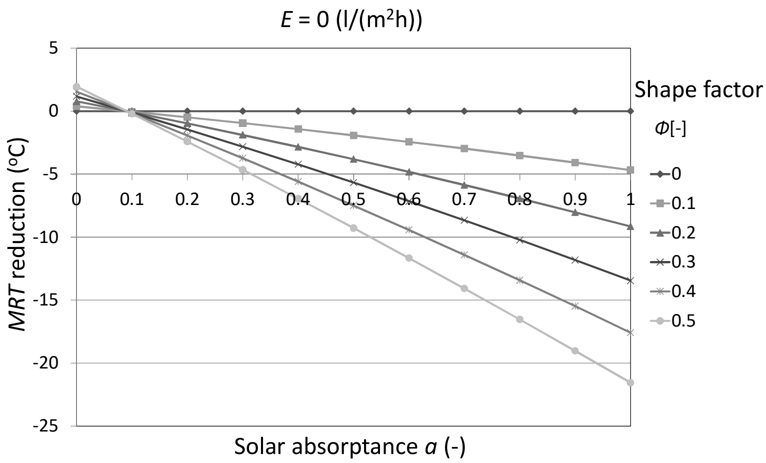



**Figure 10.** Relationship between the MRT reduction and the solar absorptance $a$ when the evaporation rate $E$ is 0 L/(m$^2$h) for different values of the shape factor $\Phi$ of the human body.

The relationship between the MRT reduction and the solar transmittance $\tau$ when the evaporation rate $E$ is 0 L/(m$^2$h) and the shape factor of the human body $\Phi$ is 0.3 for different values of the solar absorptance $a$ is shown in Figure 11. When the targeted MRT reduction was 10 °C, the required solar transmittance $\tau$ plus solar absorptance $a$ was 0.4 or less.

The relationship between the MRT reduction and the solar transmittance $\tau$ when the evaporation rate $E$ is 1.0 L/(m$^2$h) and the shape factor of the human body $\Phi$ is 0.3 for different values of the solar absorptance $a$ is shown in Figure 12. If the evaporation rate $E$ was 1.0 L/(m$^2$h) or more, MRT decreased by 10 °C regardless of solar transmittance $\tau$ and solar absorptance $a$.

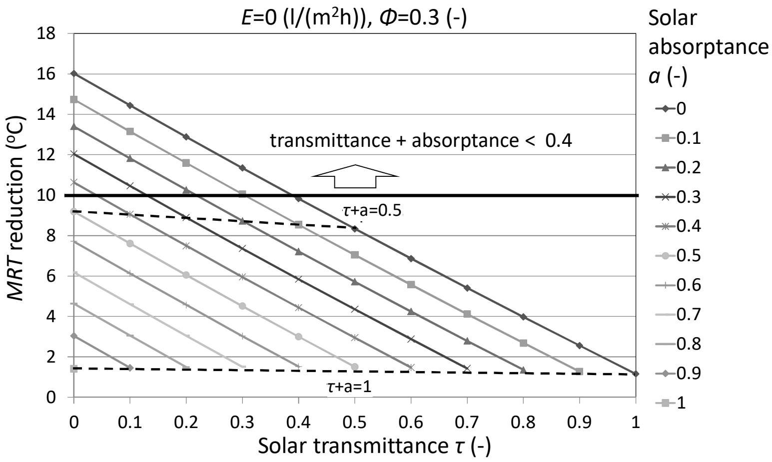



**Figure 11.** Relationship between the MRT reduction and the solar transmittance $\tau$ when the evaporation rate $E$ is 0 L/(m$^2$h) and the shape factor of the human body $\Phi$ is 0.3 for different values of the solar absorptance $a$.

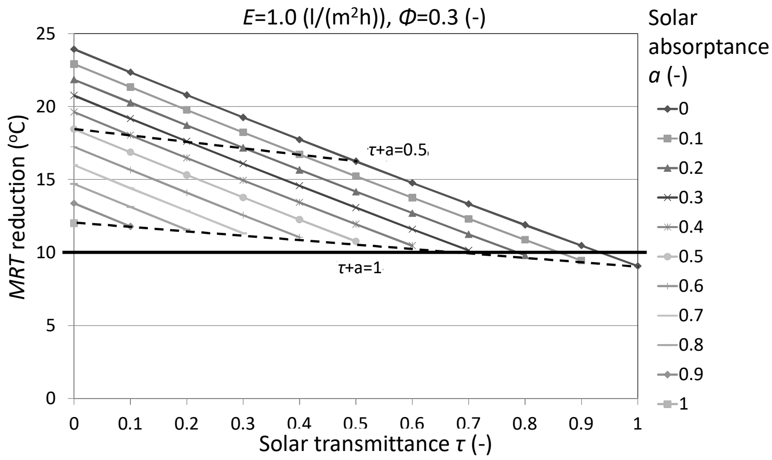



**Figure 12.** Relationship between the MRT reduction and the solar transmittance $\tau$ when the evaporation rate $E$ is 1.0 L/(m$^2$h) and the shape factor of the human body $\Phi$ is 0.3 for different values of the solar absorptance $a$.

## 4. Discussion

In a typical summer day weather condition, if the evaluation point moved from a sunny to a shaded place, the MRT decreased by 13 °C and SET* decreased by 2.8 °C. Watanabe et al. have revealed that the globe temperature in sunlight was higher than that in the building shade by 16.7 °C and was 13.9 °C higher than that in the pergola shade in a clear day with global solar radiation of 800 W/m$^2$ [55]. Changes in the MRT in this study and the globe temperature by Watanabe et al. due to solar shielding corresponded relatively. It is difficult to reduce MRT to this level using cool walls and pavements. Through several examples of the effects of adaptation measures obtained by demonstrative experiments [14], it can be seen shielding of solar radiation to pedestrians is a more effective method of lowering MRT and SET*. If the influence of long-wave radiation was ignored, complete shielding of solar radiation decreased the MRT by 15 °C. Even if the evaporation rate $E$ was 0 L/(m$^2$h), when the solar radiation absorptance of the adaptation measures $a$ was less than 0.1, the surface temperature $T_s$ was almost the same as the air temperature. A fractal-shaped sunshade was developed focusing on the utilization of the effect caused by increasing the heat transfer coefficient [17]. As the heat transfer coefficient $h$ increased, the surface temperature $T_s$ approached the air temperature value regardless of the solar absorptance $a$ and evaporation rate $E$. When the shape factor between the human body and the adaptation measures $\Phi$ and solar absorptance $a$ were large, the MRT increased due to the effect of long-wave radiation from the adaptation measures. When the targeted MRT reduction was 10 °C, the required solar transmittance $\tau$ plus solar absorptance $a$ was 0.4 or less. If the evaporation rate $E$ was 1.0 L/(m$^2$h) or more, MRT decreased by 10 °C regardless of solar transmittance $\tau$ and solar absorptance $a$.

## 5. Conclusions

Through several examples of the effects of adaptation measures obtained by demonstrative experiments, it can be seen that shielding of solar radiation to pedestrians is a more effective method of lowering MRT and SET*. The influence of the solar transmittance of adaptation measures such as shading, on MRT is approximately 1.5 °C per 0.10. The influence of the solar absorptance of adaptation measures such as an awning, on MRT is approximately 1.0 °C per 0.10, which also depends on the shape factor between the human body and adaptation measures. The influence of the evaporation rate on MRT is approximately 1.0 °C per 0.10 L/(m$^2$h). If a shielding device that reflects a large amount of solar radiation and facilitates high levels of evaporation is developed, MRT and SET* will both decrease.

**Funding:** This research received no external funding.

**Acknowledgments:** Part of the materials used in this study was provided by Ikusei Misaka of the Nippon Institute of Technology. The author thanks the members of the Study Committee of Osaka HITEC and the Cool Roof Proper Promotion Subcommittee of AIJ for their valuable comments.

**Conflicts of Interest:** The author declares no conflict of interest.

## Nomenclature

| | |
|---|---|
| $\varepsilon$ | emissivity of the adaptation measures (-) |
| $\sigma$ | Stefan–Boltzmann constant (W/(m$^2$K$^4$)) |
| $\tau$ | solar transmittance of the adaptation measures (-) |
| $\Phi_i$ | shape factor between the human body and each surface (-) |
| $a$ | solar absorptance of the adaptation measures (-) |
| $a_h$ | solar absorptance of human body (-) |
| $E$ | evaporation rate of the adaptation measures (L/(m$^2$h)) |
| $h$ | convective heat transfer coefficient (W/(m$^2$K)) |
| $J$ | solar radiation (W/m$^2$) |
| $l$ | latent heat of water (kJ/kg) |
| MRT | mean radiant temperature (°C) |
| $q$ | net infrared radiation (W/m$^2$) |
| $Q$ | incident solar radiation on the human body (W/m$^2$) |
| SET* | standard effective temperature (°C) |
| $T_a$ | air temperature (°C) |
| $T_i$ | surface temperature of each surface (°C) |
| $T_s$ | surface temperature of the adaptation measures (°C) |

## References


1. Akbari, H.; Kolokotsa, D. Three decades of urban heat islands and mitigation technologies research. *Energy Build.* **2016**, *133*, 834–842. [CrossRef]
2. Aleksandrowicz, O.; Vuckovic, M.; Kiesel, K.; Mahdavi, A. Current trends in urban heat island mitigation research: Observations based on a comprehensive research repository. *Urban Clim.* **2017**, *21*, 1–26. [CrossRef]
3. Santamouris, M. Cooling the cities—A review of reflective and green roof mitigation technologies to fight heat island and improve comfort in urban environments. *Sol. Energy* **2014**, *103*, 682–703. [CrossRef]
4. Santamouris, M. Using cool pavements as a mitigation strategy to fight urban heat island—A review of the actual developments. *Renew. Sustain. Energy Rev.* **2013**, *26*, 224–240. [CrossRef]
5. The Ministry of the Environment of Japan, Heat Countermeasure Guideline in the City. Available online: http://www.env.go.jp/air/life/heat_island/guidelineH28/city_gline_all.pdf (accessed on 9 April 2018).
6. Broadbent, A.M.; Coutts, A.M.; Tapper, N.J.; Demuzere, M. The cooling effect of irrigation on urban microclimate during heatwave conditions. *Urban Clim.* **2018**, *23*, 309–329. [CrossRef]
7. Daniel, M.; Lemonsu, A.; Viguié, V. Role of watering practices in large-scale urban planning strategies to face the heat-wave risk in future climate. *Urban Clim.* **2018**, *23*, 287–308. [CrossRef]
8. De Munck, C.; Lemonsu, A.; Masson, V.; Le Bras, J.; Bonhomme, M. Evaluating the impacts of greening scenarios on thermal comfort and energy and water consumptions for adapting Paris city to climate change. *Urban Clim.* **2018**, *23*, 260–286. [CrossRef]
9. Baklanov, A.; Grimmond, C.S.B.; Carlson, D.; Terblanche, D.; Tang, X.; Bouchet, V.; Lee, B.; Langendijk, G.; Kolli, R.K.; Hovsepyan, A. From urban meteorology, climate and environment research to integrated city services. *Urban Clim.* **2018**, *23*, 330–341. [CrossRef]
10. Gao, Z.; Bresson, R.; Qu, Y.; Milliez, M.; Munck, C.; Carissimo, B. High resolution unsteady RANS simulation of wind, thermal effects and pollution dispersion for studying urban renewal scenarios in a neighborhood of Toulouse. *Urban Clim.* **2018**, *23*, 114–130. [CrossRef]
11. Ng, E.; Ren, C. China's adaptation to climate & urban climatic changes: A critical review. *Urban Clim.* **2018**, *23*, 352–372. [CrossRef]
12. Beermann, B.; Berchtold, M.; Baumüller, J.; Gross, G.; Kratz, M. *Städtebaulicher Rahmenplan Klimaanpassung für Die Stadt Karlsruhe (Teil II)*; LUBW Landesanstalt für Umwelt, Messungen und Naturschutz Baden-Württemberg: Karlsruhe, Germany, 2014.
13. Osaka Heat Island Countermeasure Technology Consortium. HITEC News. Available online: http://osakahitec.com/active/news/news2018_01_vol14.pdf (accessed on 9 April 2018).
14. Center for Environmental Information Science. *Report on Consignment Work of Survey and Verification for the Creation of a Low-Carbon City Using Surplus Groundwater etc.*; Report Entrusted by the Ministry of the Environment in 2016 Fiscal Year; Center for Environmental Information Science: Tokyo, Japan, 2017. (In Japanese)
15. Osaka Heat Island Countermeasure Technology Consortium. Town Planning Idea Competition Considering Urban Heat Island. Available online: http://osakahitec.com/result/index.html (accessed on 9 April 2018).
16. Takayama, N.; Yoshikoshi, H.; Yamamoto, H.; Iwaya, K.; Harada, Y.; Yamasaki, T.; Tateishi, Y. Quantitative evaluation of mitigation effect for thermal load of solar radiation through the glass window by wall greening. *J. Environ. Eng. (Trans. AIJ)* **2011**, *661*, 247–254. [CrossRef]
17. Sakai, S.; Nakamura, M.; Furuya, K.; Amemura, N.; Onishi, M.; Iizawa, I.; Nakata, J.; Yamaji, K.; Asano, R.; Tamotsu, K. Sierpinski's forest: New technology of cool roof with fractal shapes. *Energy Build.* **2012**, *55*, 28–34. [CrossRef]
18. Inoue, T.; Ichinose, M.; Nagahama, T. Improvement of outdoor thermal radiation environment in urban areas using wavelength-selective retro-reflective film. In Proceedings of the PLEA 2015, Bologna, Italy, 9–11 September 2015; p. 48.
19. Sakai, H.; Emura, K.; Igawa, N.; Iyota, H. Reduction of reflected heat of the sun by retroreflective materials. *J. Heat Isl. Inst. Int.* **2012**, *7*, 218–221.
20. Takebayashi, H.; Moriyama, M. Study on surface heat budget of various pavements for urban heat island mitigation. *Adv. Mater. Sci. Eng.* **2012**, 1–11. [CrossRef]

21. Akagawa, H.; Takebayashi, H.; Moriyama, M. Experimental study on improvement of human thermal environment on a watered pavement and a highly reflective pavement. *J. Environ. Eng. (Trans. AIJ)* **2008**, *623*, 85–91. [CrossRef]
22. Takebayashi, H.; Moriyama, M. Study on the urban heat island mitigation effect achieved by converting to grass-covered parking. *Sol. Energy* **2009**, *83*, 1211–1223. [CrossRef]
23. Misaka, I.; Suzuki, H.; Mizutani, A.; Murano, N.; Tashiro, Y. Evaluation of heat balance of wall greening. *AIJ J. Technol. Des.* **2006**, *23*, 233–236. (In Japanese) [CrossRef]
24. Hirayama, Y.; Ohta, I.; Hoyano, A. Development of a surface wetting passive cooling louver system with hydrophilic and water absorbing coating film and an evaluation of its fundamental performance by outdoor experiment. *J. Heat Isl. Inst. Int.* **2015**, *10*, 24–34. (In Japanese)
25. Yoon, G.; Yamada, H.; Okumiya, M.; Tsujimoto, M. Study on cooling system by using dry mist, Validation of cooling effectiveness and CFD simulation. *J. Environ. Eng. (Trans. AIJ)* **2008**, *633*, 1313–1320. [CrossRef]
26. Farnham, C.; Nakao, M.; Nishioka, M.; Nabeshima, M.; Mizuno, T. Study of mist-cooling for semi-enclosed spaces in Osaka, Japan. *Procedia Environ. Sci.* **2011**, *4*, 228–238. [CrossRef]
27. Kojima, I.; Yoshinaga, M. Analysis of the effect by the material and color of awnings—Discussion about the outdoor test method of SC-value based on JIS A 1422. *Summ. Tech. Pap. Annu. Meet. AIJ* **2013**, *D-2*, 145–146. (In Japanese)
28. Nishimura, N.; Nomura, T.; Iyota, H.; Kimoto, S. Novel water facilities for creation of comfortable urban micrometeorology. *Sol. Energy* **1998**, *64*, 197–207. [CrossRef]
29. Nouri, A.S.; Costa, J.P.; Santamouris, M.; Matzarakis, A. Approaches to Outdoor Thermal Comfort Thresholds through Public Space Design: A Review. *Atmosphere* **2018**, *9*, 108. [CrossRef]
30. D'Ambrosio Alfano, F.R.; Olesen, B.W.; Palella, B.I. Povl Ole Fanger's Impact Ten Years Later. *Energy Build.* **2017**, *152*, 243–249. [CrossRef]
31. Gagge, A.; Fobelets, P.; Bergland, L. A standard predictive index of human response to thermal environment. *ASHRAE Trans.* **1986**, *92*, 709–731.
32. Spagnolo, J.; de Dear, R. A field study of thermal comfort in outdoor and semi-outdoor environments in subtropical Sydney, Australia. *Build. Environ.* **2003**, *38*, 721–738. [CrossRef]
33. De Dear, R.; Pickup, R. An outdoor thermal comfort index (OUT_SET*)—Part I—The model and its assumptions. In Proceedings of the International Conference on Urban Climatology, Sydney, Australia, 8–9 November 1999.
34. Tinz, B.; Jendrizky, G. *Europa- und Weltkarten der Gefühlten Temperatur*; Chmielewski, F., Foken, T., Eds.; Beiträge zur Klima- und Meeresforschung: Berlin/Bayreuth, Germany, 2003; pp. 111–123.
35. Fanger, P.O. *Thermal Comfort: Analysis and Applications in Environmental Engineering*; McGraw-Hill Book Company: New York, NY, USA, 1972; p. 244.
36. D'Ambrosio Alfano, F.R.; Palella, B.I.; Riccio, G. Notes on the calculation of the PMV index by means of Apps. *Energy Procedia* **2016**, *101*, 243–249. [CrossRef]
37. Givoni, B. *Man, Climate and Architecture*; Applied Science Publishers: London, UK, 1976.
38. Kenny, A.; Warland, S.; Brown, R. Part A: Assessing the performance of the COMFA outdoor thermal comfort model on subjects performing physical activity. *Int. J. Biometeorol.* **2009**, *53*, 415–428. [CrossRef] [PubMed]
39. Jendritzky, G.; Maarouf, A.; Fiala, D.; Staiger, H. An update on the development of a Universal Thermal Climate Index. In Proceedings of the 15th Conference on Biometeorology Aerobiology and 16th ICB02, Kansas City, MO, USA, 27 October–1 November 2002; AMS: New York, NY, USA, 2002.
40. Jendritzky, G.; de-Dear, R.; Havenith, G. UTCI—Why another thermal index? *Int. J. Biometeorol.* **2012**, *56*, 421–428. [CrossRef] [PubMed]
41. Bröde, P.; Fiala, D.; Blazejczyk, K.; Holmér, I.; Jendritzky, G.; Kampmann, B.; Tinz, B.; Havenith, G. Deriving the operational procedure for the Universal Thermal Climate Index (UTCI). *Int. J. Biometeorol.* **2012**, *56*, 481–494. [CrossRef] [PubMed]
42. Yaglou, C.; Minard, D. Control of heat casualties at military training centers. *AMA Arch. Ind. Health* **1957**, *16*, 302–316. [PubMed]
43. Alfano, F.; Malchaire, J.; Palella, B.; Riccio, G. WBGT index revisited after 60 years of use. *Ann. Occup. Hyg.* **2014**, *58*, 955–970.

44. Malchaire, J.; Piette, A.; Kampmann, B.; Mehnerts, P.; Gebhardt, H.; Havenith, G.; Hartog, E.; Holmer, I.; Parsons, K.; Alfanoss, G.; et al. Development and Validation of the Predicted Heat Strain Model. *Ann. Occup. Hyg.* **2001**, *45*, 123–135. [CrossRef]
45. International Organization for Standardization. *Ergonomics of the Thermal Environment—Analytical Determination and Interpretation of Heat Stress Using Calculation of the Predicted Heat Strain—ISO 7933 Standard*; ISO: Geneva, Switzerland, 2004.
46. D'Ambrosio Alfano, F.R.; Palella, B.I.; Riccio, G.; Malchaire, J. On the Effect of Thermophysical Properties of Clothing on the Heat Strain Predicted by PHS Model. *Ann. Occup. Hyg.* **2016**, *60*, 231–251. [CrossRef] [PubMed]
47. Höppe, P. The physiological equivalent temperature—A universal index for the biometeorological assessment of the thermal environment. *Int. J. Biometeorol.* **1999**, *43*, 71–75. [CrossRef] [PubMed]
48. Mayer, H.; Höppe, P. Thermal comfort of man in different urban environments. *Theor. Appl. Climatol.* **1987**, *38*, 43–49. [CrossRef]
49. ACGIH. *Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposures Indices*; American Conference of Governmental Industrial Hygienists: Cincinnati, OH, USA, 2011.
50. Palella, B.I.; Quaranta, F.; Riccio, G. On the management and prevention of heat stress for crews onboard ships. *Ocean Eng.* **2016**, *112*, 277–286. [CrossRef]
51. International Organization for Standardization. *Ergonomics of the Thermal Environment—Assessment of Heat Stress Using the WBGT (Wet Bulb Globe Temperature) Index—ISO Standard 7243*; ISO: Geneva, Switzerland, 2017.
52. Ishii, A.; Katayama, T.; Shiotsuki, Y.; Yoshimizu, H.; Abe, Y. Experimental study on comfort sensation of people in the outdoor environment. *J. Arch. Plan. Res.* **1988**, *386*, 28–37. [CrossRef]
53. Nakano, J.; Tanabe, S. Thermal comfort and adaptation in semi-outdoor environments. *ASHRAE Trans.* **2004**, *110*, 543–553.
54. Nagano, K.; Horikoshi, T. New index indicating the universal and separate effects on human comfort under outdoor and non-uniform thermal conditions. *Energy Build.* **2011**, *43*, 1694–1701. [CrossRef]
55. Watanabe, S.; Nagano, K.; Ishii, J.; Horikoshi, T. Evaluation of outdoor thermal comfort in sunlight, building shade, and pergola shade during summer in a humid subtropical region. *Build. Environ.* **2014**, *82*, 556–565. [CrossRef]
56. VDI 3787 Part 2, Environmental Meteorology Methods for the Human Biometeorological Evaluation of Climate and Air Quality for Urban and Regional Planning at Regional Level Part I: Climate. 1998. Available online: http://www.scirp.org/(S(oyulxb452alnt1aej1nfow45))/reference/ReferencesPapers.aspx?ReferenceID=1721475 (accessed on 16 May 2018).
57. Watanabe, S.; Horikoshi, T.; Ishii, J.; Tomita, A. The measurement of the solar absorptance of the clothed human body—The case of Japanese, college-aged male subjects. *Build. Environ.* **2013**, *59*, 492–500. [CrossRef]