Reduction of Mean Radiant Temperature by Cluster of Trees In Urban and Architectural Planning In Tropical Climates

The case of Campinas, Brazil

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ABSTRACT: This paper presents thermal bioclimate analyses using air temperature, mean radiant temperature and physiologically equivalent temperature conditions in tropical climate of Campinas, Brazil, and also, the influence of solar radiation attenuated by shade clusters in mean radiant temperature. ***Six homogeneous clusters of trees were chosen:*** *Caesalpinia pluviosa, Spathodea campanulata, Tipuana tipu, Lafoensia glyptocarpa, Delonix indica, Senna siamea. The data collected in field measurement were: solar radiation, air temperatures, relative humidity and wind speed, for the period 2007 to 2010. The simulation of shade variation were done for the period 2003 to 2010 over to verify the influence on urban climate changes in mean temperature due modifications tree canopy. The results shows not only that solar radiation can influence air temperature, but also mean radiant temperature as well. Furthermore, the simulation of shade variation conditions demonstrates that the shade clusters of trees can reduce the mean radiant temperature. Percentages of solar radiation reduction by cluster of trees as Caesalpinia peltophoroides (deciduous) have the best results, shows that canopy provides shadow, reduces the mean radiant temperature and also, improve the thermal bioclimate in micro scale conditions.*
Keywords: thermal bioclimate; physiologically equivalent temperature; vegetation and climate*; urban spaces; tropical climate, Brazil (Campinas)*

INTRODUCTION

One of the main causes of the air temperature increase and of the energy consumption, as well as the change of the people's behaviors, is the lack of appropriate landscape treatments around a building. Different methodology are used in research that confirms that the vegetation can influence in urban microclimate and improving thermal comfort and increasing the potential of health impairment of urban populations [1, 2, 3, 4]. In fact, the arboreal species behave in different ways in outdoor spaces, in especially because of the differences in shadows tree, but there are few studies that quantify these benefits [5, 6]. The tree canopy is a major component that is able to contribute to microclimatic environments because it can attenuate solar radiation and control the wind speed. In tropical climates, the possibility to change wind condition and shade modify the microclimate and improve thermal comfort [7].

This paper presents thermal bioclimate analyses using air temperature, T_{mrt} and PET conditions in tropical climate of Campinas, Brazil, and also, the influence of solar radiation attenuated by shade clusters in mean radiant temperature.

BENEFITS ASSOCIATED WITH TREES IN SUBTROPICAL CLIMATE

Additionally to their aesthetic value, urban trees can modify the climate of a city and improve urban thermal comfort in hot climates, like subtropical climate in Brazil. The urban trees, individually can also act as shading and wind-shielding elements modifying the ambient conditions around individual buildings. As well as collectively, forests can moderate the intensity of urban heat island by altering the heat balance of the entire city [2, 8]. Studies show that shade and wind speed promotion can improve the thermal comfort on tropical climates [5, 7]. Therefore, planting trees is a good solution for improve thermal comfort in tropical cities.

The canopy characteristics of trees can influence direct in thermal comfort results, therefore, the behavior of individuals arboreal in microclimate can modify according with type, high, age, season, and disposition in urban outdoor space [9, 10]. The trees leaves can absorb, reflect and transmit the solar radiation and the influence of evapotranspiration and indirect thermal comfort [11, 12].

Trees casts its own distinctive shadow, both in shape and density, and these behavior depend on the shadow and filtering the radiation influenced by the form and density of the canopy [13]. The amount of radiation intercepted depends on the density of the twigs and branches and leaf cover, where these elements influence the overall character of tree shape and density [9, 11]. Not only the form and density of canopy can influence in shade tree qualities, but, individuality of trunks and leaf needs to be considerate [12].

For example, trees species in Brazil can attenuated solar radiation between 76.3 – 92.8 % in summer [14, 5] and trees species in Malaysia have difference density value when the average heat infiltration under canopy is comparing [6]. These results confirm that structure of crown, dimension, shape and color of vegetation leaves influence reduction level of solar radiation.

Other studies show that individual trees can reduce the air temperature in different distances and consequently improve thermal comfort [14]. By computer simulation of the air temperature distribution of around 10 m height single tree, it was observed that the maximum range of air temperature is approximately 25 m from the tree [15]. The air temperature distribution as well as air humidity still depends on wind velocity and direction [16].

It is known that vegetation has a great potential to control air movement but, this effect cannot be determined with certainty. Studies show that the vegetation can influence the pattern of air movement through guidance, filtration, obstruction and deflection and it depends on vegetation characteristic, like geometry, height, permeability and crown of the vegetation are the structural vegetal characteristic that influenced the controlling air movement [11, 16].

MATERIALS AND METHODS

The research was carried in the city of Campinas, in the coastal interior of the state of São Paulo, Brazil, and it is the third largest city in the state, after São Paulo and Guarulhos, with 1,080,113 of inhabitants and 1358,63 population density (inhab./Km^2) **[17]**. Campinas, Brazil, is located at 22° 48'57 "S, 47° 03'33" W and altitude of 640 m, Fig 1. The city's climate is classified as High Altitude Tropical, Cwa **[18]**. The mean annual air temperature is 22.3° C, annual rainfall of 1411 mm, with the predominance of rain in the months from November to March and dry periods of 30 to 60 days during July and August.

The criterion for the choice of species was the one mostly used in tree planting programs by the city government in Campinas, Brazil. The trees should fulfill such conditions as: to be adult in age, to have representative physical characteristics of the species, and to be located in areas with the adequate conditions for measurements: no shading by other trees or buildings; topography of the ground around the species; accessible area for the measurement equipment; no interference of other people; uniformity of conditions around the trees.

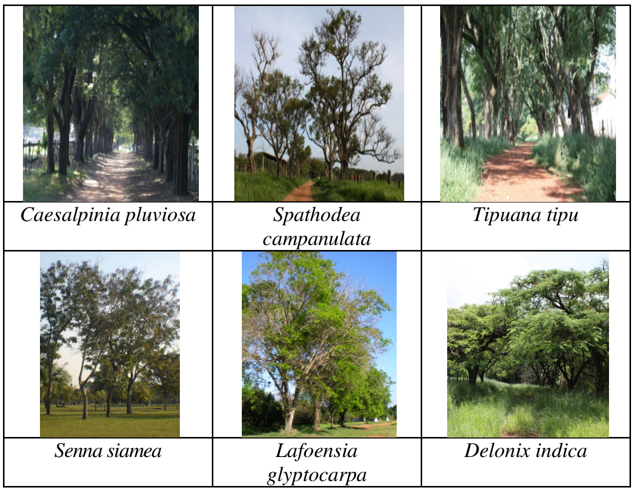

Figure 1: Clusters of Trees analyzed

Six homogeneous clusters of trees were chosen: *Caesalpinia pluviosa, Spathodea campanulata, Tipuana tipu, Lafoensia glyptocarpa, Delonix indica, Senna siamea*, Fig 1. The analyzed tree features as crown, trunk and leaf, as well as theirs dispositions are related at Table 1.

The data was collected at a meteorological urban station of Campinas Agronomic Institute (IAC) and field measurement. The meteorological data: air temperature, relative humidity, wind speed and solar radiation of an over seven year period (25.6.2003 to 14.12.2010) were used.

The energy balance of human body **[19]** is a modern human bio meteorological method used to deduce thermal indices and describe the effects of thermal environment on humans **[20, 21].** The hourly meteorological data of air temperature, air humidity, wind speed and global radiation were used to calculate the Mean Radiant Temperature (T_{mrt}) and the Physiologically Equivalent Temperature (PET). Thus, simulations were done in the RayMan model **[22, 23]** which can transfer the global radiation from an area with free horizontal urban structures and make the estimation of mean radiant temperature due to atmospheric influences firstly by clouds and other meteorological compounds such as vapor pressure or particles.

For describing real situation of urban climate change provided by different trees canopies, PET results of

Campinas during study period were used in simulations of shade modifications. The followings setups and configurations, fig. 2, and the fish-eye picture of cluster of trees, fig. 3, were used.

Table 1- Clusters of Trees analyzed features

ARBO-REAL CHARACT.		ARBOREAL SPECIES					
		Caesal-pinia pluviosa	*Spatho-dea campanu-lata*	*Tipuana tipu*	*Lafoensia glyptocarpa*	*Delonix indica*	*Senna siamea*
CROWN	H (m)	11.2	8.85	13.45	6.45	8.01	8.85
	Perm.	Med.	Med.	Med.	Med.	S.	Med.
	Density	Med.	Max.	Med.	Med.	Med.	Max.
	Shape	Globe	Elliptic	Globe	Globe	Globe	Semi-Elliptic
	W (m)	16.15	7.3	14.9	7.3	9.27	7.3
	PAI	0,89	0,775	0,775	0.72	0,73	0,52
	Phen.	Deciduous	Semi-deciduous	Semi-deciduous	Semi-deciduous	Semi-deciduous	Semi-deciduous
TRUNK	Rough	High	Med.	Med.	High	Med.	Med.
	Color	Gray	Gray	D. Brown	Brown	Gray	Brown
	Diam .(m)	0.34	0.55	0.85	0.63	0.32	0.43
	Type	Ort. Simp.	Plagiotropic	Ort. Simp.	Plagio-tropic	Plagio-tropic	Plagio-tropic
	H. bole (m)	2.93	2.2	2.87	1.3	1.75	2.2
	B.ran. Insert.	Switches	Decussate	Switches	Switches	Switches	Decussate
	B.ran. Arrang.	Horizontal axis	acute axis	Horizontal axis	acute axis	Horizontal axis	acute axis
LEAVES	Blade	Vertici-llate	Opposite	Opposite	Opposite	Opposite	Opposi-te
	Type	Palm	Bipinate	Impabi.	Impabi.	Paripinate	Simple
	Shape	Ovate	Linear	Cordate	Elliptic	Cordate	Elliptic
	H(m)	0.058	0.008	0.06	0.03	0,064	0.06
	W(m)	0.07	0.0015	0.13	0.015	0,045	0.15
	Color	Light green	Green	Dark Green	Dark Green	Dark Green	Dark Green
CLUSTER	Comp.	Homo-geneous	Homo-geneous	Homo-geneous	Homo-geneous	Homo-geneous	Homo-geneous
	Dens.	high	low	high	medium	low	medium
	Disp.	cluster	cluster	cluster	cluster	cluster	cluster
	Form	Linear (2 lines)	Linear (2 lines)	Linear (2 lines)	Linear (1 lines)	Linear (2 lines)	aleatory
	Nº trees	10	5	5	3	5	5
	Dist. (m)	10.0	9.52	9.60	12.47	12	7.4

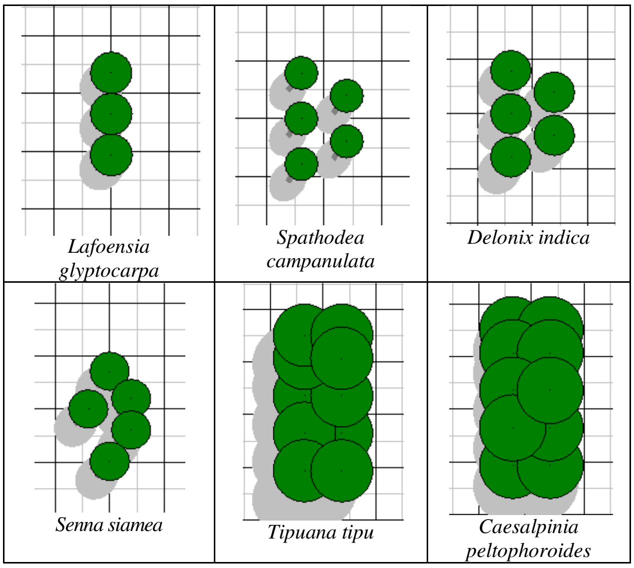

Figure 2: The configuration of analyzed cluster of trees

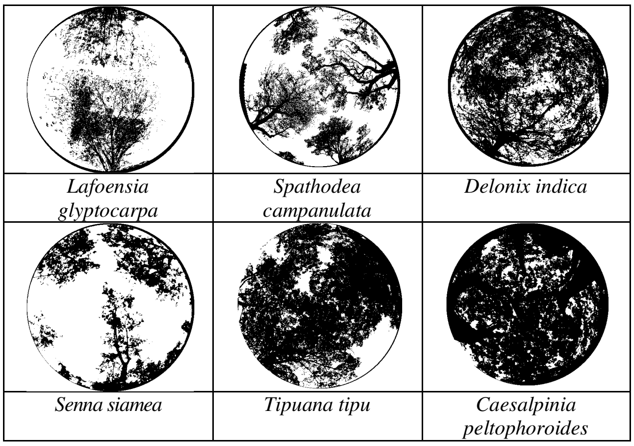

Figure 3: Clusters of Trees analyzed

RESULTS

The data were analyzed in terms of PET classes **[24]** in order to quantify the background conditions at the urban climate station. Fig. 4 shows the PET classes for the period 25 June 2003 to 14 December 2010. In general, Campinas belongs to a comfortable and warm climate region according to PET classification. Around 18.4% of the hours in the original dataset from the urban climate station in Campinas can be found in the warm (PET>29^o), slightly hot (PET>35^o), hot (PET>41^o), very hot (PET>45^o), and extremely hot (PET>50.1^o).

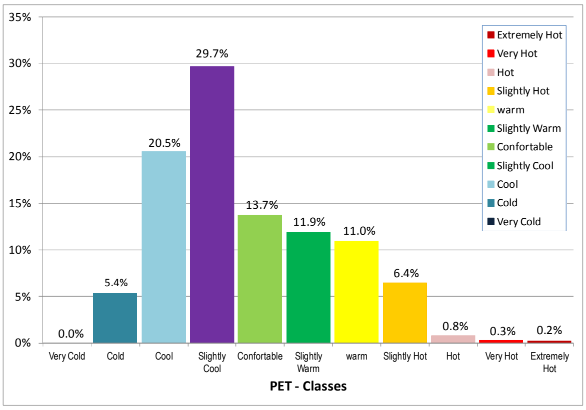

Figure 4: Physiologically Equivalent Temperature (PET) classes at the urban station Campinas for the period June 25th, 2003 to December 31st, 2010.

Figure 5 and 6 shows results of air temperature frequencies by different species in summer and winter, respectively. Figure 7 and 8 present the results of Solar radiation attenuated by different species in the summer and winter, respectively. Figure 9 and 10 show the results of PET frequencies by different species and the results of T_{mrt} frequencies by different species, respectively. These graphics present the significantly differences between shade and sun for air temperatures and solar radiations, especially during the summer period.

Figure 11 and 12 show the diurnal courses of PET and T_{mrt} for shade based on data from field measurement for the period 2007 to 2010, respectively. Figure 13 and 14 present the results of simulations of PET and T_{mrt} for shade based on data from climate station for the period June 25th, 2003 to December 31st, 2010. The *Casealpinia pluviosa* have the best performance on terms of PET and T_{mrt} from field measurements and simulations as well.

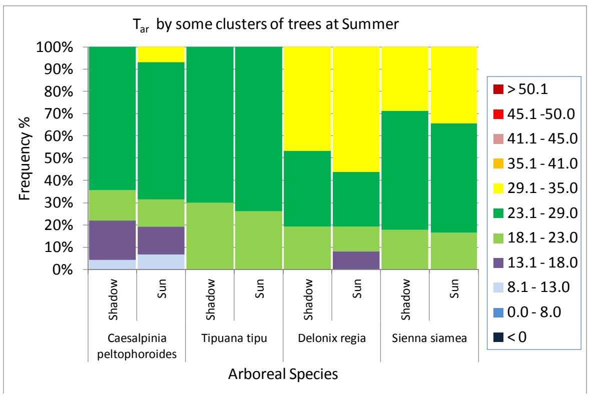

Figure 5: Results of Air Temperature frequencies by different species in summer

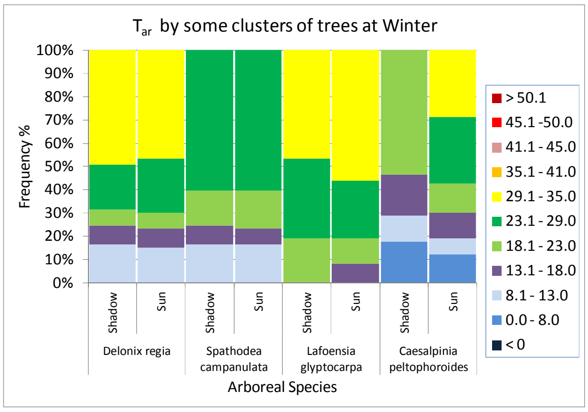

Figure 6: Results of Air Temperature frequencies by different species in winter

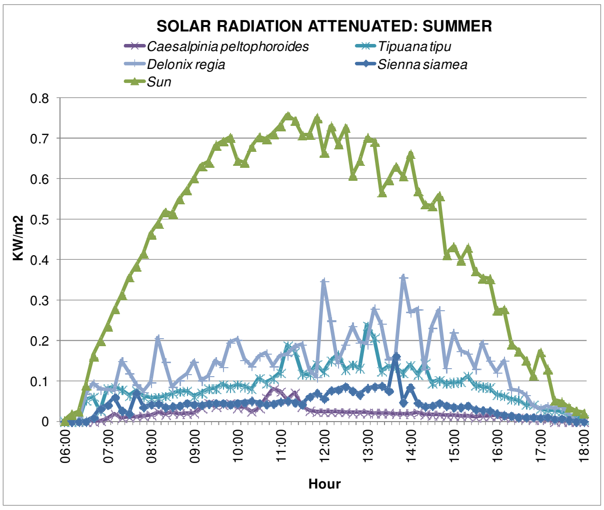

Figure 7: Solar Radiation attenuated by some cluster of trees in winter

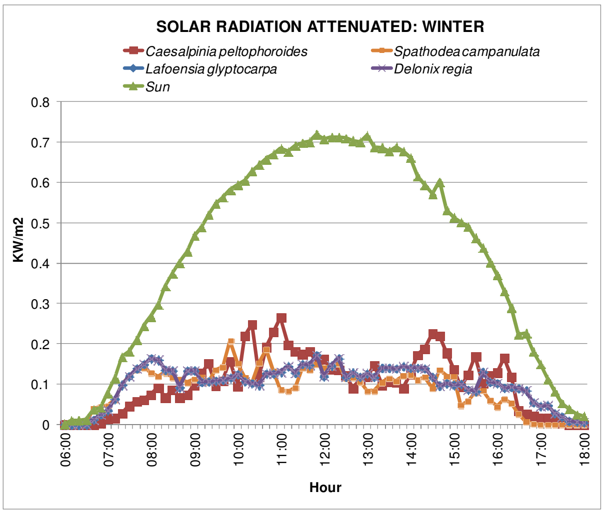

Figure 8: Solar Radiation attenuated by some cluster of trees in winter

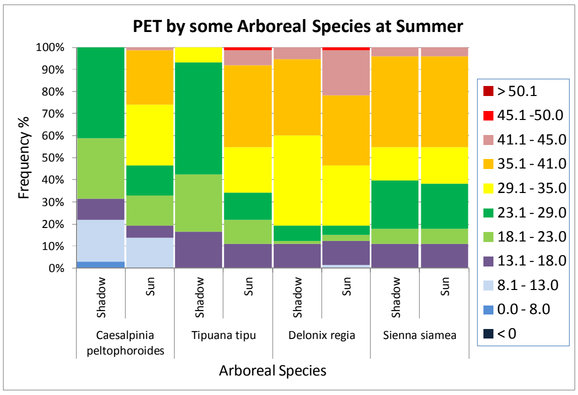

Figure 9: Results of PET frequencies by different species in summer

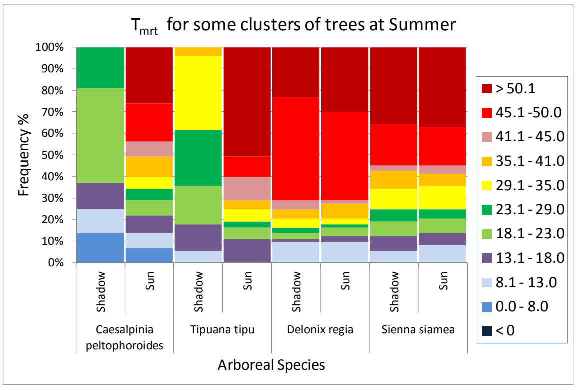

Figure 10: Results of Mean Temperature Radiant frequencies by different species in summer

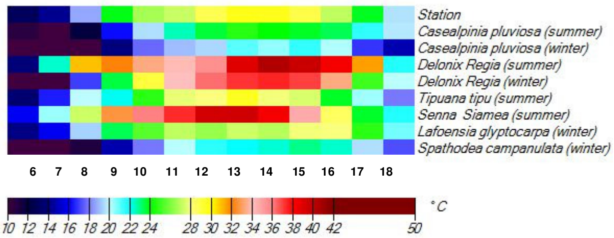

Figure 11: Diurnal courses of Physiologically Equivalent Temperature (PET) (°C) for shade based on data from field measurement for the period 2007 to 2010.

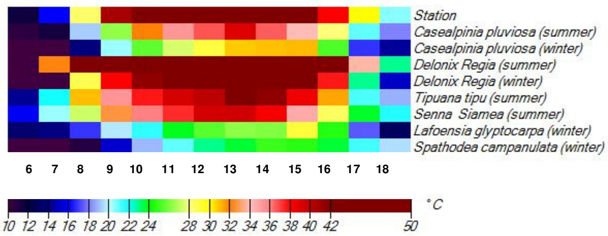

Figure 12: Diurnal courses of Mean Radiant Temperature (T_{mrt})(°C) for shade based on data from field measurement for the period 2007 to 2010.

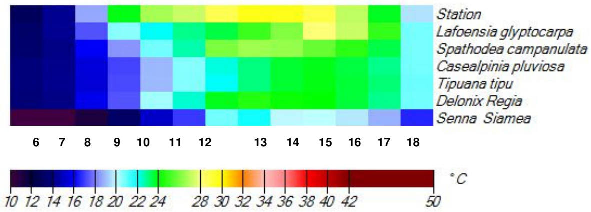

Figure 13: Diurnal courses of Physiologically Equivalent Temperature (PET) (°C) for cluster of shade's simulation based on data from urban station for the period June 25th, 2003 to December 31st, 2010.

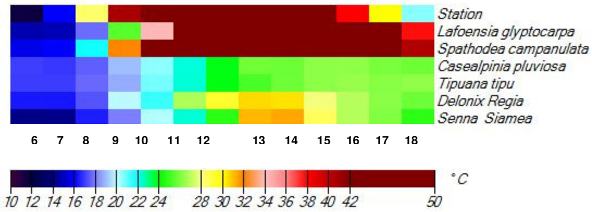

Figure 14: Diurnal courses of Mean Radiant Temperature (T_{mrt}) (°C) for cluster of shade's simulation based on data from urban station for the period June 25th, 2003 to December 31st, 2010.

DISCUSSION AND CONCLUSIONS

Thermal bioclimate analysis in terms of T_{mrt} and PET for tropical climate of Campinas, Brazil, has able to describe the climate change by the solar radiation attenuated by shade clusters of trees. However, the different arboreal species behave in different ways in outdoor spaces, in especially due to the trees features [5, 6], as well as, the clusters due to theirs dispositions. These characteristics influence the canopy in which is able to contribute to microclimatic environments.

Recently, studies of vegetation influences in urban microclimate have been focused in mitigation of air temperatures [1, 2, 5, 11] intead of Physiologically Equivalent Temperature (PET) and Mean Radiant Temperature (T_{mrt}). Ours findings suggest the vegetation can improve not only air temperatures bur also in terms of PET and T_{mrt}.

In terms of PET and T_{mrt}, the *Casealpinia pluviosa* has the best results in field measurements, but *Tipuana tipu* and *Casealpinia pluviosa* have the best performance in simulations. This results suggest that the combination of tree's features with planting strategy is the best solution for upgrading thermal comfort provide by vegetation.

Tropical Cities as Campinas, Brazil, should used the trees for controlling of thermal comfort. The solar radiation intercepted by crown provides natural protection of outdoor spaces, mitigation of temperatures and reduction of energy spent on cooling indoor spaces.

In outdoor spaces, the urban green is able to improve thermal comfort, mitigate air temperature and control relative humidity, consequently, it provides pleasure sensations. In indoor areas, the shadows can reduce the solar radiation influence in facades, accordingly, it can improve the thermal comfort, save energy spend in cooling and keep the environment healthy. These characteristics of vegetation should be taken into account by professionals of the urban built environment to improve the thermal comfort outdoors, reducing the effect of heat island so ensuring better quality of life for people.

Evaluation of different arborous species commonly found and tree planting strategies in the urbanization of cities is important information for urban planning aiming to re-qualify the urban microclimate. In addition, tree-planting is a practical and inexpensive solution, and is considered an energy-efficient alternative.

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