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Yu Xi, Jingyi Liu , Yuan Huang*
Southwest Jiaotong University, Chengdu 611756, China
**e-mail: yuanhuang@home.swjtu.edu.cn*

A REVIEW OF THE RELATIONSHIP BETWEEN URBAN GREENING MORPHOLOGY AND URBAN CLIMATE

Abstract: *Green space in built environment has the regulation on climate which contains reducing solar access, cooling, humidification, producing breeze in local area. Therefore, it has a great improvement effect on urban local climate. The investigation discovered that existing research on the relationship between morphology and climate are mainly based on hard elements as buildings, pavements and so on but few based on soft elements as green space or so. This paper tries to bring together the former studies on the relationship between green space and local climate by typology methods. First, focus on individual green Space, dividing existing research according to their research scale. Analyzing how the spatial characteristics of green space affect local climate based on these studies and how to measure and describe the spatial characteristics of green space through the landscape language. Then, extending research to green spaces in built environment on block scale summarizes the classification of green spaces and how they impact on the local climate from former research. Finally, the study summarizes the relationship between urban greening morphology and urban climate.*

Keywords: *urban greening morphology, spatial characteristics, local Climate, typology, landscape pattern.*

Introduction

With the rapid development of urbanization, the urban population and the city scale have been increasing rapidly, bringing the growth of an urban construction area and changes in the underlying surface, coupled with a number of human effect factors, forming a unique urban climate, which has led to many environmental problems. The deterioration of urban climate environment has seriously affected the daily life of urban residents (Yan, 2014; Guo *et al.*, 2017). As an important part of urban space, urban green space can obviously improve the urban climate environment around itself (Wang *et al.*, 2005). Therefore, the research on the relationship between green space and urban climate is essential for the improvement of urban climate environment. Green spaces regulate climate by absorbing, reflecting and shielding the solar radiant energy, transpiration and exchange energy with surrounding environment (Ni *et al.*, 2007). The greening morphology plays an important role in controlling the processes above, which will be discussed below.

Methodology

The relevant literature is searched by the cluster sampling method, using the key words "green space", "urban heat island" and "urban climate" on Google Academic Search engine, which contains Science Direct and other databases. And papers whose publication year are not in 1980~ 2018 were filtered out. Finally, 48 papers were left behind. It found that that literature was mainly field research but few were literature review. What is more, most of them focus on the hard elements instead of soft elements like greening or water body.

According to the research scale of green space, selected literature is summarized in the following.

Review on the research of greening morphology

The research scale is often divided into spatiotemporal scale and organizational scale in green space research. The former is abstract and precise, while the latter emphasizes the relative position of the research object in the hierarchical system composed of the ecological organization level with much fuzzy organizational scale (Lu, 2012). For the purpose of this article, the research will mainly discuss the related research under two kinds of organization scale of green space: 1) Individual patch -- patch level; 2) A patch class consisting of several individual patches - patch class level.

Patch level

As shown in Table 1, the literature of which the research objects on the two-dimensional morphology of patch level is classified according to the morphological description indexes used in the literature. The total number is more than a half, and the size or shape of the green space is mainly used. The related conclusions are summarized in Table 2.

Table 1. Two-dimensional indexes of patch level

Morphology	Description Method	Main morphological description indexes(2D)	Number of literature
Size	Quantitative	Area	12
Shape	Quantitative	perimeter	4
		The ratio of perimeter/area	4
		Rectangular perimeter ratio	1
		Shape index	6
		Reciprocal shape index	1
	Qualitative	Geometric form	3

Table 2. Two-dimensional conclusions of patch level

Morphology	Related conclusions		Number of literature
Size	The area has a positive correlation the cooling effect of green space within a certain range.	Below the lower limit, there is no obvious relationship.	2
		Above the upper limit, the cooling effect does not change significantly with the area.	1
		There is an optimal value.	4
		It only shows a qualitative conclusion.	
Shape	The shape has inevitable connection with the cooling effect of green space.	The complexity of the shape has a positive correlation with the extent of the cooling effect of green space within a certain range.	5
		The complexity of the shape has a negative correlation with the extent of the cooling intensity of green space within a certain range.	2
		It only shows the the existence of connection.	2

For green space size, since the nineties of the last century, many scholars have raised and confirmed the positive correlation of area and cooling effect of green patch (Wu *et al*., 2008; Cao *et al*., 2010; Zhang *et al*., 2010; Chen *et al*., 2014), but the area of green patch has a threshold value to meet the positive correlation above. Less than lower limit, there is no obvious relationship between the two; higher than upper limit, the cooling effect has no obvious change with area changes. *Wu et al.* (2007) discovered that when the area of a green patch is $3hm^2$, its cooling effect is obvious; when it is $5hm^2$, its cooling effect is tending towards stability; Chen's research (2013) showed that the cooling effect of green patch is obvious especially when its area is close to 1.5~1.68 hm². Tan and Li (2013) found that the area of green patch is closely related to the cooling effect if its area is higher than 10 hm². Other similar studies show that when the patch area exceeds 14hm², the area of green patch becomes the main factor affecting the cooling effect (Jaganmohan *et al*., 2016). Yu *et al.* (2017) noted that the minimum area of green space is 4.55 ± 0.5 hm² so that it takes a cooling effect. From above literature, a general law can be summarized: with the area of green space increases, the cooling effect of it increases. However, small green spaces may also be affected by other factors (such as its location or surrounding environment) (Yu *et al.*, 2017), so that it requires a minimum value to keep the cooling effect. The minimum area of the green patch is different in research above, which may be affected by the experimental environment. Further research is needed.

There is an inevitable connection between the complexity of the shape of green space and its thermal effect (Wu and Wang, 2006; Zhang *et al*., 2009; Wu and Zhang, 2011; Chen, 2013;Chen *et al*., 2014; Park *et al*., 2017), but the description methods and conclusions are not the same, as shown in Tables 1 and 2. Most scholars choose to describe quantitatively. Most of them choose one or more of the indexes such as a perimeter, the ratio of a perimeter/area, a rectangular perimeter ratio, a shape index and a reciprocal shape index to describe the complexity of the shape of green space. Among them, a rectangular perimeter ratio, a shape index and a rectangular perimeter ratio have strong independence, and they have very few significant correlations with other indexes. In addition to this, many scholars have used a visual language to describe the green patch. They simply divide green patches into shapes and conduct a comparative research (Li *et al*., 2016, Yu *et al*., 2017). In general, the complexity of the shape of green space has a positive correlation with the extent of its cooling effect within a certain range (Feyisa *et al*., 2014), and there is a negative correlation with the cooling intensity (Yu *et al*., 2017; Feyisa *et al*., 2014). This could be caused by the existence of multiple types of land cover in urban areas. The more complex the boundaries of green land are, the more opportunities it has to connect with other types of the land cover (such as impervious pavement, residential and commercial areas, etc.), Thereby, this situation leads to more thermal exchange and reduces the cooling intensity while increasing the cooling range. It can be seen that if a certain area of green space is to exert the optimal cooling range while maintaining the cooling effect, or vice versa, a more in-depth and accurate research is needed. The existing qualitative relationship alone is not sufficient to apply to actual conditions. Meanwhile, the quantitative relationship between the shape and the area or other morphological elements also requires precise knowledge, which is mentioned later in this paper.

In addition, there are also some scholars who focus on the three-dimensional morphology of green space. The adopted description of green space is shown in Table 3, which is basically distributed in the vertical structure of green space, canopy distribution, and total vegetation quantity. They basically cover the three-dimensional morphological characteristics of green space associated with the ecological processes that produce a cooling effect of green space. The related conclusions are summarized in Table 4.

As for the vertical structure of green space, the research conclusions tend to be: the more abundant in the vertical structure of green space, the stronger cooling effect will be (Wu and Wang, 2006; Chen, 2013). Qualitative descriptions are generally used, such as the structure of the arbor, shrub and grass, the structure of shrub and grass, the grassland, etc., to fully describe the hierarchical relationship of green space in the vertical direction.

For the canopy distribution of green space, the indexes and conclusions of the literature are different. Usually, the description focuses on the overall or partial, and the focus is also different, such as canopy density and tree coverage is significantly different (Figure 1).

Table 3. Three-dimensional indexes of patch level

Morphology	Description Method	Main morphological description indexes(3D)	Number of literature
Vertical structure	Qualitative	Vertically hierarchical relationship of green space	2
Canopy distribution	Quantitative	Tree coverage	1
		Tree canopy cover	2
		Tree cover	1
		Canopy density	1
		Vegetation coverage	1
		Sky view factor	1
The total vegetation quantity	Quantitative	Leaf area index	1
		Three dimensional vegetation quantity	4
		3D information of trees	1

Table 4. Three-dimensional conclusions of patch level

Morphology	Related conclusions	Number of literature
Vertical structure	The more complex the vertical structure of green space is, the stronger the cooling effect will be.	2
Canopy distribution	Indexes of canopy distribution have an impact on its cooling effect.	5
The total vegetation quantity	The total green volume of green space also determines the cooling effect that green space can exert, and it has a positive correlation with the cooling effect of green space.	4

Ng *et al*. (2012) used tree coverage to describe the vegetation within a single patch, focusing on the overall vegetation coverage of the patch. It has been found that when the tree coverage is more than one-third of the total area of the land area, the cooling effect of lowering about 1K can be achieved; when the tree coverage is greater than 34%, the overall temperature fluctuations in the entire area are small, which is another thermal benefit in addition to the absolute temperature reduction. Feyisa *et al*. (2014) used tree canopy cover to describe. The research showed that the High intensity of tree canopy cover makes the cooling effect of green space more evident at all times. Zhou *et al*. (2005) described it with the tree cover and found it has an inevitable connection with the cooling effect of green space. Meanwhile, the description of the distribution of a canopy at a certain location can also indicate that the location is affected by the cooling effect of green space. Lin (2016) measured the distribution of a canopy with canopy density and found that during most of the measured periods, there was a significant positive correlation between canopy density and the cooling effect of green space. Yan (2014) used vegetation coverage and a sky view factor to describe and found that the observed temperature decreased with the increase of vegetation coverage, and increased with the increase of the sky view factor. It is thus clear that canopy density is mainly aimed at tree plants. The above indexes such as tree coverage, a tree cover, a sky view factor, and canopy density can all be used to measure the canopy distribution of green space, with different emphasis, as shown in Table 5.

In addition to the vertical structure and the canopy distribution of green space, the total vegetation quantity of green space also determines the cooling effect of the green space. There is a positive correlation between the two (Wu *et al.,* 2008; Wu and Wang, 2006; Rafiee *et al.*, 2016). A total vegetation quantity is described by three dimensional vegetation quantity (Wu and Wang, 2006) and leaf area index (Wu *et al*., 2008).

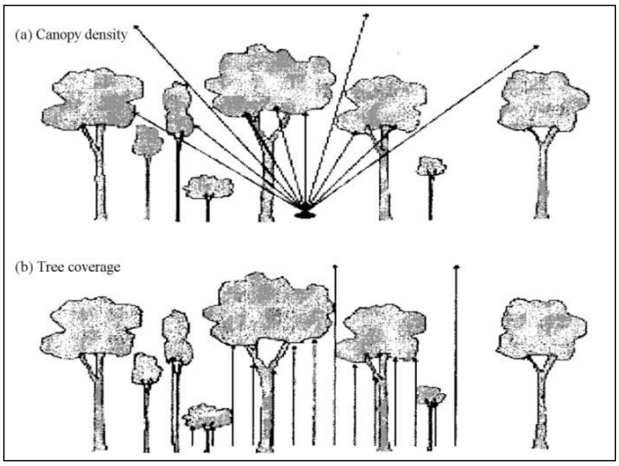


Figure 1. Comparison of tree coverage and canopy density (Source: Egan, 2010)

Table 5. Comparison of three-dimensional indexes of patch level

Index	Definition	Focus
Tree coverage	It usually refers to the ratio of forest area to total land area, which is generally expressed as a percentage.	It comprehensively reflects the arboreal vegetation in the area.
Tree canopy cover	It refers to the ratio of the vertical projection area of the canopy of the Arbor to the total area in the forest.	
Tree cover	It refers to the ratio of the vertical projected area of the above-ground area of the plant community or individual to the sample area, which is generally expressed as a percentage.	It comprehensively reflects the status of plant communities covering the surface.
Sky view factor	Radiation is emitted from a point on the ground. A part of it is blocked by obstacles such as trees or buildings, and then absorbed by these obstacles. Another part is released into the sky. The released radiation to the total radiation is called a sky view factor.	It reflects the extent to which the line of sight at a certain location is obstructed.
Canopy density	It refers to the ratio of the total projected area (crown width) of the canopy of trees in direct sunlight to the total area of the forest (stand) in the forest,which is usually expressed in tenths.	It reflects a stand structure and density.

The morphological elements mentioned above also have a mutual influence, which brings difficulties to the combination of green space morphological indexes. The current research focuses on the relationship between green area, the shape and the vertical structure. It can be seen from Table 6 that a certain green space index in different green areas will be differently related to the cooling effect due to the change of other indexes. With the increase in the number of indexes, the situation will inevitably become more complicated. To overcome this difficulty, firstly, it is necessary to have a comprehensive and clear understanding of the relationship between various indexes and the thermal effects of green areas, including the mechanism of action, the range of numerical values that have an effect, and so on. Although the road ahead will be long, some simple conclusions can be inferred from the results of the current research. For example, small and simple, large and complexly shaped green spaces may have more pronounced effects on the improvement of urban climate, and may also have guiding significance for green space design. However, further research is needed to deepen it.

Table 6. Combination conclusions of patch level

ombined indexes	Related conclusions	Number of literature
Area and shape	Interaction between the area and the shape can have an effect on the cooling effect of green space.	2
Area and vertical structure	The increase in the area of small green spaces with rich vertical structures has a positive effect on the cooling effect.	1
Shape and vertical structure	The same morphological characteristics have different degrees of influence on the cooling effect of green space in different vertical structures.	1

In summary, it has been found that the relationship between the morphological elements of the green patch on the two-dimensional level and its cooling effect have drawn relatively unified conclusions and description methods. However, for the key threshold data, due to the differences in the actual environment and other factors of the research, no more unified conclusions have been drawn. On the three-dimensional level, the relationship between the morphological elements of green space and its cooling effect have also reached a relatively unified conclusion. However, due to the complexity of the three-dimensional shape, the description method has not been unified and the threshold data is not perfect.

Patch class level

At the patch class level, the indexes selected by the literature are shown in Table 7. Field experiments or simulations have confirmed that the distribution and the total vegetation quantity have a close influence on the effect and a cooling range of green space to regulate climate in the block. The specific conclusions are summarized in Table 8.

Table 7. Horizontal indexes of patch class level

Morphology	Description Method	Main morphological description indexes(2D)		Number of literature
The total vegetation quantity	Quantitative		Greening rate	3
			Green plot ratio	1
			Green coverage	4
			Vegetation Index	4
			Tree coverage	4
			Leaf area density	4
			Vegetation coverage	4
			Green volume rate	4
	Qualitative			8
The distribution of green space	Quantitative	Degree of fragmentation	Edge density	2
			Patch density	4
		Connectivity	Mean Euclidian nearest-neighbor distance	2
			Aggregation Index	2
			Area-weighted mean radius of gyration	1
		Uniformity	Neighborhood green proportion	1
			Neighborhood green area	1

Table 8. Horizontal conclusions of patch class level

Morphology	Related conclusions	Number of literature
The total vegetation quantity	The total green amount basically has a positive correlation with the cooling effect of green space.	13
	The more concentrated the distribution of green space is, the better the mitigation effect of the heat island effect will be.	3
	Evenly dispersed green space have a greater impact on the surrounding environment.	3
The distribution of green space	The geometry of the distribution of green space (point-shape,wedge-shape, etc.) has an effect on the cooling effect.	3
	Degree of fragmentation has a negative correlation the cooling effect of green space.	1
	Uniformity has a negative correlation the cooling effect of green space.	1

In terms of the total vegetation quantity within a certain area of green space, the research conclusions are basically consistent, that is, the total vegetation quantity has a positive correlation with its cooling effect (Zhang *et al*., 2010; Wu and Wang, 2006; Saito *et al*., 1990; Tong *et al*., 2018; Li *et al*., 2003; Zhou *et al*., 2002; Kim *et al*., 2005; Gioia *et al*., 2014; Brenda *et al*., 2014; Duarte *et al*., 2015; Adeyeri *et al*., 2017; Zhang *et al*., 2017), but the adopted description indexes are not the same. The comparison between the indexes is shown in Table 9, and the total vegetation quantity of green space is fully described from two and three dimensions by them. Among them, the green volume rate and the leaf area density can reflect the vertical green structure in the area to a certain extent, which is more comprehensive than other indexes.

Table 9. Comparison of green volume indexes at patch class level

Indexes	Definition	Features
Greening rate	The ratio of the total area of green space in a given area to the total area of the given area within a certain range.	It is used as a planning indexes.
Green coverage	The ratio of the vertical projected area of green space of each type in a given area to the total area of the given area.	It is the main indexes of a city's greening level.
Tree coverage	The ratio of the area of the trees to the total area of the land, generally expressed as a percentage.	It can comprehensively reflect the arbor vegetation in the area.
Normalized vegetation index	In the remote sensing image,the difference between the reflectance in the near-infrared band and the reflectance in the red band to the sum of the two.	It can detect vegetation growth status, vegetation coverage, and eliminate some radiation errors.
Green volume rate	The ratio of the vertical projection area of the arbor, shrub and grass to the total vertical projection area.	It can reflect the vertical projected area of arbor and shrub in the vertical projected area of the area.
Leaf area density	The parameters of the total single leaf area (m^2) per unit layer volume (m^3), in each horizontal layer of the canopy.	The total plant leaf area to community volume ratio.

The distribution of urban green space plays an important role in mitigating the urban heat island effect. The more concentrated the green space is, the better the mitigation effect of the heat island effect will be (Zhou *et al*., 2002; Maimaitiyiming *et al*., 2014). Evenly dispersed green space has a greater impact on the surrounding environment (Li *et al*., 2000; Bao *et al*., 2016). The distribution of green space can be expressed by qualitative or quantitative description. Some literature simply divides the distribution of green space into several categories and expresses it in a visual language and conducts a comparative analysis (Li *et al*., 2016; Wu *et al*., 2011; Wu and Wang, 2006). For example, as shown in the Figure 2, Li *et al.* (2016) divides the distribution of green space into point-shape, radial-shape, and ring-shape, belt-shape, and wedge-shape, that the intensity of the cooling effect is ranked as: belt-shape> wedge-shape> radial- shape> ring- shape> point-shape.

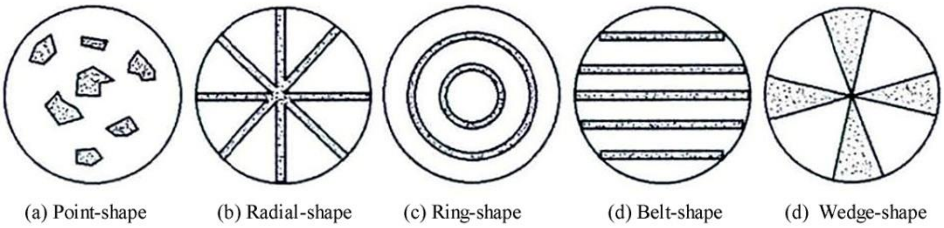


Figure 2. Common distribution of green space (Source: Li *et al*., 2016)

In addition to the qualitative description, the distribution of green space can also be described by indexes. As shown in Table 7, it is mostly expressed by the landscape pattern index, and mainly expressed in terms of a fragmentation degree, uniformity, and connectivity between patches of green space in urban landscapes. The first is the fragmentation degree of green patches in the area. The higher the value is, the higher the ratio of the number of patches to the average patch area will be, and the fewer the green area that can produce stable cooling effect. Fragmentation of green space can be expressed by the fragmentation index (FN), edge density (ED), and patch density (PD), etc. The second is the uniformity of the green space. When the distribution is more concentrated, the cooling intensity that can be generated is greater, but the range of the effect is smaller; when the distribution of green space is more evenly, the result is the opposite. Uniformity can be expressed by Euclidian nearest-neighbor distance (ENN-MN), aggregation index (AI), area-weighted mean radius of gyration (GYRATE-AM). The last is the connectivity between patches of green space. When green patches and green corridors coexist, the ecological benefits of green areas increase, and with the increase of the length of the edges, the range of influence is wider. Connectivity can be expressed by the neighborhood green proportion (NGP) and the neighborhood green area (NGA). Some scholars, such as Maimaitiyiming *et al.* (2014), Kong *et al.* (2014) and Chen *et al.* (2014), used the combination of landscape pattern index such as the percentage of landscape (PLAND), class area (CA), and edge density (ED), patch density (PD) to conduct description, also achieving a better description of the effect. Obviously, the indexes mentioned above are relatively complicated. Also, the description effect and the threshold range that promote the good thermal effect of green areas have yet to be explored.

In the same way, there is also a mutual influence between the morphological elements of the green land under the patch level. And discussions generally focus on the relationship between the distribution and the total vegetation quantity of green space at the macro level. Wu and Wang (2006) proposed that, in many cases, the distribution of green space is more important than the total vegetation quantity. For example, under the same green coverage, there is a big difference in the landscape and ecological effects from green space in the corner of the area and the evenly distributed green space; there is also a mutual influence between their respective indexes.

It is found that, for the patch class level, the method of describing the morphological description of green space is also gradually changing from a simple single index to the combination of multiple indexes. And it is often described by relying on the landscape pattern index. Although accurate, there is not a formed system. The conclusions reached are nearly consistent, but most of them still remain in the qualitative stage and need to continue to be explored.

Conclusion

Summary of Research Status

At present, it seems that the expansion and optimization of urban green space have become an inevitable trend. While carrying out a great deal of practice, rich theoretical research results are obtained at the same time. However, research in quantitative research remains to be enriched and improved. Recalling relevant literature, it has been found that researches on greening morphology mostly remain in the qualitative description stage; a few articles use a quantitative description, but a quantitative research mainly focuses on a single index of green space, and there is still lack of more comprehensive research. Although there are many research results, they have not been widely used.

Development Suggestions

The above conclusions can be simplified and summarized as the greening morphology description templates shown in Table 10 and Table 11. In the template, the morphological description indexes of the patch level and the patch type level are summarized and simplified, but the mutual combination between indexes is not shown. Among them, the distribution of green areas at the patch level only lists two broadly applicable indexes, which needs to be further added.

Table 10. Greening morphology description template(patch level)

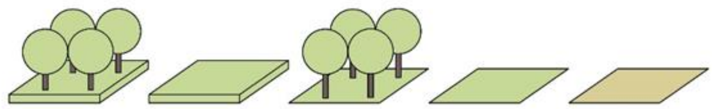
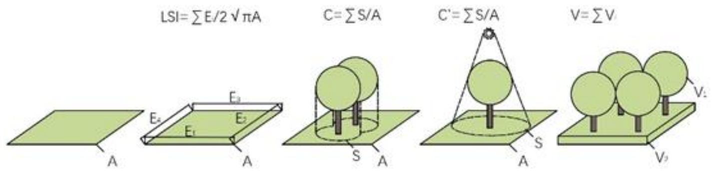
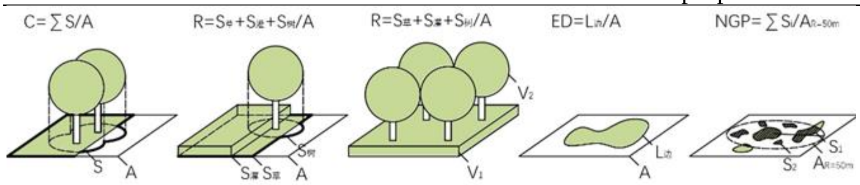
	Arbor, shrub and grass	Shrub and grass	Arbor and grass	Grass	Bare soil
Type of green space (divided by vertical structure)					
	2D		3D		
	Area	Shape index	Tree coverage	Canopy density	Three dimensional vegetation quantity
Morphological index					

Table 11. Greening morphology description template (patch class level)

	Relative vegetation quantity			The distribution of green space		
	Green coverage	Green plot ratio	Leaf area density	Edge density	Neighborhood green proportion	……
Morphological index						

On this basis, it is imperative to establish a set of comprehensive description indexes for the thermal effect of green space, which will play an extremely important role in evaluating the existing green space and guiding the design of urban green space. The index system should meet the following conditions:

1) The indexes system should be established separately on different organizational scales;

2) Taking full account of the interrelationship between different indexes, the morphological indexes can be simplified by analyzing the specific effects of the ecological processes that have a cooling effect on green space, or green space can be classified according to a certain morphological element (such as vertical structure), and then different weights can be added to other elements under different types of green space.

3) More uniform threshold data should also be provided for reference.

4) It should be easy to calculate and easy for the designer to control.

5) Attention should be paid to the potential impact of each index on air temperature while minimizing double counting.

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