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Using Daily Light Integral Concept to Construct the Ecological Plant Design Strategy of Urban Landscape

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***Abstract*—**It is an indispensible strategy to adopt greenery approach on architectural bases so as to improve ecological habitats, decrease heat-island effect, purify air quality, and relieve surface runoff as well as noise pollution, all of which are done in an attempt to achieve sustainable environment. How we can do with plant design to attain the best visual quality and ideal carbon dioxide fixation depends on whether or not we can appropriately make use of greenery according to the nature of architectural bases. To achieve the goal, it is a need that architects and landscape architects should be provided with sufficient local references. Current greenery studies focus mainly on the heat-island effect of urban with large scale. Most of the architects still rely on people with years of expertise regarding the adoption and disposition of plantation in connection with microclimate scale. Therefore, environmental design, which integrates science and aesthetics, requires fundamental research on landscape environment technology divided from building environment technology. By doing so, we can create mutual benefits between green building and the environment. This issue is extremely important for the greening design of the bases of green buildings in cities and various open spaces. The purpose of this study is to establish plant selection and allocation strategies under different building sunshade levels. Initially, with the shading of sunshine on the greening bases as the starting point, the effects of the shades produced by different building types on the greening strategies were analyzed. Then, by measuring the PAR (photosynthetic active radiation), the relative DLI (daily light integral) was calculated, while the DLI Map was established in order to evaluate the effects of the building shading on the established environmental greening, thereby serving as a reference for plant selection and allocation. The discussion results were to be applied in the evaluation of environment greening of greening buildings and establish the “right plant, right place” design strategy of multi-level ecological greening for application in urban design and landscape design development, as well as the greening criteria to feedback to the eco-city greening buildings.

***Keywords*—**Daily light integral, plant design, urban open space.

I. Introduction

GARDEN is a live artwork, and a frontier providing environmental control method in the concept of energy-saving landscape. Known as "Enviroscaping", it is aggravating the decision making rationality of design process [1]-[3]. The urban square is an important living space for densely populated metropolitan area, how to rebuild the green environment to perform its value and function depends on innovation thinking of professional landscape design [4]-[6]. In a long time, the influence of building shadow on plant design is apparent, but related studies still have the following deficiencies [7]:

1. The landscape designers know the poor sunshine of northward gardens, but they do not know the exact area of shadow and the duration of shadow in different seasons. The light environment is misjudged, the plants are arranged in inappropriate positions, or inappropriate vegetational types are selected.
2. The studies of physical environment of the open space outside buildings mostly discuss the effect of plants on reducing urban heat island effect or on comfort zone, seldom discuss the effect of buildings on plants.
3. The data provided by general meteorological literatures are merely extensive city-scale sunshine duration that cannot respond to the required microclimate scale for plant design accurately. However, the long-term light quality recording by instruments in greenhouse is inapplicable to numerous building lots requiring greening.

Therefore, this study aims to combine the concept of Daily Light Integrals (DLI) with the building shadow effect obtained by simulation and measured, in order to reflect the light environment at individual measuring points in open space, and discuss the design strategy of ecological city landscape plants.

II. Literature Review

A. Importance and Concept of DLI

The DLI for calculating the "total amount" of daily photosynthetically active radiation (PAR) is an important parameter that influences the plant growth. The DLI unit recommended by ASHS is $mol{\cdot}m^{-2}{\cdot}d^{-1}$, it is the most universal unit at present. It can reflect the growth of plants and "phenology". Above all, the yearly change of DLI approximately follows the track of sunshine duration [8]. Therefore, this study attempts to use the light environment index DLI convenient for discussing photosynthesis of plants to build a bridge between "sunshine" and "photosynthesis".

Like the way the rain gage bucket expresses rainfall per unit area, the concept of DLI can be converted into accumulation of PAR value per unit area, as shown in Fig. 1. Daily light integral is the amount of photosynthetic light received in 1 sq.m. of area each day. According to the research of Erik Runkle at Michigan State University, the yearly change of DLI is usually from $5{\sim}10 mol{\cdot}m^{-2}{\cdot}d^{-1}$ in winter to maximum $55{\sim}60 mol{\cdot}m^{-2}{\cdot}d^{-1}$ in summer, mostly reduced by 40% to 70% in greenhouse, the plant growth quality is guaranteed by minimum $10{\sim}12 mol{\cdot}m^{-2}{\cdot}d^{-1}$ supplemental lighting in controlled condition [9]-[11].

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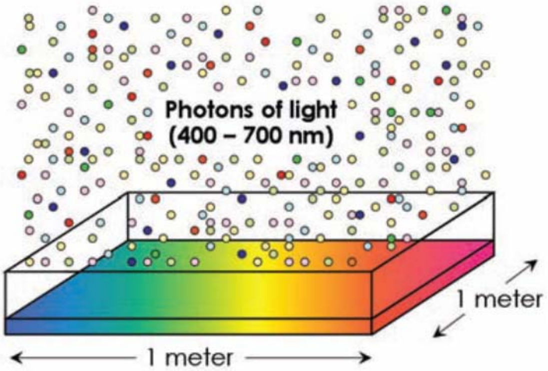

Fig. 1 Concept of DLI [9]

B. DLI Grading

Many studies have conducted experiments on the appropriate DLI value for different plants. The light requirement is determined by low, medium, high and very high ranges. The classification recommended by Jim Faust is shown in the Table I [12].

TABLE I
DLI (MOL.M^{-2}.S^{-1}) RANGES OF LIGHT REQUIREMENT OF DIFFERENT PLANTS [12]

	DLI(mol.m^{-2}.d^{-1})
Low-light crops	5~10
Medium-light crops	10~20
Hight-light crops	20~30
Very hight-light crops	30~60

To discuss the light requirement of plants in outdoor environmental design, this study selected the range of Jim Faust as basis of selecting and arranging plants in different building shadow conditions.

TABLE II
CONVERTING FOOT-CANDLES TO PAR AND DLI [14]

1st Step	Determine the average number of f.c. per hour. Take the hourly f.c. averages for the day, add them, and then divide this sum by24.	For example, you have 24 hourly f.c. readings: 0+0+0+0+0+5+12+21+40+43+159+399+302+461+610+819+567+434+327+264+126+15+4+0=4,408 f.c. 4,408 f.c.÷ 24 hours = 184 f.c. per hour
2st Step	Convert f.c. per hour to PAR (μmol.m^{-2}.s^{-1}) based on light source. Do this by multiplying f.c. per hour by a factor for the light source. Sunlight has 0.20 f.c. per μmol.m^{-2}.s^{-1}.	Using the same example as above, the PAR for crops receiving natural sunlight would be calculated like this: 184 f.c. per hour×0.20 f.c. per μmol.m^{-2}.s^{-1}=36.8 μmol.m^{-2}.s^{-1}.
3st Step	Convert PAR to DLI. Do this by using the following equation: PAR (μmol.m-2.s-1)×0.0864 The 0.0864 factor the total number of seconds in a day divided by 1,000,000	For crops receiving natural sunlight: 36.8μmol.m^{-2}.s^{-1} ×0.0864=3.2mol.m^{-2}.s^{-1}

C. Conversion of Light Intensity Units into DLI

The conversion of PAR into DLI is refer to follows as shown in Table II. This table shows how to calculate from foot-candles (f.c.) to PAR (μmol.m^{-2}.s^{-1}), and from PAR to DLI (mol.m^{-2}.s^{-1}) [13], [14].

III. RESEARCH METHOD

A. Research Subjects

This study selected the overall block of New Taipei City government as research target. Increasing the greening benefit to the densely populated places in metropolitan area has a direct effect on cooling urban heat island, and good landscape plant quality has significant benefit to city image shaping and providing public places with comfortable environment. Above all, there are dense super high-rise buildings around this site, and the building shadow impact is apparent. Besides the area of structure trunks in the block, more than 60% is open space, and there are multiple landscape plant arrangement environment types, providing relatively complete discussion about empirical research topic of multi-level greening environment.

B. Actual Measurement of Illumination

The illumination was measured during August to November, when the change of season is obvious. The measuring period was 10 days, and 8 measurement days with complete data were selected for analysis. There are 14 measuring points and 1 central plaza reference point.

1. L01, L02, L04, L05 and L06 measuring points are of the same type, "trail design" type.
2. L03 is located in the pool square on Basement 1, it is "excavated underground waterscape space" type.
3. L13 and L14 are in irregular plant site, the plane layout design of this area has no apparent geometric or symmetrically, so classified as small "irregular park layout".
4. L09 and L12 are close to the north side of New Taipei City government, using lawn as simple greening design, "greening lawn by building" type.
5. The plants and channels around L07 and L08 are designed symmetrically in geometric modeling centered on the phoenix sundial art device, so classified as small "geometric park layout" type.
6. L10 and L11 are located in the south side of New Taipei City government, the two zones are far from the central plaza, the greening space is less apparently, "corner plaza design" type.
7. The reference point is the open area of central plaza, free from shadows all day long.

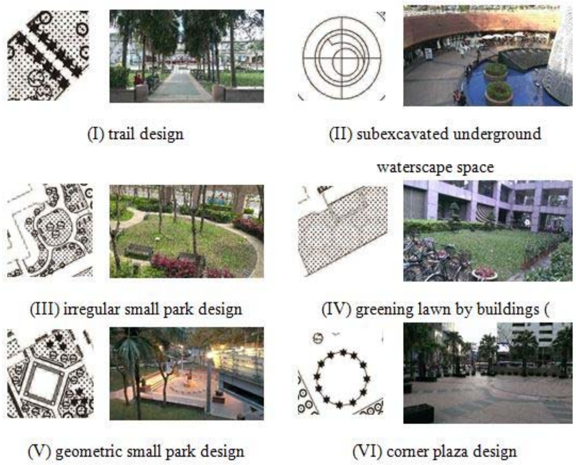

Fig. 2 Landscape design types discussed in divisions

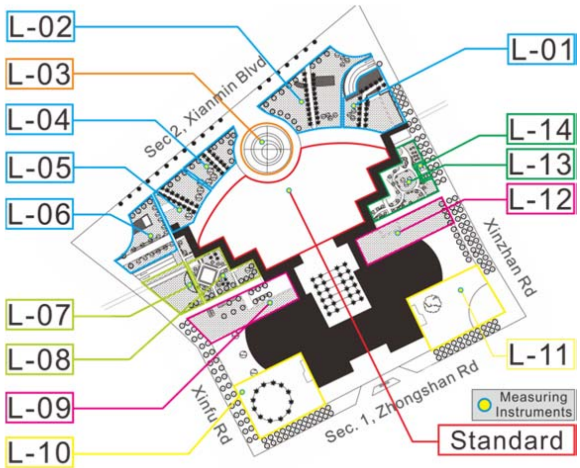

Fig. 3 The reference point and landscape division measuring points locations on the block of New Taipei City government

TABLE III
LIGHT ENVIRONMENT MEASURING POINTS OF LANDSCAPE DIVISIONS

(Type I) trail design					*(Type II) underground waterscape space*
L01	*L02*	*L04*	*L05*	*L06*	*L03*
					
(Type III) irregular small park design		*(Type IV) greening lawn by buildings*		*(Type V) geometric park design*	
L13	*L14*	*L09*	*L12*	*L07*	*L08*
					
(Type VI) corner plaza design					
L10			*L11*		
					

TABLE IV
INSTRUMENTAL IMAGE

Measuring points L01~L14 illumination:		HOBO Pendant UA-002-08 pocket temperature illumination recorder
Reference point illumination:		LM-8000 Wind speed illumination humidity temperature gage.

The measurement time was 9 a.m. to 5 p.m., at an interval of 10 minutes. The data were stored, and the six data between integral points were averaged. A group of average illumination data representing the "hour interval" was obtained. For the 8 hours from 9 a.m. to 5 p.m., there were 8 sets of data measured per day.

As the reference point and other 14 fixed measuring points use different instruments for illumination measurement, in order to avoid the two instrument product types causing data difference, the data correction was implemented for the two instruments. The correction experiment was conducted in a cloudless day. The data measurement of LM8000 was implemented. Two sets of HOBO Pendant UA-002-08 were placed in the same position. They were synchronized to check the stability of instruments, and recorded at an interval of 10 minutes. The data were collected and the data of various time intervals were averaged. The data measured by the two instruments were compared. The correction coefficient was 2.66 for correcting the illumination data measured by LM-8000.

The measured daily average illumination is converted into DLI value, except for 9 a.m. to 5 p.m. was neglected. It is relative DLI value.

IV. Results and Discussion

A. Hourly Variation of Illumination of Landscape Design Types

The reference point data of central plaza are shown in Fig. 4. The overall variation trend of eight measurement days was obtained. As seen, the illumination in the morning was higher than that in the afternoon. Some measurement days had slightly different trend due to weather condition, for example, the illumination decreased obviously as it was cloudy in the morning of August 28.

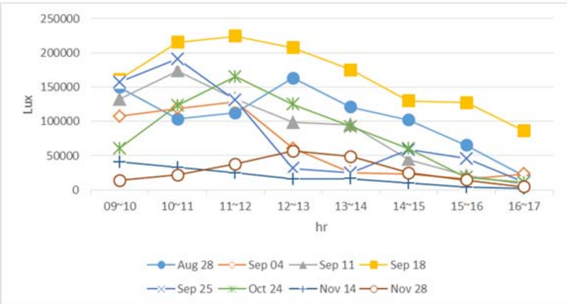

Fig. 4 Hourly variation of illumination at reference point

1. Trail Design

Most of the five measuring points of this type show the similar trend to reference point that the illumination in the morning is higher than in the afternoon. L02 shows a special phenomenon that the illumination in the afternoon is higher than in the morning, because the west side of L02 is an excavated underground space. This zone lacks shadow effect of tree species, so that the average illumination is much higher than the other four trail measuring points as shown in Fig. 5.

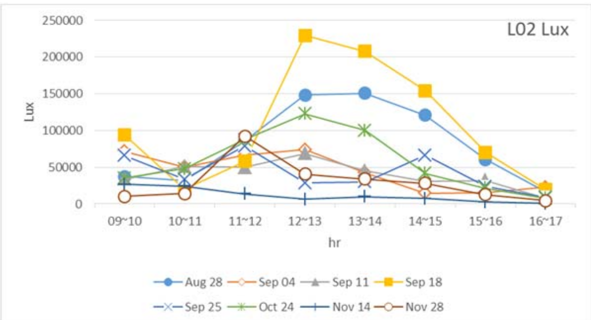

Fig. 5 Hourly variation of illumination at L02 measuring point

Another measuring point of this type with inconsistent illumination variation trend is L06. As the greening design nearby this measuring point is fully implemented, the instrument at the measuring point is likely to be shadowed by the plants all day long. The all-day illumination of all measurement days is lower than the other four measuring points, as shown in Fig. 6.

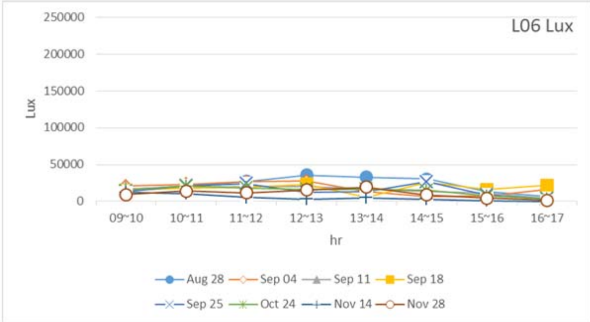

Fig. 6 Hourly variation of illumination at L06 measuring point

2. Greening Lawn by Building

The L09 and L12 measuring points of this type are influenced by the building shadows in the block significantly. They may receive much illumination only at about noon, and this type only uses lawns for greening. There is no plant shadow, so the illumination rises sharply when building shadow is insufficient at midday, as shown in Figs. 7 and 8.

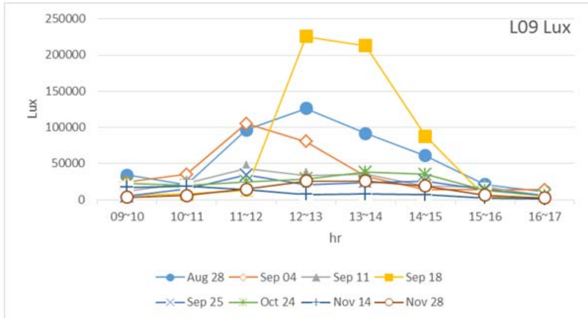

Fig. 7 Hourly variation of illumination at L09 measuring point

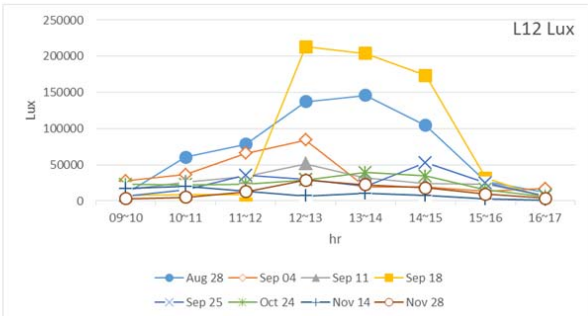

Fig. 8 Hourly variation of illumination at L12 measuring point

3. Irregular Park Layout and Corner Plaza Design

The L13 measuring point of irregular small park layout and the L11 measuring point of corner plaza design are located in the east side of this block. The two zones have very obvious variation in illumination which decreases rapidly after 12-13

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o'clock and 13-14 o'clock, as shown in Figs. 9 and 10. The difference between them is resulted from different building shadow providers, it is observed in the shadowgraph that L13 measuring point is influenced only by the building shadows in the block, whereas L11 measuring point is shadowed not only by the buildings in the block, but also by the adjacent buildings to the south side of the block, as shown in Fig. 11.

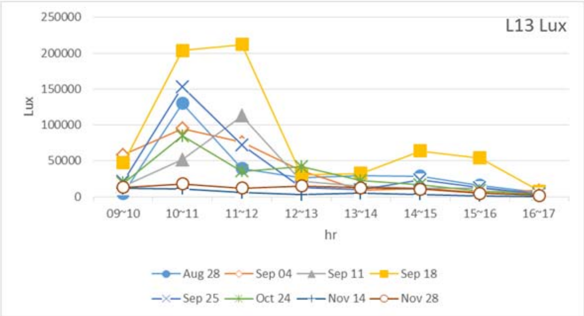

Fig. 9 Hourly variation of illumination at L13 measuring point

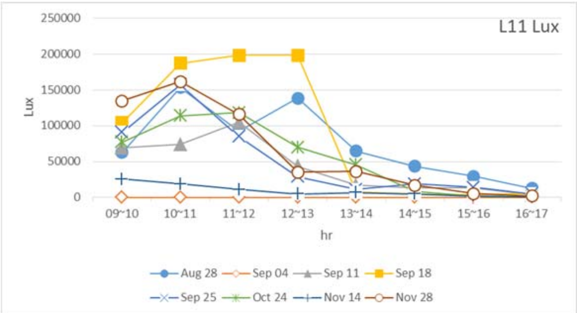

Fig. 10 Hourly variation of illumination at L11 measuring point

Fig. 11 Comparison between afternoon shadow of L09and L12, L10 and L11

4. Geometric Small Park Layout

The illumination at the L07 measuring point of this type also decreases obviously after 13-14 o'clock, as shown in Fig. 12. The shadows causing rapid decrease in the afternoon illumination are not from the buildings, but from the adjacent building group on the southwest side. As the southwest buildings are high and successive, the L07 measuring point is out of sunlight completely after midday, the illumination does not rise anymore.

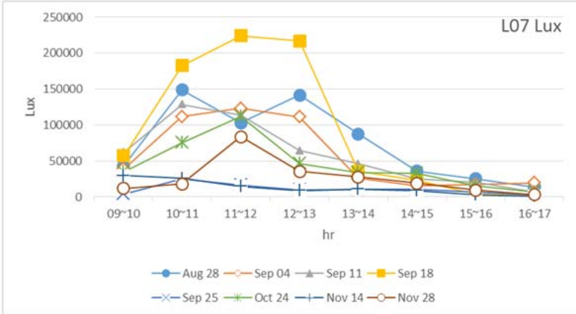

Fig. 12 Hourly variation of illumination at L07 measuring point

The two measuring points are distributed on both sides of the large hard pavement, but the variations of illumination are quite different. As the L08 measuring point is located in the block with abundant greening design of this type, the variance in illumination is always stable and relatively low, as shown in Fig. 13.

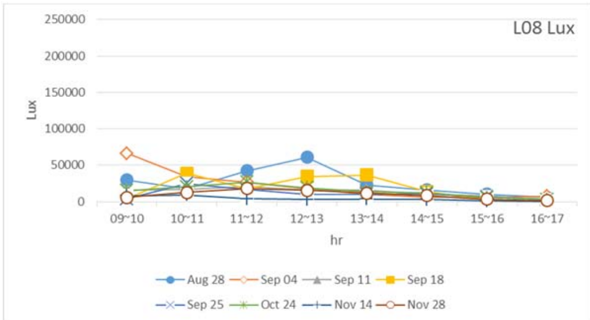

Fig. 13 Hourly variation of illumination at L08 measuring point

The differences among several models are obtained from the hourly variation of illumination at various measuring points apparently different from the reference point. The four illumination changing patterns and influencing factors are summarized as follows:

The afternoon rise type influencing factor is mainly the plants in rows of trail design, including the plant shadows in its area and the plant shadows in the adjacent area, representative measuring point L02.

The type of no obvious variation is because the greening design in the measuring point range is abundant, the instrument is disturbed by the plant shadows, the light environment is stable and low, representative measuring points L06 and L08.

The three measuring points of ***afternoon rapid decrease type*** are covered with extensive shadows in the afternoon, but the shadows of the three measuring points are from different sources, including the building shadows of adjacent block, the building shadows in the block and the composite of the former two, representative measuring points L07, L11 and L13.

The midday rapid rise type is because of too short distance to the buildings, the building shadows have significant effect, representative measuring points L09 and L12.

Fig. 14 shows the total illumination at various measuring points in various days. In terms of landscape design types, the order of total illumination is central large plaza design reference point (S) > excavated underground waterscape space (II) > corner plaza design (VI) > greening lawn by buildings (IV) > trail design (I) > geometric park design (V) > irregular park design (III).

September 18 is the measurement day in the best weather condition, the maximum total illumination is almost 165000 Lux at the reference point, the second highest illumination is 150000 Lux at L03 measuring point, the minimum illumination at L06 measuring point is almost 18000 Lux. On November 14 in the worst weather condition, the maximum total illumination is only 18000 Lux at the reference point, the second highest 17000 Lux at L03 measuring point, the minimum 4000 Lux is at L08 measuring point.

Fig. 14 Average illumination of various measurement days

As shown in Fig. 15, the total illumination of various measurement days is averaged; there are several significantly different cases at different measuring points of different landscape design types the shadow environment of landscape design types is discussed in items.

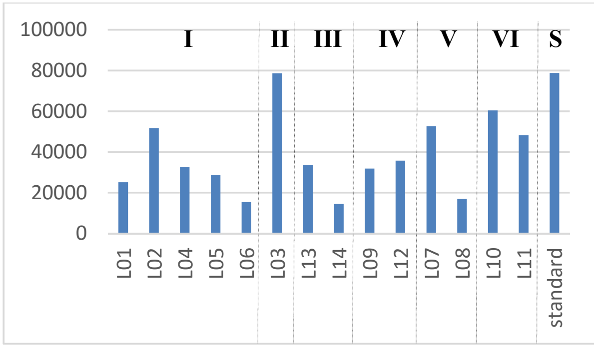

Fig. 15 Daily average illumination (8 actual measurement days)

Generally speaking, the variance in light environment: (a) the area closest to the building is influenced by building shadows most significantly, the illumination rises apparently at mid-day, especially about 12 o'clock on September 18, that atL09 measuring point and L12 measuring point increases by about 200000Lux; (b) in the area influenced by plant shadows significantly, for example, at the L02 measuring point in the afternoon, as the west side is open, the illumination rises sharply in the afternoon, it increases by 170000Lux somewhere about 12 o'clock; (c) in the area with abundant greening design, the effect of plant shadows is more significant, e.g. L06 and L08 measuring points in this study, the total illumination in various measurement days is merely 20% of that in open area.

C. Comparison Analysis of "Relative DLI" of Landscape Design Types

The measured daily average illumination is converted into relative DLI value,

1. The relative DLI at the reference point in open area is as high as 88 when the sunshine is intense in summer, as the 14 measuring points are located in different shadowed landscape types, the relative DLI value is 10~77.
2. The relative DLI at the reference point in open area decreases to 10 rapidly in about autumn, and more than 50% of measuring points are lower than 5, the illumination is insufficient.

Therefore, the microclimate around the buildings changes drastically, the weather resistant sun/shade-demanding plants shall be selected to implement "comfort zone" of plant.

V. Conclusion

Numerous studies have recorded the response of different plants to DLI. In the future greening design, as long as the reference DLI ($mol.m^{-2}.d^{-1}$) at various plant collocation points in microclimate scale is predicted, an index for discussing plant light environment can be obtained. This study used the DLI in important design decision on landscape plants. When conceiving the maximum or minimum "greenery" of a site in the preset design proposal in the future, a dynamic view of monitoring the "growth" or "decline" of a greening environment for long can be provided, so as to attain the goal for sustainable ecological environment.

TABLE V
COMPARISON OF RELATIVE DLI OF VARIOUS MEASURING POINTS/VARIOUS MEASUREMENT DAYS

DLI	Aug 28	Sep 04	Sep 11	Sep 18	Sep 25	Oct 24	Nov 14	Nov 28	AVE	R-DLI
S	56	34	47	88	43	44	10	15	42	
L01	24	17	10	14	9	13	3	11	13	30%
L02	43	24	21	57	22	31	6	16	28	66%
L03	66	44	40	77	38	38	9	23	42	100%
L04	36	18	14	25	20	14	4	8	17	41%
L05	29	14	13	28	16	14	3	6	15	36%
L06	12	9	8	10	8	8	3	6	8	19%
L07	40	31	31	50	6	24	7	14	25	60%
L08	14	12	7	10	6	8	2	5	8	19%
L09	31	21	13	37	10	12	5	7	17	40%
L10	53	36	29	65	19	29	6	20	32	77%
L11	40	20	23	47	27	29	5	34	26	61%
L12	38	19	14	43	13	13	5	7	19	45%
L13	19	20	16	44	21	15	3	6	18	43%
L14	12	8	6	13	7	7	2	4	7	17%
AVE	33	20	17	37	16	18	5	12	20	47%

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