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Study on the Fundamental Characteristics of Thermal Performance of Landscape Elements - Thermoscape - Using Infrared Thermovision Camera

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ABSTRACT

This study dealt with the analysis of the changing of thermoscape, which indicates the pattern of surface temperature condition of landscape elements, such as concrete building, trees, topiary, lawn and bare soil. Source of data was the visual data of surface temperature of those landscape elements that obtained by operating infrared thermovision camera which connected with video cassette recorder. The visual data were then employed with computer system for visual image analysis. Based on each surface temperature of landscape element, we compared the changing of surface temperature pattern through 24 pieces of thermoscapes running for 24 hours, and we analyzed each pattern of surface temperature condition.

Evaluating through the sequential thermoscapes, there was considerable difference of thermal condition of landscape element each to other. Tulip tree showed the similar changing pattern of surface temperature with that of air temperature, and concrete building showed different surface temperature in large number between the day and night. The study showed the changing pattern of thermoscape, that canopies of vegetations acted as lower surfaces temperature at mid day, but on the other hand the concrete building showed different surface temperature before and after receiving solar radiation, considerably. From the scene of thermoscapes, it was clear that, the concrete building was the domain of high surface temperature, while vegetations was the domain of low surface temperature.

INTRODUCTION

Recently, we have seen how a great number of population flowing down into city areas. City is being conscioused as a source of amenity and human civilization, is impressed to bring people more and more from countryside to inner-most city. To meet citizens' needs on housing, business and their moving, thus city serves such facilities; for those purposes city should prepare buildings and pavements for housing and business places, and according to shoot forward business city makes transportation net-work. The more advanced in civilization of city the more dense building and transportation net-work is. This phenomenon, the growth of city, then have made new problems to citizens themselves.

One of the main problems faced in city is the hot environment, especially during summer [2, 3]. As a city high densely constructed with buildings and pavements, it becomes easier to receive and store solar radiation, which hence makes the city hotter. Moreover, the existence of greenery open spaces in city have been restricted caused of higher value of land and giving priority on the development of construction. Vegetation of greenery open space growing in city has the ability to utilize energy from solar radiation for evapo-transpiration and store as carbohydrate; it means that greenery open space has an important role to control urban hot environment [2,6,7,8]. Restriction of greenery open space on one side, and the development of construction on the other side leads urban environment become hotter. This situation hence more severe during summer where more solar radiation strike to the city surface, inducing the existence of so called the urban heat island.

Hereafter, urban environment becomes uncomfort for citizens daily activities. Because of the hot condition then people ought to cool with cooling system equipments their surroundings, i.e. at home, office, building or other indoor room, but actually, this effort no more than in turn aggravate the condition outside worse caused by heat emitted from the equipments [4,7]. It seems that human comfort is being considered for human daily life. Previous studies suggested that proper conditions were the main requirements, and main stimulus, for development of civilization. And some industrial engineers also have studied productivity of workers in various countries at various times, showed that worker productivity declined in time of excessive hot [2,3].

For indoor comfort, some studies have been conducted by civil engineers and architects. They studied how to set up building which is designed to lease natural air flow and how to use natural energy to meet indoor condition favorable [10, 11]. For outdoor, some previous studies also have been conducted to look for the basic knowledge on the phenomena of urban heat island, and to look for the policy to make effort on the more using natural energy in order to lower the pressure of hot environment. Yamada [9] conducted observation on the distribution of air temperature and the effect of urban open space on urban climate at Kurihashi, Saitama Prefecture in summer. The similar study was also conducted by Pichakum et al [5] observing the distribution of air temperature and the effect of urban open space. These previous studies, unfortunately, only touch upon the relation of green space and the change of air temperature. We need much more detailed image data of thermal behavior in order to realize those results in the design activities. For this purpose, the thermal behavior of various surfaces of landscape elements in a certain scene must be analyzed, and visual thermal data should be obtained. We introduce the idea of thermoscape.

Thermoscape, therefore, is defined as that which indicate the thermal condition of surfaces of landscape elements located in urban areas, utilized to analyze the thermal effectiveness of vegetations in the context of landscape design. Thermoscape is shown by thermographs created through a newly established image-processing system, and it indicates the patterns of thermal performances which, with the help of images can be observed by man. Main purpose then is to produce visual image data of thermoscape which function as fundamental sources for evaluating comfortness of living environment in urban areas in the context of thermoscape-design process.

METHOD

This study dealt with observation on characteristics of thermoscape, a pattern of thermal condition of landscape surfaces through thermographs.

(1) Location and Time

It was considered that the site could be clearly viewed by infra-red thermovision camera (hereafter called ITC), and the scene should occupy the hard and soft materials such as trees, ground cover and building surfaces. To meet this purpose, a site at Faculty of Horticulture, Chiba University was selected for study. This site involves : (1) concrete building, (2) tulip tree (Liriodendron tulipifera), (3) topiary, (4) lawn and (5) bare soil. Those surfaces could be clearly viewed by ITC set up in room of third floor of A building.

Observation on the thermal characteristics was held on summer 1992, from 19 : 00 of August 27 to 18 : 00 of August 28. It was an observation on series of time, conducted every hour due to grasp the changing pattern of thermoscape during 24 hours.

(2) Equipments

The equipments needed in this observation were as following : (1) Infra-red Thermovision Camera (2) Thermometer Tanita (3) Video Cassette Recorder

(VCR), and (4) Computer system. ITC has the ability to reap thermal condition directly in a distance, because the surface of each landscape element emits unique electromagnetic wave that can be read by ITC it's temperature degree.

Thermometer was used to measure air temperature during observation, and the air temperature was recorded at outside of building adjacent to ITC in order to obtain input data for producing thermographs. The degree of temperature was read as round number (1℃), because ITC only able to get input ambient temperature data in round number. However ITC itself able to read the degree of surface temperature up to one decimal. The thermal data were recorded by video cassette recorder (VCR).

(3) Setting up ITC

From the observation point it was able to view each landscape element. Landscape elements were located in the west side of ITC, so that the surfaces of concrete building (of E building), tulip tree canopy and topiary canopy were observed by ITC as west side surfaces. The other two landscape elements, lawn and bare soil, positioned lower than ITC were observed as those upper surfaces.

Figure 1 shows the existing condition of landscape elements being viewed by ITC, and *Figure 2* gives more detail of distance, the section of location of study viewed by ITC. ITC was positioned at A-building at right side, and the thermometer was placed adjacent to it.

Fig.1 Existing condition of observation area viewed from measuring point.

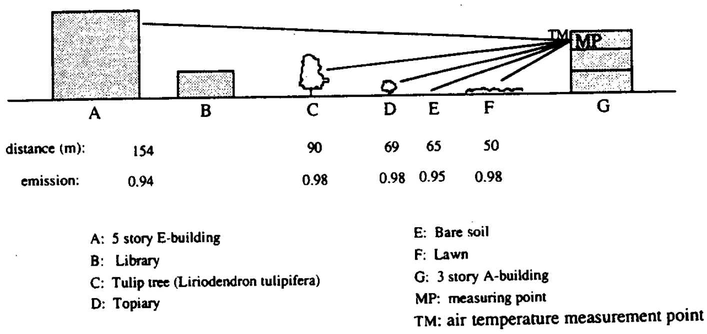

Fig.2 Cross section of observation area.

(4) Measurement

Air temperature was measured using thermometer Tanita every hour from 19:00 of August 27, to 18:00 of August 28. This measurement just only recorded air temperature as round number (1℃) without specifying into one decimal because of mechanical demand of ITC.

Operating Infra-red Thermovision Camera [1]

In order to reach properly data, ITC should be adjusted by setting up buttons built up within the body. Emission of each kind of element has specific number, for example emission for concrete building is 0.94, for vegetation 0.98, and soil 0.95. Gray tone quantification was separated into 10 intervals of color vision ranging from lowest to highest. Therefore, based on this color segmentation, it is easy to read thermal performance of surfaces of landscape elements. The color segmentation ranges from blue to white as shown in *Figure 3*. It indicates the range of temperature from the lowest (blue) to highest (white), thus, for example, any given area of thermograph with red color is higher in temperature than another area with blue color.

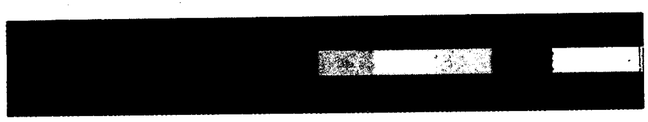

Fig.3 Color segmentation of Thermograph, ranging from lowest (left) to highest (right) surface temperature.

Figure 4 shows some samples of thermographs measured with spot and isocol. The difference of two only lies on the represent of cross sign on spot thermograph. On the right side of those two samples there is a table of recorded data built up within ITC system.

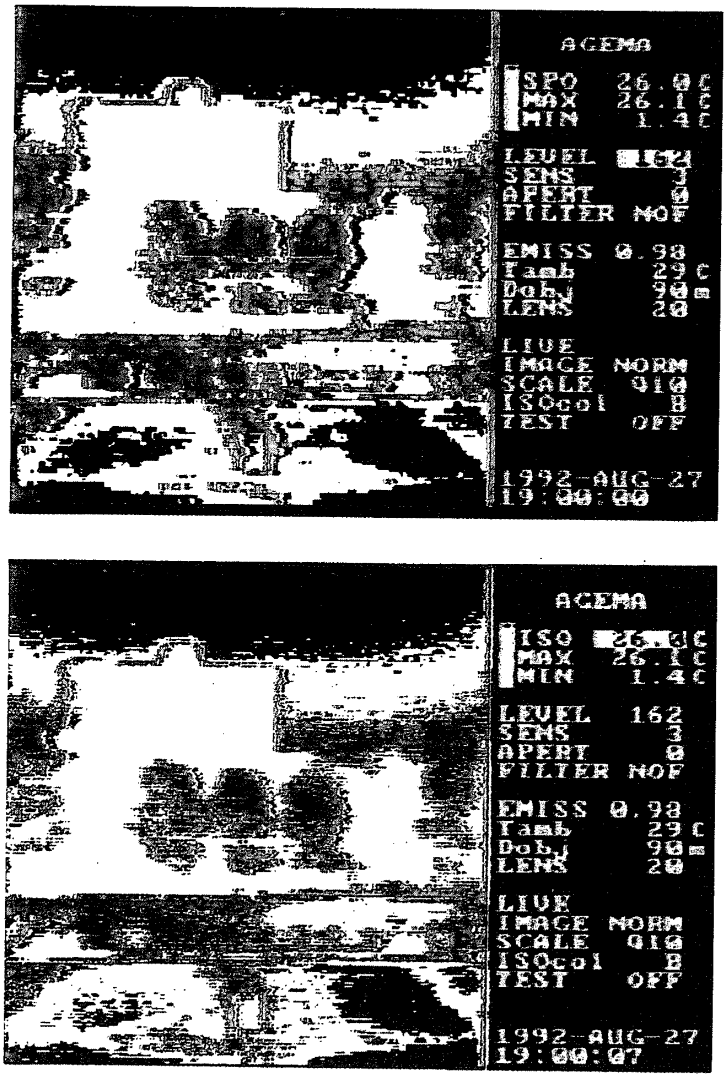

Fig.4 Samples of thermograph measured in spot and isocol surface temperature

(5) Recording Data and Analysis

Data of thermoscape was grasped by ITC for 10 seconds both at spot and isocol observation. Recorded data then was read by computer Macintosh IIFx, using software Photoshop. The changing pattern of photographs during 24 hours was produced into 24 pieces color photographs arranged by using software MacDraw-Professional. This setting of thermographs then was printed out using color printer. Thermoscape can be compared each other by using color segmentation, which was produced into 10 intervals using software Ultimage.

RESULTS AND DISCUSSION

(1) The Changing of Thermoscape through Isocol Surface Temperature

Thermographs were produced from isocol data base of each landscape element. Thus for five kinds of landscape elements during 24 hours (24 times of observation), it could be produced 120 pieces of thermographs in color. In this manner, we only select once that represent a whole scene of thermoscape involving whole landscape elements, so that we present here the changing of thermoscape observed in focus on tulip tree canopy, with the emission of 0.98.

Figure 5 shows the changing of thermoscape set up of isocol data with the emission 0.98. These thermographs represent the changing per hour of thermoscape pattern during 24 hours from 19:00 to 18:00 on the next day drawn in 24 pieces of thermographs. In overall view through all sequence of thermographs, it is clear that there is a changing in color pattern that the canopy of tulip tree surface temperature was lower than those of other landscape elements. But at 11:00 the shape of building becomes clear, indicating that the temperature difference between building surface and tulip tree canopy's surface increases. Up to 15:00 only tulip tree canopies show greenish, representing the thermal condition of them cooler than other landscape elements. At 16:00 surface of lawn is identified as red color area, showing a more little different surface thermal condition with tulip tree. The next step, from 17:00 to 06:00 the thermal distribution of each landscape element becomes clear, which represent the characteristics of their own.

Surface of concrete building shown in white color along the series of thermographs indicates hot surface all through the day. Even during night-time without sunlight from 19:00 to 03:00 building surface is shown in white color indicating hotter than other surfaces. On the contrary, tulip trees canopies are shown in green to blue colors in the whole day, indicating that tulip

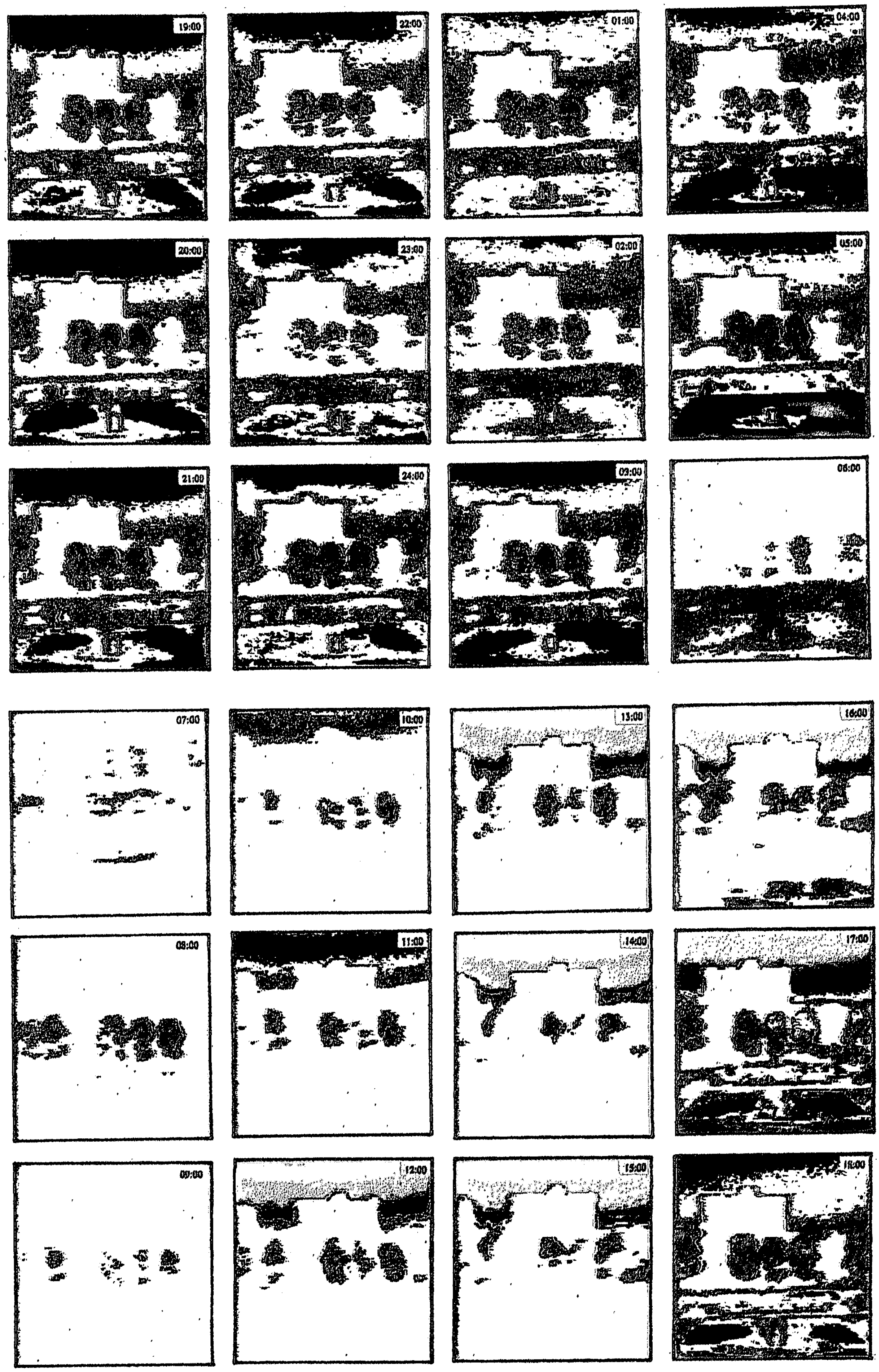

Fig.5 Set of thermographs shows the changing of thermoscape during 24 hours measured in isocol surface temperature and emission 0.98

tree canopy surface temperature is in a great difference with the building surface thermoscape.

Among the vegetations (tulip tree, topiary and lawn), tulip tree canopy clearly shows cooler during day time from 6:00 to 18:00. Even in the afternoon after receiving solar radiation directly, from 13:00 to 18:00, west-side surface of tulip tree canopy still shows cooler than those of topiary and lawn. On the other hand, building surface does not have this capacity, but store energy from solar radiation implying on the increasing of it's surface temperature [7]. In this manner tulip tree canopy shows the biggest potentials of "cooler portion" of a scene which may cause people feel comfortably.

Topiary canopies seems more responsive to solar radiation than tulip tree canopies. From 07:00 to 16:00 topiary canopies are shown in white color, indicating hotter than tulip tree canopies. Hereafter, from 17:00 to 06:00 surface temperature of topiary canopy clearly represents cooler surface than lawn surface.

Among the vegetation, lawn surface shows the hottest. From 07:00 to 15:00 lawn shows the white color, as building surface also shows white, it indicates that lawn surface is responsive to store heat from solar radiation. During 16:00 to 06:00 lawn surface shows reddish than building surface, indicating lower surface temperature during this time than building surface. Bare soil surface shows hot during sun shines, and still hotter than vegetation canopies until the mid-night. But at 06:00 it looks like lower surface temperature than lawn or building surfaces. It indicates that soil surface is more responsive than lawn in absorbing heat from solar radiation.

From the thermographs we can see how the proportion of cool area occupies, and in inverse, we also able to see how the hot area occupies to the total area of a tested scene. Concrete building acts as the domain of hot surface. Bare soil is also the domain of hot surface temperature, but shows more fluctuative than building. Cool area is the domain of vegetation, which in this study, tulip tree canopy shows the primary cool area. Thus, by evaluating of thermoscape, we conclude that vegetations, especially the tulip tree canopies have important roles to moderate visible thermoscape oriented environment.

(2) The Changing of Spot Surface Temperature

Table 1 shows changing of surfaces temperature. In this table is also shown the change of air temperature during observation in order to examine the difference of temperature with those surfaces temperature of landscape elements.

Time	Air temp.	Building	Tulip tree	Topiary	Lawn	Soil
19:00	29	29	26	26	24	26
20:00	29	27.2	24.8	24.4	23.5	24.2
21:00	29	26.6	24.2	23.8	22.9	22.8
22:00	27	27.3	24.6	24.2	23.2	23.5
23:00	27	26.7	24.5	23.7	23.2	23.5
24:00	27	26.3	24.4	23.6	22.9	23
1:00	27	26.1	24.4	23.8	22.9	23.4
2:00	27	26	24	23.7	22.9	23.2
3:00	27	25.1	23.4	23	21.6	22.1
4:00	27	24.1	22.6	21.5	21.2	21.2
5:00	27	23.6	22.7	22.2	20	20.5
6:00	28	24.7	23.4	23.1	23	22.6
7:00	31	23.6	23.6	23.6	28.5	24.3
8:00	31	25.3	23.9	25.4	31	36
9:00	31	26.6	25.9	28.8	35.2	41.2
10:00	32	27.4	26.5	29	36.7	47.3
11:00	32	29.5	28.8	31.8	37.5	49.8
12:00	33	29.7	29.2	32.9	37	52.2
13:00	33	33.8	29.9	34.9	36.5	53.1
14:00	33	38.5	30.1	36.5	36.1	49.4
15:00	32	42.7	30.9	36	34.8	47.8
16:00	32	43.8	30.1	33.9	33.1	41
17:00	31	41.3	28.3	26.7	26.7	29.5
18:00	30	31.2	25.5	25.9	24.8	26.3

Tab.1 The change of some spotted surfaces temperature (℃).

Data of air temperature are noted as round number because of the ability of ITC being inputted only by round number of air temperature. While data of spot surface temperature were noted as data with one decimal. The air temperature indicates the thermal condition of observation point, and do not represent the air thermal condition near the canopy. We need more detailed data to explain the case.

(2.1) Building Surface Temperature

Based on Table 1, here is seen Figure 6 showing the change of concrete building surface temperature compared with change of air temperat ure. It is clear that during 19 : 00 to 12 : 00

surface temperature shows lower than air tempe rature, but hereafter, during 13 : 00 to 18 : 00 shows conversely. It is caused by the situation that west-side surface of concrete building during 19 : 00 to 12 : 00 could not receive solar radiation directly falling to it, and hereafter up tu 18 : 00 it received heat from solar radiation directly causing increasing on surface temperature.

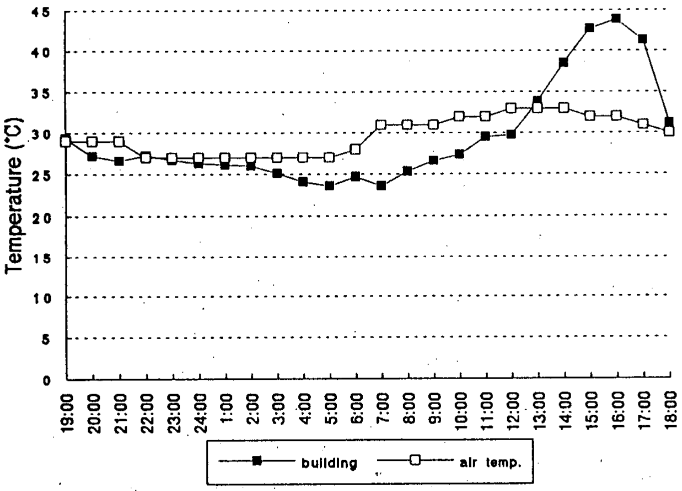

Fig.6 Change of building surface temperature compared with air temperature.

During 19:00 to 05:00 surface temperature showed decreasing smoothly as air temperature did. It was caused of no solar radiation falling into the surface. However during 7:00 to 12:00 surface temperature increased smoothly, because of eventhough could not receive solar radiation directly, but receive indirectly as diffused solar radiation. After 12:00 it received solar radiation directly causing increasing of surface temperature drastically. It reached peak of temperature at 16:00 at the value of 43.8 ℃, and then decreased drastically until 18:00. Through the whole day, surface temperature reached the lowest temperature at 05:00 at the value of 23.6℃. The highest different between air temperature and building surface temperature occurred at 16:00 with range of 11.8℃ which building surface temperature was higher.

(2.2) Surface Temperature of Tulip-tree Canopy

The changing pattern of surface temperature of tulip-tree canopy seemed similar with that of air temperature. However, it can be seen from Figure 7, along 24 hours of observation, the change of surface temperature of tulip-tree canopy is always lower than air temperature. During the whole day, the changing was smooth. During 19:00 to 05:00 temperature decreased smoothly and reached the lowest at 22.6℃, hereafter increased as air temperature did, and reached peak at 15:00 at the value of 30.9℃.

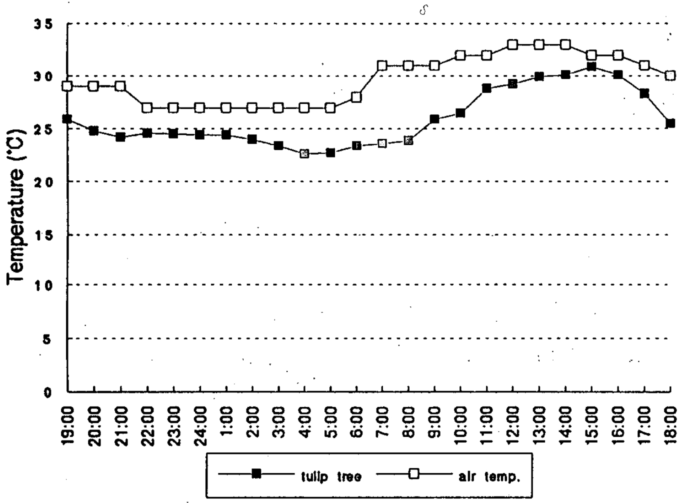

Fig.7 Change of surface temperature of tulip-tree canopy compared with air temperature.

As mentioned above, during 24 hours of observation, the surface temperature of tulip-tree canopy was always lower than air temperature. It indicates that the canopy of tulip trees is effective in using solar radiation to evapotranspirate so that surface temperature does not increase in a great number, even during solar radiation falls directly to it's surface. During very hot time (12:00 - 14:00), the canopy surface temperature showed 2.9 - 3.8℃ lower than air temperature.

(2.3) Surface Temperature of Topiary's Canopy

Figure 8 shows change of surface temperature of topiary's canopy for 24 hours during observation. During 19:00 to 4:00 as air temperature decreased, surface temperature of canopy also decreased, and reached the lowest temperature at 4:00 at value of 21.5℃. From here to 12:00 under diffused solar radiation the canopy surface temperature increased to reach equal level of air temperature. As the west-side surface directly receiving solar radiation ,after 12:00, surface temperature increased, and reach the peak at 14:00 at the value of 36.5℃. Hereafter surface temperature decreased and turn back to the cycle.

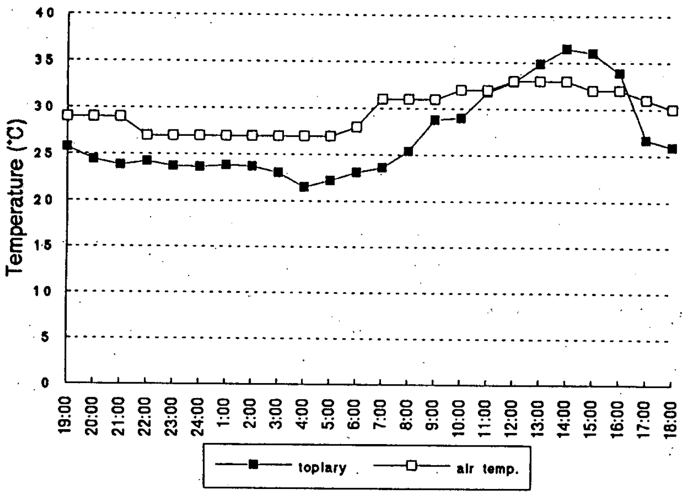

Fig.8　Change of surface temperature of topiary canopy compared with air temperature.

After receiving solar radiation directly from 13:00 to 16:00, topiary canopy's surface temperature was higher than air temperature. The difference of temperature at this time was recorded 3.5℃. The lowest temperature of topiary's canopy surface was 21.5℃ reached at 4:00. The highest difference of temperature between air temperature and topiary's canopy surface was recorded at 7:00 at the range of 6.4℃. In this time spotted surface of west-side topiary's canopy still could not received solar radiation directly. However it is considered that west-side surface of topiary increased temperature to the level higher than air temperature after directly receiving solar radiation.

(2.4)　Lawn Surface Temperature

Figure 9 shows the changing pattern of lawn surface temperature for 24 hours compared with air temperature. It can be seen that from 19:00 to 5:00 surface temperature decreased smoothly, and at 5:00 reached the lowest temperature at 20.0℃. During the period of 5:00 to 11:00 surface temperature increased drastically, and reached peak at 11:00 at the value of 36.5℃. After reaching the peak, surface temperature then slow downed, and after 16:00 drastically decreased and back to the cycle.

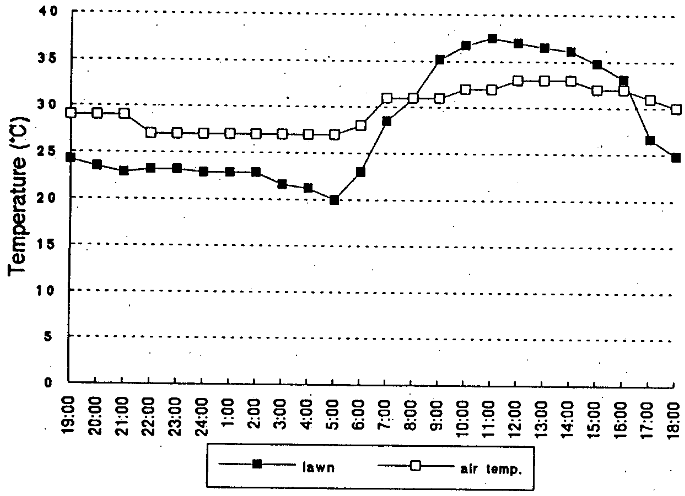

Fig.9　Change of lawn surface temperature compared with air temperature.

Lawn is planted at ground level, so that it is easier for lawn to receive solar radiation directly from sun. This evidence can be seen from figure, that after 5:00 surface temperature increased drastically. Here is also considered that just after receiving solar radiation (after 8:00), surface temperature reached to the level higher than air temperature. However after 17 : 00 to 7 : 00 surface temperature was lower than air tempera ture.

At hot time, surface temperature shows up to 3.5℃higher than air temperature. And at the lowest point of surface temperature (at 5 : 00), it shows 6.5℃ lower then air temperature.

(5)　Bare Soil Surface Temperature

Figure 10 shows change of soil surface temperature compared with air temperature during period of observation. It is clear that during 19 : 00 to7 : 00 the surface temperature was lower than air temperature, and looked like trend to decrease. At 5:00 minimum surface temperature occurred at the value of 20.5℃. After 5:00 to 7:00 gradually increased, and then drastically grew up, and reached the peak at 13:00 at value of 53.1℃. Hereafter surface temperature slowed down to turn the cycle.

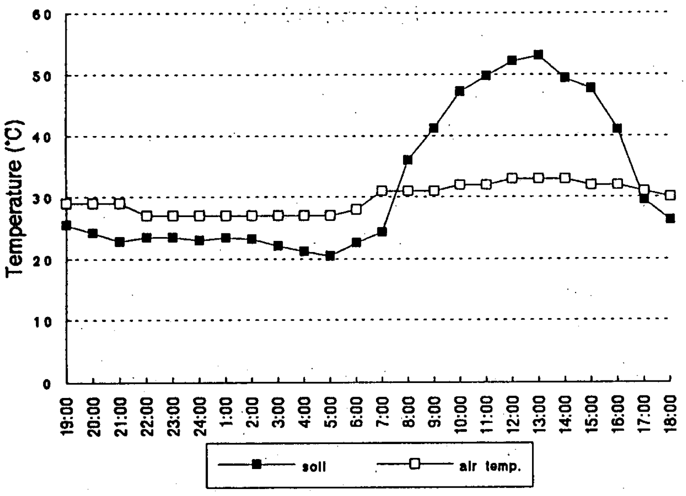

Fig.10 Change of soil surface temperature compared with air temperature.

During 8:00 to 16:00 surface temperature showed higher than air temperature, and at 13:00 reached the highest difference with air temperature at range of 20.1℃. It is also clear that after receiving solar radiation directly from sun, soil surface increased temperature drastically, and soon reached to the level higher than air temperature.

Graphic in Figure 7 shows that the changing of surface temperature of west-side tulip-tree canopy was similar with the changing of air temperature, and during observation the canopy surface temperature was always lower. Changing of west-side building surface temperature was similar with the change of west-side topiary canopy's surface compared with air temperature (Figure 6 & 8). Both indicated that after directly receiving solar radiation they increased surface temperature to the level higher than air temperature. Changing of lawn surface temperature and soil surface temperature were also similar in compared with air temperature (Figure 9 & 10). Before sun-shines, both surface temperatures showed lower than air temperature, but just after directly receiving solar radiation, they increased surface temperature drastically reaching to the level higher than air temperature.

It is identified that concrete building surface showed hotter than tulip tree canopy's surface through the whole day, while tulip tree canopy's surface temperature showed cooler than other vegetation (topiary and lawn) during sunshines. We also see that the surfaces of lawn and bare soil are very responsive to solar radiation. It is also identified that the west-side surface of topiary's canopy, after 12:00, is also responsive to the solar radiation falling to this surface.

The result of study on spot surfaces' temperature also shows in accordance with the result of previous study [2] . However this study is not in the effort to give evidence of studies conducted before, but in order to make clear on the result of observation setting on isocol surface temperature. And here, thermographs printed out based on isocol surface temperature can be used to make decision on the evaluation of thermal performance of landscape elements (thermoscape). It means that thermograph, made of isocol surface temperature data, is an important yield for evaluating the thermal characteristics of surfaces of landscape elements which form certain scene. For landscape architecture and ecological landscape design, it is a good opportunity to offer thermal performances of landscape elements, especially those of urban open spaces in the context of human comfort and amenity of landscapes.

CONCLUSION

Thermograph analysis shows the detailed judgement of the changing pattern of high and low surface temperature of landscape elements. Evaluating through the sequential pattern of thermographs makes it clear that a specific distribution pattern of lower temperature of canopy's surfaces occupy large portion of scene in the tested scene at mid-day. This lower temperature is domain of vegetation, which the canopy of tulip trees showed the lowest surface temperature. On the other hand, the specific distribution of higher temperature was also examined. In this manner, concrete building occupied a large portion in the scene.

This evidence suggests to urban landscape planner and designer in arranging ideal proportion of landscape elements to meet with comfortness of landscape. This thermal stability of tree canopies against solar radiation in the landscape scene, indicates that, when they are introduced in a proper manner or in an apppropriate proportion in the scene, they act as thermal moderator of hard landscape elements created of concrete. The behavior of thermoscape of concrete building surface indicates the necessity on the consideration of "the building face direction"in order to reduce solar radiation interception, which a building acts as heated object in the landscape.

摘　要

本研究では景観構成要素である建物、樹木の樹冠、地被としての芝生、及び裸地を取り上げ、夏季における一定のシーン（視野の範囲で定まる画像フレーム）のなかでの表面の温熱状況の変化をサーモスケープ（温熱景）の変化として分析した。データーソースは赤外線放射カメラによって得られた熱画像（ビデオ信号）であり、解析にはパソコンの画像解析プログラムを用いた。コンクリート建物など各表面について、スポット測点の24時間の温度変化を調べるとともに、各表面の**等温度分布パターン**を解析した。

素材の違いによる等温度帯分布の特徴が著しく異なったが、植物表面は気温の変化に伴ってほぼそれと同じような変化を示した。コンクリート表面は日中と夜間の変化の幅が著しく大きかった。本研究の主題であるサーモスケープのパターン変化は、樹木のキャノピーと芝生表面では一日を通じて安定しており、コンクリート表面では日射を受ける面と受けない面の差が著しかった。シーンとして見ると、コンクリートで被覆された表面は相対的に高温度領域を占め続け、それに対して植物による相対的低温度領域の分布が対比的に現れ、サーモスケープのパターン変化の特徴が明らかになった。

REFERENCES

〔1〕Anonymous. (…) : Thermovision-450 Operating Manual. Agema lnfrared System.

〔2〕American Society of Landscape Architecture Foundation. (1977) : Landscape Planning for Energy Conservation. Environmental Design Press, Virginia.

〔3〕Givoni, B. (1976) : Man, Climate and Architecture. Applied Science Publ. Ltd., London. 340-372.

〔4〕Olgyay, V. (1963): Design with Climate, Bioclimatic Approach to Architectural Regionalism. Princeton Univ. Press, New Jersey. 14-23.

〔5〕Pichakum, N., Y. Maruta and S. Yanai (1993): An investigation on the distribu tion of air temperature and the effect of open
space to the urban temperature in Minburi District Bangkok.造園雑誌56(5), 325-330.

〔6〕Sampson, N. and T. Hamilton (1992) :Can trees really help fight global warming ? Amer. Forest May／June, 13-16.

〔7〕Semrau, A. (1992) : Introducing cool communities. Amer. Forest July／Aug.: 49-52.

〔8〕Vlavin, C. (1990) Slowing global warming. Amer. Forest May／June, 37-44.

〔9〕Yamada, H. (1993): Study on the distribu tion of air temperature in Kurikashi, Saitama Prefecture and the effect of open space on the urban climate in summer days. 造園雑誌 56(5), 331-336.

〔10〕石田 信男 他 (1990):光水風緑土の設計作法・ディテール105, 65-96.

〔11〕田中 謙次 他 (1992): 住宅の熱・ディテール 112, 57-88.

〔12〕日本流体力学会 (1992): 地球環境と流体力学・朝倉書店.