FIELD STUDY OF EFFECT OF STREET AND ITS TREES ON THERMAL ENVIRONMENT OF SIDEWALKS

街路形態及び歩道樹が歩道に及ぼす熱的影響に関する実測研究

Weijun GAO*, Hirokatsu SUGIYAMA* and Toshio OJIMA**

高 偉俊, 杉山寛克, 尾島俊雄

In this study, the effect of the street and its trees on the sidewalk thermal environment has been examined by carrying out the summer and winter measurements in the four types of the urban canyon. The results can be concluded as follows,

1) The structure of the street affects its environment significantly. The winter result has shown that the wider the street is, the higher air temperature is during the day.
2) The air temperature during the night is mainly affected by the skyview factors. The narrower street results in a relatively higher air temperature than the wider street.
3) From the summer result, the street trees have a significant effect on the sidewalk thermal environment. The air temperature decreased with the amount of the street trees planted.
4) The air temperature has a close relation with the sidewalk surface temperature. The lower surface temperature, the lower air temperature.

Keywords: Street structure, Street trees, Thermal environment, Field study

街路形態、歩道樹、熱環境、実測

1. Introduction

High density land use in many parts of the cities has caused an uncomfortable environment to pedestrians on the street. High buildings built along the streets prevent direct sunlight especially in winter when desired. On the other hand, wider streets receive sunshine during summer even though shading is desired to improve the human comfort. In addition, the air temperature in the urban becomes much higher during the day due to increase of artificial surface such as concrete or asphalt and artificial heat release. In order to improve the urban thermal environment, a lot of methods have been developed. One of those is to introduce the green plant to the urban canyon to provide pedestrians with a shading in summer and enough sunlight in winter. The thermal environment in the urban canyon is determined by its physical nature such as height of buildings and width of the street. The shading effect of the street trees can be expected to mitigate the canyon environment in summer to some extent. Therefore, the intention in this study is to examine the influence of the urban canyon structure and the street trees on the sidewalks environment.

Although numerous studies have been carried out over the years which deal with the urban canyon environment by using the numerical methods1,2,3,4), some field studies has also been carried out to emphasize on the energy balance in the urban canyon5,6,7,8). Nakamura6) and Yoshida7) attempted to explain the heat transfer mechanism of the urban canyon based on measurements in Kyoto. Miura8) examined the thermal environment in the exterior space. Katayama9) tried to examine the

* Graduate Student, Dept. of Architecture, School of Science and Engineering, Waseda University
** Prof., Dept. of Architecture, School of Science and Engineering, Waseda University, Dr. Eng.
influence of solar shading by single tree in the urban canyon. Although some field studies\textsuperscript{10,11} included the effect of the street trees, all those field studies were investigated in summer.

In this research, in order to have a deep understanding of the urban canyon environment, the different urban structures with or without the trees have been selected to examine the effect of those factors on the pedestrian environment of the urban canyon in the different season. The results have shown the urban structure affected the urban canyon environment significantly in both summer and winter and the street trees could mitigate the environment to some extent.

2. Measurement sites and procedures

The field study was initiated in an effort to clarify the effects of canyon structure and street trees on the thermal environment of the sidewalks in different seasons. In order to reflect this object, the four sites with the different structures, situated in a high-dense area mixed with residential and office buildings were selected as the measurement sites, all in Shinjuku Ward, Tokyo, located around the Okubo campus of Waseda University shown in figure 1.

The cross-sections of the canyon structure have been illustrated in figure 1. Point A is along Meiji street (north-south oriented) with trees planted...
with approximately 10m intervals. The road width, east wall height and west wall height are 30m, 6m and 31m respectively. The rest of the points are located in the east-west orientation. Point B represents the narrower urban canyon without trees with road width 9m and both side wall heights about 12m. Point C has been designated as a green road with trees planted continuously along both sidewalks and also at the center of the street. The road width, east wall height and west wall height are 25m, 12m and 12m respectively. Point D is along Suwa street with trees planted continuously along both sidewalks with road width 21m and two side wall heights about 7m and 12m respectively. All the trees belong to deciduous plants.

The measurement was conducted in summer and winter. The effect of the canyon structure has been examined in the winter measurement when there is no influence of tree. The effect of the street tree has been examined in the summer measurement. Each observation was continued for 24 hours on August 23-24, 1993, and February 23-24, 1994. The variables monitored were air temperature, surface temperature, relative humidity, wind velocity by using amsmann hygrometer, anemosystem, and infrared thermometer. A moving measurement was carried out to cover four sites within about 20-25 minutes. The time spent in the observation at each point was about 5-6 minutes. The height of measurement was 1.2m from the ground surface to reflect the environment near the human being. All the sites are located on the sidewalks with the ground surface covered with asphalt. The measurement points were designated in the north side of the streets for point B, C, D and in the west side of the street for point A. The sidewalk surface, wall surface temperature were measured by the infrared thermometer.

On the surveyed days, fish-eye lens photographs were taken along the selected sidewalks which were shown in figure. The sky view factors are about 48%, 46%, 43% and 65% for point A, B, C, and D in winter and about 35%, 43%, 21% and 57% for point A, B, C, and D in summer respectively. The decrease of sky view factors in summer is due to the effect of the trees.

If the structure of the street might be represented by the ratio H/W of the average height H of both side walls to the road width W, point B should be the narrowest street with H/W 1.33 and point C should be the widest street with H/W 0.48. The ratio H/W at point A, D are 0.62 and 0.52 respectively.

| Table 1 Characteristics of the measurement site |
|-----------------|-----------------|-----------------|-----------------|
| point            | street          | H/W             | sky view factor |
| A                | north-south     | 0.62            | 48%            | 35%             |
| B                | east-west       | 1.33            | 46%            | 43%             |
| C                | east-west       | 0.48            | 43%            | 21%             |
| D                | east-west       | 0.52            | 65%            | 57%             |

3. Results of measurements
3-1. Results of measurements in winter
(1) Climate condition
The climate condition measured at Tokyo Meteorological Agency 5km east from the measurement site was a sunny winter day shown in figure 2. The air temperature was 10.8°C at the maximum and 2.0°C at the minimum. The average value of relative humidity is 31%. The wind velocity varied within 1.7-10.5 m/s which was measured at height about 74m in Tokyo Meteorological Agency. The wind direction is generally north-west during the investigated day. The total value of solar radiation was 3.9 Mcal/m²/day (16.5MJ/m² day).

![Figure 2 Climate in winter](image)

(2) Air temperature

Air temperatures of the four sites have been shown in figure 3. The diurnal air temperature
at point D which represent a wide street in east-west orientation was 12.5°C at the maximum relatively higher especially during the peak period, while point B with narrow width of the urban canyon showed the lowest air temperature about 10.5°C at the maximum. However air temperature difference among the measured sites tends to be reverse during night. The nocturnal air temperature at point B was generally higher than other points besides point A. The reason may be explained by that the point B with a relatively lower sky view factor radiates fewer long-wave radiation heat to sky in night of winter than the other points.

In addition, the difference of the maximum temperature between point C and D can also be explained by the difference of the sky view factors. Although the street trees at point C are leafless in winter, amount of tree branches at point C is larger than point D and may intercept the incoming of radiation around the diurnal peak period, which showed a lower sky view factor about 43% at point C than the point D about 65%. In the figure 4, the net solar radiation gain Note1 has been calculated for the same orientation points B, C, and D. From the results, point D has the highest value of the solar radiation gain. Point B has the lowest solar radiation gain to result in a lower air temperature than the other points.

Point A represents the north-south orientation street. Although the maximum air temperature at point A was lower than that at point D with the similar width of urban canyon, the average air temperature was higher than that at point D. For the north-south street, the west wall receives the solar radiation before noon and the opposite wall(east) receives the solar radiation after noon. For the east-west orientation street, the north wall receives the direct solar radiation during the day. As authors12) have stated, the north-south street receives more solar radiation than the east-west street when the street structures are the same. It may be said that the more solar radiation in the day is absorbed, the higher the daily average air temperature is.

---

---

---
(3) Surface temperature

The temperature of sidewalk surfaces has been illustrated in figure 5. The surface temperature at point D were 24°C at the maximum and 10°C at the average. Although the diurnal peak value of point C and point D happened around 13 o'clock, one hour time lag was seen at point B. However nocturnal temperature differences become smaller by about 2°C. The minimum sidewalk surface temperature was -1.5°C at point B, which may deduced that although the point B absorbed fewer solar radiation than the other points, the sky view factor is almost the same as the point A and C. Point A reached at the maximum value of surface temperature at about 12:00 and keep a lower surface temperature in afternoon because point A only received direct radiation before the noon.

In the east-west orientation streets, the wall surface temperatures have been displayed in figure 6 and figure 7. Generally speaking, the north wall in the east-west orientation showed a higher surface temperature than the south wall. The difference of the surface temperatures was mainly observed in the day when the sun was shining. For the south wall which hardly received the direct solar radiation, the hourly difference was smaller and point D with most high sky view factor showed the most lower surface temperature in the night. For north wall, however, point B showed the lowest surface temperature because solar radiation absorption was obstructed by the narrower structure with H/W 1.33.

(4) Relative humidity

Results of relative humidity are illustrated in figure 8. It shows that relative humidity decreases in the afternoon and rises during midnight. Noticeable differences between locations were not observed with the average value of 29%.

(5) Wind velocity

Figure 9 shows the daily variation of wind velocity measured by using the average value in one minute. Point D of relatively wide street showed a lower wind velocity and had average value about 1.1m/s. Point B which represents a narrow street displayed a higher wind velocity. Point C also showed a high wind velocity.
Figure 8 Daily variation of relative humidity in winter

Figure 9 Daily variation of wind velocity in winter

Figure 10 Climate in winter

because the trees at the center of the street may disturb the air flow and show a lower effective section area which may accelerate the air flow.

3-2. Results of measurements in summer

(1)Climate condition

The day of field study was a summer day with some cloud during 10-12 o'clock. According to the record of the Tokyo Meteorological Agency, the air temperature was 32.3°C at the maximum and 25.2°C at the minimum shown in figure 10. The average value of relative humidity was 73%. The wind velocity varied within 1.8-6.0 m/s and the wind direction was south or south-west. The total value of solar radiation was 3.6MJ/m² day (14.9MJ/m² day).

(2) Air temperature

Air temperatures of the four sites in summer have been shown in figure 11. In the summer, the highest value of the air temperature happened at point B with maximum, average and minimum, about 33.5°C, 29.3°C and 25.5°C respectively. The air temperature at point A showed the same change as that at point B, where point A is the wider street with street trees at 10m interval on the north-south orientation and point B is the narrower street without the street trees with the east-west orientation. The air temperatures at point C, D were

<table>
<thead>
<tr>
<th>variables</th>
<th>max.</th>
<th>min.</th>
<th>avg.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Point A</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Air temp.[°C]</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Surface temp.[°C]</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wind velocity[m/s]</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Relative humidity [%]</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Point B</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Air temp.[°C]</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Surface temp.[°C]</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wind velocity[m/s]</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Relative humidity [%]</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Point C</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Air temp.[°C]</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Surface temp.[°C]</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wind velocity[m/s]</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Relative humidity [%]</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Point D</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Air temp.[°C]</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Surface temp.[°C]</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wind velocity[m/s]</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Relative humidity [%]</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Figure 11 Daily variation of air temperature in summer

Figure 12 Daily variation of sidewalk surface temperature in summer

Figure 13 Daily variation of relative humidity in summer

Figure 14 Daily variation of wind velocity in summer

lower than that in point B by 0.6-0.7 °C at the average and 1.7-2.7°C at the maximum. The reason may be deduced to the shading effect of the street trees. However, there was almost no difference of air temperature among the surveyed points during the night because all the points had the similar sky view factors.

(3) Surface temperature
Surface temperature at sidewalk surface has been illustrated in figure 12. From the figure, it was clear that the trees had a significant effect on the sidewalk surface temperature especially when the whole canyon was obstructed by trees such as point C by a decrease of the maximum sidewalk surface temperature about 15°C. The average temperature of sidewalk surface in the urban canyon with the trees is generally about 5°C lower than that in the urban canyon without the trees.

(4) Relative humidity
Relative humidity has been displayed in figure 13. Although there was no evident difference between all the cases, the average relative humidity in point C, D with the street trees was slightly higher than that of point B because there are green plants.

(5) Wind velocity
The daily variation of wind velocity was shown in figure 14. As same as discussed in winter, point B showed a higher velocity than other points. Point A, C and D with the same average structure H/W presented the same average wind velocity with about 0.95 m/s. The average value of wind velocity at point B was 1.62 m/s.
4. Discussion

4-1. Air temperature and surface temperature

The relations between air temperature and sidewalk surface temperature have been illustrated in figure 15. Results from both seasons showed a relatively high correlation ratio at 0.95. And for each point there is about 0.97 regression coefficient in the different seasons. At the point B, the regression lines have the same slope for both season. In the winter, the wider streets have the fairly lower slopes, which mean the higher surface temperatures match the lower air temperature. The reason may be explained by that although the surface temperature becomes higher when the solar radiation is absorbed, the air temperature also is controlled by the ambient air flow and is not soon increased by the surface temperature. In summer, the higher slope of regression lines at point C and D is observed. Although they have a lower road surface temperature, the air temperature is still higher than that predicted by the regression analysis. The lower road surface temperature is because of the effect of the street trees. The air temperature, however, is also affected by the ambient air flow with a relative higher temperature.

4-2. Air temperature and canyon structure

Relations between air temperature and canyon structure have been investigated between point B and point C, D by using the winter data when there is no leaf of trees in the street. The results indicate that air temperature in the wider streets such as at point C, D(H/W=0.48 and 0.52 respectively) is higher than in the narrow street such as at point B(H/W=1.33) during the day because the wide street absorbs much more solar radiation than the narrow street. As shown in figure 16, the maximum difference of air temperature with a comparison to point B was 1.1°C at point C and 2.7°C at point D. However at night, air temperature at point C and D is about 1°C lower than that at point B in the maximum. This phenomenon can be explained by that wider street receives much more solar radiation than narrower street during the day and releases much more long wave radiation than narrower street during night.
4-3. Cooling effect by street trees

As was reported by Sugiyama\textsuperscript{13}, the air temperature can be lowered to some extent in summer by planting the street trees. The effect of street trees on the air temperature was shown in figure 17. The results indicate that decrease of air temperature at point C, D during the day were about 1.7-2°C in maximum higher than that at point B. It can be said that the street trees have a cooling effect to the thermal environment during the day.

During the night, point C is the same or a little higher than point B. This could be explained because the site is covered by street trees with a lower sky view factor which obstructs more long-wave radiation to sky at night. At point D, the higher sky view factor about 57\% has been reached in spite of the shading of the street trees. Therefore, a relative lower air temperature has been observed than that of point B with sky view factor about 43\%.

5. Conclusions

In this study, the relation of the street and its trees with its sidewalk thermal environment has been examined by carrying out the summer and winter measurements in the four types of the urban canyon. The results can be concluded as follows,

(1) The structure of the street affects its environment significantly. From the winter result, it may be said that the wider the street is, the higher air temperature is during the day because of larger solar radiation absorption on the urban canyon surface.

(2) The air temperature during the night is mainly affected by the sky view factors. The narrower streets results in a relatively higher air temperature than the wider street.

(3) From the summer result, the street trees have a significant effect on the sidewalk thermal environment. The air temperature decreased with the amount of the street trees planted. Therefore, the green plant can mitigate the thermal environment with the decrease of maximum air temperature about 2°C.

(4) The air temperature has a close relation with the sidewalk surface temperature. The lower surface temperature, the lower air temperature. On the other hand, the street trees affect the sidewalk surface temperature greatly. Therefore, the mitigating effect of the street trees may be mainly expressed by decreasing the surface temperature in the urban canyon and then results in a lower air temperature.

Acknowledgment

The author would like to express gratitude to Professor Nobuyuki Takahashi, Advanced Center for Science and Engineering Research, Waseda University and Professor Masao Miura, Shibaura Institute of Technology for their suggestive advice. Thanks are also extended to Dr. Kimiya Murakami for his perpetual encouragement.

Note: The solar radiation can be divided into the direct solar radiation and sky solar radiation. The direct and sky solar radiation on a considered surface are assumed as $I_{diff}$ and $I_{dif}$ respectively. The shading effect of the urban canyon walls from the direct solar radiation gain can be calculated by introducing a ratio of solar radiation absorbed in each wall or road surface which is called as sunlit area factor $r$. The sunlit area factor $r$ is defined by,

\[ r = \frac{\text{sunlit area of each wall or road surface} (m^2)}{\text{The total area of each wall or road surface} (m^2)} \]

Therefore, the calculation become to compute the sunlit area on each wall or road surface. A example for east-west oriented canyon has been given as below,

Here the following factors have been assumed,

- $\phi$ = Solar altitude
- $r_1$, $r_2$ and $r_3$ = sunlit area factor for $H_1$, $D$, $H_2$ surface
- $H_1$ and $H_2$ = the building height of the canyon walls
- $D$ = the street width

$F_1, F_2, F_3$ = area of the both wall and road surface

\[ F = \text{area of the both wall and road surface} \]

![Figure 18 Sunlit area calculation](attachment:image)

if $\phi > \arctan(H_2/D)$ then

\[ r_1 = 1; \quad r_2 = (D-H_2/\tan \phi)/D; \quad r_3 = 0 \]

if $H_2 > H_1$, $\phi < \arctan(H_2/D)$ and $\phi > \arctan((H_2-H_1)/D)$ then

\[ r_1 = (D \tan \phi - H_2 + H_1)/H_1; \quad r_2 = 0; \quad r_3 = 0 \]
if H2 < H1, \( \phi = \arctan(H2/D) \) and \( \phi = \arctan((H1-H2)/D) \) then

\[ r1 = (D \tan \phi + H1-H2)/H1: r2=0; r3=0 \]

if H2 > H1, \( \phi = \arctan(H2/D) \) and \( \phi = \arctan((H1-H2)/D) \) then

\[ r1 = D \tan \phi : r2=0; r3=0 \]

The solar radiation gain due to sky radiation can be estimated by the view factor. The view factor \( \phi \) is calculated by:

View factor for road surface D
\( \phi = \frac{\pi - 2 \arctan(H1/D) - 2 \arctan(H2/D))}{\pi} \)

View factor of wall surface H1
\( \phi = \frac{\pi - 2 \arctan(D/2)}{\pi} \)

View factor of wall surface H2
\( \phi = \frac{\pi - 2 \arctan(H1/D)}{\pi} \)

Therefore the solar radiation gain (SRG) in the urban canyon can be calculated by the following equation,

\[ \text{SRG} = \sum (r_l d_l + \phi ) I_{dl}/F_l \]

References


和文要約

1. 概要
多くの都市における高密度な土地利用は路上の歩行者にとって不快な環境を作り出している。沿道に建てられた高い建物は冬には日射を遮断し、逆に夏の広い街道で必要以上に日射を取得している。加えて、都市ではコンクリートやアスファルトでの土地被覆の変化や人工排熱の増加により気温が高くなる。これらの都市の熱環境を改善するために様々な手法が考えられているが、街路樹を導入することが最も一般的に試みられている。特に冬の日射取得を妨げずに夏の日射遮蔽をもたらす街路樹の影響を街路の形態との関係を踏まえて把握することは歩行者の快適性を向上させるために重要である。

そこで天气の季節において街路の形態と街路樹の有無による影響評価を行った結果、街路の形態が夏冬ともに大きく影響を及ぼしている一方で、街路樹は夏の熱環境緩和に効果的であることを示した。

2. 実測方法
本研究では、街路の形態と街路樹が街道上の熱環境に及ぼす影響を夏と冬、24時間に渡って実測調査を行った。実測地点は図1に示す東京都新宿区の早稲田大学大久保キャンパス周辺の4地点。地点Aは南北街道で街路樹が約10m間隔にある。地点B、C、Dは東西街道上に位置し、地点Bは街路樹のない狭い街道、地点Cは緑化道路で両側の歩道沿いと道路中央に街路樹の樹冠が連続している。地点Dは道路の両側に街路樹の樹冠が連続している。実測地点Aは西側街道、地点B、C、Dは北側街道上に位置し、路面の素材はアスファルトであった。
実測は1993年8月23日～24日、1994年2月23日～24日、各地点は共通して地上1.2mの高さにおいて移動計測によって気温、湿度、風速、歩道の表面温度、壁面温度をアスマン乾湿計、熱線式風速計、赤外線放射温度計を用いて測定した。所定時は24時間を通じて各々20～25分であった。

3・実測結果
3-1. 冬の実測結果
図3に気温の日変化を示す。東西方向の広い街路にある地点Dが日中最も高く最高気温は12.5℃であった。一方で、狭い街路にある地点Bが一番低く、最高気温は10.5℃であった。しかししながら夜間では地点Bが地点Aを除いてよくなる傾向を示した。これは地点Bの夜間が低いことから夜間の放射冷却が抑えられているためと考えられる。また地点Cと地点Dの最高気温の差は温度計に起因している。図4では東西方向の差異を示す地点B、C、DにてはB下射が計算した。これより室温のB下射よりも高く、地点Bが最も少ない。つまり地点Bが他の地点と比べて気温が変わるのは、取得するB下射が少ないからである。また同じ幅員の街路両方の異なる地点Aと地点Dを比較すると最高気温では地点Dの方が高いにもかかわらず、平均気温でみると地点Aの方が高い。これは日中を通じて南北街路の方が東西街路より日射を多く受けていることが日平均気温の上昇につながっていると思われた。

図5は昼の表面温度を示す。最高気温は地点Dで24℃、最低気温は地点Bで12℃であった。日中は地点間の温度差が大きいが、夜間にはその差は縮小した。日中の最高気温は地点Cと地点Dでは13時付近で安定されたが、地点Bとは1時間の差があった。また地点Aでは直射日射を午前中に入射していったために最高気温は12時付近でみられた。

図6と図7には東西街路の壁面温度を示す。表面温度差は日中において顕著にみられ、直射日射をほとんど受けない南壁では温度差は小さく、天空率の最も低い地点Dが夜間において壁面温度が最も低くなった。しかしながら、北壁については地点BはH/W1.33で狭い街路であることから日射が遮断され最も低い壁面温度を示した。

図8は気温の日変化を示す。温度は午後低くなり、夜間に上昇する傾向がみられたが、地点間の差は認められなかった。

図9は風速の日変化を示す。地点Dのような広い街路では風速が増えるような傾向がみられた。一方では地点Bのような狭い街路では風速が強くなる傾向がみられた。

3-2. 夏の実測結果
気温の日変化を図11に示す。夏には地点Bが日中に通して気温が高く、地点Aと同様の変化を示す。これに対し、地点C、Dは平均気温で60℃以上、最高気温で17.2℃低くなり、街路樹の日射遮蔽により、気温を緩和する効果が認められる。

図12は歩道上の表面温度の日変化を示す。街路樹によって覆われている地点Cは他の地点と比較して最高で約15℃低い。また、平均でみると街路樹のある地点の表面温度の方が街路樹のない地点と比較して約5℃低くなる。温度の日変化を図13に示す。街路樹のある地点C、Dは街路樹のない地点Bと比較して僅かながら温度が高くなる傾向がみられた。

図14には風速の日変化を示す。冬と同様に地点Bは他の地点と比較して風速が最も強くなる傾向にあった。

4. 考察
図15は気温と歩道の表面温度間の関係を示す。冬と冬の結果は、街路空間の気温が街路の表面温度と高い相関関係にある。

気温と街路樹の影響の関係については冬のデータを用いて、地点Bと地点C、Dの間で検討した。その結果、図16に示すように日中は地点C、Dが地点Bに比べて気温が高くなるが、夜間にはむしろ地点C、Dが地点Bに比べて気温が低くなった。これは街路樹が日中は日射を多く遮蔽するが、逆に夜間には狭い街路に比べて放射冷却が大きくないことを示している。

図17は街路樹の気温に対する影響を示す。地点C、Dは地点Bに比べて最高で1.7℃から2℃低いが、街路樹は日射を遮蔽することにより、日中の熱環境を緩和する効果が明らかである。

一方で夜間には地点Cは地点Bとほぼもしかしは僅かながら気温が高い。これは地点Bが低い天空率にもかかわらず街路樹によって覆われ、夜間の放射冷却が抑えられていると考えられる。また地点Dは街路樹があるにもかかわらず、地点Bと比べて天空率が高いために気温が低く推移したとみられる。

5. 結論
本研究は街路樹と歩道上の熱環境との関係を夏と冬の実測調査により次のような成果を得た。
(1) 街路樹の影響について冬の結果を解析すると街路樹の幅員が広いほど取得する日射量が多くなり、日中の気温が高くなる。
(2) 夜間の気温は真に天空率によって影響され、狭い街路
ほど広い街路に比べて気温が僅かがら高くなる。
(3)夏の結果からは街路樹により最高気温が約2℃緩和
されることがわかった。つまり、街路樹の冠によって
気温は低下し、街路樹が歩道の熱環境の緩和に非常に
効果的であることが確かめられた。
(4)気温は歩道の表面温度と高い相関関係にあり、歩道の
表面温度が低くなると、気温も低くなる傾向であった。一方で
街路樹は歩道の表面温度に対して大きな影響を
及ぼしている。つまり街路樹の緩和効果は主に歩道の
表面温度の低下によって表れ、結果として気温の低下
につながっているといえる。

（1994年5月10日原稿受理、1994年12月22日採用決定）