Study of the Effects of a River on the Thermal Environment in an Urban Area

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ABSTRACT

This paper describes the results of field observations on the micro-climate in and around the Ota River flowing through Hiroshima City. At first, detailed measurements of temperature distribution within the river section were carried out along the bridge. Then, both the horizontal and vertical extent of a thermal river-effect were confirmed by moving observations along the streets crossing the river and by simultaneous balloon observations above the river and in the downtown area. In addition to these short-term observations on fine days, long-term temperature measurements were conducted at several stationary points in and around the river during 14 months.

The drop in air temperature above the river exceeds 5 °C on fine days in warmer seasons, and is proportional to the surface temperature difference between the river water and the asphalt pavement. These thermal effects were discernible at least a few hundreds meters horizontally and more than 80 m vertically. However, temperatures were also affected by the building density and wind direction and velocity.

Therefore, we intended to clarify the effects of rivers on the micro-climate in which a river influences the air temperature of the surrounding areas. In this paper, we show the results of observations on the micro-climate within and around the Ota river flowing through Hiroshima City where we have the six effluents of the Ota river in the urban area of the city. The six river effluents are called the Ota flood-channel, the Tenma, the Honkawa, the Motoyasu, the Kyobashi and the Enko coming from the west side.

2. OUTLINE OF THE OBSERVATIONS

Figure 1 shows the street map of Hiroshima City. In this area, we selected several stationary points to take measurements of

![Fig. 1. Measuring sites of each observation in Hiroshima City.](image)

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meteorological elements, for example, air temperature, humidity, wind direction and velocity, and so on.

The observations are grouped within four sections as follows.

(1) The temperatures of river sections along the bridges were measured as well as the surrounding areas of rivers and several stationary points. The selected sections of rivers were the Tsurumi bridge of the Kyobashi river, about 100 m wide, and the Mitaki bridge of the Ota flood-channel, about 270 m wide.

The observations were carried out once in each season at the Tsurumi bridge and in the spring and summer seasons at the Mitaki bridge. In each observation, we carried out the measurements during a 24-hour period from the early morning until the next morning as follows:

**Tsurumi bridge:**
- May 22 and 23, 1985
- August 2 and 3, 1985
- November 15 and 16, 1985
- January 14 and 15, 1986

**Mitaki bridge:**
- May 31, 1985
  - (ceased at 21:00 because of rain)
- July 30 and 31, 1985

Figure 2 shows the temperature-sensing unit used for this observation. A thermistor thermometer sensor (time constant = 0.7 s) was set in the ventilated double-cylinder shelter. For the measurement of temperature distributions within the river sections, the two sets of pole-equipped shelters (shown in Fig. 2) at several heights were used. One was used for the traverse measuring along the bridge, the other was used for the stationary measuring at the center of the bridge for time correction.

(2) Next, in order to make clear the extent of the influences of cooling from the river based on the above-mentioned results, we measured the horizontal distributions of temperatures at the selected three areas. These areas, A, B and C, are shown on the map of Fig. 1. The routes of measurement were selected from the differences of the river width, the road width and the building density. Areas A and B are located in the central area of town, but area C is some distance from the downtown area and has a district of low building density dotted with farming lands.

The measurements were carried out from noon to 22:00, on these days as follows,
- **Areas A and B:** July 27 and September 1, 1987
- **Areas A and C:** July 28 and September 2, 1987

(3) As to the following observation, we carried out the measurement of the vertical distributions of air temperature using the captive balloons at each point of the river and the downtown area to clarify the influence of the river on the vertical conditions of the micro-climate. The selected points are at the Tsurumi bridge mentioned above and at the small park of Fukuro-machi which is about 900 m from the bridge. The park is about 60 m × 60 m long, and surrounded by buildings of two or three stories on the north side and from four to six stories on the other three sides. The observation times were as follows.
  - From 05:00 on August 11 to 09:00 on August 13, 1986 (during 52 hours).
  - From 05:00 on June 14 to 05:00 on June 16, 1988 (during 49 hours).
  - From 05:00 on August 2 to 05:00 on August 4, 1988 (during 49 hours).

The measurements were taken up to a height of 80 m from the ground except the first time when they were taken up to 50 m high.

(4) The above-mentioned observations were only done for a short term in each season when it was usually fine weather. In order to make sure of the results in general and to get more data, we continuously took measure-

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**Fig. 2. Temperature sensing unit with ventilated double cylinder shelter (ventilation speed: 6 m/s).**
ments at the stationary nine points located at the bridge, the riverside and the downtown area. The term of measurement was during 14 months from July 1986 to August 1987. These results were analyzed with the meteorological elements which had been measured by the Hiroshima Meteorological Observatory.

3. RESULTS OF THE OBSERVATIONS AND ANALYSES

3.1. Distributions of temperature at the section within the river

Figure 3 shows the one example of the temperature distributions in daytime (14:00) and at nighttime (21:00) in the summer season at the section of the Mitaki bridge where the river has floodplains of about 60 m wide covered with grass and bare land on each bank.

In the daytime, the temperature distributions on the water body and on the floodplains show a very different contrast because of high temperatures on the surface of the floodplains. On the other hand, at nighttime, the large daytime temperature differences above the border of water and floodplains disappear and the distribution of temperature is almost uniform within the river. From Fig. 4, the daytime temperature differences between the floodplains and the water body are large as the measurement points get nearer to the surface. The solid lines of the same value show the ratio of the temperature difference between the city area and the same level from the water surface at the center of bridge. For example, the solid line of 0.5 value shows that the drop of temperature from the city area is half in comparison with the location of the center of the bridge. Being under the influence

Fig. 3. Typical temperature distributions within the river section at the Mitaki bridge on a fine summer day. (a) Daytime. (b) Nighttime. (The underlined values show the surface temperature at each point.)

Fig. 4. Averaged daytime air temperature distribution above the floodplain. The values are the ratio of the temperature difference from the city area to that at the center of bridge.
of a very high surface temperature of the bare ground, the effects of the water body on the micro-climate are reduced near the ground.

On the other hand, after 17:00, the air temperature differences between the floodplains and the water body disappear, and the mean temperature within the river is about 2 °C lower than the city area.

3.2. Horizontal influences of the river on the micro-climate

The measurement points in each route of areas A, B and C are shown in Fig. 5. The routes A1 and B1 have roads of 100 m wide with green belts, these are named the Heiwa Odori, which means Peace Boulevard. The routes A2 and B2 indicate roads 10 m wide bearing heavy traffic, and the routes A3 and B3 are 20 m wide but not having as much traffic as A2 and B2. Figure 6 shows the distributions of air temperature along each route of areas A, B and C. These results are shown as the mean values from 12:00 to 17:00. On this time zone, the surface temperature differences between the asphalt pavement and the river water are larger than 20 °C.

From these results on routes A1, A2 and A3, it can be mentioned that the most influenced area is route A1 which has the widest road among the three routes. But, the reasons for the inverse results between routes A2 and A3 are explained by the surrounding environment, because route A3 has the bank 4.3 m high and does not have a bridge across the river. The fall in temperature is relatively small in area B where the river width is narrow. On the east side of routes C1 and C3, there is a wider spread of temperature falls due to the influence of the river width, as compared to routes A1, A2 and A3. So, it appears that the influences of the river on the micro-climate are different with the width of river and road and the building density in surrounding area.

Figure 7 shows the relation between the surface temperature of the ground and the air temperature in each area. The horizontal axis shows the surface temperature difference between the asphalt pavement and the river water. The vertical axis shows the mean air temperature differences between the streets and the bridge, where the street temperatures, T(ü) and T(û) are shown as the average values calculated from all points in each area and in each street, respectively, over 250 m distance from the riverside. These points are indicated by asterisks on the map. From these figures, it can be pointed out that the air temperature differences between the streets and the river depend on the surface temperature at each point. On the gradients of regression equations in Fig. 7, area C is larger than A and A is larger than B, and also route A2 is larger than A3, and A3 is larger than A1. Therefore, it can be mentioned that the drop of relative temperature between the streets and the river is large as the river is wider or the building density is lower or the road is narrower.

Furthermore, we analyzed the influenced areas of cooler temperature along the streets from the riversides in each route. As one example, Fig. 8 shows the differences between the temperatures of each point and the mean temperatures of the street, T(ü). The curved line in Fig. 8 shows the estimated distribution of the temperature which is calculated from the regression equation. This relation can be shown as the approximate equation by the following expression.

\[ Y = b \times \exp(a \times X) \]

where

- \( Y \) = the difference of temperature (°C)
- \( X \) = the distance from a river side (m)
- \( a \) and \( b \) = coefficients
Fig. 6. Averaged daytime air temperature distributions along each street.

Fig. 7. Relations between the air temperature drop at the bridge and the surface temperature difference. $T(B)$, $T(\bar{u})$ are the air temperatures at the bridge and averaged city area temperature, and $T_s(A)$ and $T_s(W)$ are the surface temperatures of the asphalt pavement and the water body of the river, respectively.

Fig. 8. Change of the air temperature differences from averaged city temperature due to the distance from riverside, and an example of fitting in an exponential curve.

Figure 9 shows the estimated distribution curves of the temperatures on each route. These relations were analyzed under the conditions of the wind directions. In this case, the direction of the river is a standard against which we define the two wind directions blowing to the measurement points from the river and the city area, which are named “the river wind” and “the city wind” respectively.

The temperature differences at the river sides, $X = 0$, are shown with almost the same values on every route except routes A3 and
Fig. 9. Estimated daytime temperature distribution curves in each route. The upper graphs indicate the condition of “River-wind” (the sea-breeze contains the component from the river to the city, including the parallel condition); the lower graphs indicate the condition of “City-wind” (the sea-breeze contains the component from the city to the river).

C3. These differences of temperature on routes A3 and C3 are smaller than the other routes, because both routes are surrounded with banks 4.3 m high. Here, we will consider the distance from the riverside instead of “the bank’s effects”. If these curves are shifted in the X-axis direction as the riverside temperature differences correspond to those of the other routes, the transferred distance will be about 70 m in each route. These shifted curves are shown in Fig. 9 as routes A3’ and C3’. It means that the bank has the equivalent effect at 70 m distance from the riverside. The distance will be about 25 times as large as the height of the bank including the measurement height of 1.5 m.

On the influences of wind direction, a comparison of the temperature distribution with “the river wind” and “the city wind” in each route A1, A2 and A3 is shown in Fig. 10. The area affected by the river wind is spread wider than the city wind. So, it can be said that the influences of wind direction are large as both streets and rivers are wider.

3.3. Vertical influences of the river on the micro-climate

Figure 11 shows the vertical distributions of air temperature difference between the Fukuro-machi park and the Tsurumi bridge. The horizontal axis shows the time of the observation term, two days, and the vertical axis shows the height from the ground. The large air temperature difference appears up to 20 m high during the time zone from about 10:00 to 16:00. The maximum value of the difference is about 3.5 °C near the ground. The air temperature differences between the two points are influenced not only by the surface temperature of the ground and the water body.
but also by the wind velocity. When the wind is weak, large influences appear in the spaces up to 20 m high which are surrounded by buildings. And also, the influences are spread to the upper spaces more so in the summer than in the spring.

Figure 12, based on measurements in the summer of 1986, shows the relation between the wind velocity at 1.5 m high of the Tsurumi bridge and the temperature difference at each height at the two points as a ratio of the temperature difference at 0.3 m high. The samples for analyses were chosen when the wind velocity was faster than 2.0 m/s at Tsurumi bridge and the surface temperature difference was larger than 20 °C between the two areas.

Figure 13 shows the vertical distributions of the temperature differences between the two points in the cases of 2 m/s and 5 m/s at Tsurumi bridge. These values were calculated by the regression equations obtained from Fig. 12. From these results, in the case of 2 m/s, the differences of temperature between the two points are almost the same up to 10 m high. But in the case of 5 m/s, the influence of surface temperature is reduced at the higher spaces, and the difference is reduced considerably within a height of about one meter.
3.4. Results of long-term observations

The nine stationary points are shown in Fig. 14. These points are selected from various areas including a bridge, riversides and streets within Hiroshima City.

As one example of the measurement results, the differences of mean temperature during the time zone from 12:00 to 14:00 between the Tsurumi bridge and street G and the riverside I are shown in Fig. 15 for each condition of the weather. In the case of point I, the air temperature differences and the fluctuations of the value are small. But, in the case of point G, the differences of air temperature show a value of about 5 °C on a cloudless day in the spring and summer.

The change of temperature differences due to the wind velocity on the cloudless days in the summer are shown in Fig. 16. For these analyses, we used the mean wind velocity during the time zone from 12:00 to 14:00. From these results, it was found that the temperature differences between bridge A and point G

![Fig. 12. Effects of wind velocity on the air temperature difference between two sites at each height. The values of the vertical axis give the ratio of the temperature differences at each height to that at 0.3 m height.](image)

![Fig. 13. Change of vertical distributions of temperature difference between two sites due to wind velocity.](image)

![Fig. 14. The locations of stationary points for long-term observation.](image)

![Fig. 15. Annual variation of daytime temperature differences from the Tsurumi bridge (Point A), in the upper graph at the riverside (point I), in the lower graph in the built-up area (point G).](image)
are small as the wind velocity is faster. On the other hand, the temperature difference between bridge A and point I are almost constant in spite of the wind velocity.

4. CONCLUSIONS

We could clarify the influences of a river on the micro-climate in an urban area from the results of observations about the distributions of temperature at sections of the rivers and at the horizontal and vertical spaces around the rivers.

The water body of the river operates as the cooling source in summer on the micro-climate of the surrounding area. If we compare the air temperature between the river and the city area, the difference is about 3~5 °C on a fine day because the surface temperature of a paved road with asphalt rises very high as it absorbs solar radiation.

When the effects of cooling sources appear around the area of the river, the air temperature differences between the bridge and the city area are in proportion to the surface temperature differences between the water body and the ground, and there is also the influence of winds.

Concerning the effects of the river as a cooling source, cooler temperatures are more widely spread when the density of buildings is lower and both streets and rivers are wider.

So, in conclusion, we suggest when building a house in the hotter climates of Japan, it is better to consider the location and design of the house in order to benefit from cooling breezes from the direction of the river.