Spatial Structure of City Blocks with Vacant Lands in Edo, Early Modern Tokyo - Introducing the Appropriate Wind into Outdoor Living Spaces –

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ABSTRACT

One of the main factors of urban heat island phenomena is surface temperature, and surface temperature is mainly affected by spatial geometry and material of cities. The townsmen’s areas in the city of Edo, early modern Tokyo, were totally different from the present day metropolis in these factors. A series of papers evaluated the summer thermal environment of these townsmen areas using numerical simulation, in order to acquire knowledge for designing an environmentally symbiotic city in Asia. In the previous paper, summer surface temperature and sensible heat flux from surface in a typical Machiyashiki (= city block) was evaluated using numerical simulation. The following result was obtained; the nighttime heat flux was negative, indicating that the townsmen residential areas in Edo were never subject to the nighttime heat island phenomenon. Although the residential areas were notorious for their densely populated and low-rise wooden buildings, some vacant lands were scattered in Machiyashiki temporarily, according to historical materials. In this paper, summer thermal and wind environment in several city blocks with vacant lands, located next to the previous target site, was calculated using coupled analysis of heat balance and airflow, concerning the influence of south wind from the bay. The result showed that, in outdoor living spaces, people could attain moderate wind, which was blowing down to the south-north alley through vacant lands and gardens, in the evening. From this, it was confirmed that some vacant lands and spatial structure of Machiyashiki in Edo made it possible to introduce the appropriate wind into outdoor living spaces under the comfort thermal radiant environment on a specified time section. The daily changes of sensible heat flux from surface in several city blocks were also calculated, and the result showed that these vacant lands had effect on reducing daytime heat island phenomena.

1. INTRODUCTION

The urban heat island phenomenon has become a serious modern-day problem. Surface temperature is one of the main factors that determine this phenomenon, and mainly affected by spatial geometry and building materials used in urban areas. The city of Edo was a metropolis that existed from the 1790s to the 1860s, after which it was renamed as Tokyo. The urban residential areas in Edo differed greatly from those in present-day Tokyo in terms of their spatial geometry and building materials. The objective of this study was to acquire a fundamental understanding of how to design a better summer thermal environment based on the Edo townsmen areas for an environmentally symbiotic city in Asia.

In previous studies [1], [2], the summer surface temperature of Machiyashiki (city block) in Edo...
The nighttime heat flux load was lower, indicating that the townsmen residential areas in Edo were never subject to the heat island phenomenon. Although the Edo townsmen residential areas were notorious for their densely populated and low-rise wooden buildings, some vacant lands were scattered in Machiyashiki temporarily because of frequent fires, according to historical materials (Fig. 1). In addition to the constant south wind from the bay, these vacant lands might have affected the thermal and wind environment of outdoor living spaces in these city blocks. In this study, the summer thermal and wind environment in several Machiyashiki was calculated using the coupled analysis of heat balance and airflow. The influence of vacant land in city blocks was also evaluated.

2. SELECTING MODELS AND ARRANGING INFORMATION FOR SIMULATION

2-1. Selecting Simulation Models

To reproduce the thermal and wind environment in outdoor living areas, the reproduction model calculated three components: the distribution of (1) wind velocity, (2) surface temperature, and (3) air temperature. For complicated spatial structures in Machiyashiki, the coupled analysis of heat balance and airflow, proposed by Hoyano (2007) [4], was suited for this study. This analysis consisted of two simulation models: a 3D-CAD-based thermal simulation tool [3] and generalized CFD software (STREAM). The 3D-CAD-based thermal simulation tool could calculate the detailed distribution of the surface temperature in consideration of the airflow distribution. The turbulence model used in the generalized CFD software carried out a steady-state analysis in a high Re $k-\varepsilon$ turbulence model, which had enough precision on account of the average airflow in Edo Machiyashiki. In this method, the output condition of one simulation model is made the input condition of the other model until the calculation converges with sufficient precision.

2-2. Arranging Information for the Coupled Analysis

According to the proposed method [4], the necessary and sufficient information for the coupled analysis was arranged and the information was classified as known and unknown. The insufficient information for the coupled analysis, especially related to CFD, was identified (Table 1). In this section, this unknown information is presented as obtained from previous studies and historical materials.

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Figure 1. Spatial composition of the Target Area and Major Outdoor Living Area
### 2-2-1. Signboards in the Streets

Ito (2003) [5] classified the placement and frequency of different objects in the arterial streets of the Edo townsmen area from the pictures in *Kidai-Shoran* [6]. Based on this study, the objects were classified into six groups from a total of 89 townhouses and three signboards were selected as having a high number. In this study, eaves, signboards, and standing signboards were selected as located signboards (Fig. 2). The size of the signboards was set as 1212 mm depending on *Edofuina-Ehonfuzokuourai* [7], which describes the life and customs of townsmen in Edo.

#### Species

<table>
<thead>
<tr>
<th>Species (%)</th>
<th>Eaves signboard (22%)</th>
<th>Standing signboard (13%)</th>
<th>Located signboard (9%)</th>
<th>Roof signboard (5%)</th>
<th>Head-on signboard (3%)</th>
<th>Leaning signboard (1%)</th>
<th>Without signboard (47%)</th>
</tr>
</thead>
</table>

### 2-2-2. Ground Covers in Vacant Lands

According to Ito (1986) [8], vacant lands in the city blocks were used as drying areas, scrapyards, or open space. In areas where it was hard to identify the things placed in the field, the use for vacant lands was classified as open space. Based on previous studies in weed science [9] and the summer weather on a particular day [1], it was determined that the vacant lands were covered in weeds. In this study, vacant lands were classified as open space with green fields.
2-2-3. Greens in the Townhouse Garden

*Kaso-sho*, which was a textbook on house physiognomy, was very popular in Japan at that time. In this study, the information contained in the textbook was used to identify the species and placement of greens in townhouse gardens[10]. The placement of greens was decided as follows: divide the garden into nine sections which was the same way as at the time, and decide which greens are suitable for each section according to good and bad luck suggested in the *kaso-sho* (Fig. 3). The size of the greens was decided depending on studies and documents obtained from the Japanese Institute of Landscape Architecture.

2-2-4. Residents’ Summer Living Activities in Vacant Lands

For the evaluation of outdoor living areas, the summer living activities on vacant lands during each time section at that time were identified from previous studies and historical materials. According to Ito (1986)[8], vacant lands in the *Edo* townsman area were used as drying areas during the day and used to enjoy the evening breeze during the evening. In *Edofunai-Ehonfuzokouurai* [7], there was a description about vacant lands which stated that, “many vendors and food stalls had been opened up from evening till night, and all the people live in Machiyashiki got together to enjoy cool evening breeze.” From this information, the vacant lands in the target site could be set as outdoor living areas that some residents occupied during the morning, and all residents occupied to enjoy cool breeze during the evening. The identified information was added into the table of outdoor living space of residents, proposed in the previous study[2] (Table 2).

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Table 2. Outdoor Living Space of Residents (Including Vacant Land)

<table>
<thead>
<tr>
<th>Living Areas</th>
<th>Dawn 6</th>
<th>Morning 7</th>
<th>Noon 8</th>
<th>Noon 9</th>
<th>Noon 10</th>
<th>Noon 11</th>
<th>Noon 12</th>
<th>Noon 13</th>
<th>Evening 17</th>
<th>Evening 18</th>
<th>Evening 19</th>
<th>Evening 20</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alleys</td>
<td>C, D, E</td>
<td>E</td>
<td>E</td>
<td>E</td>
<td>E</td>
<td>B, E</td>
<td>A, B, C, D, E</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Communal Areas</td>
<td>E</td>
<td>E</td>
<td>E</td>
<td>E</td>
<td>E</td>
<td>B, E</td>
<td>A, B, C, D, E</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vacant Lands</td>
<td>E</td>
<td>E</td>
<td>E</td>
<td>E</td>
<td>E</td>
<td>B, E</td>
<td>A, B, C, D, E</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Streets</td>
<td>—</td>
<td>—</td>
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<td>—</td>
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</tbody>
</table>

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3. PRECISION OF REPRODUCTION MODELS AND BOUNDARY CONDITIONS

3-1. Concerning Precision of Reproduction Models

Considering the width of streets and the lengths of the members of buildings, which were different depending on the type of outdoor living spaces, the precision of the reproduction model was set. The buildings in the city of Edo were measured using the Japanese measuring system. The simulations in this study were calculated in a structured grid. As a result, the minimum width of each mesh in CFD was 300 mm for streets and 100 mm for alleyes. Finally, a model of the target site was created for this simulation (Fig. 4).
3-2. Setting Boundary Conditions on Building Parts

The coupled analysis needed to calculate not only values of thermal physical properties but also boundary conditions of building members. Although the thermal physical properties of building members had been prepared in the previous study [1], boundary conditions of building members had to be considered. As the predominant wind direction in the streets was arranged vertically with respect to the wooden lattice gate, the gate served as a substitute for a grid-like panel in CFD, and the pressure loss boundary of the gate was determined depending on the architectural design data corpus [11]. The parameters (coefficient, LAE, green coverage ratio) necessary for calculating the effect of trees in CFD were set depending on Yamada (1982) [12].

4. EVALUATING THE INFLUENCE OF VACANT LANDS ON THERMAL AND WIND ENVIRONMENT IN EDO MACHIYASHIKI

In this chapter, the distribution of surface temperature, wind velocity, and air temperature of the target site was calculated on a clear summer day [1] using the coupled analysis [4], and the influence of vacant lands in Machiyashiki on the outdoor thermal and wind environment was evaluated.

4-1. Calculation of Surface Temperature, Air Temperature, and Wind Velocity

The surface temperature at the target site on a clear summer day was calculated using the 3D-CAD-based thermal simulation tool [3]. The room and air temperatures were maintained at the same value because the buildings at that time were not airtight. Depending on the average vertical thermal distribution calculated previously, the ground temperature at time 0:00 was set as the underground thermal boundary condition. The simulation was calculated over five days and was run for the first 4 days under the conditions mentioned above. The distribution of surface temperature on the fifth day was regarded as the periodical steady state adapted to CFD as input data in the coupled analysis.

Airflow was calculated using generalized CFD software (STREAM). The nested grid method was adapted to the airflow analysis to incorporate the influence of surroundings. Table 2 lists the boundary conditions used in this calculation. First, in the wide area, only the airflow analysis was adopted with a minimum mesh size of 900 mm. The wind velocity and direction were considered as boundary conditions (inflow and outflow) for the middle area. Next, in the middle area, the coupled analysis was adopted with a minimum mesh size of 300 mm. The air temperature, wind velocity, and wind direction were considered as boundary conditions for the middle area. Finally, in the narrow area, coupled analysis was adopted with a minimum mesh size of 100 mm. The boundary conditions were the same as those for the middle area (Fig. 5).
4-2. Surface Temperature and Heat Flux from Target Site

Both during the day and at night, the surface temperature of the roof in long houses (Japanese cedar) and townhouses (clay tile roofing) had the same tendency as was found in the previous study [1]. Because of the low thermal conductivity and thermal capacity, the surface temperature of Japanese cedar and clay tile roofing was more than 55°C (up to 65°C) during the day and 1–3°C lower than the air temperature at night. The surface temperatures of vacant lands fell from 35°C to 25°C at night. Although there were trees inside Machiyashiki, the trees had little effect on creating shade because of their size.

The sensible heat flux from each of the 17 Machiyashikis in the target site was evaluated from the heat island potential (HIP) [13], an index that indicates the amount of heat transferred to the surrounding air from an area on a typical day in terms of the heat island phenomenon (fine weather and low wind speeds). Note that all the vertical unevenness of the surfaces is also regarded to be part of the horizontal surface area. The index was calculated using the equation below (Eq. (1)).

$$\text{HIP} = \frac{\int \text{all surfaces} \ (T_s - T_a) \ ds}{A} \quad \ldots \ (1)$$

$T_s$: surface temperature of a minute plane inside the area of interest (°C),
$T_a$: air temperature in the area for interest (°C),
$A$: horizontal projected area of the target site (m²),
$ds$: area of a minute plane (m²)

The difference in the spatial structure of each Machiyashiki was considered from the daily change in the HIP (Fig. 6). The sensible heat flux from all Machiyashikis were extremely high during the day and low at night, which means that most of the solar radiation at the target site was immediately radiated back toward the surrounding air. Therefore, during the summer, the heat island phenomenon never developed in the city blocks of Edo at night with or without vacant lands. However, the daytime HIP of Machiyashiki with vacant lands was getting lower in inversely proportional amounts to the area of vacant land during the day (5–15°C lower than usual one).
4-3. Thermal and Wind Environment in Outdoor Living Areas

At Noon 7 (during 16:20 to 18:39), which was Japanese local time section in 19th century, most of the residents in Edo Machiyashiki stayed in the streets and alleys to enjoy the evening breeze (Table 2). The influence of vacant lands on the thermal and wind environment in the residents’ living areas was evaluated during this period.

4-3-1. Street (east-west)

The distribution of mean radiant temperature (MRT) at the living height (1.5 m) in the vacant areas facing the east-west street was lower than the air temperature because the surface temperatures were the same as the air temperature and the area was open to the sky and was able to get nocturnal radiation cooling. Whereas wind blew into the street from the vacant land at 2.5 m/s, the air temperature, owing to heat from nearby building roofs, was 30.5°C, which was 0.5°C higher than the wind temperature (Fig. 7a). In this case, the spatial structure of Edo Machiyashiki had a negative effect on the thermal and wind environment, and it was difficult for the residents to enjoy cool air in the evening.

4-3-2. Street (north-south) Facing Large Vacant Lands

As the wooden gate reduced the wind velocity, the wind in the large area of vacant land facing the north–south street was getting mild (1.5–2.0 m/s). The distribution of MRT at the living height (1.5 m) in the vacant area was 0.5°C lower than the wind temperature (about 29.5°C). The air temperature at the same height was also the same as the wind temperature (Fig. 7b). Concerning the living activities during this period of time [2], it is considered a possible reason for the ability to enjoy the evening cool air in the vacant land.

4-3-3. Alley (north-south) inside Machiyashiki

Considering heat balance and airflow, the distribution of MRT was 27–28°C and was 2°C lower than the wind temperature because of the spatial structure of the north-south alleys and thermal capacity of building members, as was the result in the previous studies [1][2]. Although it was expected that there would be little wind in the north-south alley with a dead end, wind collided with the roof of a townhouse and down flow flew into the alley at about 2.0 m/s next to the common area (Fig. 7c). The air temperature in the alley with the down flow of air heated by the wooden roofs of townhouses is about 30°C, and a little higher than MRT. Consequently, the environment in the north-south alley with vacant lands, gardens or common areas in Machiyashiki is good both in terms of thermal and wind conditions, and it was suited for residents to enjoy the cool air in the evening.
5. CONCLUSION

In this study, the townsmen residential area of Edo, early modern Tokyo, in the 1790s to the 1860s was the focus, and the summer thermal and wind environment over several city blocks was calculated using the coupled analysis of heat balance and airflow. As a result, the influence of south wind from the Edo bay and vacant lands was evaluated and the influence of vacant lands in the townsmen residential areas were determined quantitatively. One influence is that townsmen residential areas in Edo with vacant lands had never become susceptible to hot summer nights because the spatial structure, vacant lands, and gardens in Edo Machiyashiki contribute to reducing HIP during the day as well. The other influence is that it is clear that some vacant lands works well with the spatial structure of Machiyashiki to introduce the appropriate wind into outdoor living spaces under the better thermal environment during a specified period of time, and this seemed to work well with the residents’ living activities at that time. One of the future subjects is the analysis of the indoor thermal and wind environment.

REFERENCES