New City Block Design Approaches Incorporating Environmental Assessment for Downtown Districts in Cities with Severe Winter Climates

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Abstract
Urban design approaches in many Japanese cities are based on principles that are similar throughout the country without considering the variety in regional climates. Especially in cities with severe winter weather, providing desirable environments for public spaces under conditions of snow and strong winds is an important issue in urban design. This paper proposes new approaches to urban design with environmental assessments using snow and wind simulations to enable the development of original urban design concepts to improve the quality of public space. Using city blocks in downtown Sapporo, Japan as a case study, a design process flow is established together with conceptual models of city block design, assessing each of the steps of the process. The results of the assessment are then reflected back to the models and re-evaluated with an environmental assessment. With the results, the authors identify a number of principles of city block design for downtown Sapporo.

Keywords: city block design; snow simulation; wind tunnel; environmental assessment; winter cities

1. Introduction
1.1 Purpose of the Research
Japan has a variety of regional climate conditions. However, the urban design approaches in different regions are similar and do not consider climate differences. Every city has unique environmental problems in urban spaces caused by its specific climate. Here, cities in areas with severe winters suffer from heavy snowfalls and cold winds and spend large sums of money to overcome their climate-induced problems. This makes it important to establish urban design principles to protect areas from the harsh winter climate in cities in cold regions that experience heavy snowfalls, as is the case in Hokkaido, Japan. Specifically, the issues concerning the environmental impact of snow and wind on public space needs to be addressed, in addition to developing desirable urban design criteria to improve the environment of public spaces to protect against snow and wind in winter.

This makes it necessary to study city block designs that aim to reduce the effects of snow and wind on public spaces. City blocks are the most important units for studying the relationship between public spaces and urban designs, and this paper proposes a new approach to achieving climate responsive city block design for cities with harsh winters.

This paper uses city blocks with medium-rise buildings in downtown Sapporo, Japan as a case study, and a series of medium-rise buildings with a variety of city block design concepts are assessed with snow and wind simulations to determine how city block designs affect snow and wind conditions in these public spaces. Finally, attractive concepts for city block designs in downtown Sapporo are presented.

1.2 Previous Studies
There are many studies of environmental assessments of building design with only wind simulation tests. Bosselmann (1984) studied Downtown San Francisco in the U.S.A., and showed that new developments with high-rise buildings cause environmental problems due to changes in the wind and sunlight conditions in the surrounding areas. Bosselmann compared the environmental impact of high-rise and medium-rise buildings with wind simulation tests using a wind tunnel.
Tomabechi (2002) showed simulations of the impact of snowfall using a wind tunnel. That approach is suitable to determine desirable building locations in relation to snow and wind in Hokkaido, but the results are only applicable to building design, not to urban space design. There is little research on the environmental influences of snow and wind for urban designs with snow simulation tests using wind tunnels. Setoguchi (2004) (2006) (2007) (2009) (2012) discussed the urban design process including snow and wind environmental assessments for cities in severe winter areas, comparing high-rise buildings with medium-rise buildings, and showed that high-rise buildings have a more negative effect on the surrounding snow and wind conditions than medium-rise buildings. Based on the results of the above research, this paper focuses on medium-rise buildings in city blocks and discusses the effects of the snow and wind conditions based on the design form of city blocks (Table 1.).

Table 1. Studies of the Environmental Impact of Snow or Wind Using Wind Tunnels

| Simulation          | Building design | Urban design |
|---------------------|-----------------|--------------|
| For Wind Only       | (Several reports) | Bosellmann (1984) |
| For Wind and Snow   | Tomabechi       | This Paper / |
|                     | (2002)          | Setoguchi |
|                     |                 | (2004-2012) |

2. Methodology
2.1 Winter Climate of Sapporo City

Hokkaido is in the northern part of Japan, a cold region with heavy snowfall with numerous cities and towns which suffer from severe problems with snow in winter. Specifically, the northernmost large city in Japan, Sapporo, is the world’s largest city with a severe winter climate. Sapporo has one of the most serious snow problems affecting an urban area in the world and an urban design to alleviate the snow problems here is required (Photo 1.).

Fig.1. shows snow data for a winter in downtown Sapporo as reported by the Japan Metrological Agency. The snow cover began to form there from the beginning of December and remained until the end of March of the following year, so the ground was covered with snow for almost four months of the year in downtown Sapporo. The snow depth increased from December and reached a peak of 91cm on January 20 and sidewalks were also covered with snow for four months.

The wind conditions reported in the climate data of the Meteorological Agency covering the five years from Dec 2010 to Mar 2015, showed strong winds with snow blowing from the northwest (NW). Strong winds in Sapporo mostly blow from the northwest, and the strongest wind velocity from a northwesterly direction was adopted for the snow simulations here (Fig.2.).

2.2 Target Area for the Simulations

Tanuki-koji is the oldest shopping passage in Sapporo, a pedestrian street with a covered arcade. The passage is a popular area of downtown Sapporo where most pedestrians walk outside, and it is near the Odori and Susukino areas (two commercial centers in downtown Sapporo) and many commercial and office buildings. There are many pedestrians here in winter, and the target area stretches across two city blocks (Fig.3.) including the crossing of the Sapporo station road and Tanuki-koji which attracts the most customers in the Tanuki-koji area. The land use is zoned as commercial and the Floor Area Ratio (FAR) is 800%. Recently the buildings on these two city blocks are expected to be redeveloped.

Fig.3. Target Area

2.3 Wind Tunnel for the Snow Simulation Tests

The method of the snow simulations is the same as in a previous paper (Setoguchi (2012) ). The snow simulation tests were carried out using the boundary-layer wind tunnel in the Hokkaido Research Organization Northern Regional Building Research Institute (HRO). The wind tunnel is seven meters long, with a cross section that is 150cm wide 70cm high in the tunnel (Fig.4.).

The re-creation of the situation with snow cover (snow fall) involved blowing the model snow with
compressed air from the windward supply nozzle. The snow model used white soil powder with a 8.5% moisture content, an average diameter of 20μm, and a 48~51° repose angle, which is near the repose angle of snow in Hokkaido. The model snow was supplied to the wind tunnel in increments, the supply set to about 480g/min and the total supplied amount was 10kg in one experiment. The deposited depth was measured by a laser manufactured by Keyence LK500.

The average wind velocity is 2.46m/s in winter in downtown Sapporo (Original data from the Japan Meteorological Agency), and wind conditions were simulated with the velocity and turbulence intensity profile shown in Fig.5. The wind velocity in the wind tunnel was set to be equal to the actual average wind velocity based in Anno (1984).

2.4 Wind Simulation Setup

The wind simulation tests were also carried out in the boundary-layer wind tunnel at the HRO. The cross section of the wind tunnel is 180cm by 180cm. In this paper, the environments of the wind and snow are assessed by snowdrifts and discomfort due to the cold wind, with each experiment measured at 30 sidewalk locations. A thermistor anemometer (Kanomax Climomaster model 6542) was used to measure the wind velocity. The probe stopped for 30 seconds at each sampling point to gather data at the height of 5mm. A sampling time of 30s was adopted for the experiments in order to obtain a stable average scalar value of the wind velocity at each measurement point.

2.5 Models for Snow and Wind Simulations

For the snow and wind simulation tests, the target area was made of Styrofoam in 1 to 500 scale. The lengths of the district are 1,190m (in the northwest-southeast direction) by 745m (in the northeast-southwest direction) and the district model measured 2,238mm long by 1,490mm wide for the snow simulation tests. The wind direction ranges of the models were 8.7 times the height of the highest building model (129mm), and sufficiently high for reproducible snow simulations (Fig.6).

2.6 Process for Evaluating the City Block Design

Fig.7 shows the evaluation process for the city block design linking it with environmental assessments in this paper.

STEP 1: Analysis of a non-controlled city block design: A model of the non-controlled city block design was set and assessed with snow and wind simulations to be able to identify the environmental problems that arose.

STEP 2: Analysis of the city block design concepts: First, planning issues of the targeted city blocks were analyzed including the environmental problems which were identified in STEP 1. Then three city block design concepts were considered based on the planning issues and these were assessed with snow and wind simulations. From the results of the assessments, the most desirable concept was chosen and the environmental problems of that concept were identified.

STEP 3: Two detailed design concepts were determined based on the most desirable concept of the city block design, analyzed, and assessed with snow simulations.

Finally, several suggested details of city block design were identified based on the assessments and evaluation process.

3. Analysis of an Uncontrolled (as is) City Block Design

3.1 Design Concept for an "as-is" Uncontrolled City Block

This chapter focuses on analyzing problems of the snow and wind environment without any set city block design. The Individual Redeveloped Type (IR Type) was used as a model where some city blocks were not controlled (Fig.8). The buildings were assumed to be redeveloped individually (without conforming to the...
surroundings) and were not merged. Buildings of 3 floors and less were assumed to be redeveloped to 8 floors. The FAR of the east block was set to 570%, and the FAR of the west block set to 630%. These values present FAR (the east block: 518%, the west block: 573%) plus 10%.

3.2 Environmental Assessment of the IR Type

Fig. 9 shows the results of the snow and wind simulations for the IR Type. Many snowdrifts were formed on South-2 Street (points A, B, C, and D). Since the depths of the snowdrifts were over 200mm, they would be major traffic hazards.

Large snowdrifts were formed on the sidewalk of South-3 Street (points E and F). Since the depths of the snowdrifts here were over 200mm, they could be problematic for pedestrians. The snow cover on the Sapporo Station Road was different on the east and west sides. Snow covered the west sidewalk uniformly, and there was little snow cover on the east side. There were snowdrifts on the east sidewalk of the road (point G), and the snowdrifts would be obstacles for many pedestrians.

Intolerable wind conditions above 3.0m/s, were observed along South-2 Street; these were around the corners of the blocks, and could cause problems for pedestrians.

4. Analysis of City Block Design

4.1 Planning Issues

The analysis of the city block design for the targeted blocks considered four urban planning issues (PI-A, B, C, and D) and four environmental issues (PI-A1, C1, C2, and C3) determined based on the results in chapter 3 (Fig.10).

PI-A) Sapporo Station Road is located in the center of downtown Sapporo and it is the most important urban axis. Since there are many workers and customers visiting offices and commercial facilities along the road, a design considering the pedestrians on Sapporo Station Road is required in the planning here.

PI-A1) In the IR Type, large snowdrifts were observed on the east sidewalks of Sapporo Station Road, and these snowdrifts could pose problems for pedestrians.

PI-B) As detailed above, both the Sapporo Station Road and Tanuki-koji are important streets in downtown Sapporo; therefore, the crossing needs to be designed as an urban symbol.

PI-C) The target city blocks are expected to be redeveloped for commercial and office facilities. Since their entrances will be used by many visitors and will be all around the blocks, the sides of the blocks need to provide an attractive environment for pedestrians.

PI-C1) In the IR Type, large snowdrifts were observed on South-2 Street and the snowdrifts could be a source of problems for traffic.

PI-C2) In the IR Type, large snowdrifts were observed on the sidewalk of South-3 Street and these snowdrifts would pose problems for pedestrians.

PI-C3) In the IR Type, strong wind conditions were observed on South-2 Street and this would be a problem for pedestrians.

PI-D) As detailed above, Tanuki-koji is a very important pedestrian area (passage) in downtown Sapporo. Since it has arcades (a covering roof), there are many pedestrians in all seasons, and it would benefit from a design creating a human-friendly space.

4.2 City Block Design Concepts

Based on the planning issues (PI) detailed above, three city block design concepts were analyzed (Fig.11.). The FAR of the three types were set to be the IR Type, and the Unified Height type was the model with all buildings designed based on one principle and two other types were based on PI (Table 2.).

1) Unified Height Type (UH Type)

All buildings in the city blocks were set at the same height, 8 floors. Adjacent buildings on narrow and constricted sites were set to be redeveloped by merging
these sites. Here, keeping the same building heights was the priority in the design for each of the planning issues evaluated.

2) Mountain Shaped Type (MS Type)

This type was set to prioritize PI-C over PI-D. [Design for C]: The outer buildings in the blocks were set to be lower, 5 floors to allow access of light and wind. [Design for D]: The inner buildings in the blocks were set to be higher, 10 floors. [Design for A and B]: The buildings along Sapporo Station Road were set at 10 floors considering the streetscape and the parts of the buildings at the crossings were low-rise (4 floors) to create enclosed public spaces here.

3) Close Rounded Type (CR Type)

This type prioritized PI-D over PI-C. [Design for D]: The inner buildings in the blocks were set to be lower, 4 floors to allow access of light and wind to Tanuki-koji. [Design for C]: Outer buildings in the blocks were set to be higher, 10 floors. [Design for A and B]: The buildings along Sapporo Station Road were 14 floors creating landmarks and the buildings at the crossings were low-rise (4 floors) to create enclosed public spaces here.

Table 2. Details of the Urban Planning Issues and the Building Heights in the Three Model Types

| UH Type | PI-A | PI-B | PI-C | PI-D |
|---------|------|------|------|------|
|         | Middle | Middle | Middle | Middle |
| MS Type | High | Tower | Low | High |
| CR Type | Tower | Low | High | Low |

Fig.11. City Block Design Concepts

4.3 Environmental Assessment of the City Block Design Concepts

The results of the snow and wind simulations are shown in Figs.12. to 14. Table 3. shows the amount of snow cover on the target blocks calculated from the results of the simulations. The discussion mainly focuses on PI-A - C3 and does not include PI-D because Tanuki-koji has covered arcades and was not affected by changes in the snow and wind situation.

1) Planning Issues A, A1, and B (PI-A, A1, and B)

In the UH Type, large snowdrifts were not formed and the snow cover was uniformly distributed along Sapporo Station Road (Fig.12.). This snow situation was caused by the unimpeded movement of the snow above the target block. The UH type had no differences in the building heights, and the snow movement was not impeded by the falling snow, causing uniform snowdrifts (snow cover). In addition, for PI-A1 in the UH type, snowdrifts on the east side of the road were very similar to those with the IR Type (see point A1). In the MS Type, large snowdrifts were formed on the southwest side of the road (see points A, B, and C, in Fig.12.) and there were no snowdrifts on the east side (see points A1, A1, and B1, in Fig.12.). Comparing the MS and IR types, the wind velocity on the east side was much higher. These snow and wind situations are caused by a backlash of snow and wind from the east side landmark towers. The backlash of snow and wind is deflected to the ground, increasing the wind velocity around buildings and bringing much snow to the surrounding areas. This is the reason for the presence or absence of snowdrifts in the different locations. The MS Type reduced the PI-A1 snow cover, but increased wind velocity in this area.

In the CR Type, snowdrifts were formed on the southwest side of the road and there are no snowdrifts on the east side (see point A, B, and C, in Fig.12.). The snowdrifts are smaller than with the MS Type. The low-rise buildings at the crossings with the CR Type curbed snow flow to the ground, keeping the snow on the roofs, resulting in a smaller amount of snow at the street level. The no snowdrifts on the east side was a result of the backlash of wind from the 14 floor buildings. Around the crossing of Sapporo Station Road and Tanuki-koji, there are no large snowdrifts, and for PI-A1 in the CR Type, snowdrifts on the east side of the road were very similar to those with the IR Type (see point A1). In the CR Type, snowdrifts were formed on the southwest side of the road and there are no snowdrifts on the east side (see point A, B, and C, in Fig.12.). The snowdrifts are smaller than with the MS Type. The low-rise buildings at the crossings with the CR Type curbed snow flow to the ground, keeping the snow on the roofs, resulting in a smaller amount of snow at the street level. The no snowdrifts on the east side was a result of the backlash of wind from the 14 floor buildings. Around the crossing of Sapporo Station Road and Tanuki-koji, there are no large snowdrifts, and for PI-A1 in the CR Type, snowdrifts on the east side of the road were very similar to those with the IR Type (see point A1).

2) Planning Issues C and C1-C3 (PI-C and C1-C3)

The pedestrian spaces around the target blocks with the MS Type had many snowdrifts, and on the UH and CR Types there were only a few. Comparing the PI-C1 issues for the UH and IR Types, snowdrifts with UH on South-2 Street were larger (see point C1 and C1, in Fig.12.). This may be ascribed to the buildings of the same height not disturbing the passage of snow and wind, as a result the snow was not evenly distributed resulting in larger snowdrifts there. For PI-C2 in the UH type, snowdrifts on South-3 Street were very similar to those with the IR Type (see point C2). Comparing the results with PI-C1 for the MS and IR Types, snowdrifts with MS on South-2 Street were larger (see point C1, C1, and C1, in Fig.12.). For PI-C2, the snowdrifts on South-3 Street were also larger (see point C2, and C2). Large snowdrifts were
formed at the crossing of South-3 Street and Sapporo Station Road (see point C). Here the outer buildings were low, and snow reached ground around target blocks easily, thereby causing the large snowdrifts there.

Comparing the results with PI-C1 for the CR and the IR Types, snowdrifts with the two types on South-2 Street were very similar (see point C1f, C1g, and C1h in Fig.14). For PI-C2, the snowdrifts on South-2 Street were smaller (see point C2e and C2f). These two block types have low-rise parts in the center, snow remained on the roofs of the low-rise buildings, reducing the size of the snowdrifts on the leeward (wind shadow) side.

For PI-C3, the UH Type was very similar to the IR Type but the MS Type and CR Type reduced the wind velocity on the corners of the target blocks.

3) Amounts of Snow Cover on Target City Blocks

Comparing the other three city block types to the IR Type, the UH Type increased and the MS and CR Types reduced the amount of snow cover on the target blocks. The UH Type has no differences in building heights, the snow was blown smoothly without piling up on the roofs, thereby causing the snow cover on the ground to increase. Further, the MS Type increased the snow cover on the sidewalks and the percentage of snow cover on the sidewalks was the highest of the four. The outer buildings were low, and snow easily reached the ground around the target blocks, with a resulting increase in the amount of snow cover (Table 3.).

5. Analysis of Detailed Designs

5.1 The Detailed Design Concepts

This chapter focuses on distinguishing the impact of snow and the effect of detailed design concepts. According to the results of the assessment in chapter 4, the CR Type was the most desirable city block concept of the four to improve the snow and wind environment. With the CR Type, however, there was the problem of snowdrifts forming on Sapporo Station Road. To investigate this further two detailed design concepts were designed to focus on the shapes of the snow accumulating on the Sapporo Station Road based on the CR Type. The particulars are shown in Fig.15. These design concepts are very common in downtown Sapporo, and are also

Table 3. Amounts of Snow Cover on Target Blocks

|                        | IR Type | UH Type | MS Type | CR Type |
|------------------------|---------|---------|---------|---------|
| Amount of snow cover on the target blocks | m$^3$/day (%) | 1,159 (100) | 1,218 (100) | 1,071 (100) | 1,045 (100) |
| Amount of snow cover on the streets | m$^3$/day (%) | 842 (72.7) | 873 (71.7) | 739 (69.0) | 768 (73.4) |
| Amount of snow cover on the sidewalks | m$^3$/day (%) | 317 (27.3) | 344 (28.3) | 332 (31.0) | 278 (26.6) |
popular for the streetscape. The FAR of the two were set to be the same as in the city block design concepts.

1) Arcade Type (AC Type)

The AC type has 1~3 floors near the ground level opening spacious sidewalks along Sapporo Station Road. This design concept is very common in cities with warmer climates, and is considered to protect people from all types of weather. The width of the arcade was set at 10m, and the height was also 10m.

2) Setback Type (SB Type)

The buildings along Sapporo Station Road were set to have a setback of the 4th and higher floors. In this type, more sunlight reaches the road and pedestrians will feel it is more open. Additionally, in this type the heights of buildings facing Sapporo Station Road were better scaled in terms of human perception.

5.2 Environmental Assessments of the Detailed Design Concepts

Comparing the AC and CR Types, the AC Type reduces the size of the snowdrifts on the east sidewalk of the road (see point A_e in Fig.16.) but the AC type creates snowdrifts on the west side of the road (see point A_w). In addition, this type resulted in snowdrifts in the arcades. The east arcades increased wind velocity on the ground and also the backash of snow and wind from the east to the west side, thereby not forming snowdrifts on the east side but forming snowdrifts on the west side. The west arcades prevented snow from blowing upwards and the snow remained in the arcade.

Comparing the SB and CR Types, the SB Type reduces the snowdrift size on the east sidewalk (see point A_e in Fig.17.) but increases the snowdrift size on the west side of the road (see point A_w). The east setback prevented snow and wind flowing to the ground, thereby causing reduced snow cover. The west setback reduced wind velocity on the sidewalks, thereby causing an increase in snowdrift size.

Comparing the results of the snow simulations in the detailed design concepts to the city block design concepts, the differences in the snow situations in the detailed design concepts were very limited. The amounts of snow cover on the target blocks with the two detailed design concepts were very similar to the CR Type (Table 4.).

6. Conclusions and Further Study

Based on the analysis, the proposal for city block design with the assessments suggested in the results here is shown in Fig.18. Advice concerning the city block design considering environmental assessments was concluded to be as follows:

1) Concepts of City Block Design

1a) Direction of city block design:

Unifying all building heights is one common city block design for ordinary urban designs in cities with...
warm climates, but it cannot be recommended in cities with severe winter weather because it could increase the amount of snow cover.

1b) Relationship between outer and inner buildings:
The city block design with low-rise inner buildings and high-rise outer buildings, like the Close Rounded Type (CR), could improve the snow and wind environment. That makes this design a desirable concept in cities with severe winter weather. A city block design with high-rise inner buildings and low-rise outer buildings, like the Mountain Shaped Type (MS), may increase the amount of snow cover and it is not recommended for cities with severe winter weather.

1c) Design of road crossings:
In designing road crossings of important streets, low-rise enclosed public spaces facing the crossing would be an effective choice for cities with severe winter weather to improve the snow and wind environment. Landmark towers facing road crossings could result in a negative effect on snow and wind conditions and it is not recommended for cities with severe winter weather.

2) Suggested Process for City Block Design

2a) According to the results of the simulations, different city block design concepts have different effects on snow and wind conditions. The results show possible city block designs for improving the snow and wind environment.

2b) Comparing the analysis of the city block design and the detailed design, the city block design could have a stronger impact on urban environments than the detailed design. Hence, integrating the early steps of the urban design process with environmental assessments is important to design effectively to improve the quality of public spaces.

In this paper, the city block design approach linking with environmental assessments is discussed. In cities with severe winter weather, this approach to urban design should be employed to provide better environments for pedestrians. In the further related research, more detailed studies are required to design desirable urban spaces in the cities.

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Notes

In the simulation, 2.88 minutes was equivalent to one day; 2.88 minutes was obtained by dividing 24 hours by 500 (scale of the model). Consequently, the average depth of model snow was 0.14mm, and it was equivalent to 7cm snow depth per day, and one week of snowfall was equivalent to 20.2 minutes and an average depth of the model snow of 0.98mm. Therefore 10 kg of model snow and a 20.2 minute duration of simulation were equivalent to 7cm thickness of deposited snow per day, continuing for one week.

The previous researches reported the reproducibility of this snow simulation. This paper discussed the results of snow simulation which were found to be affected by the building forms.

The results of simulations were measured on the models in a 1 to 500 scale. The measured values and time required for experiments in the simulations were set to be proportional to the model scale based on "the theory of homothetic ratio for model experiments". In Sapporo, over 200mm depth of snowfall for 12 hours triggers a heavy snow storm warning. Hence over 200mm of snowdrifts was set to be the depth which would cause problems for pedestrians.

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