LED TRAFFIC SIGNALS IN SNOWY AREAS

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1. Abstract

The LED-type traffic signal, which has recently come into practical use, provides significant advantages over the bulb-type traffic signal in that (1) it has a uniform luminous intensity over the entire light-emitting surfaces so that it is superior to the bulb type in terms of visibility, (2) it has a long life (30,000-50,000 hours) and delivers an extended period of maintenance-free performance, and (3) it features low power consumption, thereby providing substantial energy savings. These advantages can be effectively exploited in both snowy and non-snowy areas. In particular, the high visibility of the LED traffic signal is considered to be very effective in securing the safety of traffic when vision is limited by snow. On the other hand, since LEDs are very energy-efficient and generate only a small amount of heat as compared with bulbs, the lens surfaces of the LED traffic signal are kept at relatively low temperature so that snow may accrete to them without being melt to reduce the visibility of the light, or make it difficult to distinguish between signal colors, at the time of snowfall. Generally speaking, the degree of snow accretion is dependent on the atmospheric temperature and the temperature of the object on which snow falls, and snow accretion tends to occur easily when the speed of the wind is nearly constant and it hardly occurs when the wind is either light or strong. As for the traffic signal, since a sunlight-intercepting hood is provided for each lens so as to visor the upper part of it, it is presumed that the wind blowing on the lens surfaces should decelerate or stagnate, thereby causing snow to accumulate on and then accrete to them.

A method of preventing snow from accreting to the lens surfaces is by warming them by a heater. However, this method would impair the advantage of energy conservation offered by the LED type traffic signal, and we therefore examined the use of two different types of snow accretion control plates which utilize the flow of the wind for the prevention of snow accretion. One of these two types of snow accretion control plate is of such a shape that a strong wind blowing on the lens surface from the front side of the traffic signal may be guided downward without being made to stay above the lens surface, and the other is of such a shape that such a wind may be guided to the lower left and right sides. We have carried out snow accretion experiments in a low-temperature laboratory in which conditions of snowstorm were artificially created to find that these plates, through the utilization of the flow of the wind, effectively prevent snow from accreting to the traffic signal. We now plan to conduct verification tests on the snow accretion control effect of these plates, as well as the field visibility of the traffic signal, in order to promote the practical utilization of snow-resistant traffic signals.

2. Introduction

The traffic signal is vital to the safe and smooth flow of traffic and it is required to uninterruptedly operate with a high degree of reliability. In order to maintain stable operation over an extended period of time, the devices and parts that make up the traffic signal are subjected to strict quality control in any of the design, production, and maintenance phases. In addition, to ensure high visibility for the traffic signal, special consideration is given to its luminous intensity distribution characteristics. For traffic signals for use in very snowy areas, further consideration must be given to preventing snow from accumulating on top of them or from accreting to their lens surfaces. It is to be noted that the greater the amount of snow accreted to the lens surfaces, the more would it be difficult for drivers to visually identify the signal colors.

The present paper discusses the results of snow accretion experiments conducted in a low-temperature laboratory for verification of the condition of snow accretion to the lens surface.

3. Accretion of Snow to the Lens Surfaces

Accretion of snow to the lens surfaces, among others, can have a detrimental effect on traffic because it makes it difficult for drivers to judge which signal lamp is lit. In conventional bulb-type signals, which employ 60-70 W incandescent lamps as their internal signal source, their lenses are warmed by these lamps, so that they resist snow accretion. Even if snow accretes to the lens surfaces, their temperature is increased by heat from the incandescent lamps when snow stops falling or the speed of the wind decreases—thus, the snow on the lens surfaces are melted in a relatively short time without seriously affecting the flow of traffic.

With the improvement in luminous intensity and reliability of yellow and red AlInGaP LEDs and the development of green InGaN LEDs, the LED-type traffic signal, which has previously in the research-and-development stage, has now entered the phase of practical application. The LED-type traffic signal offers significant advantages over the conventional bulb-type traffic signal in that (1) it has a uniform luminous intensity over the entire signal-emitting surfaces so that it is superior to the bulb type in terms of visibility, (2) it has a long life (30,000-50,000 hours) and delivers an extended period of maintenance-free performance, and (3) it features low power consumption, thereby providing substantial energy savings. These advantages can be effectively exploited in both snowy and non-snowy areas. In particular, the high visibility of the LED traffic signal is considered to be very effective in securing the safety of traffic when vision is limited by snow. It has been verified by experiment, however, that snow can accrete to the lens surfaces in snowy areas. Since LEDs are very energy-efficient and generate only a small amount of heat as compared with bulbs, the lens surfaces of the LED traffic signal are kept at relatively low temperature, so that snow may accrete to them without being melt at the time of snowfall and, even after improvement of the weather, it takes considerable time for the snow on the lens surfaces to melt away (Table 3-1).

Table 3-1. Comparison in Power Consumption and Lens Surface Temperature between Bulb- and LED-Type Signals

	Power consumption			Lens surface temperature (Outside air temperature: -10°C, windless)
	Green	Yellow	Red	
LED-type signal	16 W	13 W	12 W	1 °C
Bulb-type signal	60-70 W	60-70 W	60-70 W	10 °C

Among the measures to prevent snow from accreting to the lens surfaces are: (1) to increase the lens surface temperature until the snow melts away, (2) to blow the snow away by the wind, and (3) to make the lens surface smooth and free of protrusions. The measure described in (1) can be carried out by melting the snow by a heater. However, this method would impair the advantage of energy conservation offered by the LED type traffic signal, and we therefore carried out structural studies on the lens surfaces to implement the measures shown in (2) and (3) above.

4. Snow Accretion Control Design Review

Generally speaking, the degree of snow accretion is dependent on the atmospheric temperature and the temperature of the object on which snow falls, and snow accretion tends to occur easily when the speed of the wind is nearly constant and it hardly occurs when the wind is either light or strong.

As for the traffic signal, since a sunlight-intercepting hood is provided for each lens so as to visor the upper part of it, snow does not reach the lens surfaces when the wind is away or down. If the speed of the wind is such that snow reaches the lens surface, the wind blowing on the lens surface will decelerate or stagnate because of the presence of the vertical lens surface and the upper hood after it shifts in all the four directions. Snow borne by the wind will stay on the lens surface and, if both the lens surface temperature and the outside air temperature are within certain limits, it will accrete to the lens surface (Fig. 4-1).

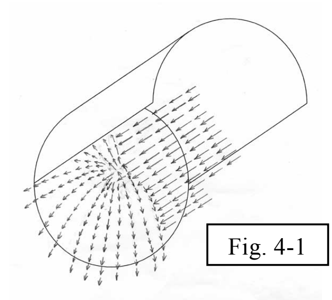


Fig. 4-1

When a strong wind blows on the lens surface from the front side of the traffic signal, it will only flow to the lower left and right sides because it is blocked both by the upper hood for the lens and by the lower hood for the lower lens.

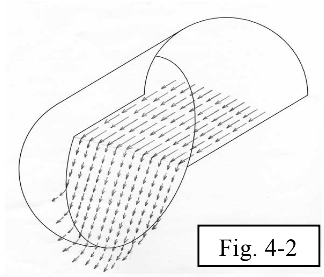


Fig. 4-2

For the above reason, we prepared as a trial two different types of snow accretion control plates, one being of such a shape that a wind blowing on the lens surface may be guided downward without being made to stay above the lens surface and the other being of such a shape that such a wind may be guided to the lower left and right sides, created artificially conditions of snowstorm in a low-temperature laboratory, and examined the condition of snow adhering to the snow accretion control plates.

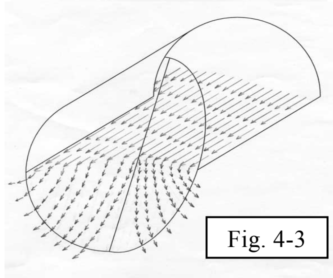


Fig. 4-3

a. Snow accretion control plate 1 (flat type) (See Fig. 4-2.)
   Snow accretion control plate designed to be installed at an angle of 20° with respect to the vertical direction so as to guide the wind downward
b. Snow accretion control plate 2 (V-shaped type) (See Fig. 4-3.)
   Snow accretion control plate formed into a V shape so as to guide the wind downward and to the lower left and right

5. Snow Accretion Experiments

5-1. Brief Description of the Experiments

Using four different types of traffic signals—a bulb-type traffic signal, an LED-type traffic signal with no snow accretion control plate, and an LED-type traffic signal equipped with snow accretion control plates 1 (flat type) or 2 (V-shaped type), we examined how snow accretes to their lens surfaces in a low-temperature laboratory while changing various parameters including temperature, snow fall rate, wind speed, and wind direction. Because of limitations of facilities, the experiments were conducted only with one unit of vertical-type signal. With consideration given to the flow of the wind near the signal, the hood and lens immediately below the lens under test were left attached to the signal.

5-2. Method of the Experiments

5-2-1. Test Samples

The following four test samples were used for the experiments.

(1) Bulb-type traffic signal
(2) LED-type traffic signal with no snow accretion control plate
(3) LED-type traffic signal with snow accretion control plate 1 (flat type)
(4) LED-type traffic signal with snow accretion control plate 2 (V-shaped type)

5-2-2. Experiment Conditions

The low-temperature laboratory used and the environmental conditions for the experiments were as shown below.

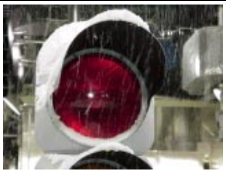
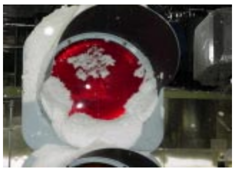
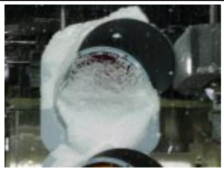
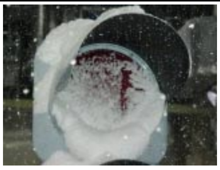
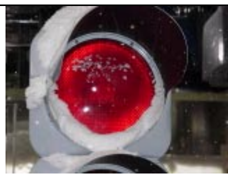
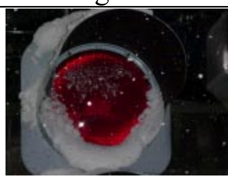
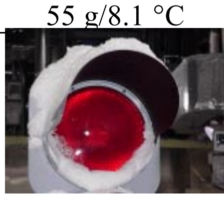
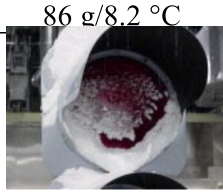
(1)	Low-temperature laboratory	:	Institute of Disaster Prevention Science and Technology (Independent Administrative Corporation) Shinjo Branch of the Nagaoka Institute of Ice and Snow Disaster Prevention Science and Technology
(2)	Snowfall crystal type	:	Spherical model (diameter: about 0.025 mm)
(3)	Humidity (RH%)	:	60-70
(4)	Temperature (°C)	:	-10, -5
(5)	Snow fall rate (mm/h)	:	35, 28, 21, 14, 7
(6)	Wind speed (m/s)	:	5.0, 4.0, 3.0, 2.0
(7)	Wind direction	:	Frontward

5-2-3. Traffic Signal Operating Conditions

Since traffic signals generate heat when they are lit, the test samples were repeatedly turned on and off at intervals of 30 seconds with consideration given to the actual average lighting time.

6. Results of the Experiments

6-1. Conditions of Snow Accretion for the Bulb-Type Signal (Fig. 6-1)

Outside air temperature (°C)	Snow fall rate (mm/h)	**Wind speed (m/s)** : Condition of snow accretion after the lapse of 60 min (photo) : Amount of snow (g)/surface temperature (°C)			
		2-2.5	**2.5-3.5**	**3.5-4.5**	**4.5-5**
-10	**28**	 1 g/6.1 °C	 76 g/5.7 °C	 211 g/5.5 °C	 429 g/10.2 °C
	35	 7 g/6.0 °C		 281 g/6.7 °C	
-5	**28**		 55 g/8.1 °C	 86 g/8.2 °C	 213 g/9.6 °C
	35	 1 g/-	 72 g/-	 95 g/-	

(1) For all the traffic signals under test, little snow accreted to the lens surface when the outside air temperature was -5°C or -10°C, the wind speed was 2.0 m/s or lower, and the snow fall rate was 35 mm/h or lower.

(2) When the wind speed was 4.5 m/s or higher, snow accreted nearly all over the lens surface, regardless of snow fall rate or outside air temperature.

(3) When the wind speed was between 2.5 m/s (inclusive) and 4.5 m/s (not inclusive), a considerable amount of snow accreted to the lens surface at the outside air temperature of -10°C. At the outside air temperature of -5°C, however, no snow accreted to the center part of the lens surface, although there occurred snow accretion on the periphery of the lens surface, under the same wind speed condition.

(4) The lens surface temperature was +5°C or higher under all sets of test conditions. This phenomenon was caused by heat from the lamp. When the outside air temperature was -5°C, the snow accretion control plates proved to be effective. At the outside air temperature of -10°C, fallen snow tended to slip down the lens.

(5) In the bulb-type signal, there is an about 15 mm difference in level for hood mounting on the lower side of the lens, and snow began to accrete from that part of the signal. The amount of snow accreted for the bulb-type signal was therefore larger than that for the LED-type signal.

6-2. Conditions of Snow Accretion for the LED-Type Signal with No Snow Accretion Control Plate (Fig. 6-2)

Outside air temperature (°C)	Snow fall rate (mm/h)	**Wind speed (m/s)**: Condition of snow accretion after the lapse of 60 min (photo) : Amount of snow (g)/surface temperature (°C)			
		2-2.5	**2.5-3.5**	**3.5-4.5**	**4.5-5**
-10	**28**	 1 g/-6.8 °C	 48 g/-5.1 °C	 136 g/-5.9 °C	 298 g/-8.4 °C
	35	 1 g/-6.4 °C		 210 g/-6.2 °C	
-5	**28**		 55 g/-4.5 °C	 22 g/-5.1 °C	 213 g/-4.5 °C
	35	 0 g/-	 30 g/-	 45 g/-	

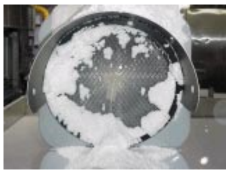
(1) For all the traffic signals under test, little snow accreted to the lens surface when the outside air temperature was -5°C or -10°C, the wind speed was 2.0 m/s or lower, and the snow fall rate was 35 mm/h or lower.

(2) When the wind speed was 4.5 m/s or higher, snow accreted nearly all over the lens surface, regardless of snow fall rate or outside air temperature.

(3) When the wind speed was between 2.5 m/s (inclusive) and 4.5 m/s (not inclusive), snow accreted nearly all over the lens surface at the outside air temperature of -10°C. At the outside air temperature of -5°C, however, only a small amount of snow accreted to both the periphery and the center part of the lens surface under the same wind speed condition.

(4) The lens surface temperature was -4°C or lower in all the tests.

6-3. Conditions of Snow Accretion for the LED-Type Signal with Snow Accretion Control Plate 1 (Flat Type) (Fig. 6-3)

Outside air temperature (°C)	Snow fall rate (mm/h)	**Wind speed (m/s)** : Condition of snow accretion after the lapse of 60 min (photo) : Amount of snow (g)/surface temperature (°C)			
		2-2.5	**2.5-3.5**	**3.5-4.5**	**4.5-5**
-10	**28**	 4 g/-9.0 °C	 73 g/-9.3 °C	 117 g/-9.2 °C	 256 g/-9.0 °C
	35	 4 g/-9.3 °C		 73 g/-8.9 °C	 324 g/-6.9 °C
-5	**28**		 28 g/-4.2 °C	 42 g/-4.5 °C	 180 g/-4.0 °C
	35				

(1) For all the traffic signals under test, little snow accreted to the lens surface when the outside air temperature was -5°C or -10°C, the wind speed was 2.0 m/s or lower, and the snow fall rate was 35 mm/h or lower.

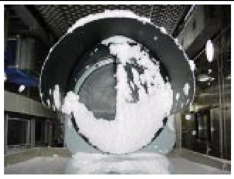
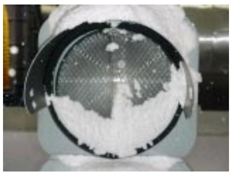
(2) When the wind speed was 4.5 m/s or higher, snow accreted nearly all over the lens surface, regardless of snow fall rate or outside air temperature.

(3) When the wind speed was between 2.5 m/s (inclusive) and 4.5 m/s (not inclusive), snow accreted to about 3/4 of the entire lens surface at the outside air temperature of -10°C. At the outside air temperature of -5°C, however, snow accretion occurred on the periphery of the lens surface but only a small amount of snow accreted to the center part of the lens surface under the same wind speed condition.

(4) The lens surface temperature was -4°C or lower in all the tests.

(5) There is an about 5 mm difference in level on the lower side of snow accretion control plate 1, and snow began to accrete from that part of the lens. The amount of snow accreted for this type of signal was rather large.

6-4. Conditions of Snow Accretion for the LED-Type Signal with Snow Accretion Control Plate 2 (V-Shaped Type) (Fig. 6-4)

Outside air temperature (°C)	Snow fall rate (mm/h)	**Wind speed (m/s)** : Condition of snow accretion after the lapse of 60 min (photo) : Amount of snow (g)/surface temperature (°C)			
		2-2.5	**2.5-3.5**	**3.5-4.5**	**4.5-5**
-10	**28**	 5 g/-9.5 °C	 40 g/-9.8 °C	 60 g/-9.4 °C	 120 g/-9.5 °C
	35	 5 g/-9.7 °C		 41 g/-9.7 °C	 157 g/-8.3 °C
-5	**28**		 20 g/-4.6 °C	 40 g/-4.3 °C	 80 g/-4.6 °C

(1) For all the traffic signals under test, little snow accreted to the lens surface when the outside air temperature was -5°C or -10°C, the wind speed was 2.0 m/s or lower, and the snow fall rate was 35 mm/h or lower.

(2) When the wind speed was 4.5 m/s or higher, snow accreted to about 3/4 of the entire lens surface, regardless of snow fall rate or outside air temperature.

(3) When the wind speed was between 2.5 m/s (inclusive) and 4.5 m/s (not inclusive), snow accreted to about 1/2 of the entire lens surface at the outside air temperature of -10°C. At the outside air temperature of -5°C, however, snow accretion occurred on the periphery of the lens surface but only a small amount of snow accreted to the center part of the lens surface under the same wind speed condition.

(4) The lens surface temperature was at most +2°C higher than the outside air temperature in all the tests.

(5) There is an about 5 mm difference in level on the lower side of snow accretion control plate 2, and snow began to accrete from that part of the lens. The amount of snow accreted for this type of signal was rather large. Experiments were also conducted on an improved type of signal which had no such difference in level. When the outside air temperature was -10°C and the snow fall rate was 28 mm/h, the amount of snow accreted was 62 g at the wind speed of 5 m/s and 9 g at the wind speed of 3.5-4.5 m/s; it was near half of that for the original signal.

6-5. Relation between Wind Speed/Snow Fall Rate and Snow Accretion

(1) Fig. 6-5 shows the relationship between snow fall rate and snow accretion, and Fig. 6-6 the relationship between wind speed and snow accretion. In both cases the outside air temperature was -10°C.

(2) The higher the snow fall rate, and the higher the wind speed, the greater was the amount of snow accreted.

(3) In the bulb-type signal, snow began to accrete from the stepped part on the lower side of the lens. The amount of snow accreted for the bulb-type signal was therefore larger than that for the LED-type signal, but the snow accretion area for the former was smaller than that for the latter.

(4) Although both types of snow accretion control plates proved to be effective in preventing snow accretion, the V-shaped type was more effective than the flat type.

(5) There is a difference in level on the lower side of each snow accretion control plate, and snow began to accrete from that part of the signal. To cope with this problem, improved types of snow accretion control plates were developed which have no such difference in level. The amount of snow accreted for the LED-type signal with an improved type of V-shaped snow accretion control plate was about 1/6 of that for the LED-type signal with no snow accretion control plate.

(6) For the bulb-type signal, the difference between the lens surface temperature and the outside air temperature was +15-20°C when the wind speed was 0 m/s. For the LED-type signal, however, it was only about +5°C under the same wind speed condition. The temperature of the snow accretion control plates was nearly the same as the outside air temperature. (See Fig. 6-7.)

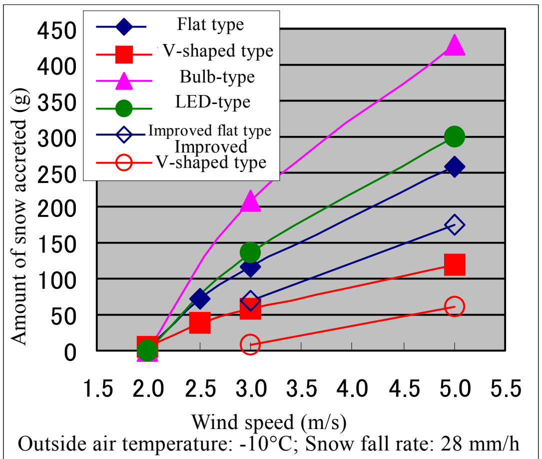


Fig. 6-5 Relation between Wind Speed and Snow

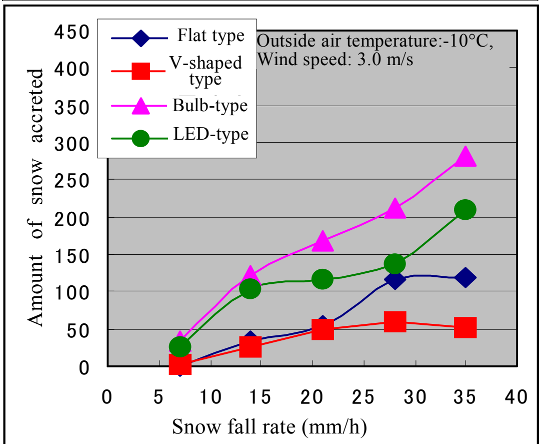


Fig. 6-6 Relation between Snow Fall Rate and Snow Accretion

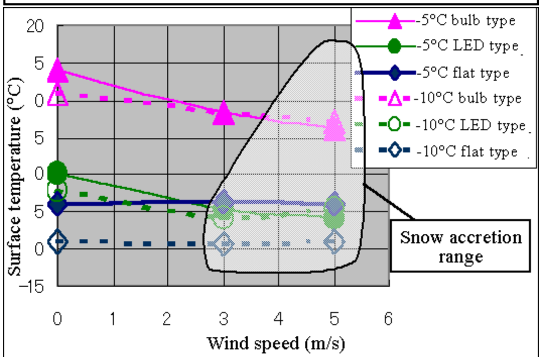


Fig. 6-7 Relation between Wind Speed and Lens Surface Temperature

7. Considerations

7-1. Comparison between the Bulb-Type and LED-Type Signals

(1) No snow accretion occurred when the wind speed was lower than 2 m/s. This phenomenon is attributable to the hood provided for each lens.

(2) The lens surface temperature for the bulb-type signal was +5°C or higher even when the outside air temperature was -10°C and the wind speed was 5 m/s. In our experiments snow accretion occurred even when the lens surface temperature was +10°C. As is clear from photographs of lens surfaces, however, the snow accreted to the lens surface showed signs of slipping down the lens surface due to heat from the lens. It is therefore concluded that although snow accretes to the lens surface during snowfall because the lens surface is cooled by snow and wind blowing on it, the snow disappears from it due to internal heat in relatively short time after the snow and wind go off.

(3) As initially expected, the lens surface temperature for the LED-type signal was only 1 to 5°C higher than the outside air temperature because of the small amount of heat generated by it. It is therefore concluded that when the outside air temperature is -10°C or lower, snow accretion tends to occur more easily in the LED-type signal than in the bulb-type signal. In addition, it is also presumed that for the LED-type signal, it takes considerable time for snow to be melted by heat from the light itself even after the weather clears up.

7-2. Snow Accretion Control Plates

(1) The two types of snow accretion control plates, developed for the purpose of decreasing the possibility of snow accretion through the use of the flow of the wind, had the effect of preventing snow accretion when they are attached to the LED-type traffic signal. In particular, the V-shaped type snow accretion control plate, which guided the wind to the left and right sides of the lower hood, kept snow from accreting all over the lens surface. This type of plate is particularly promising for preventing snow accretion.

(2) The surface temperature of the snow accretion control plates was nearly the same as the outside air temperature. When the outside air temperature is -5°C or lower, snow will not be melt by heat from the signal itself. Consequently, once snow accretes to the lens surface, it will not easily melt away even after it stops snowing, although snow will not easily accrete all over the lens surface. It is therefore desired to further enhance the performance of the snow accretion control plates.

(3) The snow accretion control plates initially had in its lower section a stepped part from which snow began to accrete. Improved types of snow accretion control plates were then developed which has no such step. The amount of snow accreted for the LED-type signal with an improved type of snow accretion control plate was 1/6 of that for the LED-type signal with no snow accretion control plate and 1/2 of that for the LED-type signal with an original stepped snow accretion control plate. It is therefore expected that snow accretion will be further lessened by giving the plate a protrusion-free, more efficient shape with careful regard to the flow of the wind.

8. Conclusion

In the above-described experiments, by using a low-temperature laboratory, we successfully evaluated the performance characteristics of the snow accretion control plates under the same sets of conditions. The experiments have revealed that snow may accrete to the bulb-type signal, depending on the conditions, and snow accretion tends to occur more easily in the LED-type signal than in the bulb-type signal because the former consumes less power and generates less heat than the latter. It has also been verified that even for the traffic signal, snow accretion can be prevented to a certain extent by keeping snow from staying through the use of the flow of the wind. We now intend to analyze the mechanism of snow accretion to determine how the process of snow accretion varies depending on the quality of snow and the material of the lens. In addition, we also plan to conduct verification tests on the snow accretion control effect of the snow accretion control plates, as well as the field visibility of the traffic signal, in order to promote the practical utilization of snow-resistant traffic signals.