FINAL REPORT
CPP PROJECT 9494

MCMURDO STATION SNOW MODELING

McMurdo Station, Antarctica

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TABLE OF CONTENTS

1. INTRODUCTION

In 2015, CPP conducted a snow scouring and deposition modeling study of McMurdo Station in Antarctica (CPP, 2015). The initial study provided the design team valuable information regarding areas of that my pose a challenge due to snow deposition and suggested strategies in building placement and design that would help mitigate snow accumulation.

Since the completion of the previous wind tunnel assessment, three new buildings have been added to the masterplan, the Vehicle Equipment Operations Center (VEOC), Lodging and IT Primary Operations (IT). Furthermore, the footprints of other McMurdo campus buildings have been modified since the last snow modeling effort.

CPP therefore conducted additional physical snow deposition and drift modeling of the modified campus layout of McMurdo Station. For general reference, Figure 1 shows an annotated 3D rendering of the planned McMurdo campus layout.

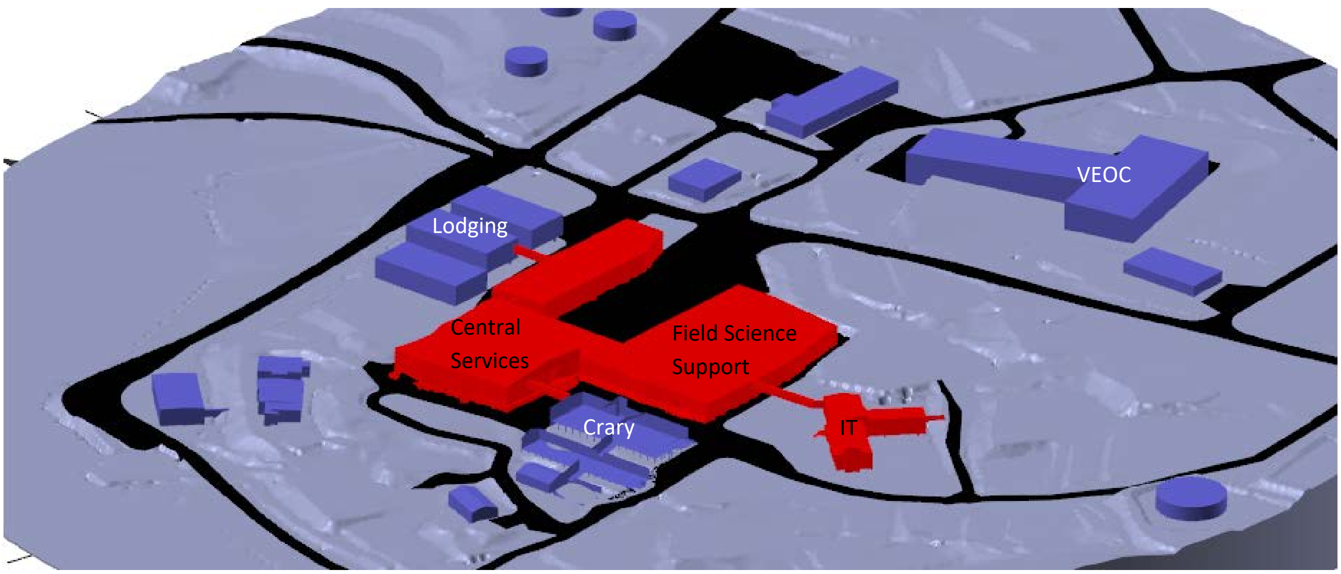


Figure 1. 3D rendering of the McMurdo building layout

The existing 1:240 scale model of the project site was modified and some portions were re-built. The model was placed on a turntable in a boundary layer wind tunnel of CPP, Inc. in Fort Collins, Colorado. An approach boundary layer with the appropriate mean profile and turbulence characteristics representative of a snow and ice environment was established in the test section of the wind tunnel. Modeled snow material was placed on the scale model and high wind speeds drifted the snow. Measurements of snow depth were made for baseline conditions as well as alternate building configurations for the two main wind directions of concern: east (90 deg.) and south-southeast (157.5 deg.). Please refer to the initial McMurdo snow scouring and deposition modeling report (CPP, 2015) for more information on the meteorological data analyzed for the project site.

2. WIND-TUNNEL TEST METHODOLOGY

2.1. WIND TUNNEL SETUP

Please refer to the initial McMurdo snow scouring and deposition modeling report (CPP, 2015) for more information on wind tunnel modeling similarity requirements.

The wind-tunnel test was performed in the boundary-layer wind tunnel shown in Figure 2. Turning vanes at the tunnel elbows were used to maintain a homogeneous flow at the test-section entrance. Spires and a trip at the leading edge of the test section begin the development of the atmospheric boundary layer. The long boundary layer development region between the spires and the site model is usually filled with roughness elements to develop the appropriate approach boundary layer wind profile and approach surface roughness length. For this project, however, the long boundary layer development region was left empty, to develop a boundary layer characteristic for an open snow and ice approach. The wind tunnel has a flexible roof, adjustable in height, to maintain a pressure gradient of zero along the test section and to minimize blockage effects.

The terrain model under study was constructed of insulation foam board at a scale of 1:240, permitting a reasonable test model size with an adequate portion of the adjoining environment to be included in a proximity model, and was well within wind-tunnel blockage limitations. The extent of modeled area on the turntable is shown in Figure 4. Buildings were constructed of foam blocks to the same scale. The IT Building, the Central Services Building edges and the delicate stilts under some of the other buildings were constructed of wood or by stereolithography. Photographs of the model are shown in Figure 3 and in Section 3.

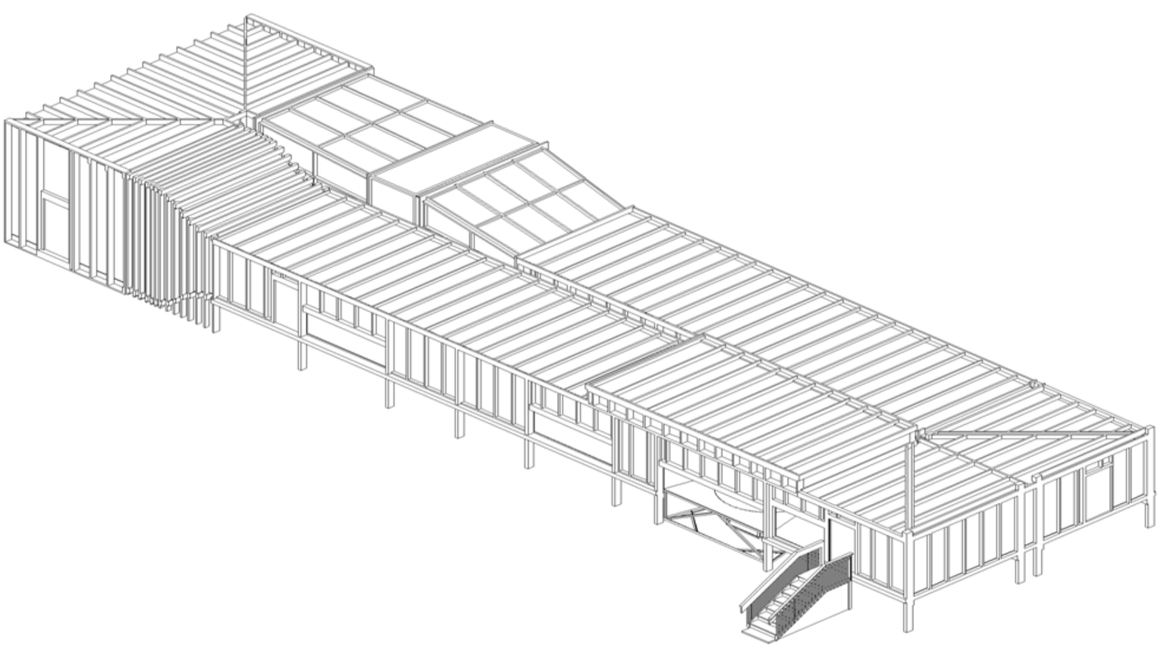


Figure 2 : Schematic of the wind tunnel used for testing.

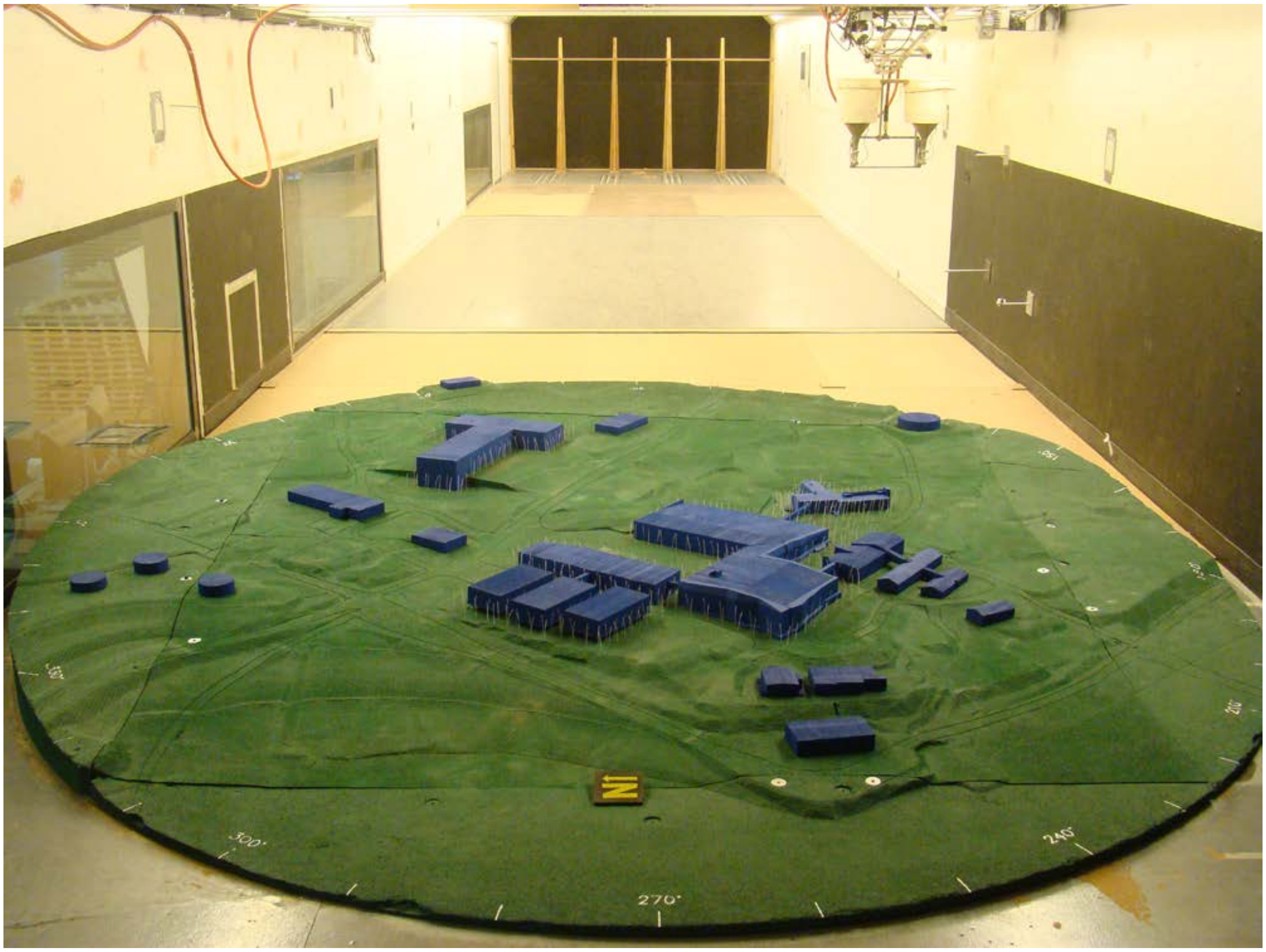
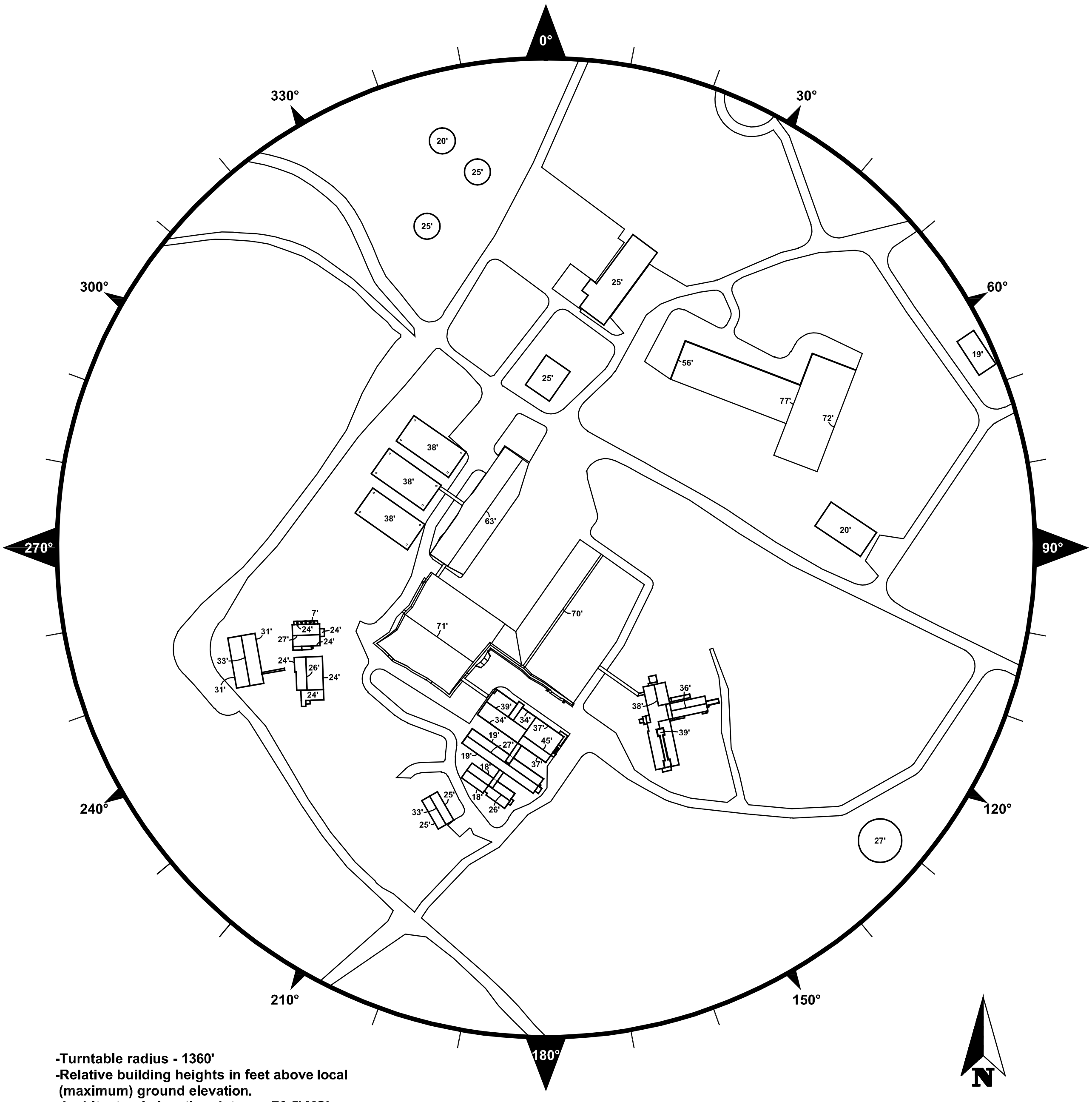


Figure 3 : Photograph of the wind-tunnel configuration. The snow deposition device is visible at the top of the photograph. The light-colored filaments on the model are measurement standards posted at each measurement location.



-Turntable radius - 1360'
-Relative building heights in feet above local (maximum) ground elevation.
-Architectural elevation datum = 73.5' MSL.

CONFIGURATION A

0' 200' 500'
100' 300'

Figure 4a*: Site plan of the McMurdo Station with building heights: Model Configuration A*

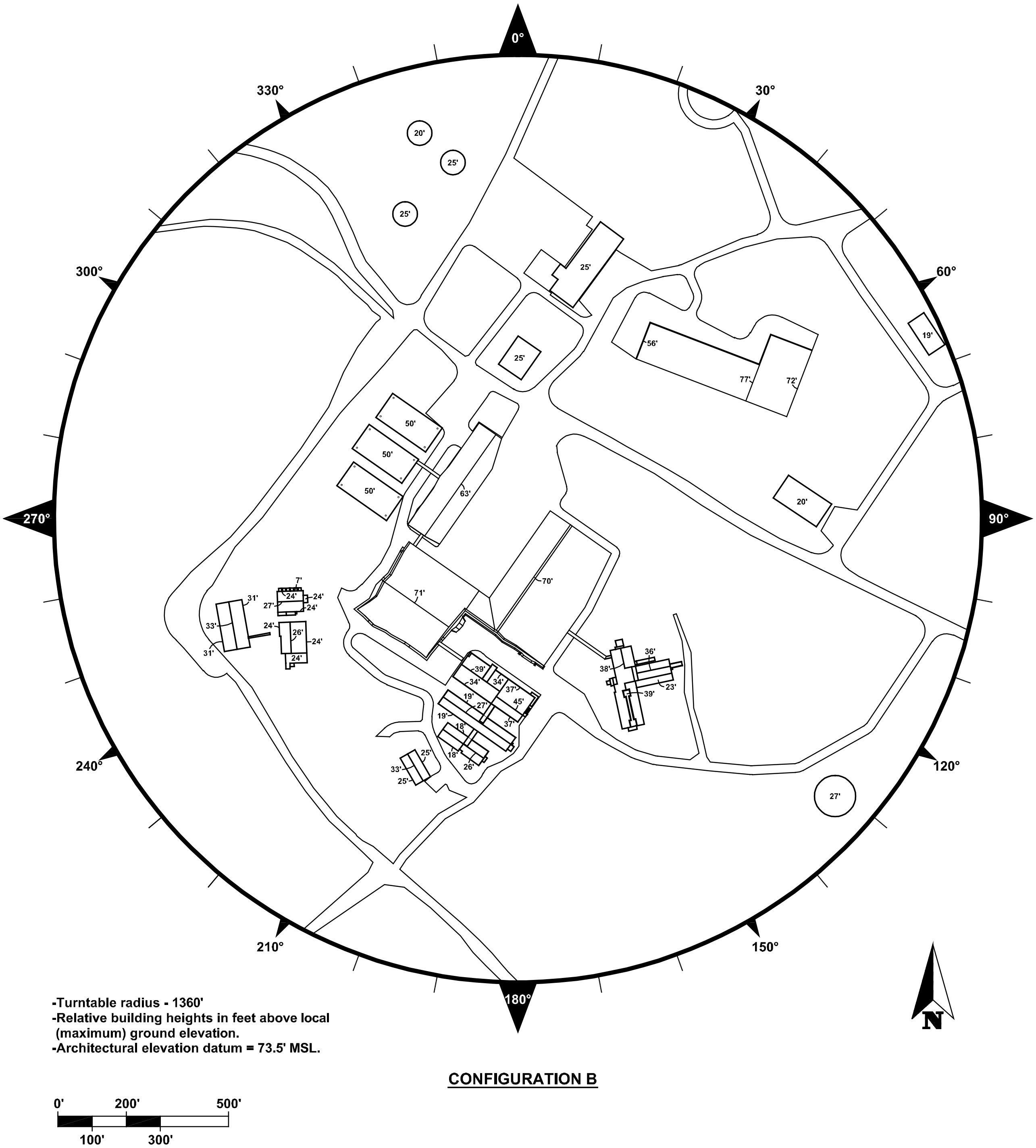


Figure 4b: *Site plan of the McMurdo Station with building heights: Model Configuration B*

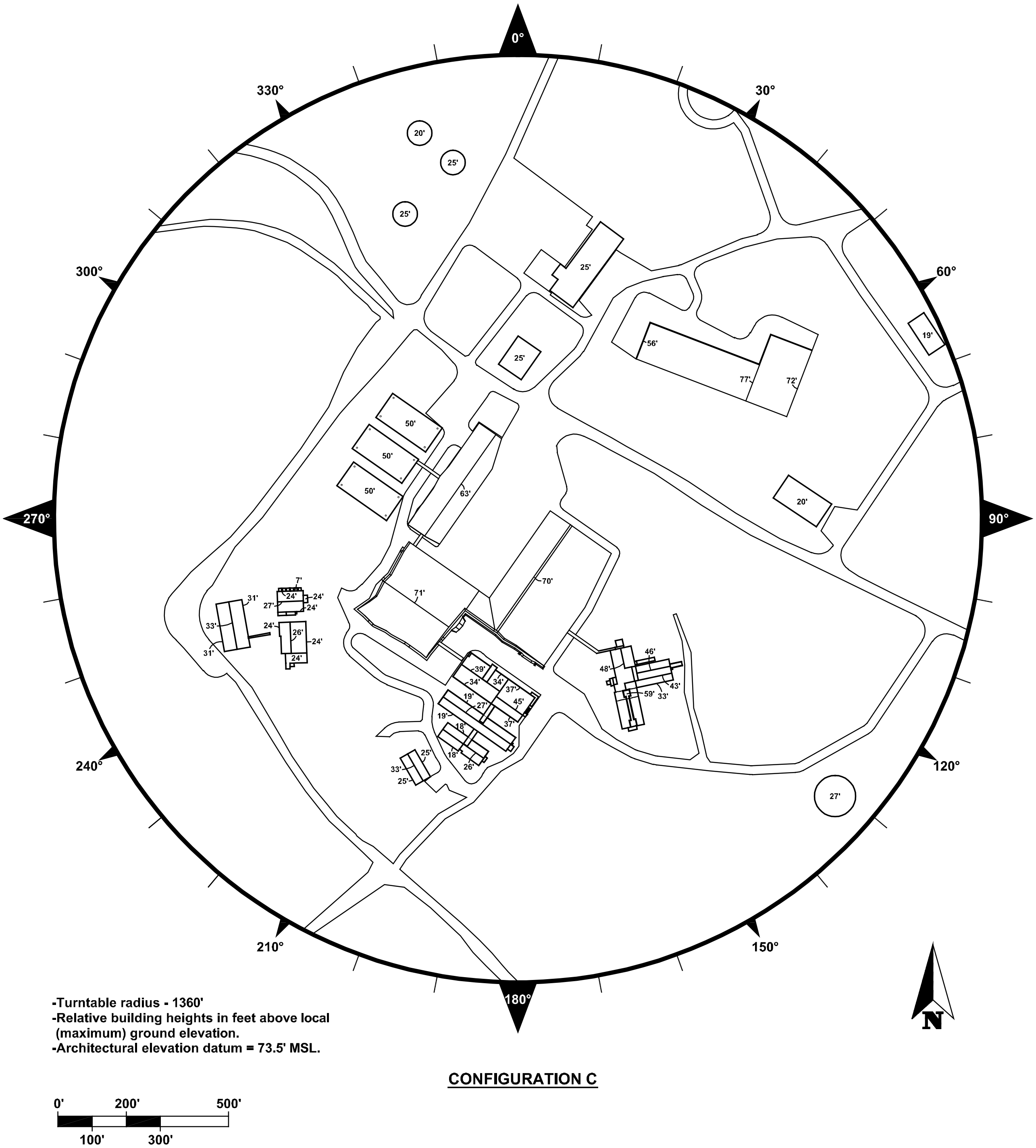


Figure 4c: *Site plan of the McMurdo Station with building heights: Model Configuration C*

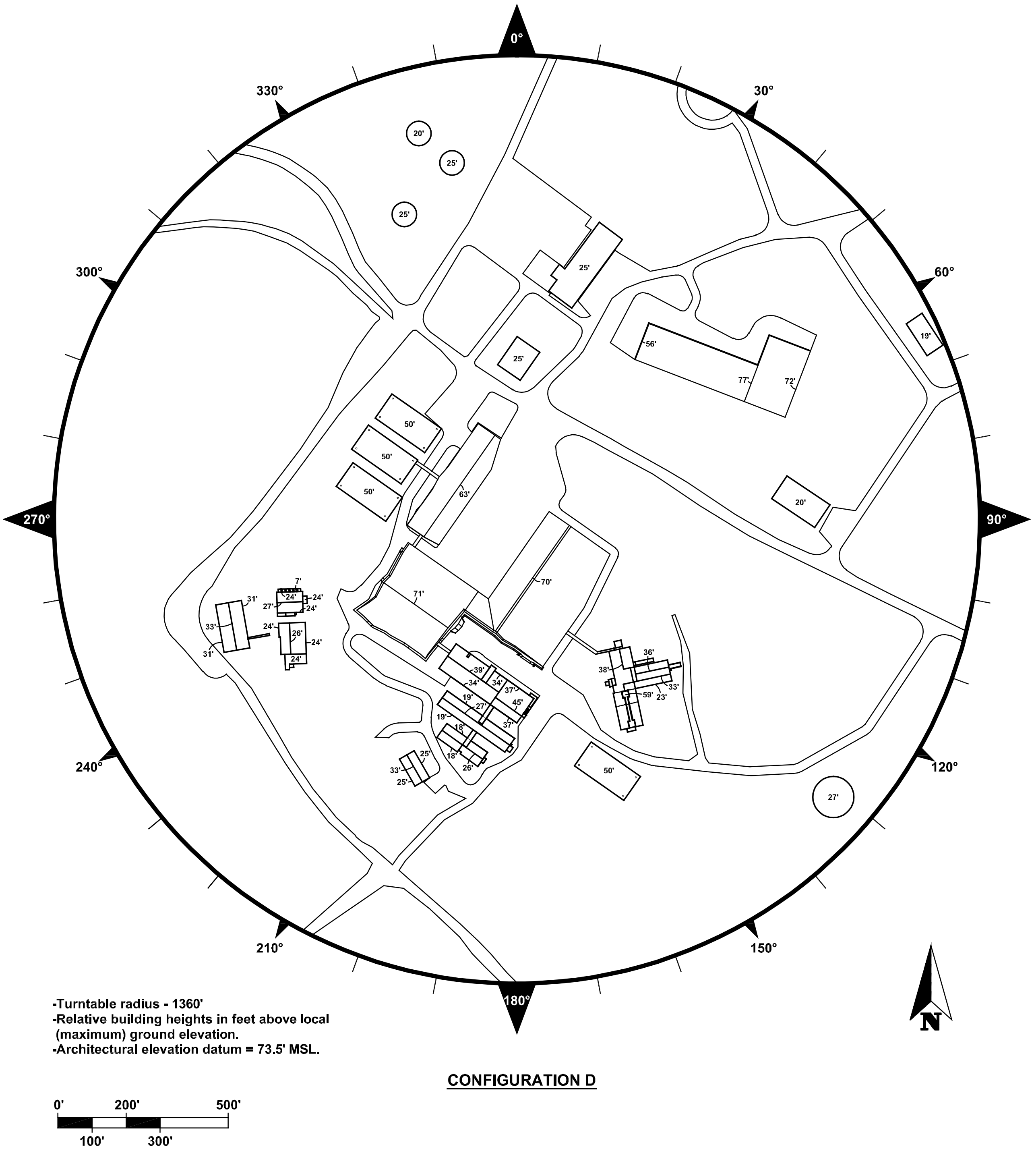


Figure 4d: *Site plan of the McMurdo Station with building heights: Model Configuration D*

Mean velocity and turbulence intensity profiles for the boundary layer flow approaching the modeled area are shown in Figure 5. The mean velocity profile approaching the modeled area can be described in form of the "log-law" and is given by:

$$\frac{U}{U_*} = \frac{1}{k} \ln\left(\frac{z}{z_o}\right)$$

in which U is the mean velocity at height z, U_* is the friction velocity, z_0 is the surface roughness length (z_0=0.001m is estimated in full scale for the open snow/ice exposure of McMurdo Station) and k is von Kàrmàn's constant (which is generally taken to be 0.4). The measured turbulence intensities are appropriate for the approach mean velocity profile selected.

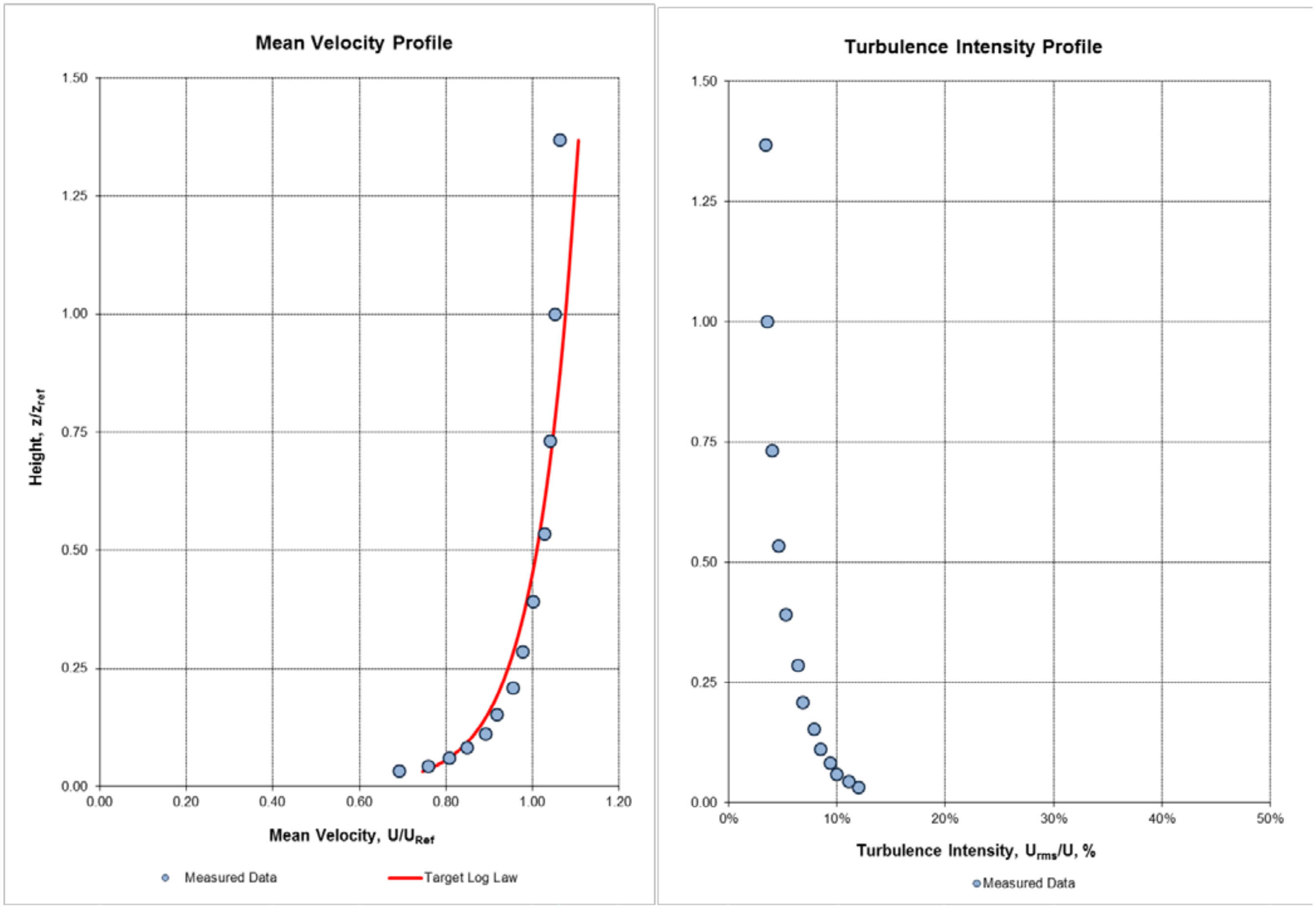


***Figure 5** : Wind tunnel measured velocity and turbulence profiles approaching the model.*

2.2. WIND TUNNEL TEST PROCEDURES

Calibration

A snow deposition device (Figure 3) was positioned above and upstream of the model so that the falling snow would be deposited on the turntable area with a uniform distribution over the test model. A calibration of the system was performed prior to testing with the model replaced by a flat, open-country environment to ensure that a uniform snowfall occurred over the turntable. Wind speed in the wind tunnel was set at 2.5 m/s for the snow deposition. In the calibration, a measured volume of snow was deposited on the open area until its depth was 0.2 inches. Snow measurement sticks were fabricated using thin lengths of plastic, marked with a color scale and were placed at regular intervals in the test section to simplify the snow depth measurement procedure. The baseline depth represents 48 inches full scale, a relatively large snow depth. This is significantly larger than the record for McMurdo of about 14 inches of snowfall in a 24-hour period. The purpose of the wind tunnel study is, however, to establish deposition and drift ratios that can be applied to any large storm.

Testing

The test model was installed in the wind tunnel test section and the same volume of snow described above was deposited. As during the calibration, the wind speed in the wind tunnel was set at 2.5 m/s for the snow deposition. Once the entire amount of snow material was deposited, the wind speed in the wind tunnel was increased to about 12 m/s for a 5 minute interval to simulate the wind-driven snow drift around the project site. This time was long enough to permit maximum transport of deposited snow, and just exceeded the time, at many outlying locations on the model, where accumulation was complete and depletion of the snow was beginning.

Following the drift simulation, the depths of snow material were measured at each test location. Again, snow measurement sticks placed around the main buildings were used to measure the depths. Measurements of the snow material depth on the model yield multiples of the calibrated 0.2-inch depth in the open-country environment. Thus, areas of snow drifting and scouring can be established. Photographs of each test case were taken from multiple angles. After recording depths, the model was cleaned, a new building configuration or new mitigation devices were installed, and a new snow deposition test was performed. These test procedures were repeated for each of the runs. A snow deposition test matrix and results for each area are discussed in the following section.

3. RESULTS

The model was constructed to a linear scale of 1:240, so that 1 ft on the model represents 240 ft in full scale. Effects of snowfall followed by high-speed winds were examined in wind tunnel tests for multiple model configurations. Quantitative and qualitative data were obtained for the two different wind azimuths (90 deg. and 157.5 deg.). Table 1 below lists the different test cases evaluated in the wind tunnel. All measured snow depth data files are available upon request.

Table 1: *Test Plan*

Case Number	Azimuth	Model Configuration
1	90°	**Model Configuration A:** Baseline Testing –
2	157.5°	
3	90°	**Model Configuration B**: Taller dorm buildings Addition of cold storage to IT Building Removal of VEOC Building south portion
4	157.5°	
5	90°	**Model Configuration C**: Same tall dorm buildings and no change in VEOC Building IT Building: alternate bridge, addition of sloped roof to cold storage and increase in overall building height above grade
6	157.5°	
7	90°	**Model Configuration D**: No change in VEOC Building Dorm Buildings: Same tall dorm buildings west of Central Services. Addition of a dorm building south of IT. IT Building: alternate bridge, addition of sloped roof to cold storage and increase in building height above grade of IT addition(existing Building portion stays close to grade), and increase in the width of the breezeway Crary Lab: Extension of Crary Lab building, so the gap between Crary and Central Services matches the previous wind tunnel assessment
8	157.5°	

The following sub-sections describe the model setup for each individual case, present the resulting snow accumulation and scouring areas and discuss the effectiveness of the selected building modifications.

3.1. MODEL CONFIGURATION A – BASELINE TESTING

A site plan of the model configuration A with building heights is shown in Figure 4a. Photographs of the model setup in the wind tunnel are shown below in Figure 6.

Snow material was deposited and drifted on the model as described in Section 2.2. Photographs of the resulting snow accumulation and scouring patterns are shown in Figure 7a and Figure 7b for the east and south-southeast wind directions. Site plans with color-coded measured snow depths for both wind directions are shown in Figure 8. Drawings with snow depths, color-coded by depth, for all cases are shown in Appendix A. The color scale is linear and ranges from blue (less than half of the open field [0.2-inch] calibration depth) to red (more than 2.5 times the open field [0.2-inch] calibration depth).

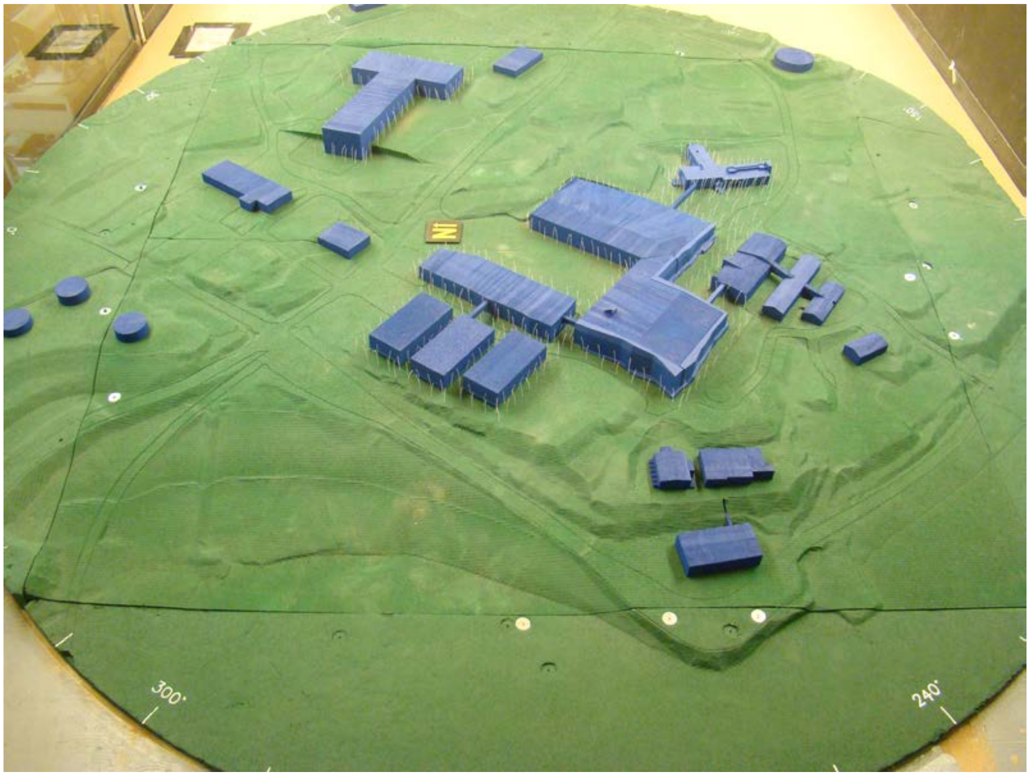


Figure 6a: *Photographs of the model setup in the wind tunnel for Model Configuration A: View from the west.*

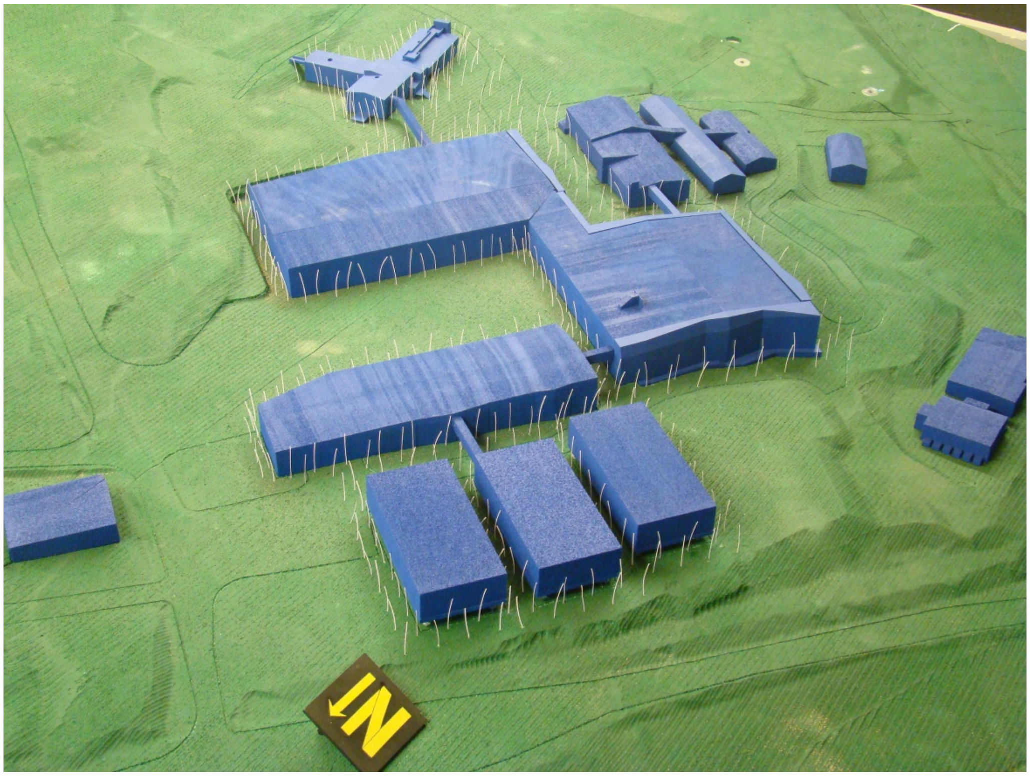


Figure 6b**:** *Photographs of the model setup in the wind tunnel for Model Configuration A: View from the north.*

Figure 6c*: *Photographs of the model setup in the wind tunnel for Model Configuration A: View from the south.

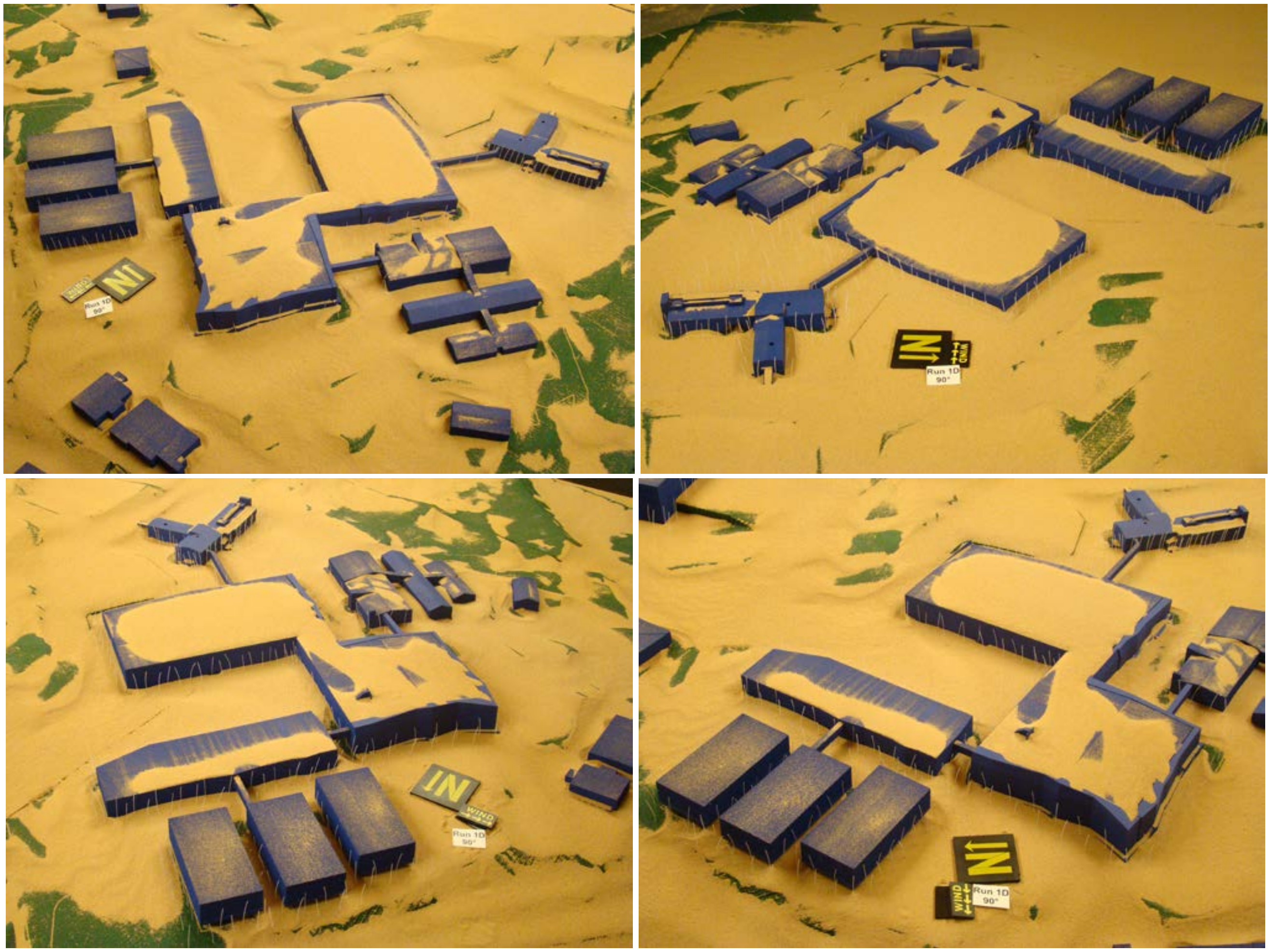


Figure 7a: *Photographs of the snow accumulation and scouring: Case 1: Model Configuration A with a wind direction of 90°.*

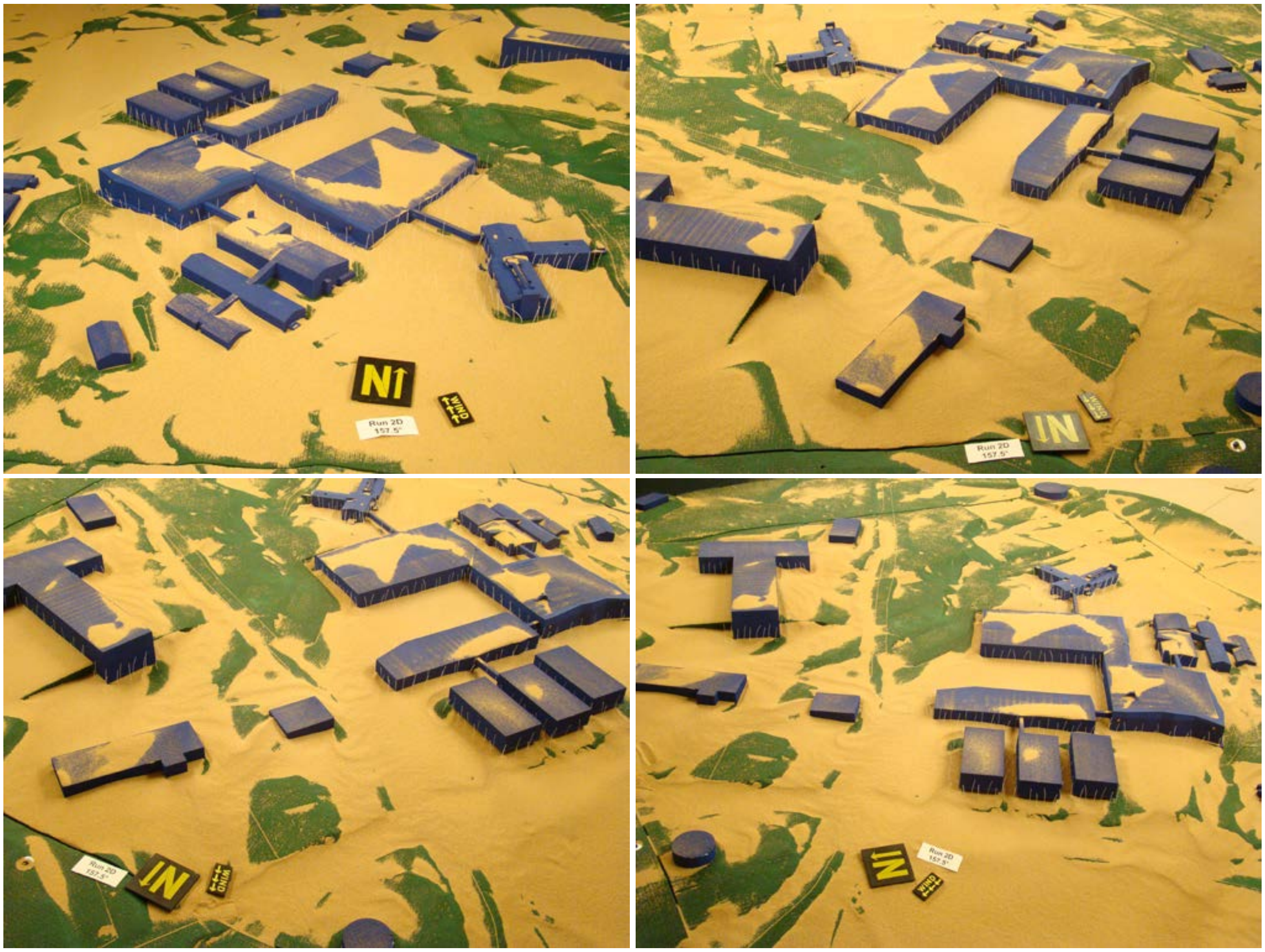


Figure 7b: *Photographs of the snow accumulation and scouring: Case 2: Model Configuration A with a wind direction of 157.5°.*

Figure 8a: Measured snow depths: Case 1: Model Configuration A with a wind direction of 90°.

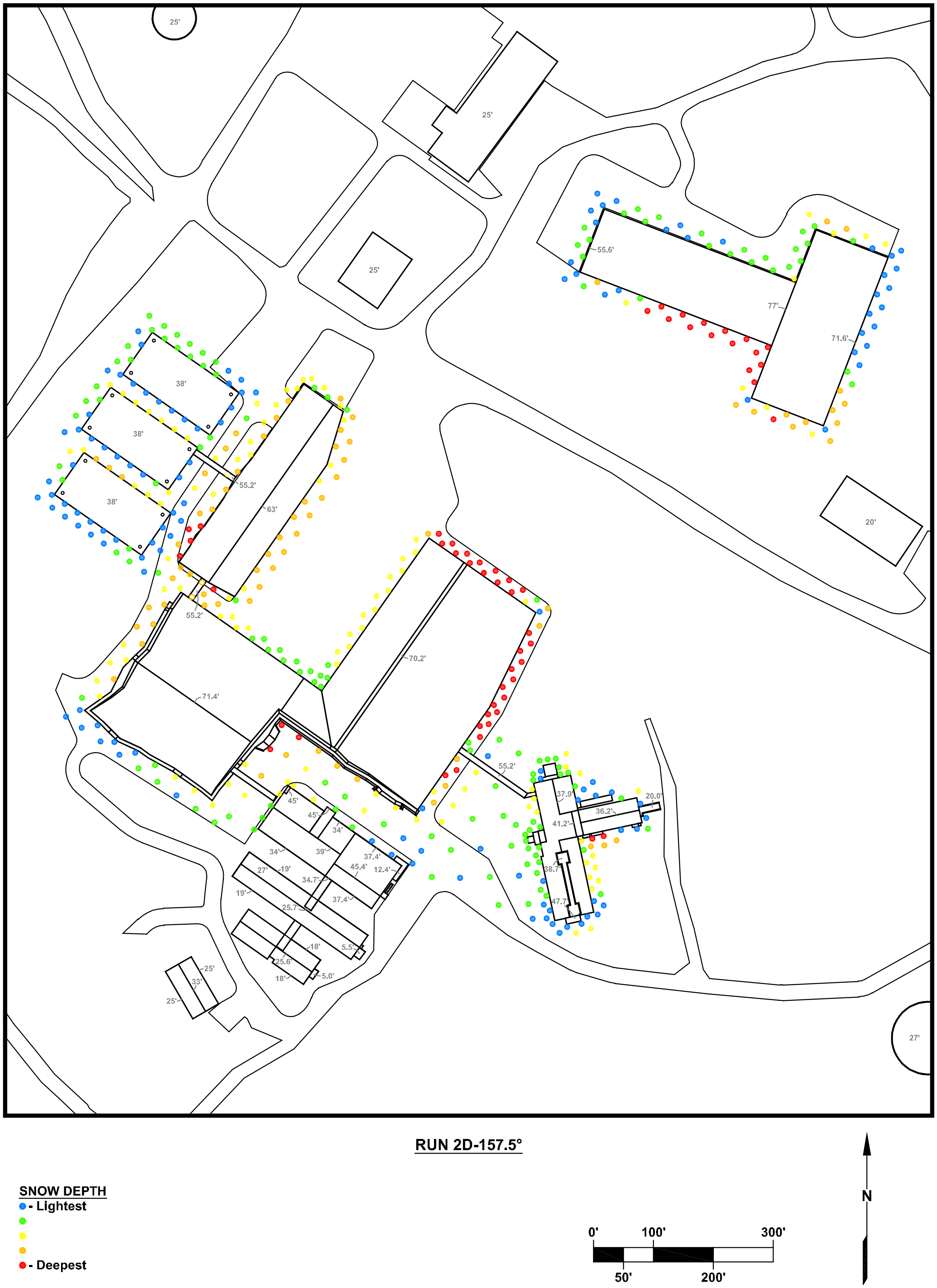


***Figure 8b**: Measured snow depths: Case 2: Model Configuration A with a wind direction of 157.5°.*

VEOC

The snow accumulation around the VEOC is shown in the photographs below. Only a slight increase above ambient snow levels can be seen along the east wall of the VEOC building for easterly wind directions. For south-southeast winds, significant snow accumulation is observed along the southern building walls. Snow scour is observed in places where the wind accelerates, such as around corners. For the south-southeast wind direction, snow along the east side of the building is almost completely scoured away.

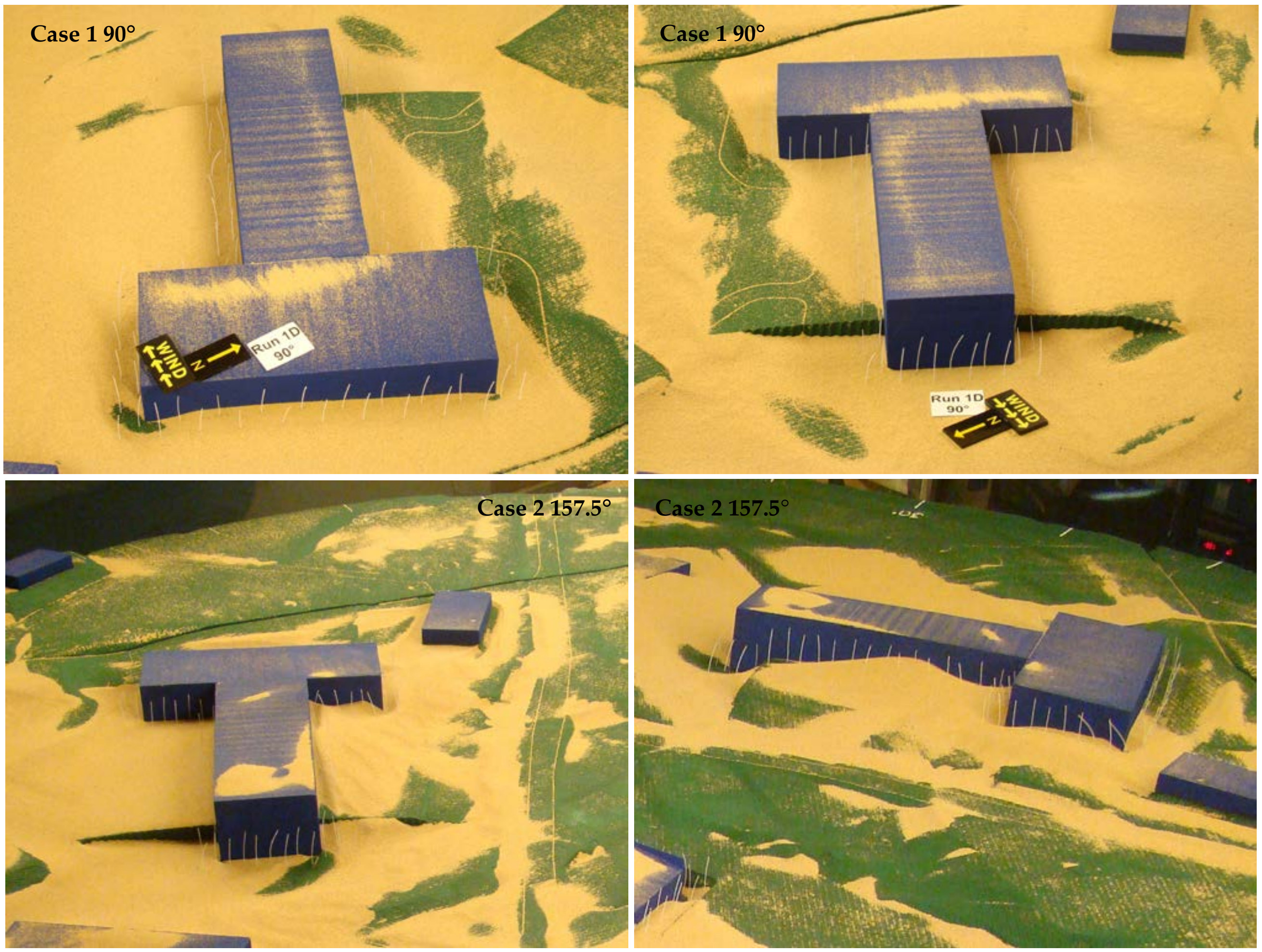


***Figure 9** : Photographs of the snow accumulation and scouring around the VEOC (Model Configuration A).*

IT

Photographs of the snow accumulation around the IT Building are shown in Figure 10 below. Significant snow accumulation can be seen in the pocket created by the existing east wing and the new south wing of the building. The breezeway stayed mostly clear of snow for both wind directions.

***Figure 10** : Photographs of the snow accumulation and scouring around the IT Building (Model Configuration A).*

Lodging

Overall, snow deposition around the Lodging Buildings is minor, as shown in the photographs below. The wind accelerates around the building corners, scouring the snow in these areas. Some accumulation can be observed between the buildings; however, the area underneath the buildings stays fairly clear.

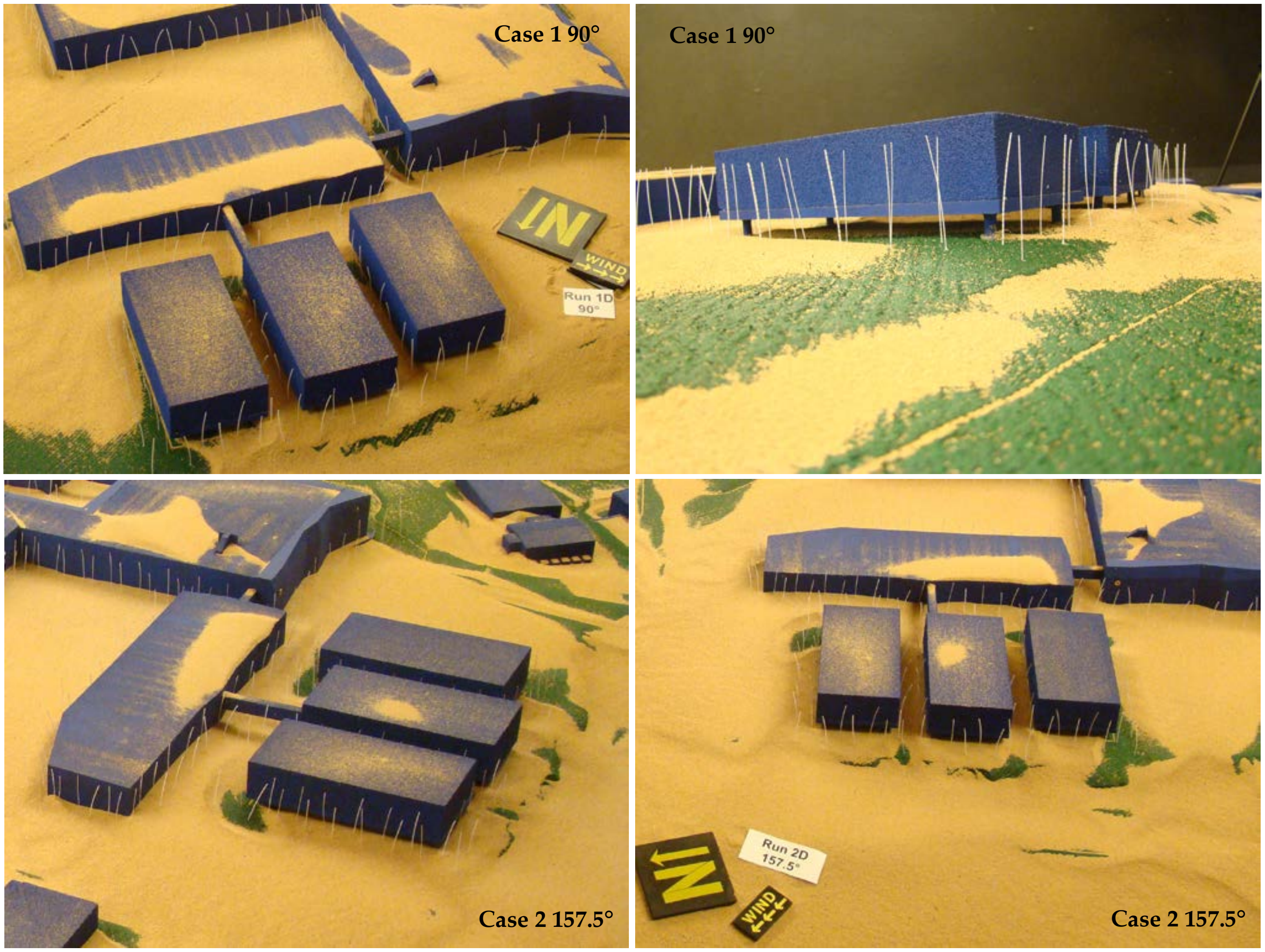


***Figure 11** : Photographs of the snow accumulation and scouring around the Lodging Buildings (Model Configuration A).*

Other Areas of Concern

For both wind directions, significant snow accumulation was observed along the north walls of the main entrance area (similar to the accumulation observed during the previous wind tunnel assessment), as well as along the east wall of the Field Science Support Building (see photos below).

Significant snow scouring was observed between Crary and Field Science Support and along the gap between Central Services and Crary. For the 157.5° wind direction, wind flows both through the gap between Central Services and Crary and along the main entry way, creating a snow trap in the northwest corner of the main entrance area.

The proposed grading plan creates a pocket along the north and east sides of the Field Science Support Building, which –fills almost completely with the snow material.

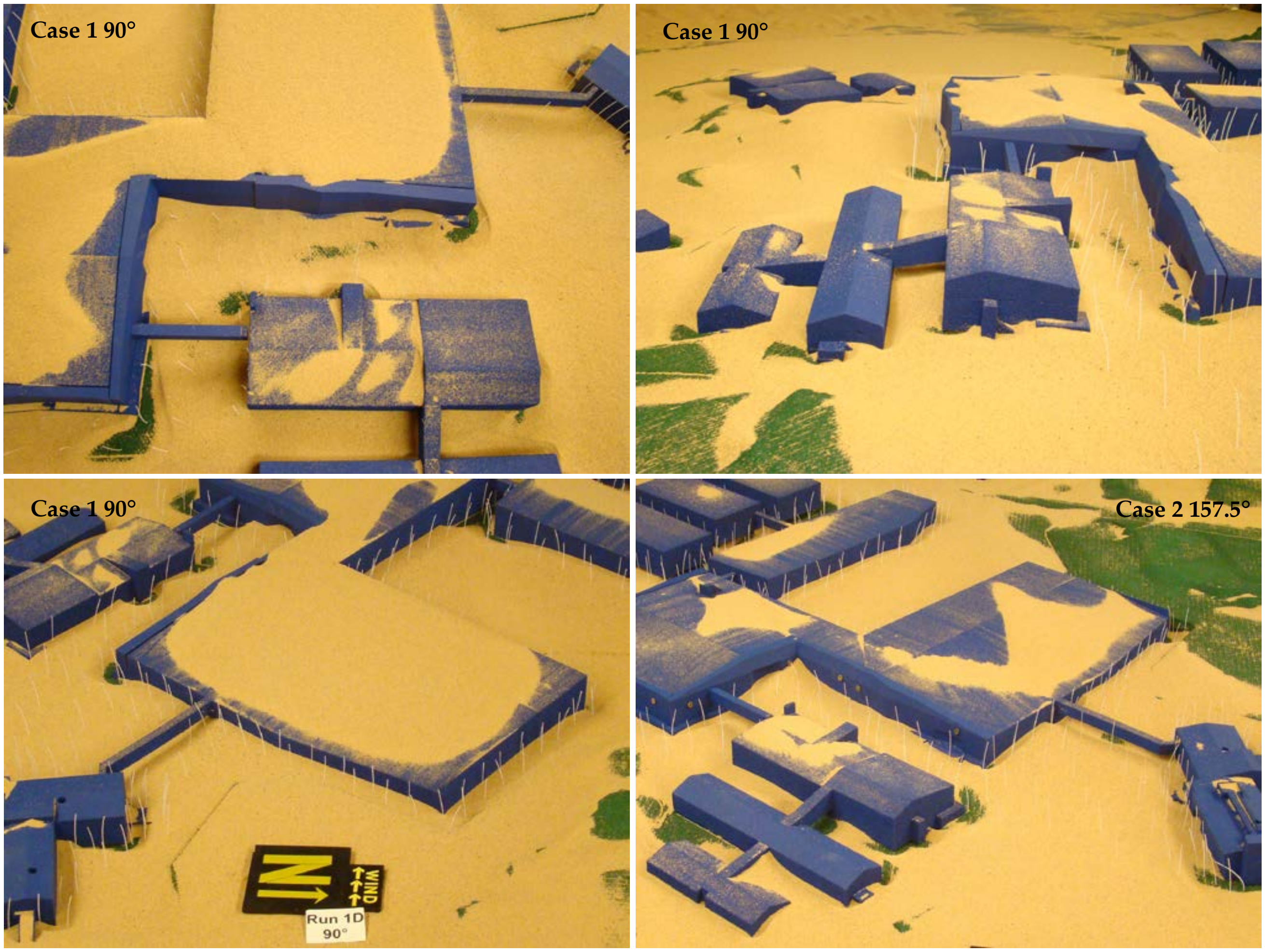


***Figure 12** : Photographs of the snow accumulation and scouring around the Central Services and Field Science Support Buildings (Model Configuration A).*

3.2. MODEL CONFIGURATION B

Several building changes were evaluated for the two different wind directions. In Cases 3 and 4, taller dorm buildings were installed and the cold storage facility was added to the IT Building. The south wing of the VEOC Building was removed as well. Photographs of the individual buildings are shown below (Figure 13).

***Figure 13**: Photographs of the model setup in the wind tunnel for Model Configuration B.*

Photographs of the resulting snow accumulation and scouring patterns for Cases 3 and 4 are shown in Figure 14 Drawings with the color-coded snow depths for all test cases are shown in Appendix A.

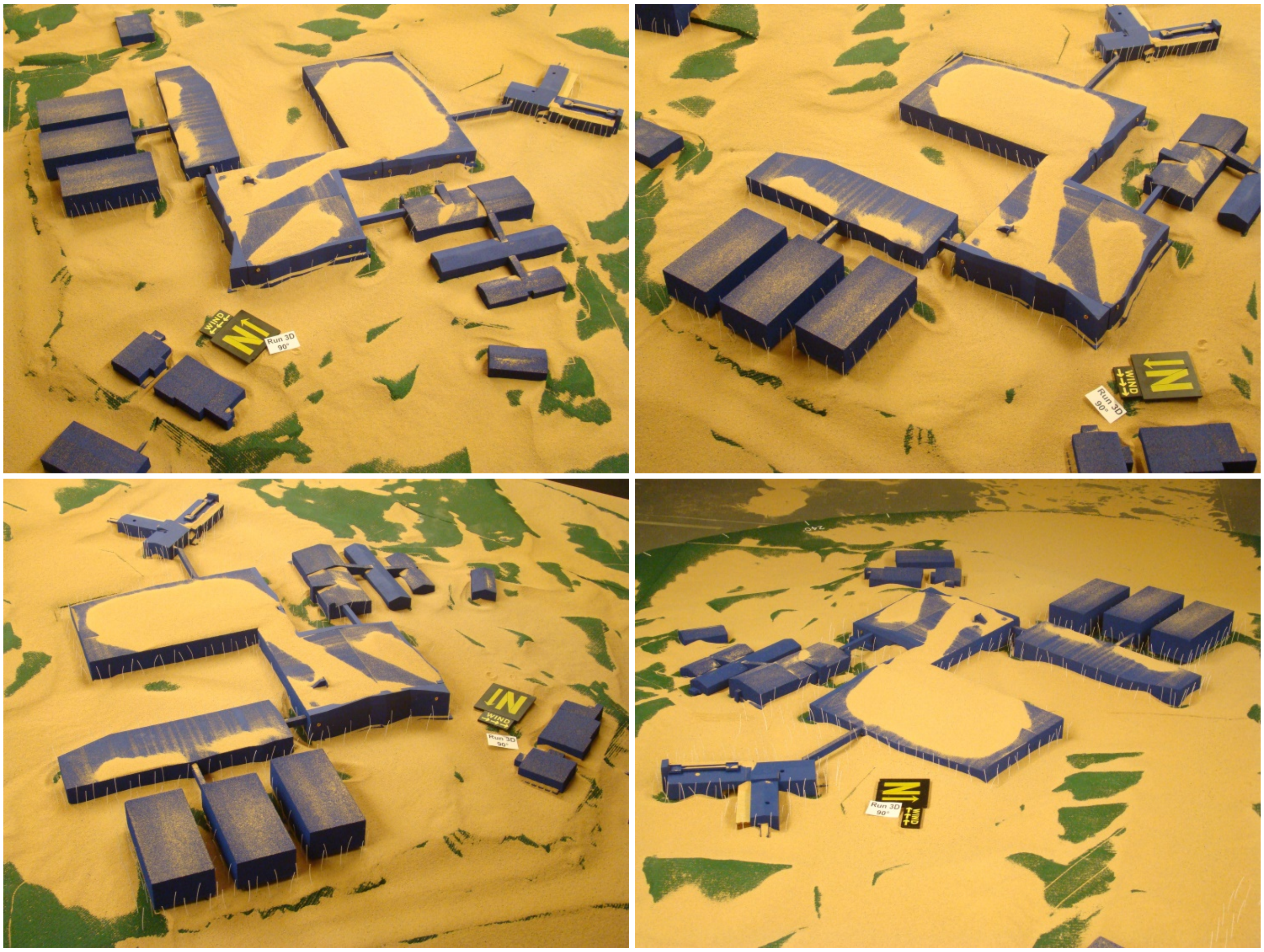


Figure 14a: *Photographs of the snow accumulation and scouring: Case 3: Model Configuration B with a wind direction of 90°.*

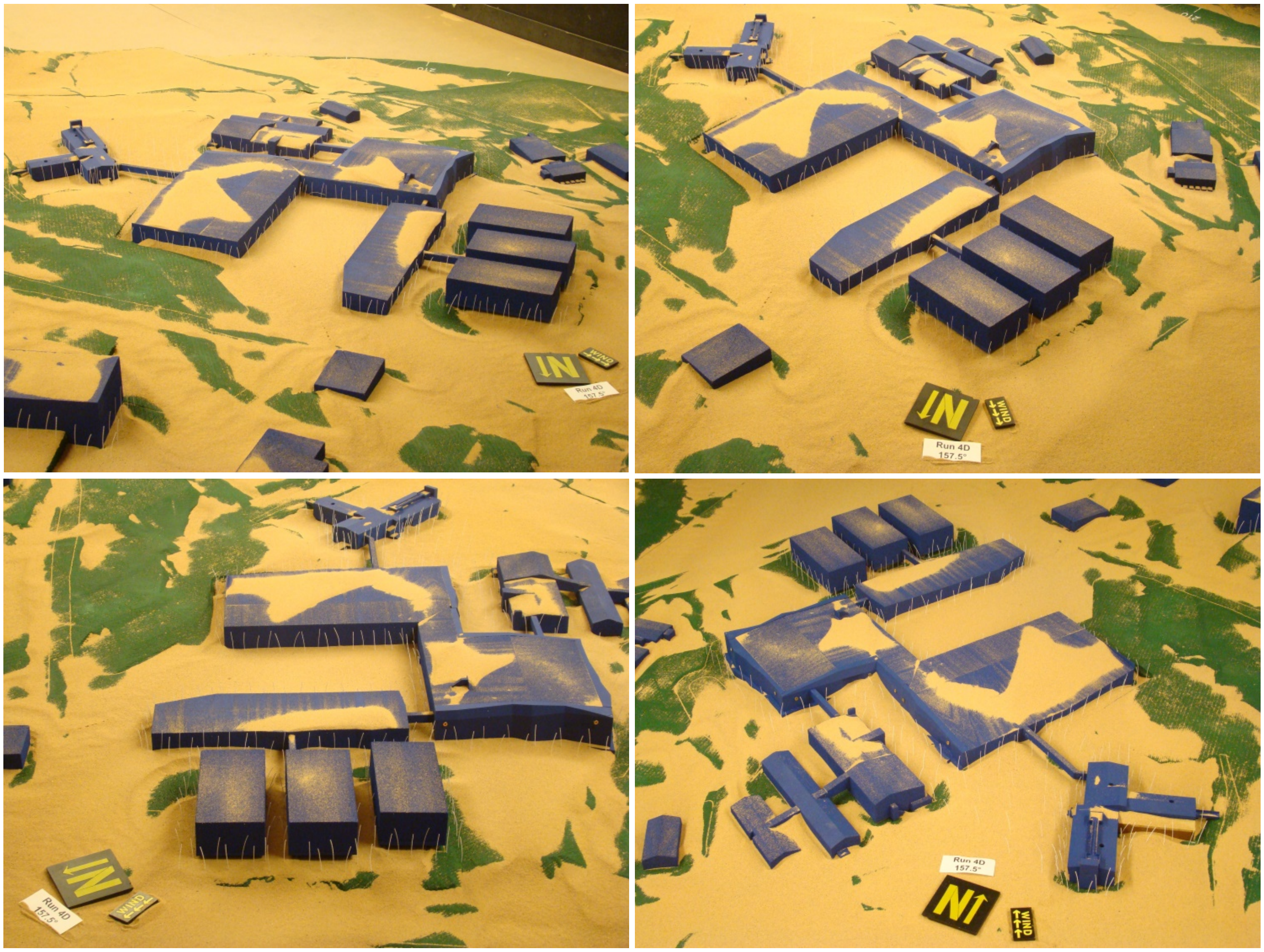


Figure 14b**:** *Photographs of the snow accumulation and scouring: Case 4: Model Configuration B with a wind direction of 157.5°.*

<u>VEOC</u>

Removing the south wing of the VEOC Building did not change the snow accumulation around the building significantly, see photographs in Figure 15 below. For both wind directions, the wind accelerates around the southeast building corner, scouring most of the snow material in that area.

Removing the south wing of the VEOC Building also caused a slight shift of the main snow deposition farther to the west along the southern building wall, as illustrated in Figure 16. The overall area around the VEOC with significant snow deposition was reduced slightly without the south wing, potentially reducing the amount of snow removal needed around the perimeter of the building.

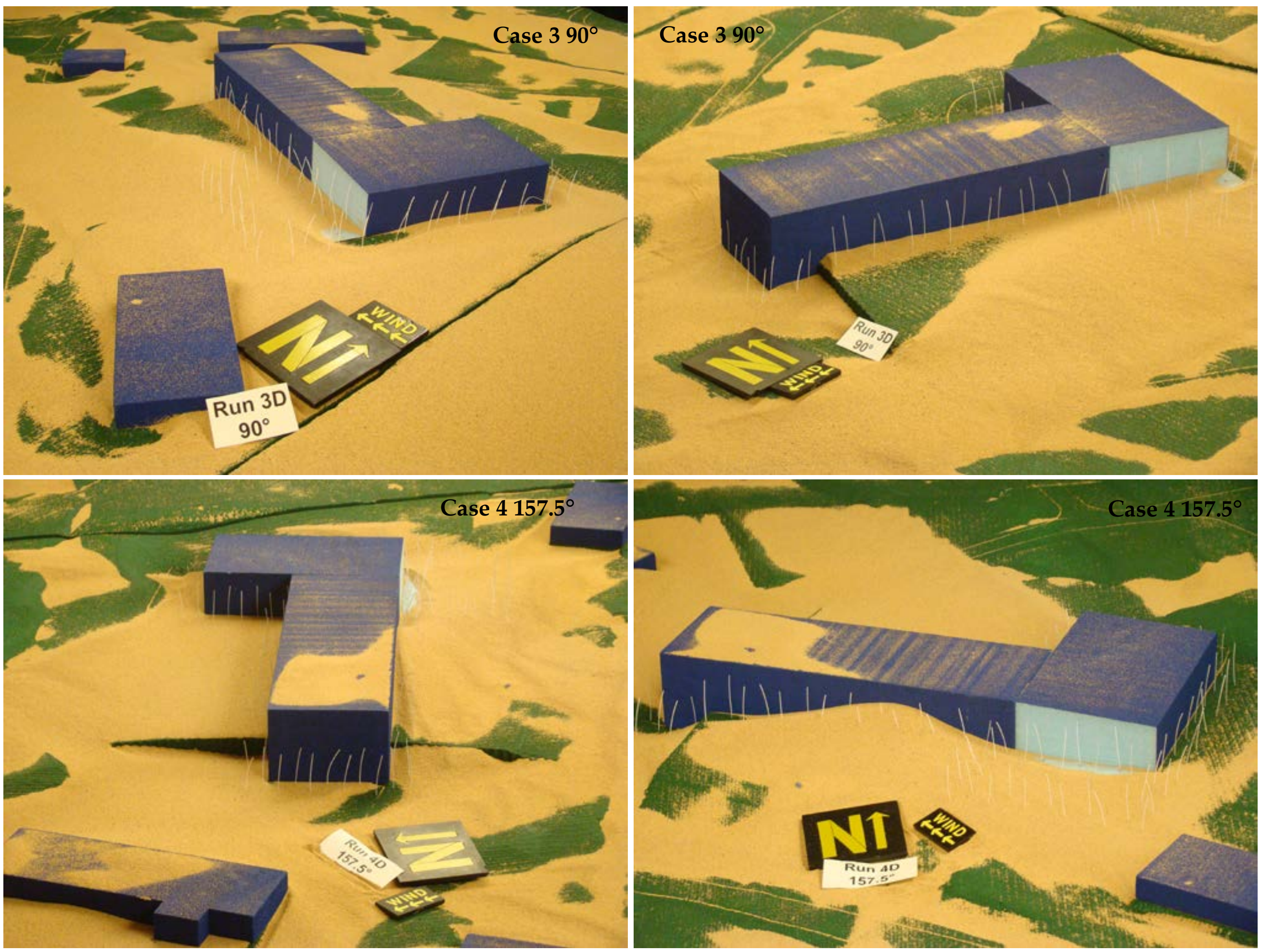


Figure 15 *: Photographs of the snow accumulation and scouring around the VEOC (Model Configuration B).*

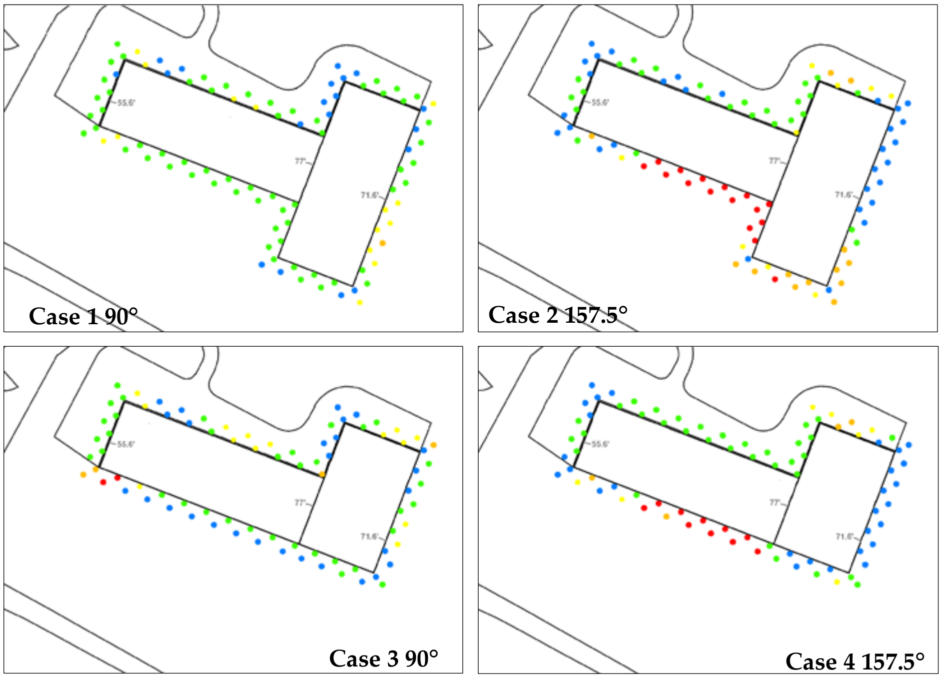


***Figure 16** : Comparison of the snow accumulation and scouring around the VEOC for Model Configurations A and B.*

IT

For Building Configuration B, a cold storage facility was added to the IT Building. Photographs of the snow accumulation around the IT Building are shown in Figure 17 below. Overall, the snow accumulation around the building did not change significantly due to the building modifications.

The roof of the cold storage addition shows some snow accumulation due to the lower height than the surrounding roofs. As for the previous model configuration, significant snow accumulation can be seen in the pocket created by the existing east wing and the new south wing of the building. The breezeway stayed mostly clear of snow for both wind directions.

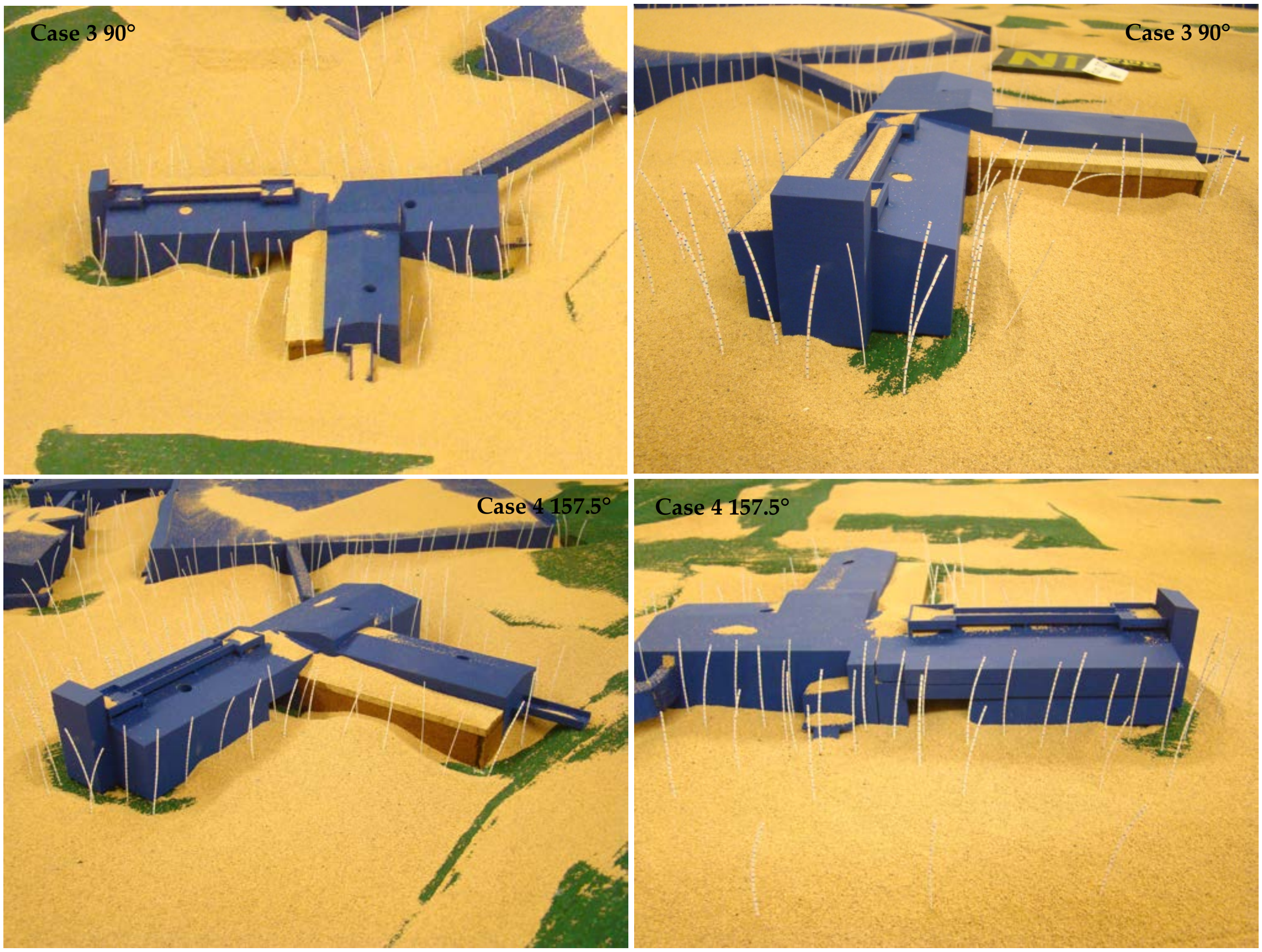


***Figure 17** : Photographs of the snow accumulation and scouring around the IT Building (Model Configuration B).*

Lodging

The Lodging Buildings increased in height for this Building Configuration. Photographs of the snow accumulation around the Lodging Buildings are shown in Figure 18 below.

Overall, snow deposition around the Lodging Buildings was minor for Building Configuration A and was reduced even more with the additional building height (see Figure 19). Again, significant scour around building corners can be seen due to accelerations of the wind in these areas.

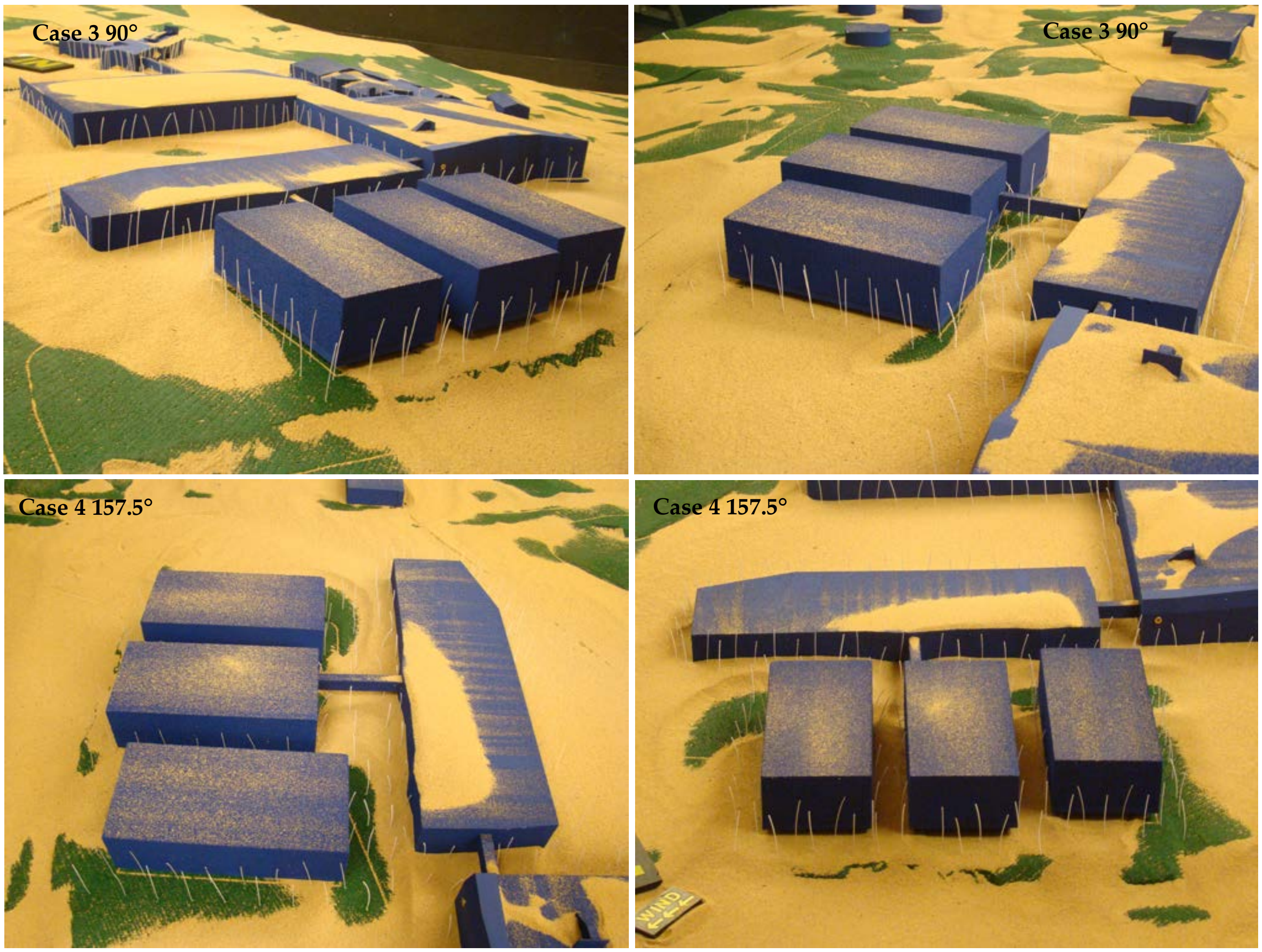


***Figure 18** : Photographs of the snow accumulation and scouring around the Lodging Buildings (Model Configuration B).*

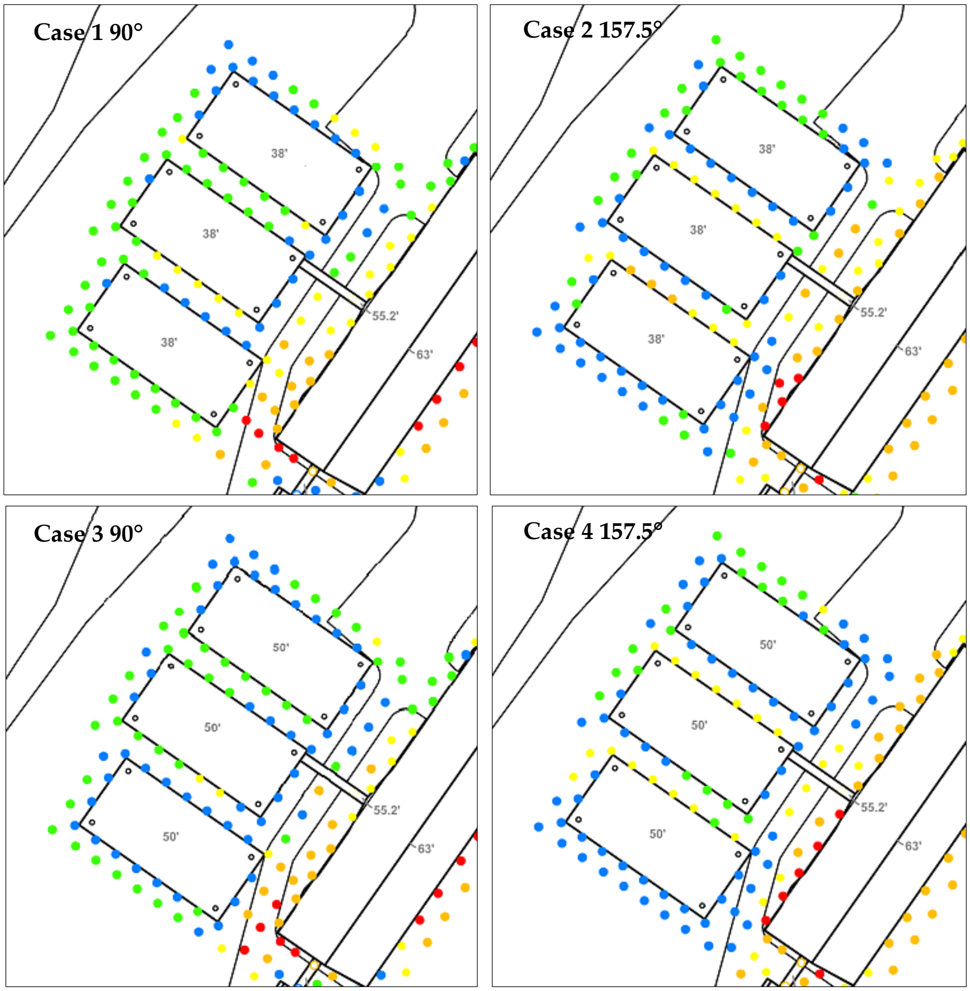


Figure 19 *: Comparison of the snow accumulation and scouring around the Lodging Buildings for Model Configurations A and B.*

3.3. MODEL CONFIGURATION C

In Cases 5 and 6, the taller Lodging Buildings remained and the VEOC Building layout stayed unchanged. An alternate bridge was installed connecting the Field Science Support and the IT Buildings. The roof of the added cold storage facility of the IT Building was sloped upward and the overall IT Building height above grade was increased. Photographs of the IT Building modifications are shown below (Figure 20).

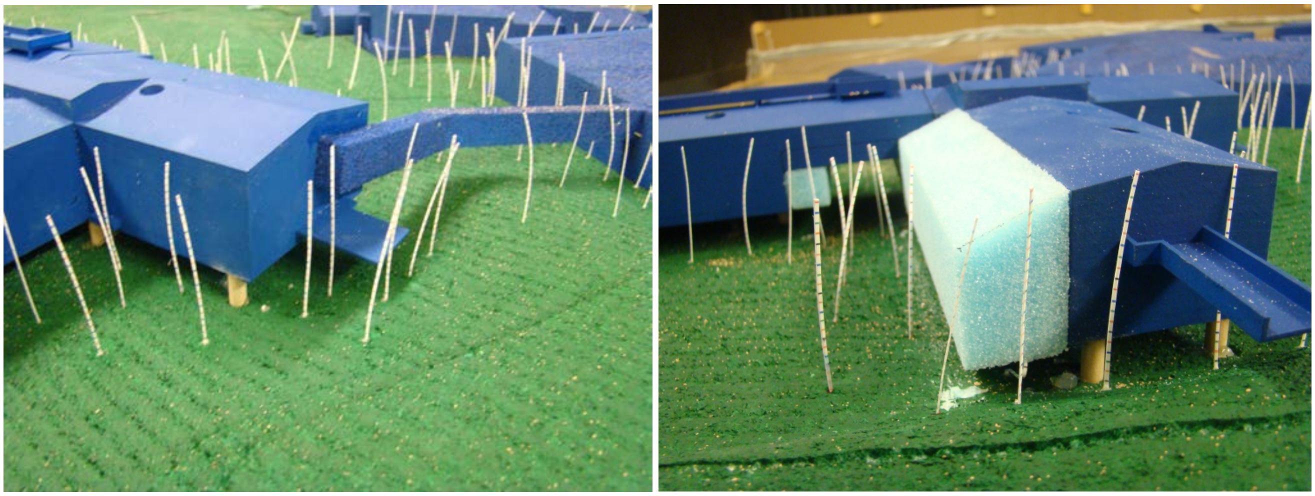


***Figure 20**: Photographs of the model setup in the wind tunnel for Model Configuration C.*

Photographs of the resulting snow accumulation and scouring patterns for Cases 5 and 6 are shown in Figure 21. Drawings with the color-coded snow depths for all test cases are shown in Appendix A.

***Figure 21a**: Photographs of the snow accumulation and scouring: Case 5: Model Configuration C with a wind direction of 90°.*

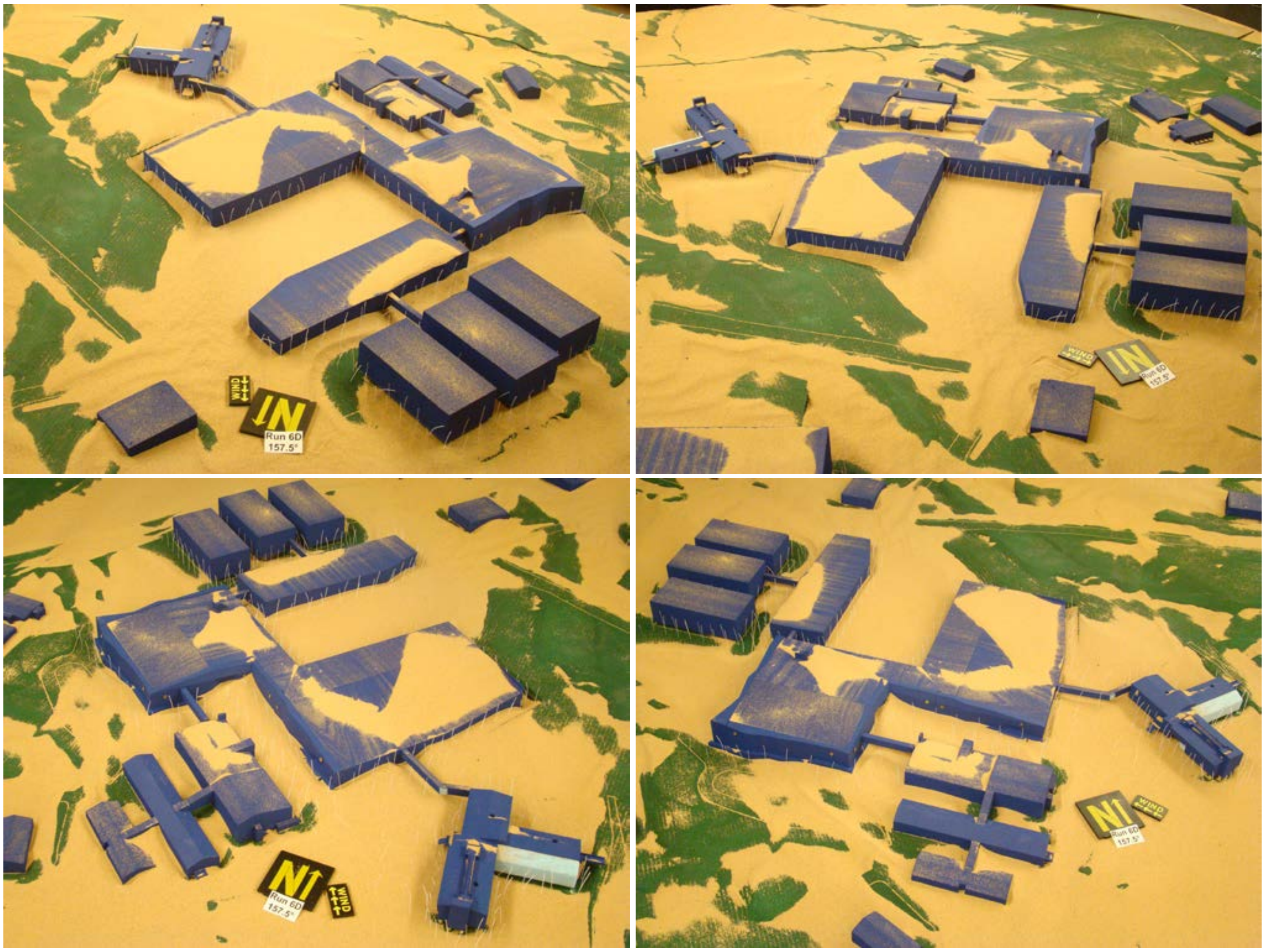


***Figure 21b**: Photographs of the snow accumulation and scouring: Case 6: Model Configuration C with a wind direction of 157.5°.*

IT

For Building Configuration C, the roof of the added cold storage facility was sloped upward to connect with the east wing roof. The overall IT Building height above grade was increased, raising the entire building up on stilts. In addition, an alternate bridge was installed connecting the Field Science Support and the IT Buildings.

Photographs of the snow accumulation around the IT Building are shown in Figure 22 below. Overall, the snow accumulation around the building decreased significantly (see Figure 23). The gap underneath the building allows air flow and snow scouring; significantly reducing the snow accumulation around the building. The breezeway stayed clear of snow as well.

The sloped cold storage roof eliminates the snow accumulation due to roof the height differences in Building Configuration B. The change of the bridge connecting the IT Building to Field Science Support had no impact on the surrounding snow accumulation patterns.

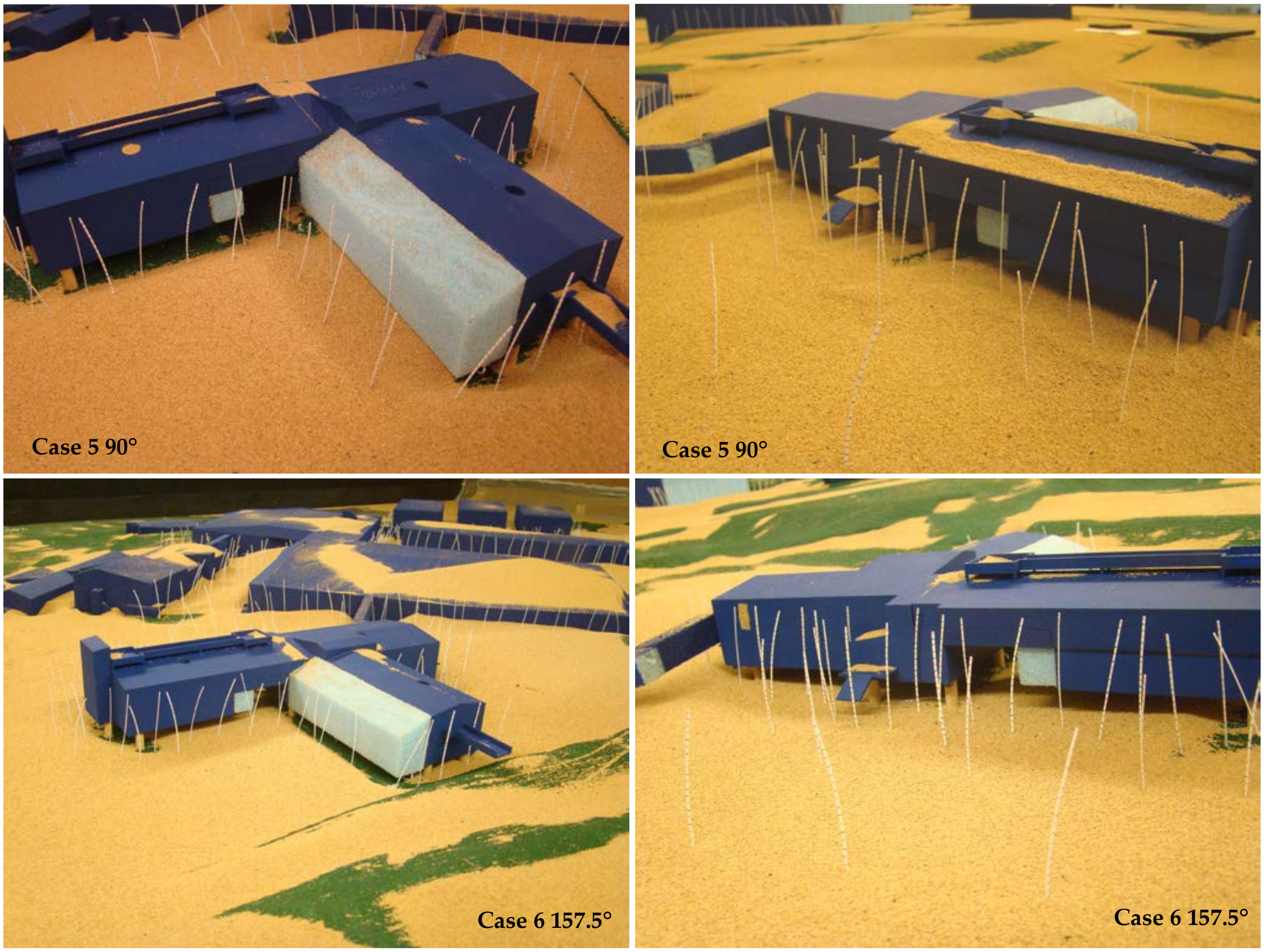


***Figure 22** : Photographs of the snow accumulation and scouring around the IT Building (Model Configuration C).*

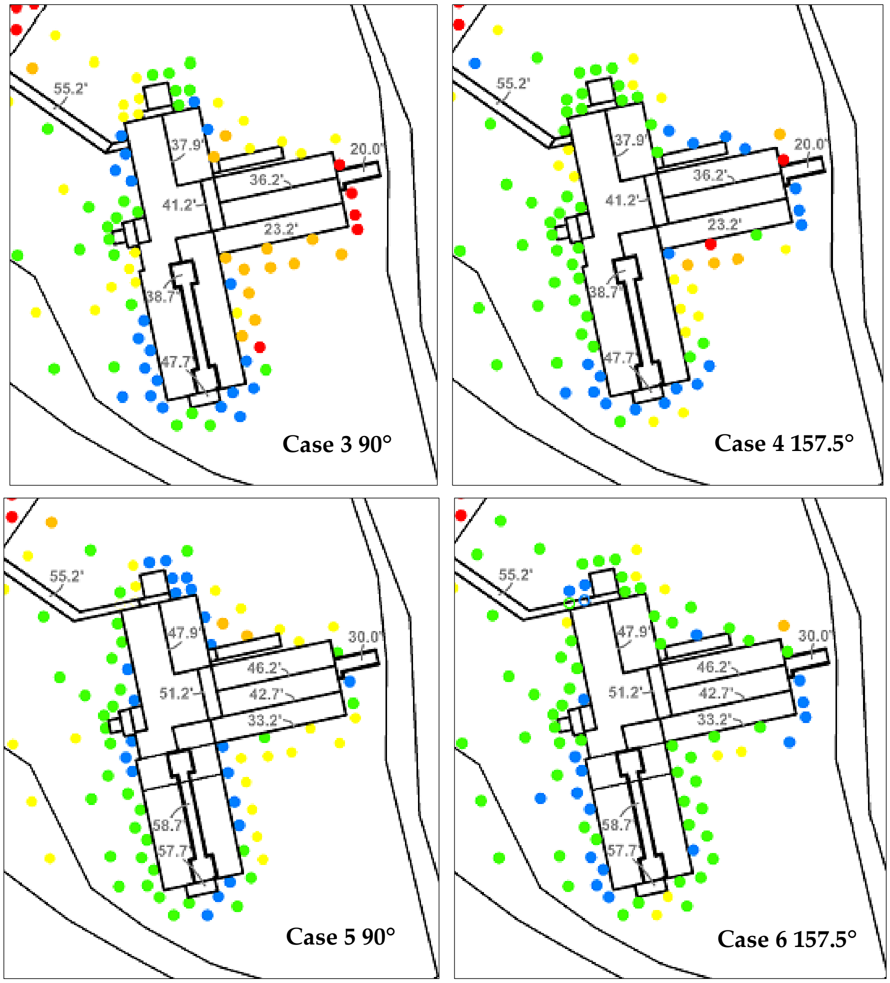


Figure 23 *: Comparison of the snow accumulation and scouring around the IT Building for Model Configurations B and C.*

3.4. MODEL CONFIGURATION D

In model Configuration D, no changes were made to the VEOC Building. The taller Lodging Buildings west of the Central Services Buildings remained; however, an additional Lodging Building of the same height was placed south of the IT Building. The alternate bridge configuration of the IT Building remained, as did the addition of the sloped roof to cold storage. The height of the IT Building above grade changed, however. The existing IT Building portions (north and east wings) stayed close to grade and the new building portion (south wing) was raised ~10ft above grade on stilts. Furthermore, the width of the IT Building breezeway was increased. The Crary Lab Building was extended to the west, in an effort to reduce the width of the gap between Crary and Central Services, to more closely match the previous wind tunnel assessment.

Photographs of the added and modified Buildings are shown below (Figure 24).

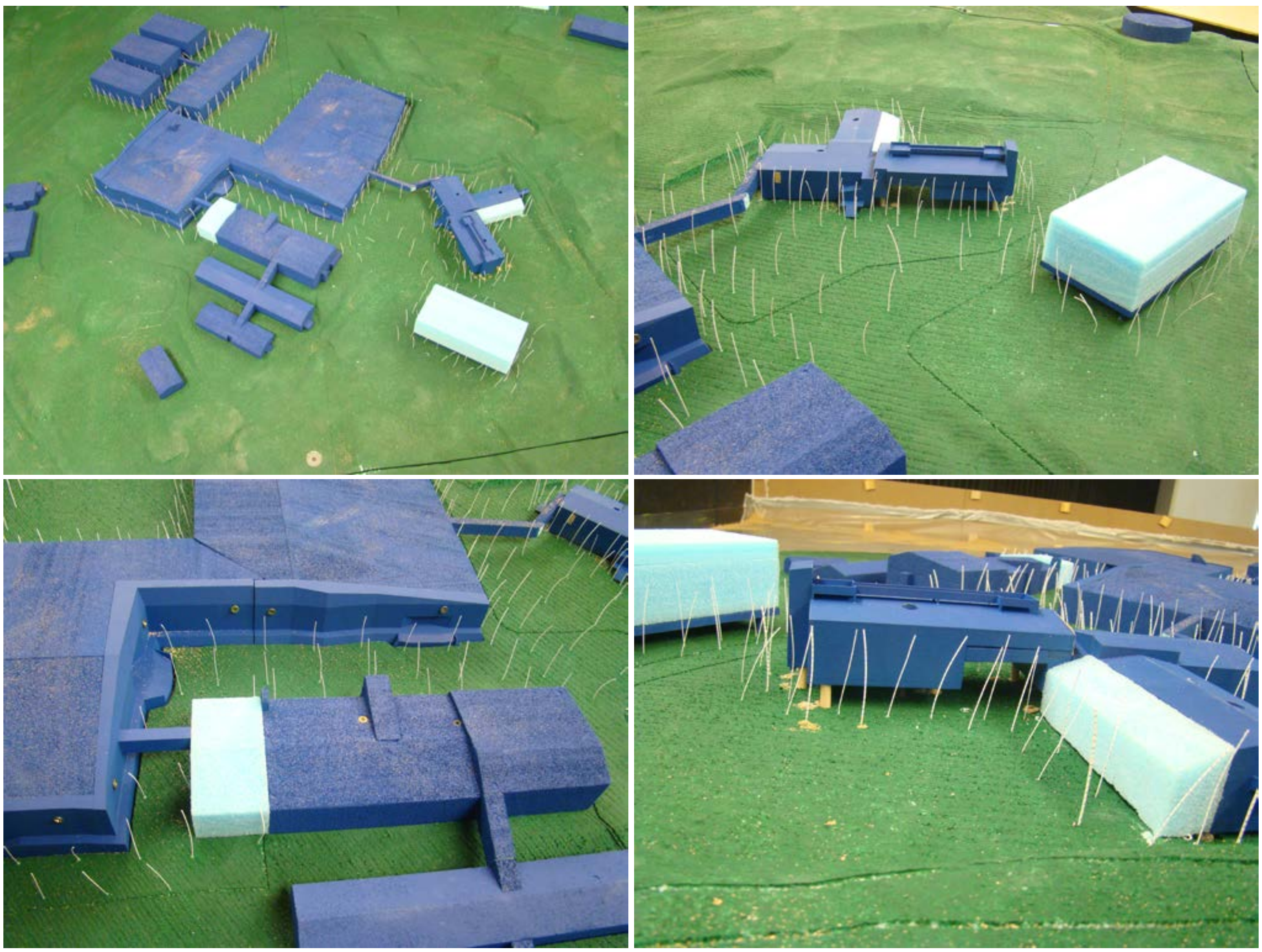


Figure 24*: Photographs of the model setup in the wind tunnel for Model Configuration D.*

Photographs of the resulting snow accumulation and scouring patterns for Cases 7 and 8 are shown in Figure 25. Drawings with the color-coded snow depths for all test cases are shown in Appendix A.

***Figure 25a**: Photographs of the snow accumulation and scouring: Case 7: Model Configuration D with a wind direction of 90°.*

Figure 25b: *Photographs of the snow accumulation and scouring: Case 8: Model Configuration D with a wind direction of 157.5°.*

<u>IT</u>

For Building Configuration D, the alternate bridge configuration and the addition of the sloped roof to the cold storage remained. The base of existing IT Building portions (north and east wings) stayed at grade and the new building portion (south wing) was raised up on stilts. The width of the breezeway was increased.

Photographs of the snow accumulation around the IT Building are shown in Figure 26 below. Overall, the snow accumulation around the south side of the building decreased (see Figure 27). The gap underneath the south building portion allows air flow and snow scouring; reducing the snow accumulation in the area. The sloped cold storage roof eliminates the snow accumulation due to roof the height differences in Building Configuration B. Again, the alternate bridge configuration did not change the nearby snow accumulation patterns and the breezeway stayed mostly clear of snow for both wind directions. Increasing the width of the breezeway does not seem to have a significant effect.

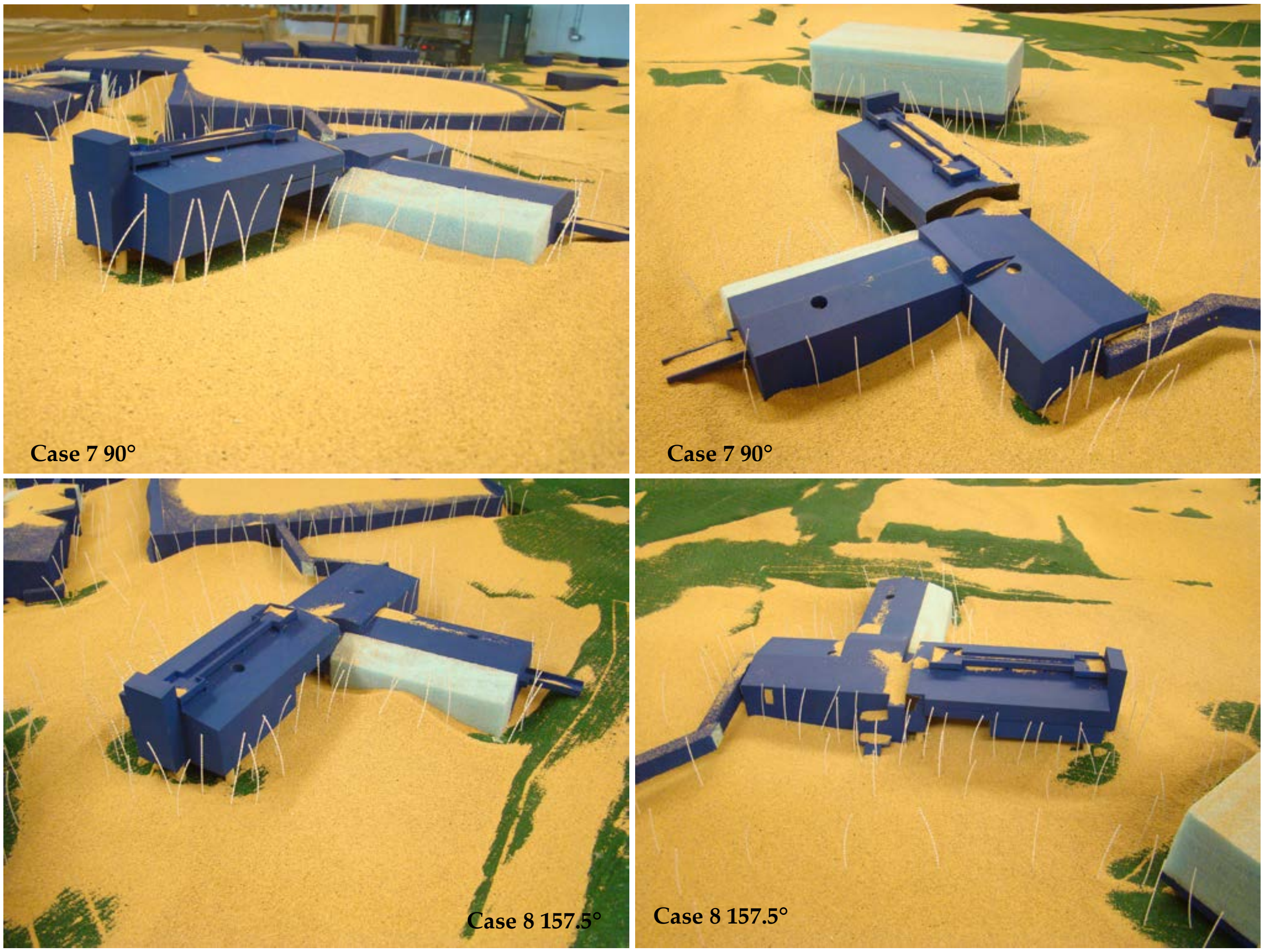


***Figure 26** : Photographs of the snow accumulation and scouring around the IT Building (Model Configuration D).*

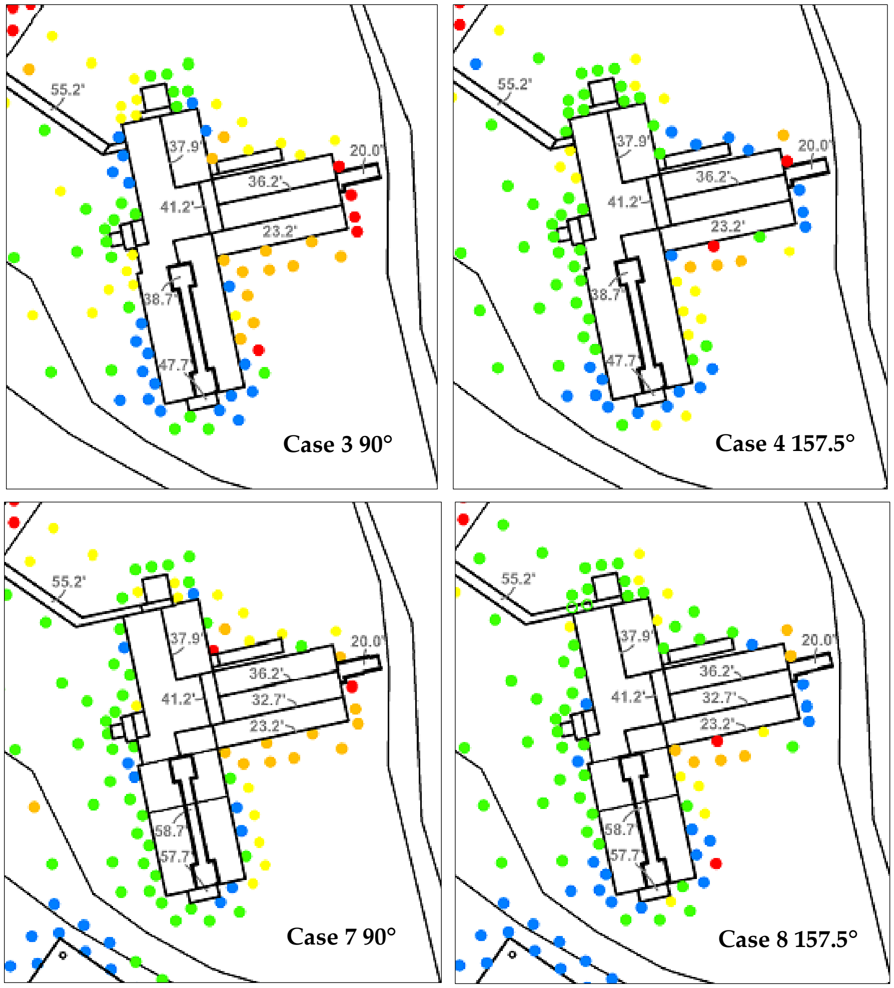


Figure 27 : Comparison of the snow accumulation and scouring around the IT Building for Model Configurations B and D.

Lodging

An additional Lodging Building was placed south of the IT Building. Photographs of the snow accumulation around the additional Lodging Building are shown in Figure 28 below.

Significant scour around building corners as well as underneath the building can be seen due to accelerations of the wind in these areas. Overall, snow accumulation around the additional Lodging Building is insignificant.

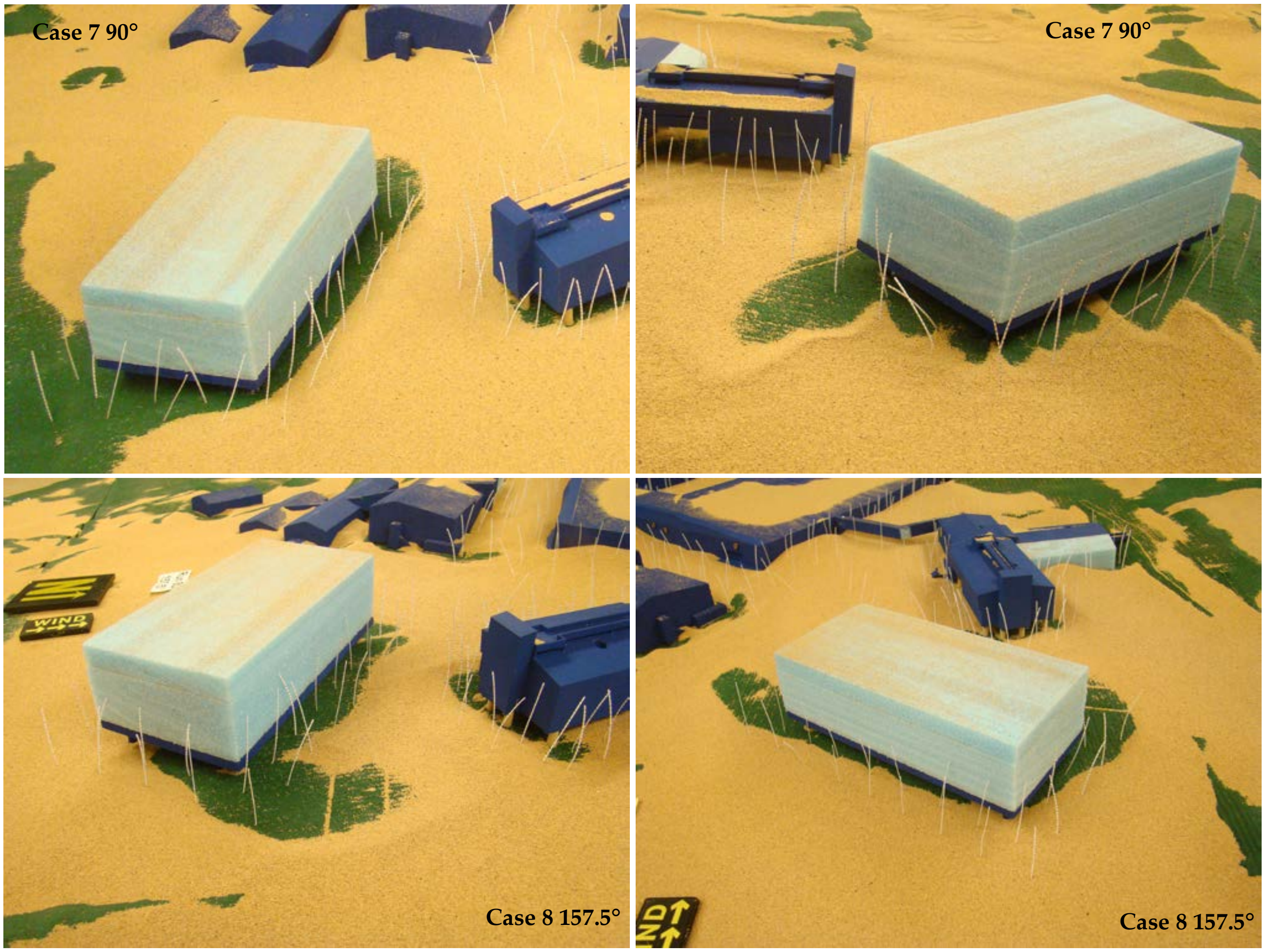


Figure 28 *: Photographs of the snow accumulation and scouring around the additional Lodging Building (Model Configuration D).*

Central Services Main Entrance Area

For Building Configuration D, the Crary Lab Building was extended to the west, in an effort to reduce the width of the gap between Crary and Central Services, in an effort to increase flow accelerations in the area. Photographs of the snow accumulation in the Central Services Building Entrance area are shown in Figure 29 below.

Overall, the snow accumulation in the main entrance area is very similar for both Building Configurations A and D (see Figure 30). Reducing the gap between Crary and Central Services did indeed increase flow accelerations in the area, however, the overall deposition of snow in the building corner north of the entrance stayed the same.

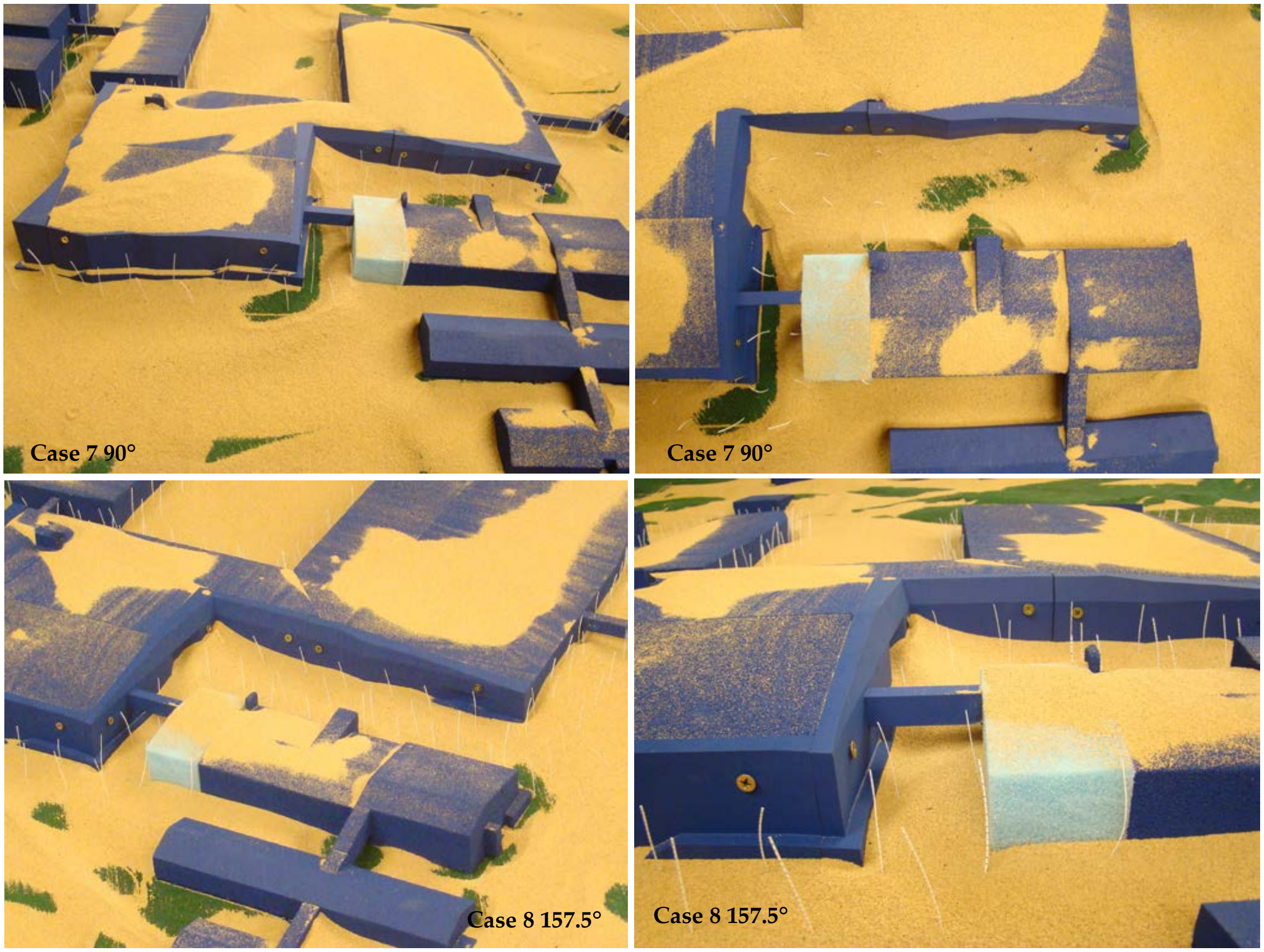


***Figure 29** : Photographs of the snow accumulation and scouring in the Central Services Building Entrance area (Model Configuration D).*

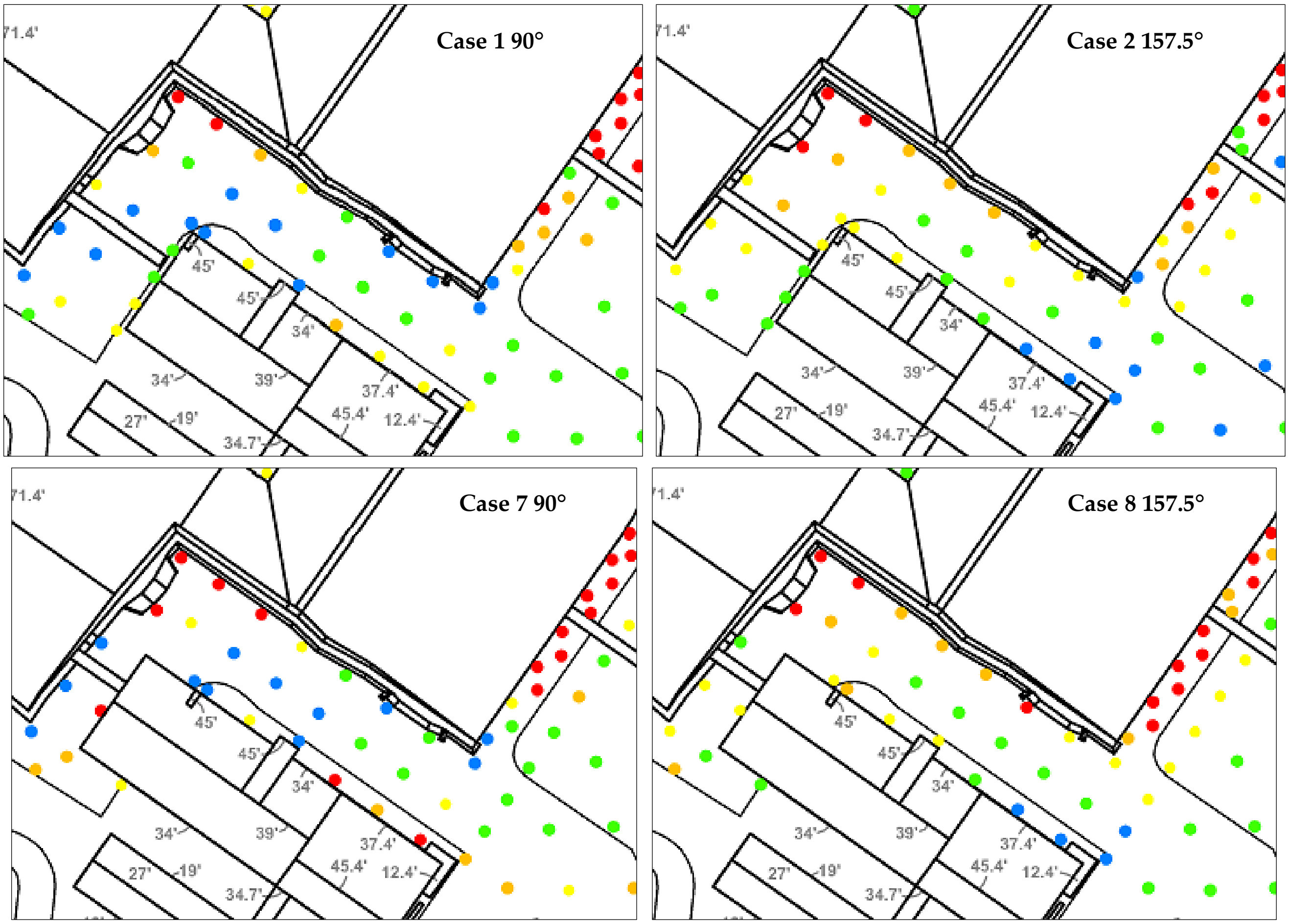


***Figure 30** : Comparison of the snow accumulation and scouring in the Central Services Building Entrance area for Model Configurations A and D.*

4. CONCLUSIONS

An additional snow scouring and deposition modeling study was conducted in the wind tunnel for McMurdo Station in Antarctica. The objective of the study was to help the building design team optimize the layout of the three new buildings (VEOC, Lodging and IT Addition) that have been added to the masterplan since the completion of the initial wind tunnel assessment.

Snow material was deposited and drifted on a scale model of the McMurdo campus in the wind tunnel. Four Building Configurations were evaluated.

General Findings:

- Lodging Buildings: Snow accumulation around the Lodging Buildings (including the additional Lodging Building south of IT) was minor and can reduced even more by increasing the Lodging Building heights

- IT Building: Increasing the Building height above grade by placing the building (or building wing) on stilts (with a clear flow path underneath) prevents snow drifts immediately against building walls and reduces snow accumulation in the nearby area.
- VEOC: Simple rectangular building shapes avoid snow drifts in wall insets.
- Other Areas of Concern: significant snow accumulation was observed along the north walls of the main entrance area (due to the reduction in velocity in the corner) and along the north and east walls of the Field Science Support Building (due to the proposed grading in the area)

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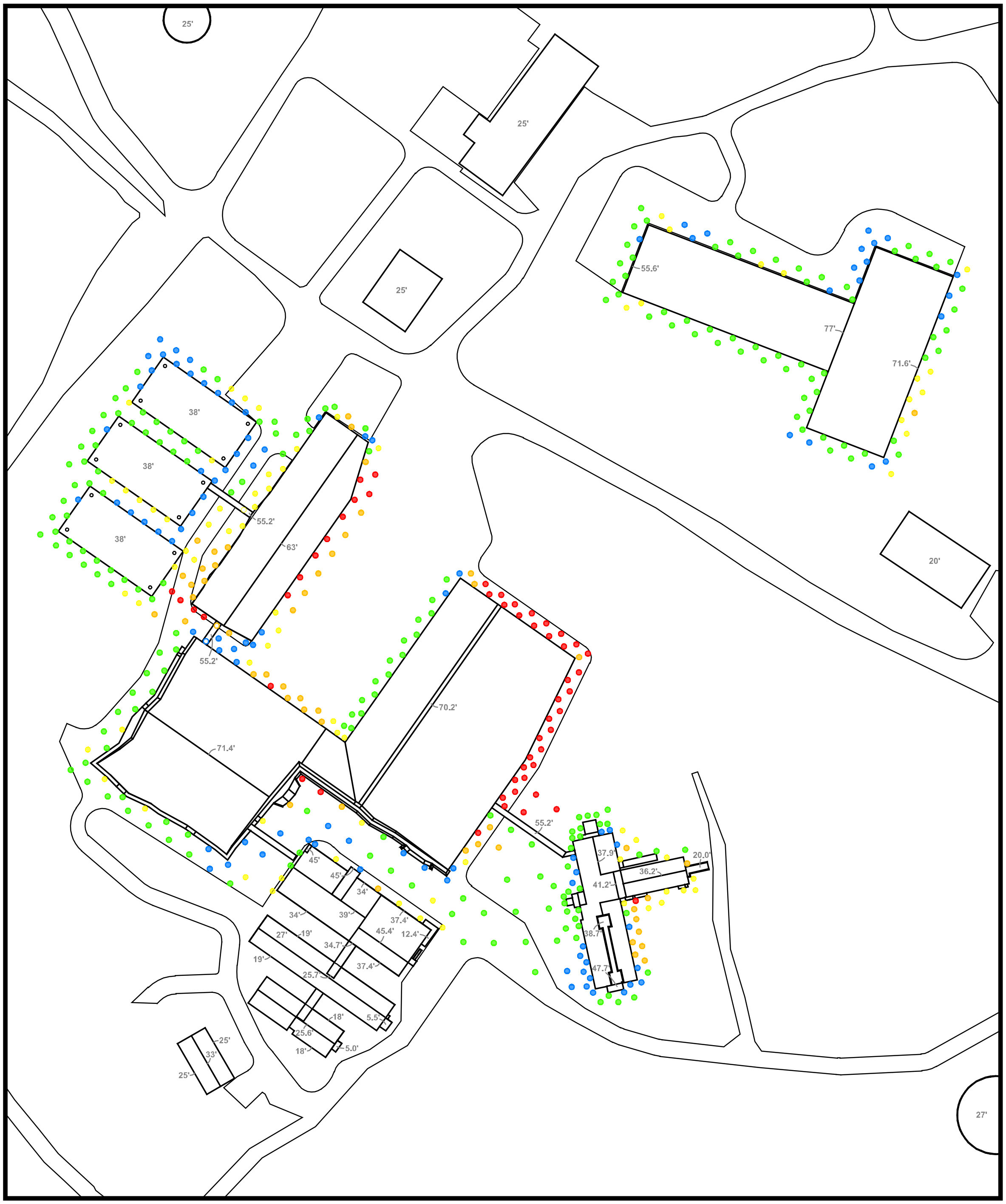
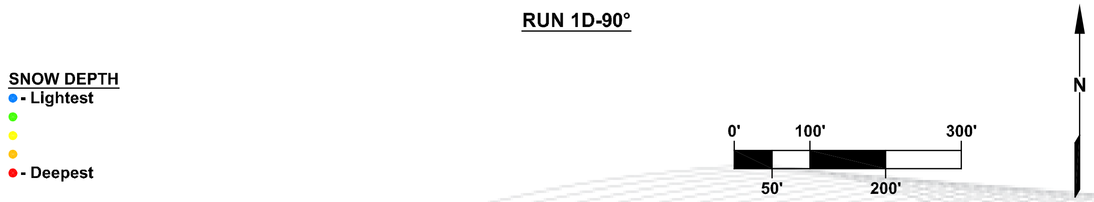
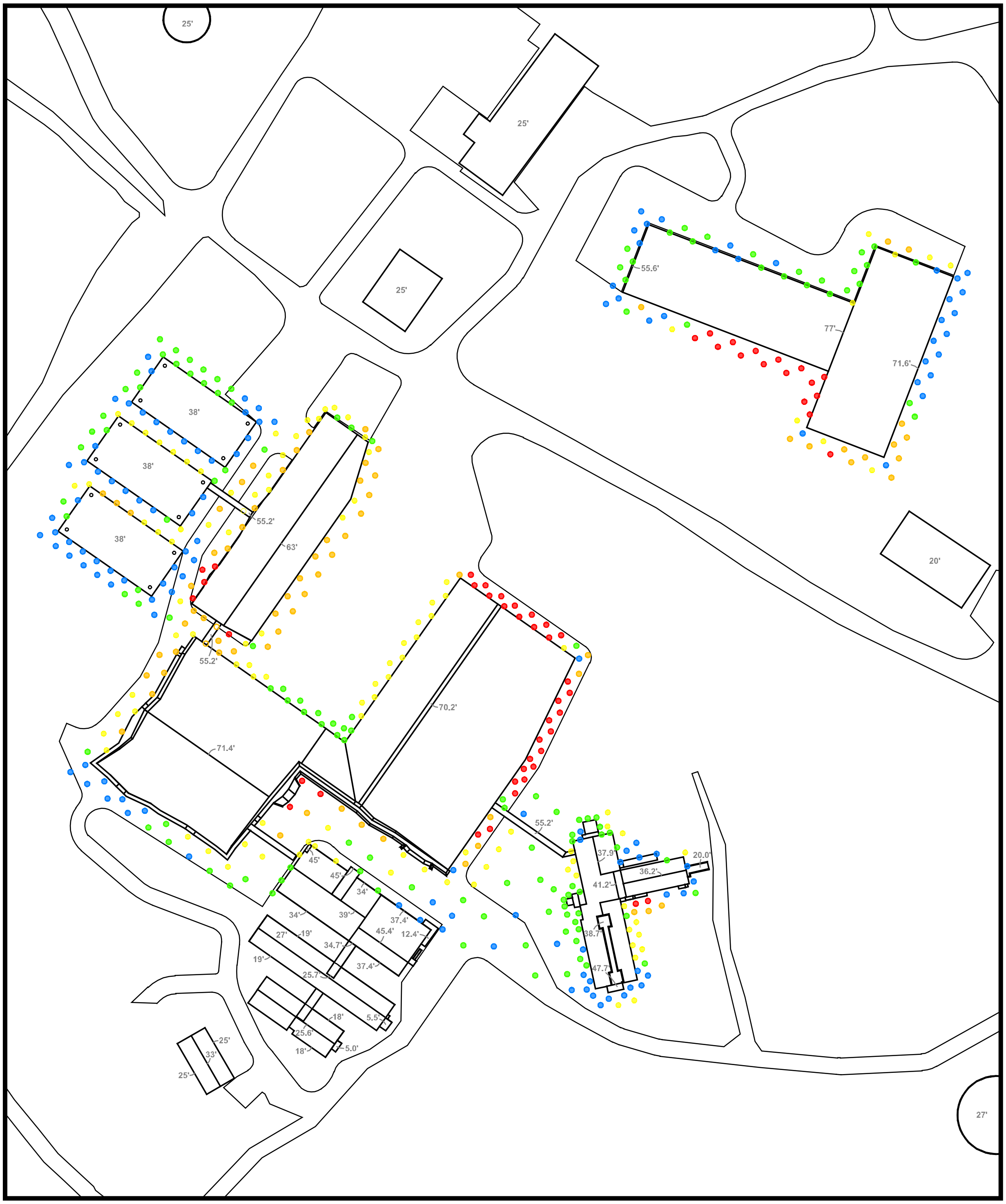
APPENDIX A – MEASURED SNOW DEPTHS



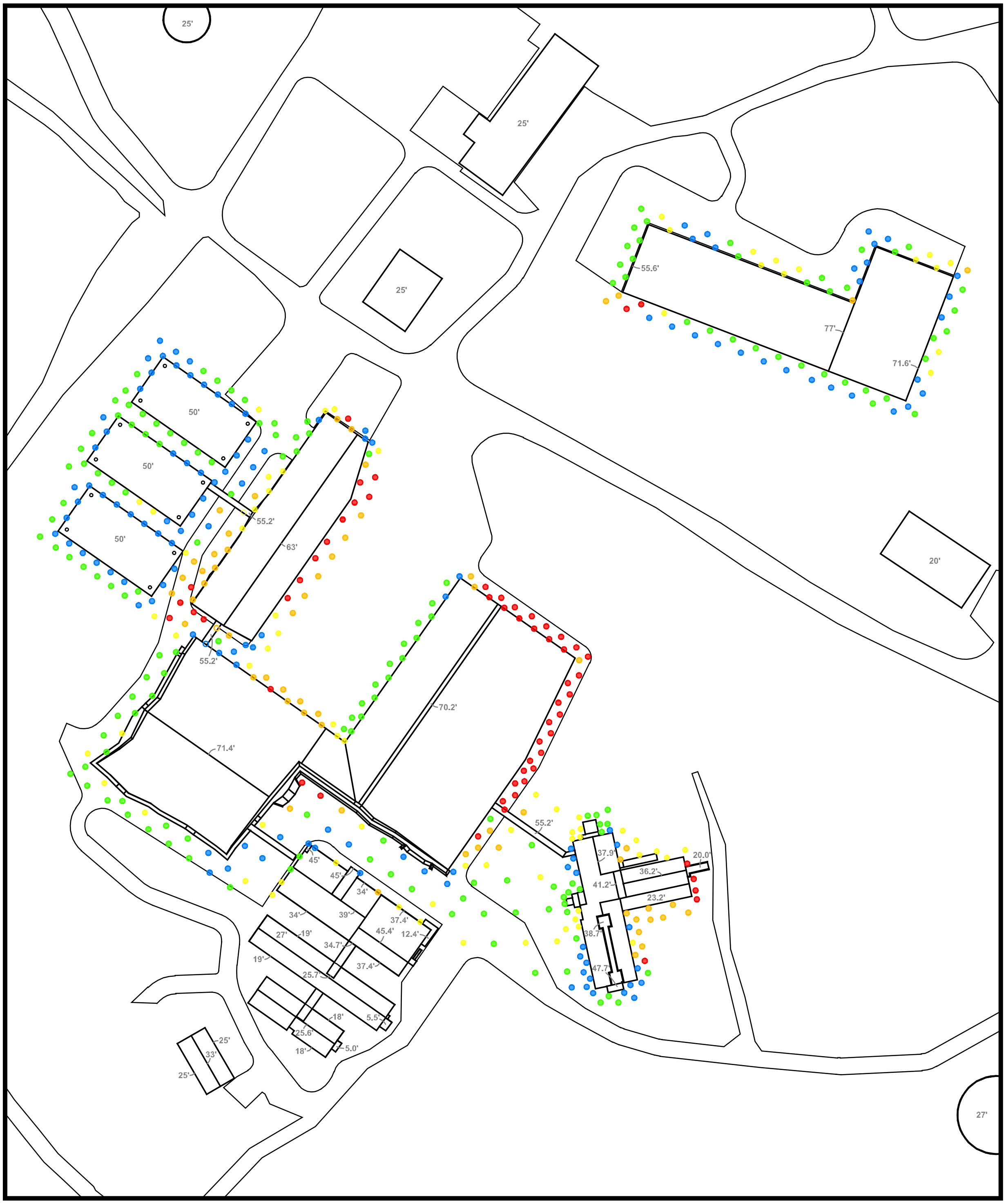
RUN 1D-90°




25'
25'
25'
55.6'
77'
71.6'
38'
38'
38'
55.2'
63'
20'
55.2'
70.2'
71.4'
55.2'
37.9'
20.0'
36.2'
41.2'
45'
45'
34'
34'
39'
37.4'
45.4'
12.4'
27'
19'
34.7'
19'
37.4'
25.7'
38.7'
47.7'
18'
5.5'
25.6'
18'
5.0'
25'
33'
25'
27'

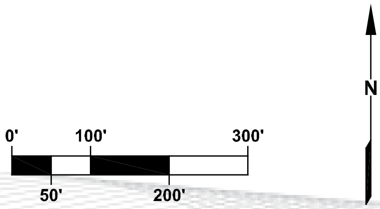
RUN 2D-157.5°

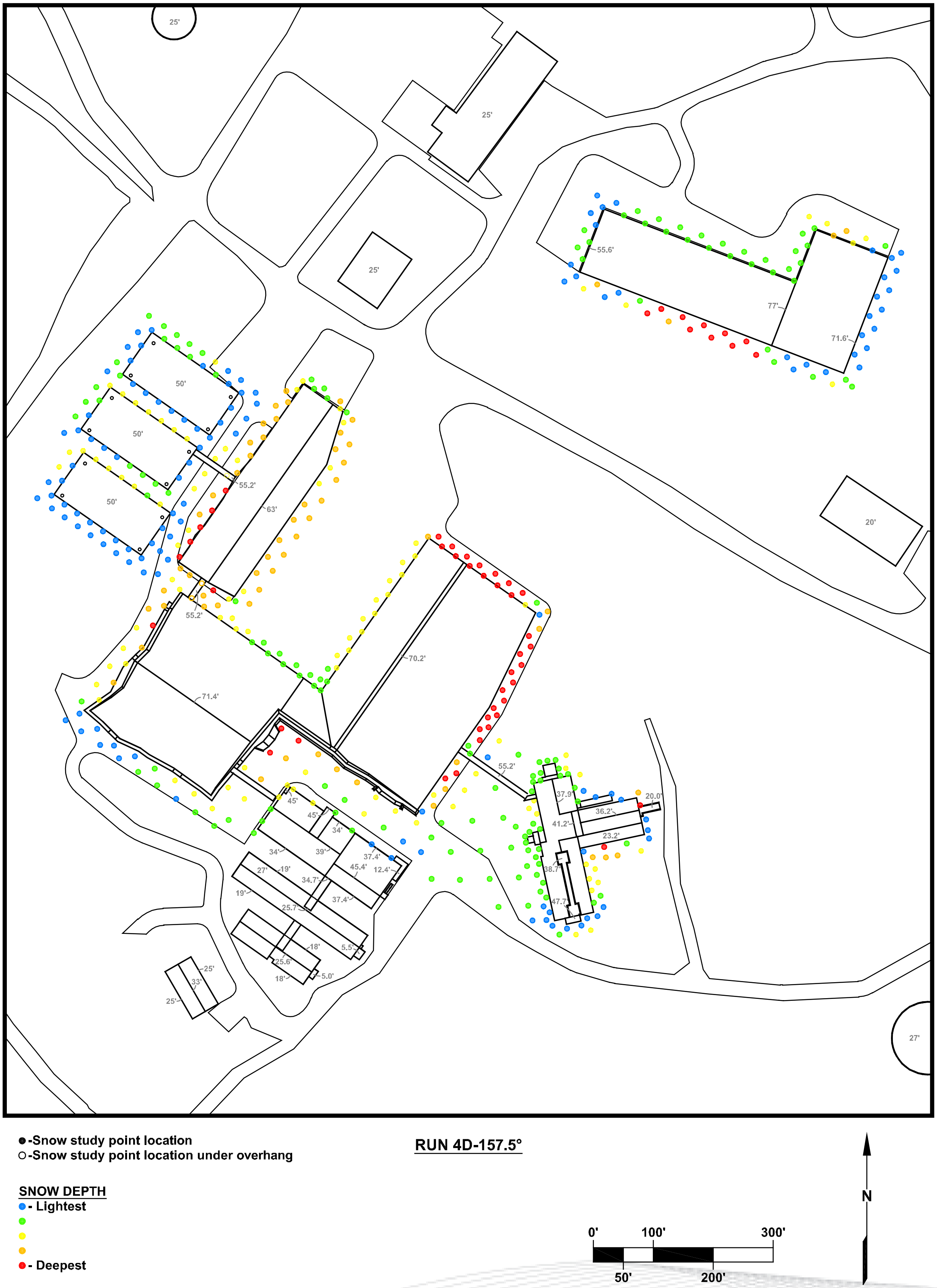

SNOW DEPTH
- Lightest
- Deepest
0'
100'
300'
50'
200'
N

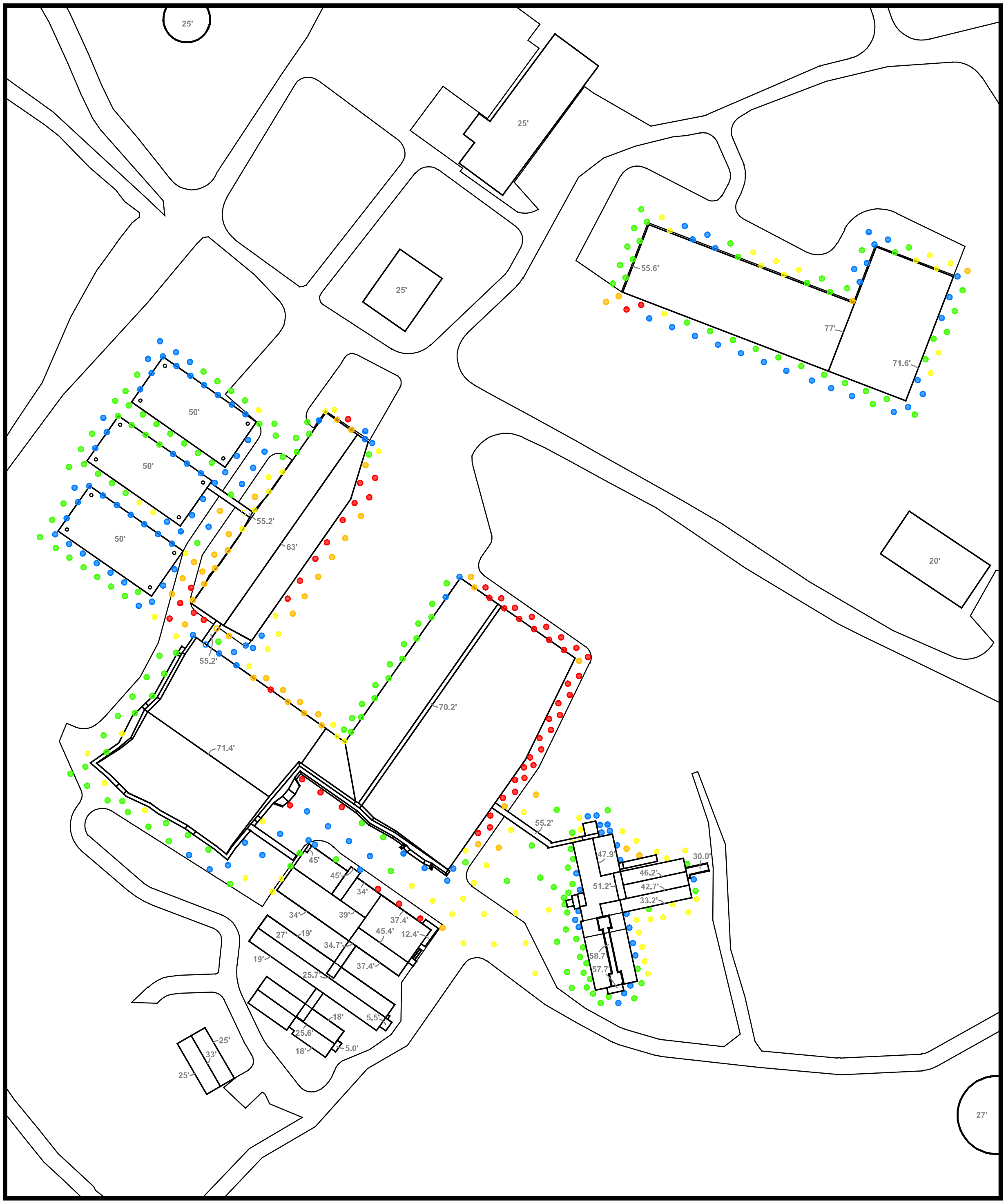


RUN 3D-90°

SNOW DEPTH
- Lightest
- Deepest




●-Snow study point location
○-Snow study point location under overhang
RUN 4D-157.5°
SNOW DEPTH
- Lightest
- Deepest
0'
100'
300'
50'
200'
N



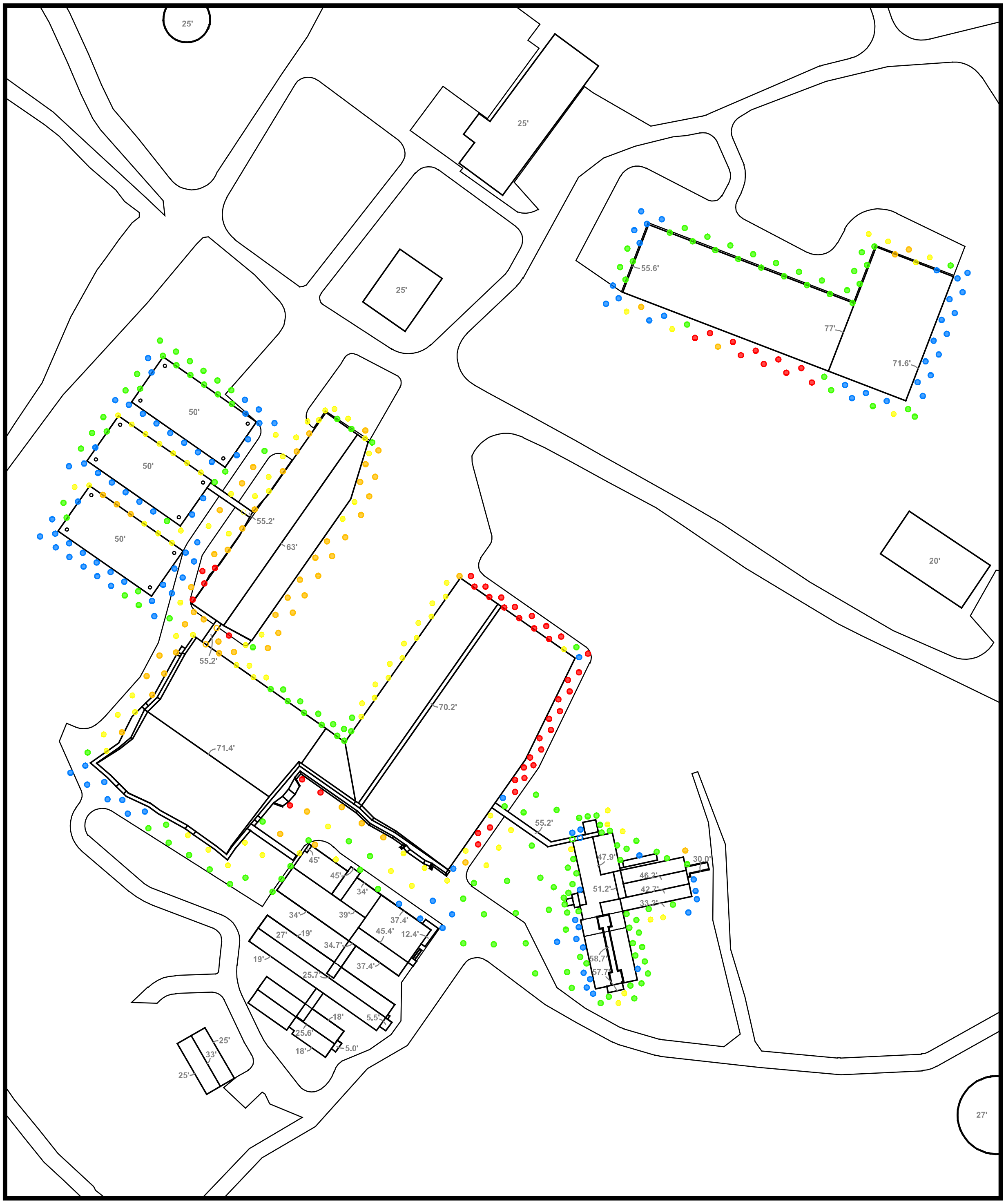
●-Snow study point location
○-Snow study point location under overhang

RUN 5D-90°

SNOW DEPTH
- Lightest
-
-
-
- Deepest

0' 100' 300'
50' 200'

N



● -Snow study point location
○ -Snow study point location under overhang

RUN 6D-157.5°

SNOW DEPTH
- Lightest
-
-
-
- Deepest

0' 100' 300'
50' 200'

N

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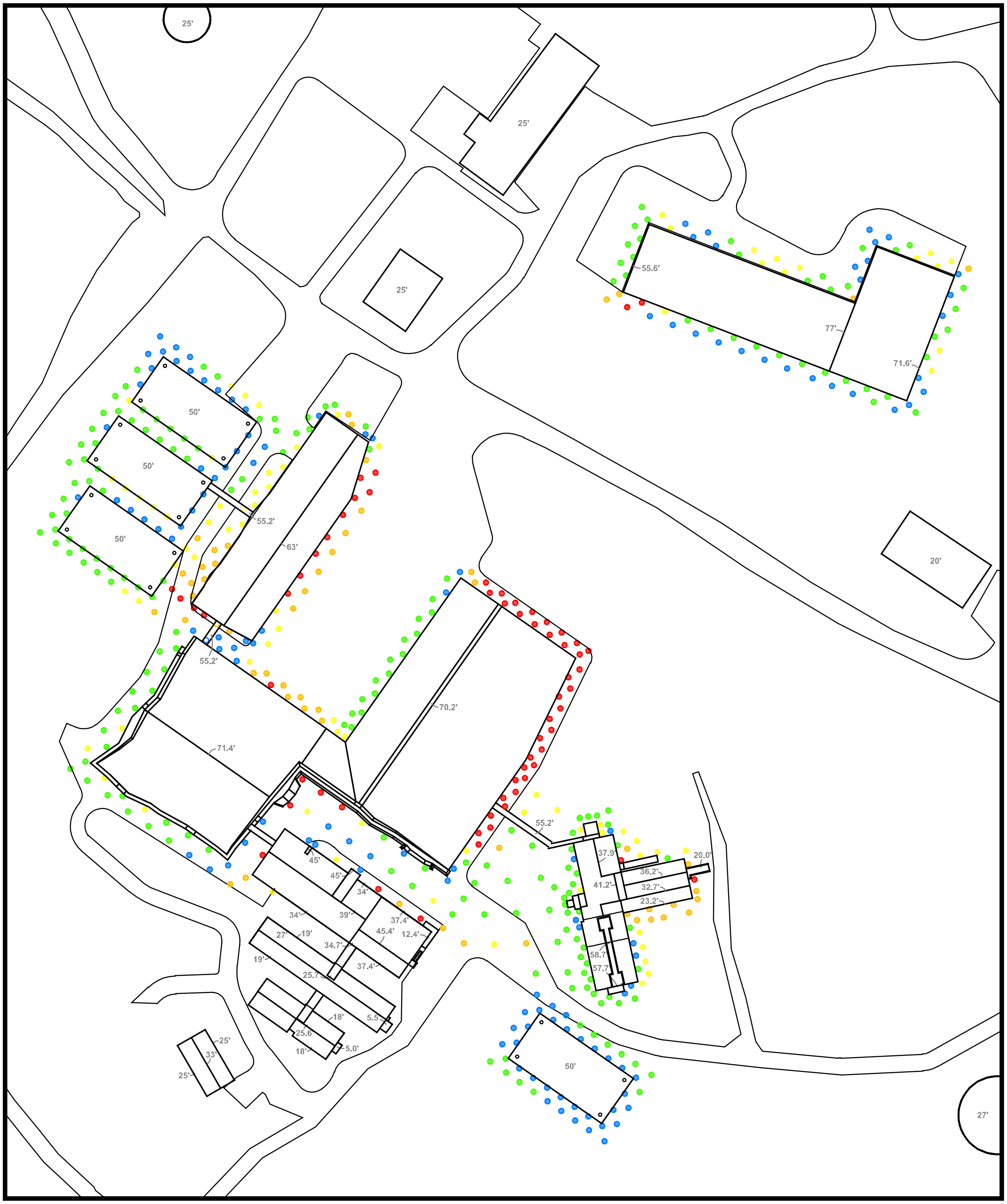
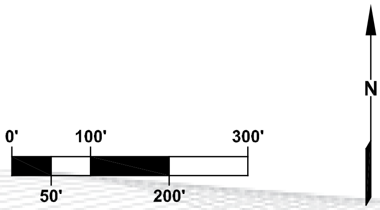
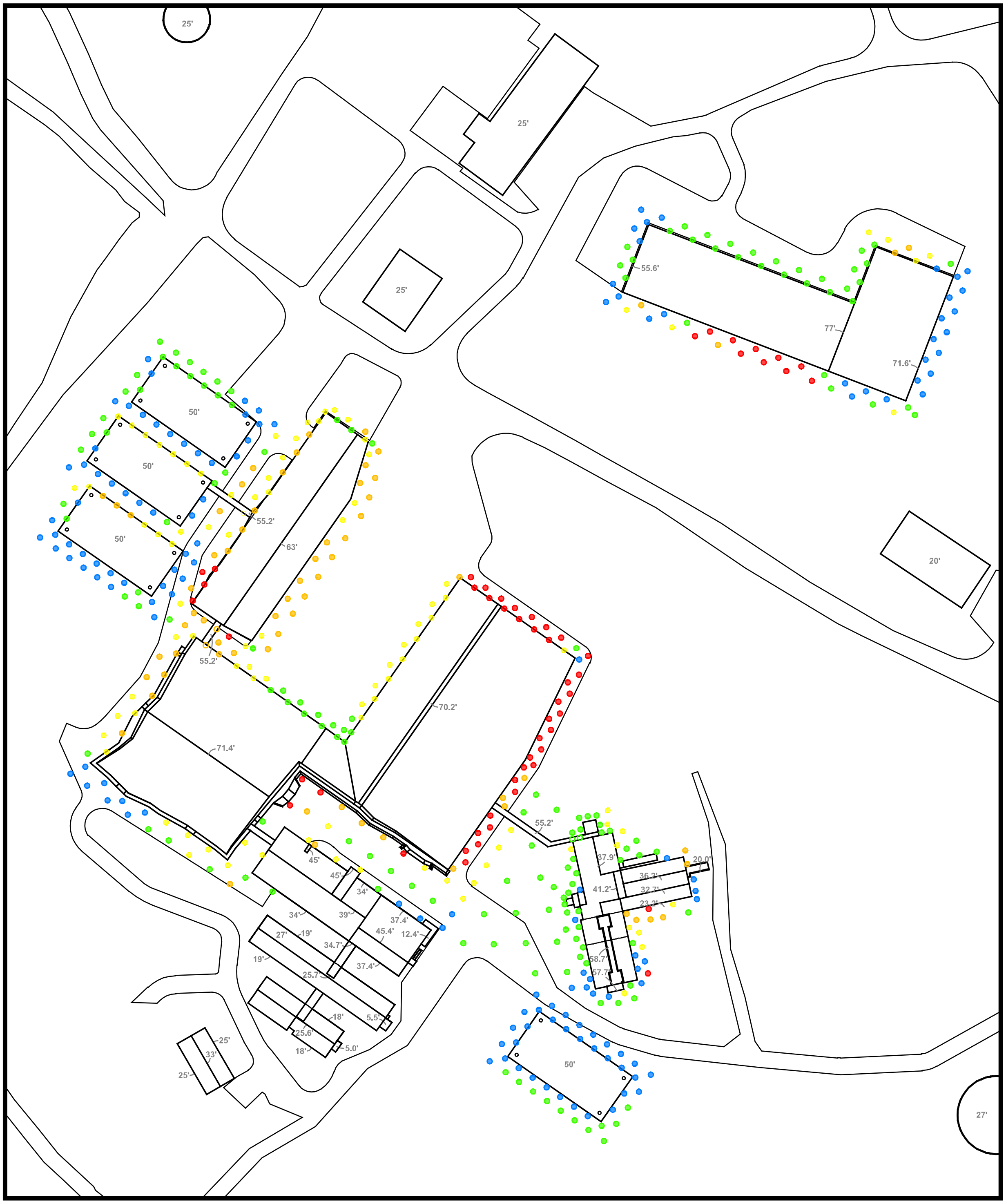


●-Snow study point location
○-Snow study point location under overhang

SNOW DEPTH
- Lightest
-
-
-
- Deepest

RUN 7D-90°





●-Snow study point location
○-Snow study point location under overhang

RUN 8D-157.5°

SNOW DEPTH
- Lightest
- Deepest

0' 50' 100' 200' 300'

N