LARGE-SCALE MEASUREMENTS OF SNOWDRIFTS AROUND FLAT ROOFED AND SINGLE PITCH ROOFED BUILDINGS

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ABSTRACT: Snowdrifts around buildings can cause serious problems when formed on undesirable places. The formation of snowdrifts is highly connected to the wind pattern around the building, and the wind pattern is again dependent on the building design. The snowdrifts around three different model buildings are investigated. The buildings have the same floor space, 2500 x 2500 mm but different rooftops. The buildings were placed in a valley 3 km wide and 20 km long on Spitsbergen, Norway. The wind in this valley is blowing in the same direction approximately 90% of the time during winter and the site is well suited for studies of snowdrifts and snowdrifting. The wind direction and vertical wind profile is measured. The snowdrift height around each building were surveyed in approximately 200 points and contour maps produced. The different roof designs proved to have a significant influence on the size of the snowdrifts produced. A flat roof gives larger snowdrifts than a single pitch roof, and a single pitch roof tilted upstream the wind gives a larger snowdrift than a single pitch roof tilted downstream the wind. The results can be used to improve building design in areas with snowdrifting conditions.

KEYWORDS: snowdrifting, snow accumulation, snow, buildings

1. INTRODUCTION

Building in regions with severe snowy and windy conditions call for special planning to avoid snowdrift problems. The shape of the building is in this context essential, since the shape of the building will influence greatly on the air flow and thus the snow deposition around the building. Full scale measurements of air flow around buildings is sparsely reported, but the main features of the flow can be recognised from wind tunnel experiments. However, such experiments suffer from scaling problems.

Treating the building as a cube with the upwind leading edge perpendicular to the wind direction, the general air flow around it can be summarised as follows (figure 1); on the upwind wall, at the centre line, there is a stagnation point of higher pressure than the rest of the wall. From this point, the air flows in every direction. The downward flowing air forms a system of vortices at the transition between the ground and the wall. This recirculation zone is deflected downwind the sides of the cube, creating a horseshoe shaped system of vortices. The stagnation point and the upwind separation point on the ground is defining the size of the recirculation zone. Wind tunnel studies have shown that the position of the upwind separation point is strongly dependent on the ratio of the thickness of the upstream boundary layer to the height of the cube, δ/H, (Castro and Robins, 1977). Since the atmospheric boundary layer usually extends far beyond the building height, it is reasonable to assume that the size of the upwind recirculation zone is dependent on the ratio of the horizontal wind speed gradient to the building height. A steep gradient or a thin boundary layer will produce a recirculation zone of less upwind extension than a more gentle gradient or a thicker boundary layer.

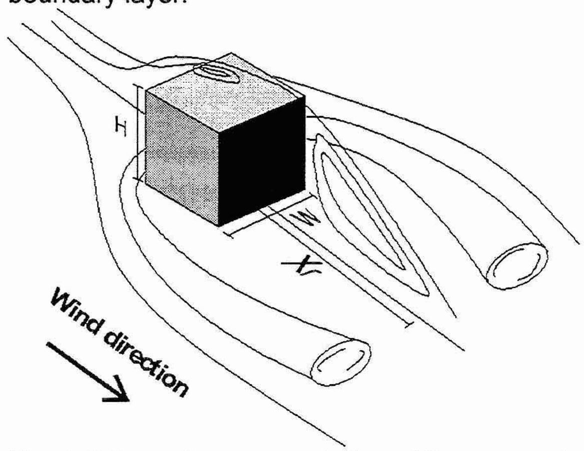

Fig. 1 Schematic representation of flow around a cube

Downwind the cube, between the horseshoe vortices, there is a wake region. The variation of the normalised leeward reattachment length

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X_r/H, of the wake is studied in a channel flow and is considered to be linearly increasing up to an aspect ratio of $W/H \approx 4$ and then asymptotically approach an end value. Here X_r is the downwind distance from the cube and W is the with of the cube. For ratios above $W/H \approx 6$ the flow in the middle of the wake appears to be two dimensional with little influence from the sides of the building. (Martinuzzi and Tropea, 1993).

The wake region has a close interaction with the horseshoe vortex, and it is suggested that the wake is entraining air from the vortex and, between the trailing edge and the reattachment point, pulling the sides of the horseshoe towards the axis of symmetry. Downwind the reattachment point the horseshoe opens up and the wake expands rapidly due to the increase of mass flux in the wake caused by the reattaching shear layer (Martinuzzi and Tropea, 1993). Similar characteristics are assumed to be valid to cubes in boundary layer flows.

The extension of the downwind wake region is shown to be sensitive to upstream turbulence intensity defined as

$$I = \frac{\sqrt{\overline{(u')^2}}}{\overline{u}} \quad (1)$$

where $\overline{u}$ is the time averaged horizontal velocity and u' is the fluctuation of the horizontal velocity. As I increases, the wake takes shorter to decay and the downwind wake region decreases (Castro and Robins, 1977). Connecting this to buildings in a terrain, it means that upwind smooth terrain with low turbulence intensity will produce a longer wake region behind the building than rougher terrain with a higher turbulence intensity.

Just behind the trailing edges of the cube there are two strong vortices. These vortices join together in an arc at the symmetry plane, somewhere between the top of the cube and the ground. On the top and sides of the cube, just downwind the leading edge, vortices are formed, fed by air from areas further downwind the cube (Martinuzzi and Tropea, 1993).

Turning the cube 45° in the air flow will modify the pattern of vortices a lot, especially the top and side vortices (Castro and Robins, 1977). It is yet clear that the larger scale features like the horseshoe vortex and the downwind wake region remain. Variation in the Reynolds number is also believed to cause some smaller scale modifications of the vortices close to the building.

The case of single pitch roof on a building introduces other air flow patterns. Evans (1972) found that if the higher side of the roof is on the downwind side of the building, an increase of the roof pitch from 5° to 14° had little effect on the extension of the downwind wake region, though the wake is longer than the wake behind a house with a flat roof. If the higher side of the building is facing upwind, the downwind wake region seemed to increase when the roof pitch increased, and produce the longest wake of the three investigated roof designs.

The transportation of snow can occur in three different modes; creep - rolling particles near the ground, saltation - jumping particles some centimetres above the ground and suspension - free flying particles ten folds of meters above the ground. The mode present depends on the ratio of particle weight to wind force exerted on the particle, though saltation and creep must occur before suspension takes place, and saltation is initiated first when creep is occurring.

The deposition of snow occurs where the shear stress from the wind exerted on the ground is decreasing below a threshold value. Close to the surface, the shear stress is defined as

$$\tau_0 = \rho u_*^2 \quad (2)$$

where u_* is the friction velocity and ρ is the density of air. Another key property to deposition is the concentration of snow in the air. Air in motion has a carrying capacity, which when exceeded, will cause snow particles to fall out of the air and form snowdrifts. Such oversaturated blowing snow conditions are typical when the airflow is rapidly changing direction near obstacles, "ploughing" the blowing snow to the sides and increase the concentration of snow in the air at the sides of the obstacle.

2. STUDY SITE AND METHODS

The experiment was performed in Adventdalen, a 3 km wide and 20 km long valley with a uniform flat bottom, on Spitsbergen, Norway, and was a part of a large measuring program. The wind pattern in this valley has previously been found to be mainly down the valley during winter. The experiment lasted for 14 days, which was sufficient to form significant snowdrifts. The precipitation in the period was 0.8 mm and the thickness of the snow cover in the valley was approximately 300 mm of hard wind packed snow. The small amount of precipitation combined with the uniform wind direction makes the area well suited for snowdrift experiments because accumulated, wind transported snow show a very distinct pattern compared to conditions of more precipitation.

Three model buildings of the size 2500 . 2500 . 2500 mm were placed on a line across the valley with spacing of 50 m or more. The incidence angle of the wind was equal for the three buildings and was ranging from 15° to 45° for the significant wind speeds. On top of two of the buildings a single pitch roof with the angle 23° was mounted, making the total height 3500 mm. The buildings were positioned so that one of the buildings had its lower edge facing against the wind (case b), and one had the higher edge facing against the wind (case c), figure 2. The buildings were built of 9 mm plywood and roped to beams frozen to the ground.

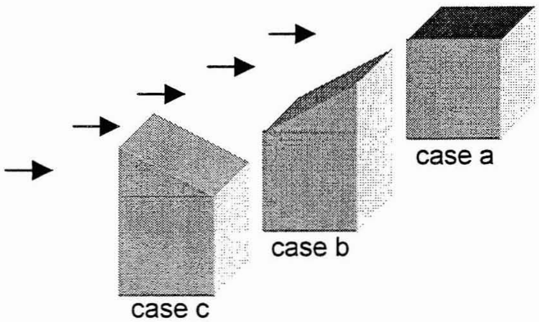

Fig. 2 Model building setup

The upstream wind profile and direction was measured in four heights up to 10m on an automatic weather station. The wind speed sensors were of the cup anemometer type and the sampling interval was five minutes. At the end of the experiment period, the height of the snowdrifts was measured with a surveying total station in approximately 200 points around each building. The points were chosen for optimal description of the curvature of the snowdrifts. The Kriging method was used to interpolate a surface between the measured points.

3. RESULTS

The temperature during the experiment ranged between -5°C to -35°C. The 5 minute average wind speed in the period was ranging from 1 m/s to 20 m/s. The friction velocity is determined from the expression

$$u_* = u(z)\kappa / \ln\left(\frac{z}{z_0}\right) \qquad (3)$$

where z_0 is deduced from wind speed measurements in two heights, and the expression

$$z_0 = \exp\left(\frac{u(z_2)\cdot\ln(z_1) - u(z_1)\cdot\ln(z_2)}{u(z_2) - u(z_1)}\right) \qquad (4)$$

u_* was found to range from zero to 0.9 m/s.

The angle of the perpendicular to the upwind side of the building and north, β, was 65°. It can be seen from figure 3 that the highest wind speeds are associated with smaller incidence angle to the building.

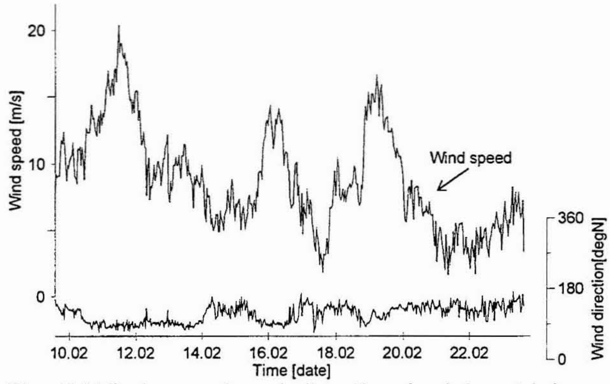

Fig. 3 Wind speed and direction in Adventdalen 09.02 - 23.02 1998

The snowdrifts around the different buildings, presented in figure 4, have more or less the same basic characteristics. The deposited snow was very compact with a surface of high hardness. The snowdrifts show a typical horseshoe pattern, similar to the wind induced vortices, with no snow accumulation close to the buildings. Just upwind the buildings there is a steep inclining snowdrift ending in a sharp edge, indicating the extension of the upwind recirculation zone. The distance between the building and the upwind snowdrift is varying for the three investigated roof designs, being 2.5 m for case c, 2.0 m for case b and 1.6 m for case a (measured perpendicular to the centre of the wall). The reason for this is that the stagnation point on higher buildings is positioned higher above ground level, and therefore increasing the size of the upwind recirculation zone. Farther upwind the snowdrift slopes to the ground level with the same inclination for all three buildings. The snowdrifts along the sides and further downwind the buildings show a much smoother shape. The flat roofed building produces a longer and more narrow snowdrift than the other two buildings, but is still collecting a higher volume of snow. The shape of the side snowdrifts are following the path of the previously described horseshoe vortex, being pulled towards the centre line of the wake of the building, and released after the reattachment point. The maximum deposition of snow is occurring just downwind this point, where the wake expands and mass flux increases.

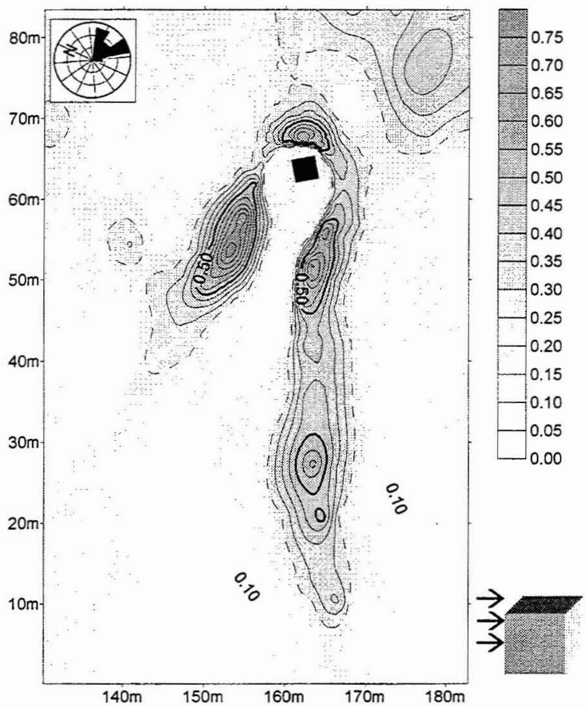

Fig. 4 a) Snowdrifts around a flat roofed building.

One distinct difference between the buildings is the deposition of snow along the sides of the building. While for the flat roof, the horseshoe snowdrift is continuous from upwind the house to the end 60 m downwind, the single pitch roofed houses produce snowdrifts that are broken apart at the sides of the house. This is probably due to stronger horseshoe vortices, caused by the higher stagnation points on the upwind walls, that are capable of transporting the snow farther downstream before it is deposited. This is more evident for the building with the highest wall towards the wind (case c), and also for the side of the building which has the lowest angle towards the incoming wind. The total downwind length of the snowdrift is also dependent on the strength of the horseshoe vortex. Thus the flat roofed building with a weaker vortex produces a longer snowdrift than the single pitch roofed buildings associated with stronger vortices.

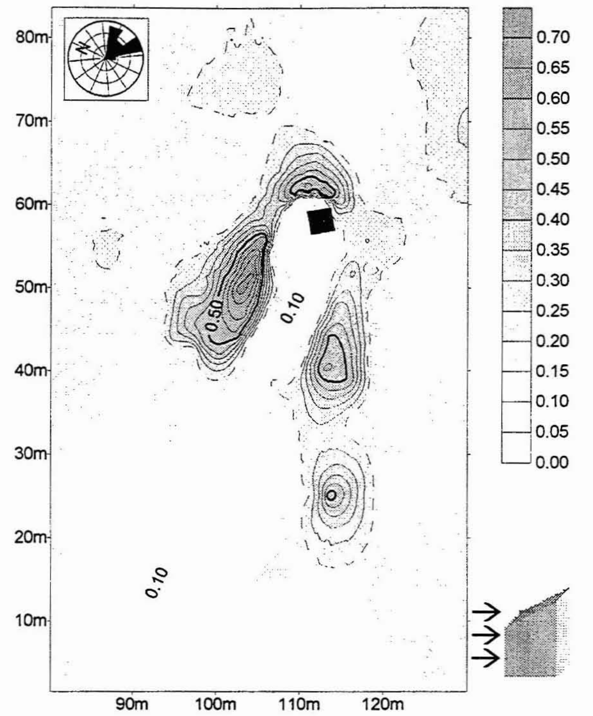

Fig. 4 b) Snowdrifts around a single pitch roofed building with the highest wall away from the wind

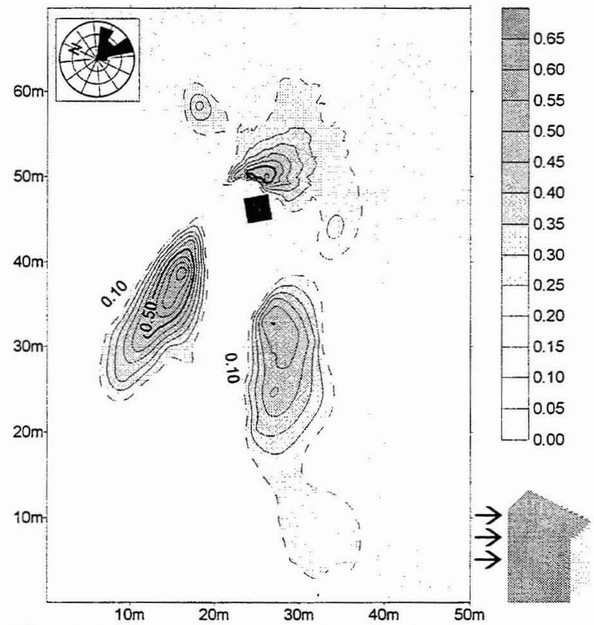

Fig. 4 c) Snowdrifts around a single pitch roofed building with the highest wall against the wind

4. DISCUSSION

The snowdrifts around the investigated buildings show a slightly different pattern than

reported earlier, where the ridge shaped leeward snowdrift close to the building is emphasised (Smedey et.al., 1993, Mitsuhashi, 1982, Schaerer, 1972).
A reason for this can be that the this leeward snowdrift causes more problems for the residents and it is therefore the most important snowdrift for detached buildings. It is also possible that a higher precipitation rate relative to the wind transported snow in the previously mentioned experiments will conceal the snowdrifts on the sides of the building, and make them impossible to measure. Different building designs can also suppress the formation of snowdrifts on the sides of the buildings.

The reason why the formation of a leeward snowdrift is not present in the current experiment is probably because the transport mode was mainly saltation. The snow particles was ploughed to the sides by the buildings, and even if the wind conditions just behind the buildings was suitable for snow accumulation, there was no snow present for accumulation. The transport rate of saltating snow crossing a lane of unit with is proposed to be

$$Q_s = 0.68\left(\frac{\rho}{g}\right)\left(\frac{u_{*t}}{u_*}\right)\left(u_*^2 - u_{*t}^2\right) \qquad (5)$$

(Pomeroy and Gray, 1990) This expression is valid only for steady state conditions, in this case upwind the buildings. It can easily be seen that if the friction velocity u_* is lower than the snow threshold friction velocity, u_{*t} ,determined by the physical properties of the snow, there will be no transport. In fairly smooth terrain, where steady state is a good assumption, it even makes sense to talk about accumulation where $u_* < u_{*t}$ (Sundsbø, 1997, Liston et.al, 1993). If, however, the airflow is disturbed by larger obstacles, there is in all probability areas where $u_* < u_{*t}$ and at the same time no snow is present to accumulate. It is therefore appropriate to propose that accumulation of snow is a function of both the concentration of snow in the air C_{snow} and the inverse of the shear stress, τ_0^{-1}. C_{snow} is dependent on both the upwind snow concentration and the wind pattern created by the obstacle. The dependency upon the wind pattern created by the obstacle is weaker for smoother obstacles, causing C_{snow} to be dependent only on the upwind snow concentration for homogenous conditions. To obtain a leeward snowdrift close to a building it is therefore necessary to have the suspension transport mode present, thus the particles can pass over the building and accumulate in the low shear stress region behind the building.

The variation of the size of the downwind wake seems to correlate well with the measurements of Evans (1972). Assuming that the maximum snow deposition is occurring near the reattachment point at the end of the wake, studies of the airflow around buildings makes a good basis for determination of the position of the snowdrifts around a building. According to (Castro and Robins, 1977), the reattachment point and thus the maximum snow deposition will move closer to the building when upwind turbulence increases. This is however measurements of buildings in wind tunnel with low Reynolds number relative to full scale conditions, where other effects may be more important.

5. CONCLUSION

The present measurements show that even small differences in building design can cause large variation in the surrounding snowdrift pattern. The size and extension of the snowdrifts formed around buildings can only to a very limited extent be looked upon as a measure of the disturbance of the wind, because the building can produce speed up zones that will inhibit snowdrift formation. It is therefore difficult to make a quantitative calculation of the snowdrift just by looking at the building design. However, a qualitative description of the position of the snowdrifts and relative size, is possible on the basis of knowledge about the airflow around the building. A basic understanding of air flow around isolated buildings is again vital to understand more complex cluster configurations, and situations of alternating wind directions.

NOMENCLATURE

C_{snow}	= concentration of snow in the air
H	= building height [m]
I	= $\frac{\sqrt{\overline{(u')^2}}}{\overline{u}}$, turbulence intensity ($u = \overline{u} + u'$)
W/H	= obstacle aspect ratio
X_r/H	= normalised downstream reattachment
Q_s	= transport of snow [kg/m.s]
g	= gravity [m/s^2]
u_*	= friction velocity [m/s]
u_{*t}	= threshold friction velocity [m/s]
z	= height above ground [m]
z_0	= roughness height [m]

δ = boundary layer thickness [m]
κ = von Karman constant
ρ = density of air [kg/m^3]
τ_0 = shear stress on the ground [N/m^2]

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REFERENCES

Castro, I.P., Robins, A.G., 1977, The flow around a surface mounted cube in uniform and turbulent streams, *Journal of Fluid Mechanics,* 79, part 2, pp. 307-335

Evans, B.H., 1972, Natural Air Flow around Buildings. *CIB/WMO Colloquium, Teaching the Teachers,* vol1. Statens Institut for byggnadsforskning, Stocholm.

Liston, G. E., Brown, R.L., Dent, J.D., 1993, A two dimensional computational model of turbulent atmospheric surface flows with drifting snow, *Journal of Glaciology,* 18.

Martinuzzi, R., Tropea, C., 1993 The flow around surface mounted, prismatic obstacles placed in a fully developed channel flow. *Journal of Fluids Engineering,* vol. 115, pp 85-92

Mitsuhashi, H., 1982, Measurements of snowdrifts and wind profiles around the huts at Syowa Station in Antarctica, *Antarctic Record,* 75.

Pomeroy, J. W., Gray, D.M., 1990, Saltation of snow, *Water Resources Research*, vol. 26, no. 7, pp 1583-1594

Schaerer, P.A., 1972, Control of snow drifting about buildings, *Canadian Building Digest,* 146.

Smedley, D.J., Kwok, K.C.S., Kim, D.H., 1993, Snowdrifting simulation around Davies Station workshop, Antarctica, *Journal of Wind Engineering and Industrial Aerodynamics,* 50. pp. 153-162

Sundsbø P.A., 1997, Numerical modelling and simulation of snow drift, Ph.D Thesis, *Norwegian Institute of Science and Technology.*