Snowdrift Control Design: Application of CFD Simulation Techniques

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ABSTRACT: Computer modelling techniques, employing computational fluid dynamics (CFD) and a finite area element model (FAE), were used to predict snowdrift deposition patterns around a new building at the South Pole Station, Antarctica. Through interpretation of the wind flow field predicted through CFD, snowdrift prone areas around an existing building, that is raised above the snow surface, were identified. The wind flow field, generated by CFD, was subsequently used as input to an FAE computer snowdrift prediction model. The characteristics of the drift deposition patterns predicted by the computer simulation techniques were in satisfactory agreement with snowdrift patterns measured around the existing reference building at the South Pole. It was concluded that the FAE model predicted realistic snowdrift accumulation patterns when CFD-predicted local wind velocity fields were combined with local meteorological data.

1 INTRODUCTION

Snowdrift formation on and around structures that are located in areas of significant snow accumulation or blowing snow activity is an important design issue. Wind tunnels and water flumes have often been used to predict snowdrift patterns around buildings (Melbourne and Styles 1967, and Irwin and Williams 1983) and in more recent years, computation fluid dynamics (CFD) techniques have been employed (Nakata et al. 1993). A combination of computational fluid dynamics (CFD) and a finite area element (FAE) snowdrifting computer model was used as a design technique to investigate the snowdrift performance of new science facilities planned for construction at the Amundsen-Scott South Pole Station in Antarctica. CFD modelling was used to predict wind velocities around and below the new building, which is elevated above the snow surface. The CFD-predicted velocities near the ground were then used as input to the FAE model to predict snowdrifting. The FAE model was first developed to use measured mean wind speeds from wind tunnel tests. In many cases, however, the CFD method gives a higher resolution of the wind flow field, which was expected to improve the accuracy of the predictions of the snowdrift patterns.

This present study was conducted in two stages. The first was a field comparison stage where a CFD-predicted velocity flow field, specifically low velocity areas, was compared to actual snowdrift patterns recorded around an existing building to assess the accuracy of the velocity predictions. In the second stage, the combined CFD and FAE modelling method was applied to a new building design to predict the extent of snowdrift accumulation that will occur close to the building. If the predicted snow buildup was unsatisfactory, these models were to be used to test the effects on snowdrifting of modifications to the aerodynamic aspects of the new building design.

2 MODELLING METHOD

A three-dimensional CFD model of the actual (full scale) reference building that exists at the South Pole was developed. The computational grid was constructed as a rectangular box and is described as follows. The upwind boundary of the box, inflow boundary into the computational domain, was 10H from the windward edge of the test building, where H is the height of the building, measured from the ground. The downwind, or outflow boundary of the computational domain was located approximately 20H from the end of the building. The side boundaries of the grid were approximately 10H from the lateral edges of the building. The top boundary of the grid was approximately 20H above the roof of the building.

The total number of nodes (calculation points) used in the simulation was approximately 70,000. More than 80% of the nodes were concentrated around the building. Beyond the regions of the flow steered by pressure effects of the building and the wake region, the grid resolution was reduced by expanding the node spacing geometrically to the outer boundaries of the grid. The average node spacing around the building was 30 cm to 90 cm in all directions.

A view of the actual (reference) building, which is raised above the snow surface, and a perspective view of the 3-D CFD model are shown in Figure 1. Note the inclusion of the structural steel trusses on the CFD model, since they would retard wind flows beneath the actual reference building and therefore affect snowdrift formation. The reference building is an existing building at the Amundsen-Scott South Pole Station.

Boundary conditions were specified on the various faces of the grid. The upwind, or inflow, boundary was given a uniform wind velocity. The sides of grid were defined as being periodic with each other. This allowed several wind directions to be tested that were not co-incident with the orientation of the grid. The top boundary of the grid had slip-wall conditions applied. The downwind boundary of the grid had fully developed (zero-gradient) outflow conditions applied. The bottom of the computational grid was modelled as a rough wall, characteristic of wind flow over flat snow-covered terrain.

The CFD simulations prepared in this study used the commercial computer code called TASCflow[1]. In all cases, TASCflow was run using the incompressible flow formulation for this forced convection (isothermal) flow problem. The time-averaged Navier-Stokes equations were solved with the standard k-ε turbulence model. The discrete equations were a primitive variable, collocated, finite-volume flux-element formulation. This approach combines the geometric flexibility of the finite-element methods with the conservation of transported quantities over each finite volume. The advection terms in the equations were modelled with an accurate upwind differencing method called the mass-weighted-skew (MWS) scheme. This scheme accounts for convection along streamlines of the flow.

The solution procedure was iterative, involving solutions of the linearized discrete mass and momentum equations which were solved simultaneously as a coupled set. The equations for k and ε were solved in a segregated fashion at each iteration. The iterative process was terminated when the maximum normalized residuals of the mass and momentum equations converged to less than the user specified tolerance of 10^{-3}. Each simulation required approximately 12 hours of CPU time on an IBM RISC 6000/550 running in core.

The FAE computer model is described in detail in a number of published papers, including: Irwin et al. (1995); Gamble et al. (1991); and, Irwin and Gamble (1988). In simple terms, the FAE model divides a site or building roof into a large number of elemental areas (grid) and computes where snow will be deposited or scoured on an hour-by-hour basis in each elemental area. Statistical methods are then typically used to derive design snow loads; however, in this application the volume of snow "blowing toward" the site in the FAE computer model was determined through application of known snow flux expressions (Kobayashi 1972, and Dyunin 1954) to the meteorological data recorded at the South Pole and the resulting wind speeds predicted by the CFD model. In areas with a climate that is less extreme (cold) than the South Pole, other parameters (e.g., temperature, humidity, rainfall, solar radiation, etc.) that affect snowdrift build-up, erosion, melting, etc., would also have been considered in the FAE simulation.

The meteorological data for the winter of 1992 at the South Pole was reviewed to determine the prevalent wind directions associated with the snowdrift patterns that developed around the reference building. The wind speed and direction recorded on an hourly basis throughout the polar winter were used as inputs to the snow flux expressions to estimate the volume of drifting snow approaching the site for each wind direction. This flux rate was used as an input for the FAE model. The highest flux rate for the winter was associated with wind approaching from the north (360E or 0E), which is measured relative to the station's Grid North (the Greenwich Meridian).

Although snowdrift patterns are the result of drifting events that occur from a variety of wind directions and speeds, a majority of the snow transport winds at the South Pole occur from a limited 30E sector (i.e., 0E - 30E). The CFD model investigation of the reference building therefore focused on the single most dominant wind direction, north, that occurred during the one winter being studied. A more complex simulation would consider all combinations of wind speeds and directions that occurred during the winter and also account for the effects of changes in topography or aerodynamics due to snowdrift deposition and growth. Examination of a single dominant wind direction was considered adequate for

[1] TM of ASC Ltd., Waterloo, Ontario, Canada.

a first order comparison to the actual field data (snowdrift patterns) for the one winter.

The wind velocity field from the CFD model was nondimensionalized by the approaching wind speed at 10 m above ground to scale the hourly wind data to each grid point in the FAE model. The FAE snowdrifting model used hourly meterological records and a grid system superimposed on the snow surface, dividing the surface into approximately 3500 finite area elements whose horizontal dimensions equalled the CFD grid at a 1.2 m reference height. Values for wind velocities at the reference height at the four corners of each elemental area were used by the FAE model to compute the snowdrift fluxes through the sides of the element. Empirical relationships based on field data are used in the model to relate drift rate to the local mean wind velocity. For this reason, turbulence effects are not explicitly required as input.

The computations were completed for every area element and the change in snow mass contained in each area element during a one-hour time interval was thereby evaluated. This procedure was repeated for each time step covering the entire winter of 1992. The FAE simulation provided a complete history of the snow accumulation in each elemental area for each hour of the year being examined.

3 COMPARISON OF WIND FLOW FIELD TO ACTUAL SNOW DEPOSITION

The velocity patterns predicted through CFD were compared to actual snowdrift patterns measured at the site, around the reference building. The main purpose of this data comparison step was to acquire confidence in the ability of CFD modelling to provide realistic velocity patterns at the reference height used in the FAE model. For this exercise, the seasonal mean wind speed at the South Pole for the winter of 1992 was modelled as the approaching wind in the CFD model.

The snowdrift deposition pattern measured around the reference building as a result of snowdrifting events during the winter of 1992 (March 1992 through October 1992) was used in this study. The reference building is situated in a remote location where surrounding structures would not affect the local drift patterns. Figure 1 shows the reference building and the CFD model. The building itself is elevated approximately 2.4 m above the snow surface. The three-dimensional model of the elevated reference building included the open truss foundation system beneath the building, but not the entry stairs. Based on a review of photographs showing snowdrift conditions around the building, the cumulative effect of the trusses on the wind flows was considered more important than the local effect of the stairs. The CFD-predicted wind velocity field at the reference height of 1.2 m is shown in Figure 2.

A line drawing showing the snow depth contours surveyed around the reference building was superimposed on top of the CFD-predicted wind velocity patterns (Figure 3) for comparison. High wind speeds were predicted through CFD at "A" in the figure with low wind speeds at "B." The upwind corner of the reference building is at "C." The most significant accumulation of snow around the elevated reference building occurred at "D," which is approximately 9 m downwind. The snowdrift developed in an area where the CFD-predicted wind speed was less than approximately 5 m/s. The wind speed “approaching” the CFD model building was the same as the seasonal mean wind speed recorded at the South Pole during the winter of 1992. Other researchers (Melbourne and Styles 1967, Durgin and Floyd 1971, and Jackson and Carroll 1978) support a snowdrift initiation wind speed of approximately 5 m/s. This correlation of a predicted low wind speed zone, based on the seasonal mean wind speed, with the location of an actual major drift accumulation provided sufficient confidence in the validity of the CFD simulation, as it provided a satisfactory representation of the flow field around an elevated building, to use it as input for the FAE model.

A significant difference between the CFD-predicted wind speed contours and the snow surface contours is the elongation of the drift peak perpendicular to the general flow direction. This effect would not be explained by the velocity contours. It was hypothesized that this effect was due to the variability in wind direction over the course of the winter at the site. The actual snow surface contours, shown in the topographic plan, are the result of many different wind directions and wind speeds for the entire winter of 1992, whereas the CFD-predicted contours represent wind speeds for one wind direction only, similar to most wind tunnel and water flume modelling techniques.

Another possible explanation could be the modification of the flow field by the accumulated snowdrift. However, our experience is that this modification would tend to cause accelerated flow at the sides of the snowdrift's peak, that would erode the snow and deposit it in the wake of the peak, thus elongating the drift parallel with the wind direction.

4 APPLICATION

The comparison of the CFD results (i.e., wind speed contours) to the actual snow surface contours, provided the confidence that the CFD simulation provides a satisfactory representation of the flow field around an elevated building. The study was then extended to examine a new building shape, which may be used during future development at the South Pole. The combination of CFD and FAE models, previously described, was used for the new building which is elevated 3 m above the snow surface. In this study of the new building, the CFD-predicted flow fields for the six prevailing wind directions were used to refine the accuracy of the FAE-predicted snow deposition patterns.

The results of the detailed hour-by-hour prediction of snow accumulation around the new building, for the winter of 1992, are presented in Figure 4. Comparison of the drift depth contours predicted for the new building with those actually measured near the reference building (Figure 3) shows a similarity in the drift pattern. The most significant common feature is the broad drift peak running roughly perpendicular to the approaching wind. This similarity lends support to the hypothesis that the broad nature of the peak is due to the wind direction variability. This points to the need to include as many of the prevailing wind directions in an FAE study as is feasible in order to refine the snowdrift definition and thereby increase the accuracy of the snowdrift predictions.

5 CONCLUSIONS

Computer modelling of wind flow patterns around elevated buildings using CFD provides useful and realistic results that assist in locating areas prone to snowdrift deposition. Velocity patterns, predicted by CFD, with regions of reduced wind speed (i.e. # 5 m/s) near the snow surface (grade level), correlate well to actual snowdrift deposition areas measured in the field. The prediction of actual accumulation amounts is a more complicated issue, requiring an hour-by-hour simulation, performed here with the FAE model.

In this study, the FAE model predicted realistic snow drift accumulation patterns when CFD-predicted local wind velocity fields were combined with local meteorological data.

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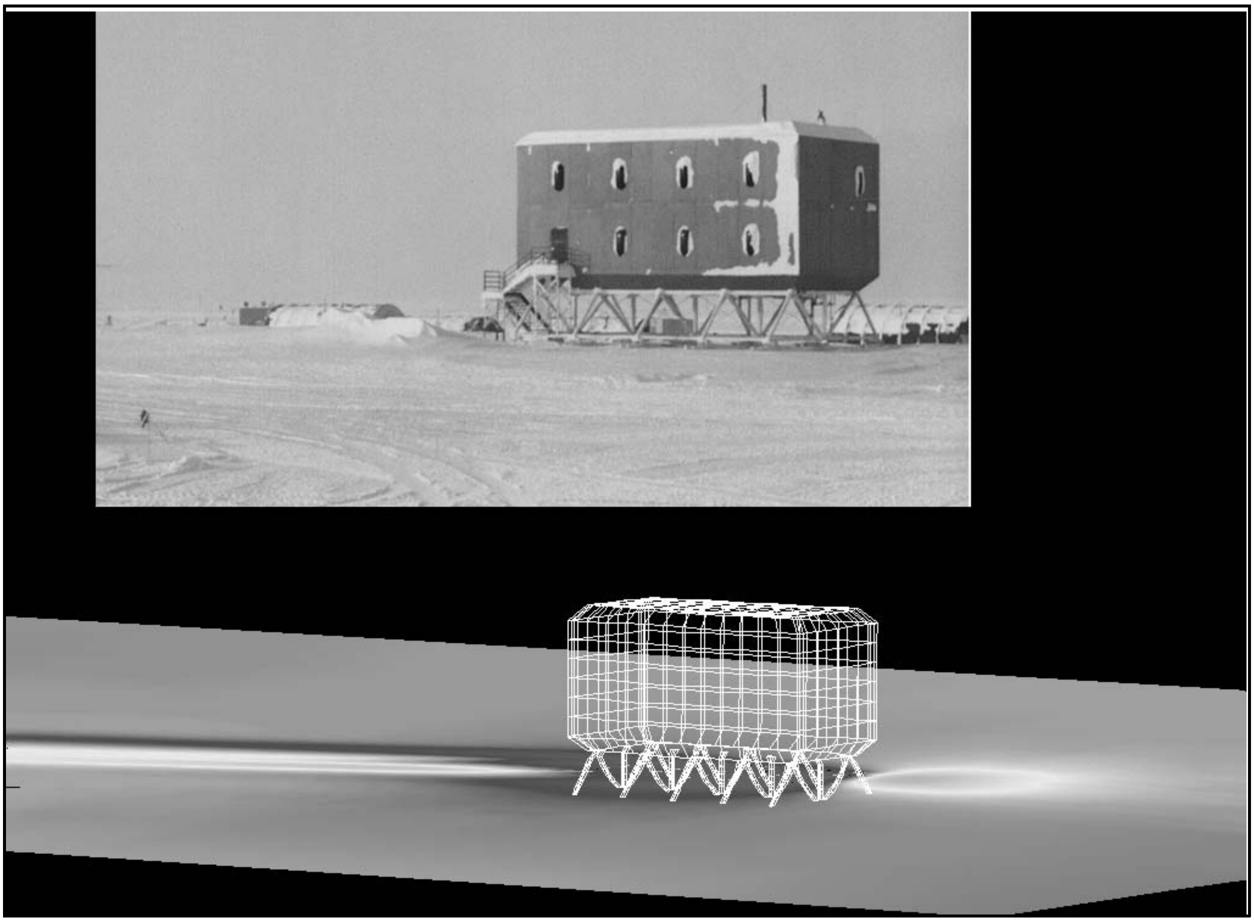

Figure 1 Reference building: CFD model and actual.

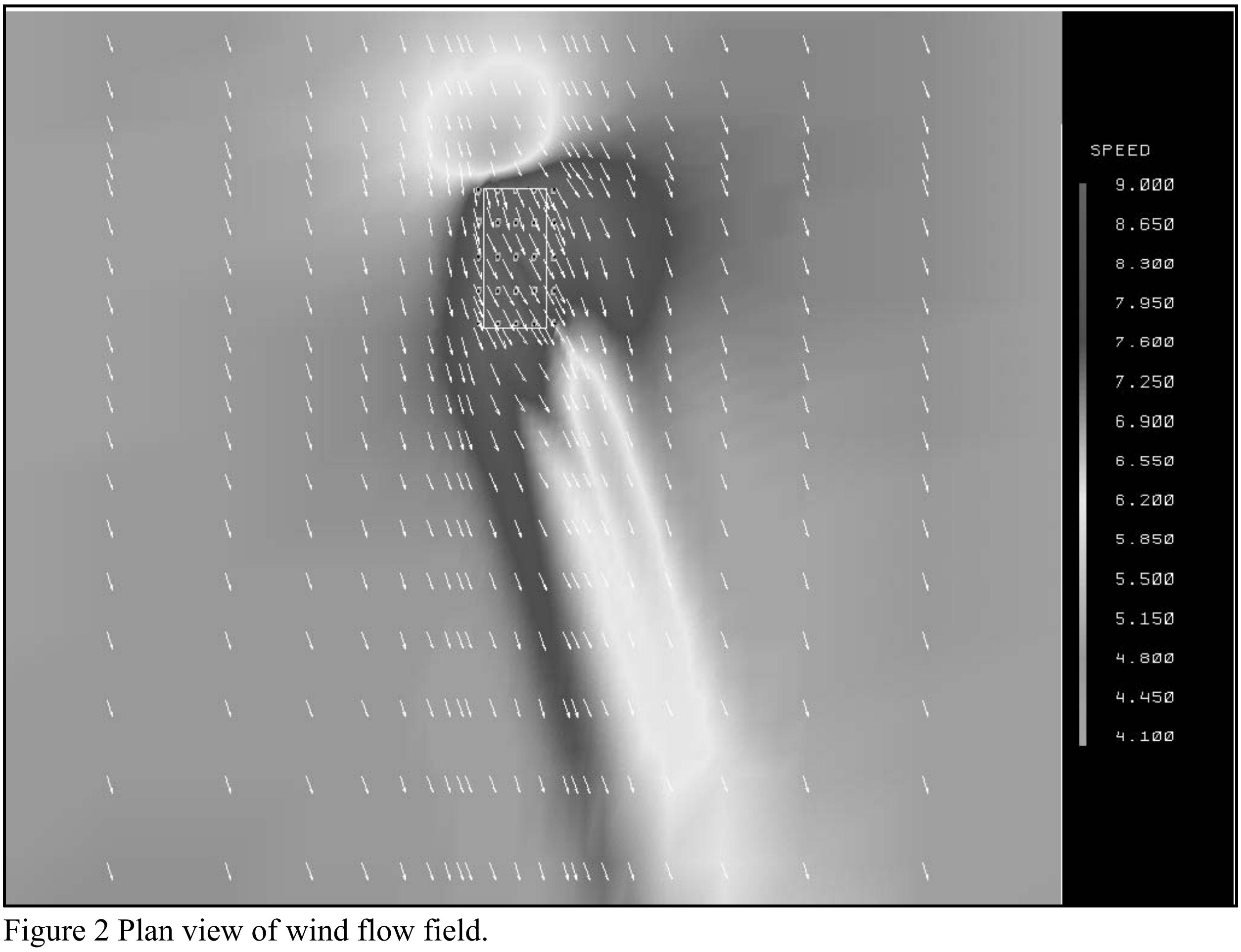

Figure 2 Plan view of wind flow field.

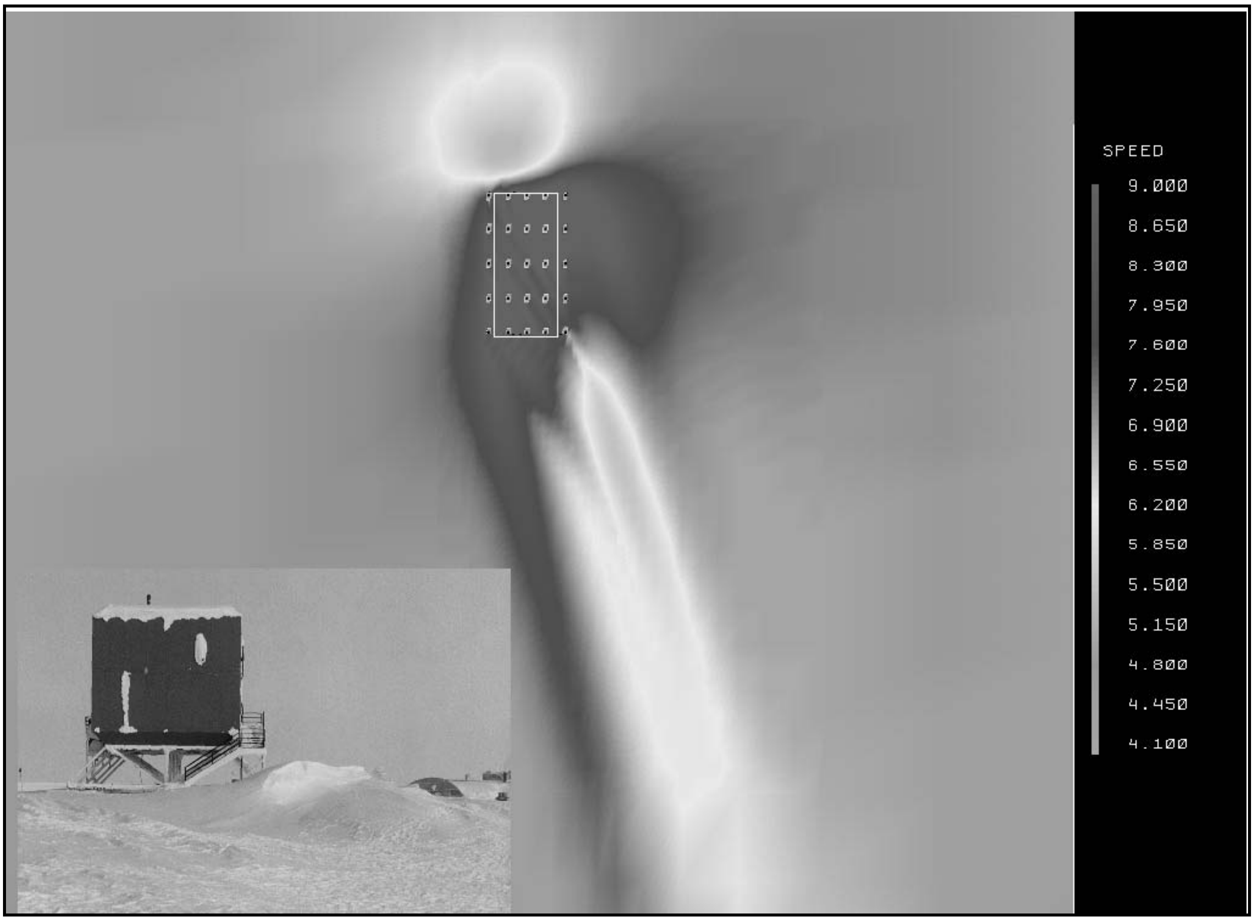

Figure 3 Comparison of CFD wind speeds to snow surface contours.

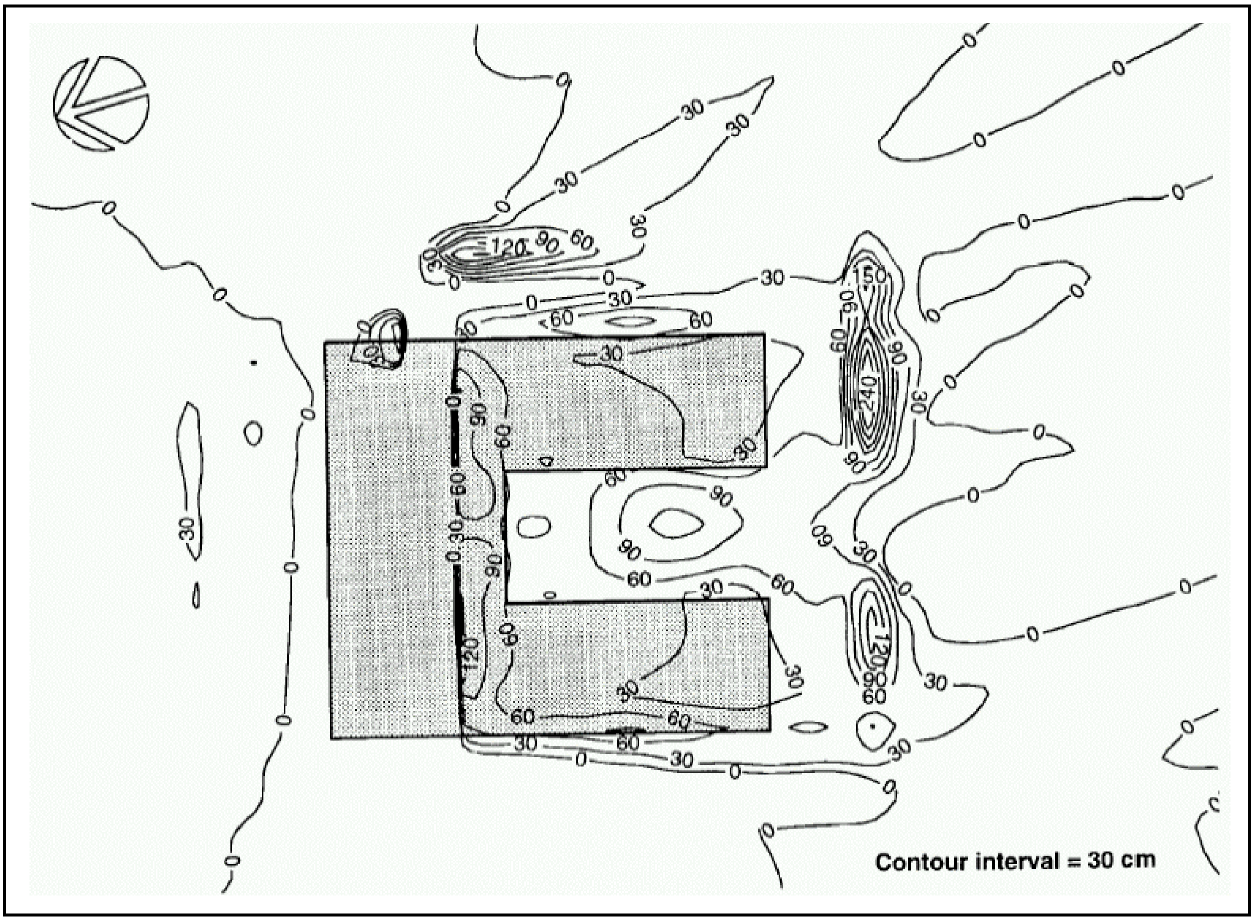

Figure 4 Snow deposition pattern predicted through CFD and an FAE computer snow model.