#7507

Journal of Wind Engineering and Industrial Aerodynamics 51 (1994) 71–91
Elsevier

A wind tunnel study of the pressure distribution around sealed versus open low-rise buildings for naturally ventilated livestock housing

Y. Choinière[a], H. Tanaka[b], J.A. Munroe[c] and A.S.-Tremblay[a]

[a] *Direction de la gestion des ressources, Collège de technologie agricole et alimentaire d'Alfred, Alfred, Ont., Canada*
[b] *Dept. of Civil Engineering, University of Ottawa, Ottawa, Ont., Canada*
[c] *Centre for Food and Animal Research, Agriculture Canada, Ottawa, Ont., Canada*

(Accepted in revised form February 26, 1993)

Summary

A 1:20 scale model of a low-rise naturally ventilated building was tested in a wind tunnel. External pressure coefficients were determined for an open model with various combinations of ridge, sidewall and end wall openings, as well as for a sealed model. The pressure distribution is influenced by all structural modifications at various wind angles. The differences between the open and sealed models were pronounced especially at the ridge and the leeward sidewall. In general, the more opening areas a building has, the larger is the discrepancy in pressure determined for the open versus sealed model.

1. Introduction

During hot weather, naturally ventilated agricultural buildings depend mainly upon wind induced forces to evacuate gases and excess animal heat from the building. However, following an extensive literature review [1], it was found that very few studies are currently available for examination of the complete pressure distribution around such agricultural buildings [2–8]. In fact there is no precise pressure coefficient data set which is immediately applicable to low-rise agricultural buildings with large continuous sidewall openings in combination with a series of intermittent chimneys or a large continuous ridge opening.

The objective of this study was to measure pressures on a low-rise, naturally ventilated building in order to: (1) observe the effects of wind direction on the

Correspondence to: Y. Choinière, Direction de la gestion des ressources, Collège de technologie agricole et alimentaire d'Alfred, Alfred, Ont., Canada.

SSDI 0167-6105(93)E0031-S

pressure distribution around the building, (2) examine the effect of various structural configurations such as sidewall, end wall and ridge openings on the pressure distribution, and (3) compare the results for sealed versus open models.

2. Method and procedure

Different scale models have been used in the past for the purpose of flow visualization and airflow measurements in natural ventilation studies. The effects of scaling on the internal flow velocity and natural ventilation measurements have been discussed by many researchers [9–14].

2.1. Description of scale models

Figures 1 and 2 present the dimensions and the pressure tap locations of the sealed and open models. These are 1:20 scale models of a typical dairy or swine, gable roof barn 12.2 m wide by 24.4 m long, having 2.7 m high sidewalls, a roof with a 4/12 slope (18.4°), and a 0.3 m eave overhang. There are no interior partitions and the ceiling has the same slope as the roof. Both figures show 10 windows on both sidewalls and 2 windows on both end walls. In the open model, two sizes of sidewall windows were tested, one having a dimension of 110 mm × 40 mm which simulated a continuous opening 800 mm high, the other having a dimension of 110 mm × 55 mm which simulated a continuous opening 1100 mm high. The former size of sidewall window was equal to 27% of the sidewall surface and the latter to 37%. A vertical support was left between

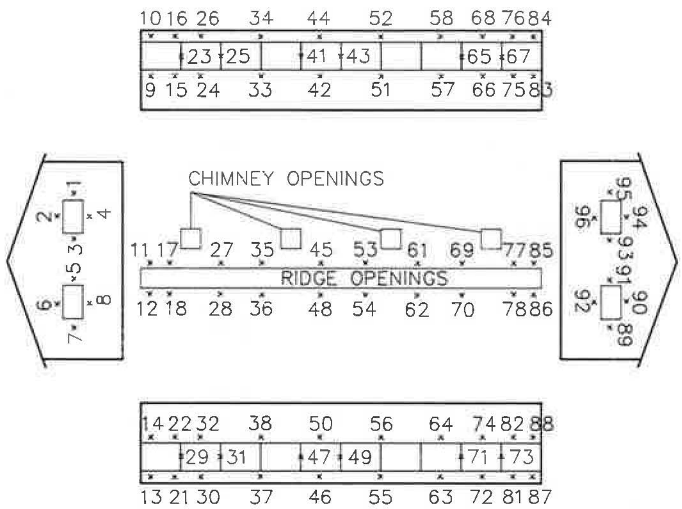

Fig. 1. Tap locations for the open model.

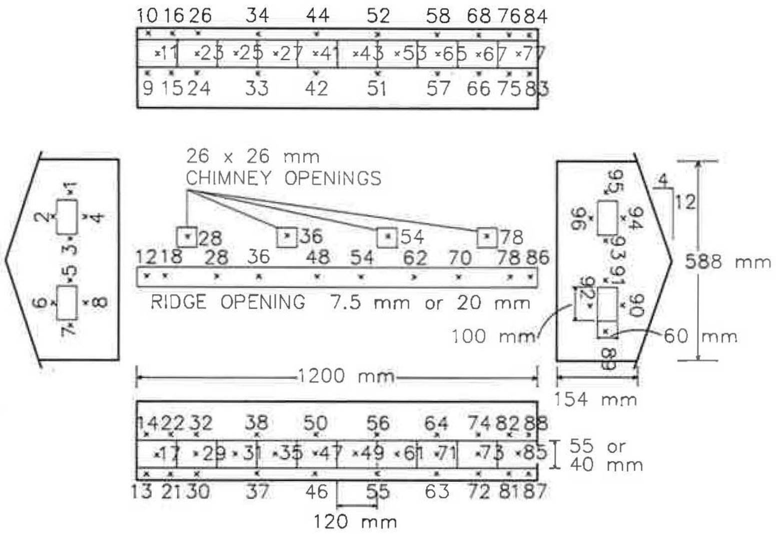

Fig. 2. Scale model dimensions and tap locations for the sealed model.

each window, which represented the building's structural posts, spaced 2.4 m apart. The size of each end wall window was 60 mm × 100 mm.

Three roof opening configurations were tested. As shown in Figs. 1 and 2, four chimneys 26 mm × 26 mm (interior dimensions) (520 mm × 520 mm, full scale) were used in order to respect the recommended minimum ridge opening [15,16] for livestock housing. Also, continuous ridge openings of 7.5 mm and 20 mm (150 mm and 400 mm full scale) were selected because they are commonly used today in agricultural buildings [7,11,13–16]. Expected high negative and positive pressures towards the ends of the building explain the higher concentration of taps near the ends of the sidewalls and ridge [3–8].

Figures 3 and 4 show the locations of the pressure taps for the sealed and open models. With the sealed model the pressure coefficients were measured on the simulated chimneys or continuous ridge openings without having actual outflow through the opening. The intent was to measure the pressure generated by the obstacle inside the cavity. With the open model, a set of four taps around the chimneys was used, tentatively assuming that the same suction would apply to the chimney's outflow. For the open ridge tests, taps were located as closely as possible to the ridge edges on the windward and leeward sides of the continuous ridge opening (Fig. 4).

The tests are identified with the following symbols: OP = open model, SE = sealed model, 150 or 400 = the full scale ridge width in mm, 800 or 1100 = the full scale sidewall opening in mm, C = closed end wall, and O = open end wall. Each of these variables was studied for seven wind angles of incidence, 0°, 10°, 20°, 30°, 45°, 60°, and 90°, where 0° represents winds parallel to the building length. More measurements were made between 0° and 45°,

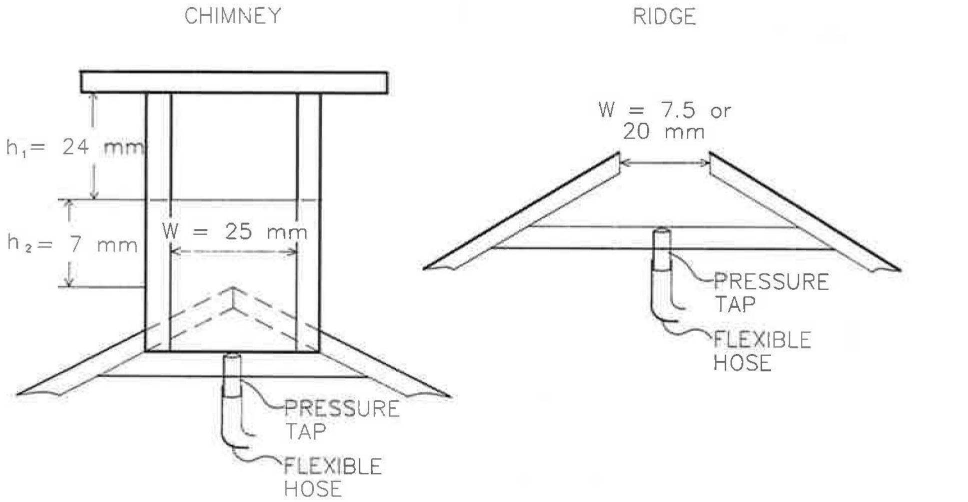

Fig. 3. Sealed model – chimney and ridge opening widths simulating 150 mm or 400 mm – location of pressure taps.

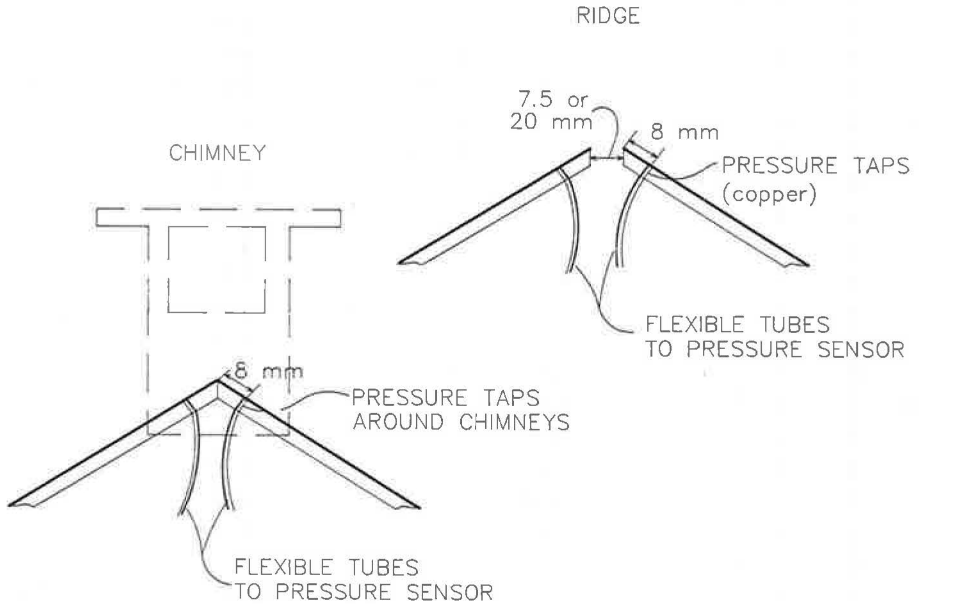

Fig. 4. Open model – chimney and ridge opening widths simulating 150 mm or 400 mm – location of pressure taps.

because the pressure pattern was expected to change more within this octant [2–8]. A total of 84 and 21 tests were performed for the open and sealed model, respectively.

2.2. Wind tunnel

The 2×3 m low speed wind tunnel of the Institute for Aerospace Research, National Research Council Canada in Ottawa was the testing site for this study. An isothermal boundary layer flow representative of the wind for the lower neutral atmospheric surface was simulated in order to study the wind loading over this low-rise buildings [2–5,8,12]. The necessary conditions were: undistorted scaling of the model geometry, vertical profile of wind speed, turbulence intensity, turbulence integral scale, and small blockage of the wind tunnel.

For the simulation of natural wind, several spires were installed at the upstream end of the test section. These spires were designed to produce a 0.35 m thick turbulent boundary layer with the power law exponent of 0.173, and turbulence intensities of 7.9% and 11% at the ridge and eave heights, respectively. This was considered a typical representation of flow over open country terrain. It was not feasible to reproduce the atmospheric turbulence integral scale. However, other work [3,6] suggested that this criteria could be relaxed for the measurements of average pressure coefficients. Consequently, preliminary tests on the effects of sampling time [3] on the measurements of the average pressure coefficient were made. The results indicated negligible differences between average pressure coefficients when the sampling time was above 3 s using a 200 Hz sampling frequency.

For the present study, the freestream speed was 20 m/s and the reference wind speed was about 16 m/s at mid-wall height of the scale model, giving $Re = 6.5 \times 10^5$ by taking the building width as a linear dimension. The selection of a scale of 1:20 and a freestream wind speed of 20 m/s was appropriate with respect to the recommended minimum $Re = 2 \times 10^4$ [12], which should be maintained for natural ventilation studies.

2.3. External pressure coefficients

Contour lines were used to plot the external pressure coefficients over the building surfaces. The mapping program Macdrain [17] was adapted to produce these contour lines. The program interpolates between tap values and extra polates over the control surface. For the sealed model, 30 tap locations were used on each sidewall and 8 on each end wall. For the open model, 26 taps locations were used on each sidewall and 8 on each end wall (Figs. 1 and 2). For both model conditions, the pressure distributions for the chimneys and continuous 150 mm and 400 mm ridges were numerically represented using 10 tap locations for the sealed model and 20 tap locations for the open model.

3. Results and discussion

3.1. Open model

The results of the open model are used as the reference for comparisons. All pressure coefficients are based on the wind speed at the 10 m height.

Figures 5 and 6 present the results for the chimney, simulated 800 mm sidewall openings and closed end wall tests, (OP–CH–800–C) for $\theta = 0°$ and 90°, respectively, where θ represents the wind angle of incidence. The results at $\theta = 90°$ (Fig. 5) show a uniform pressure distribution along the windward sidewall. The contour lines indicate a slight increase in the pressure from the base to the top of this wall (near the overhang). This phenomenon was also noted by other researchers [5,6,8]. The pressure distribution on the leeward sidewall is fairly uniform along its length. On the vertical axis, there is an average pressure coefficient difference of 0.15 from the base of the wall to the overhang height (Fig. 5). Similar behaviour for full scale buildings have been reported elsewhere [18,19]. Both end walls are subjected to a large pressure gradient from the upwind to the downwind edge and show similar contour lines as compared to previous reports [2–8].

The pressures are generally negative along the ridge. Higher suctions (negative pressures) were recorded on the leeward side of the ridge as compared to the windward side. This observation is consistent with other researchers [2–8,18,19]. However, in contrast to most of the previous reports with regular closed ridge, pressures noted here are not uniform along the ridge. This would be attributed to the presence of the chimneys. Complete sets of pressure coefficient contour lines for $\theta = 10°$, 20°, 30°, 45°, and 60° are presented elsewhere [3].

At $\theta = 0°$, the pressure distributions along both sidewalls are very similar. The suction declines to mid-length of the building and then stabilizes over the remainder of the sidewall. The pressure distribution over the upward end wall for $\theta = 0°$ behaves in the same way as over the windward sidewall for $\theta = 90°$ except that the vertical pressure gradient is influenced by the shape of the roof.

3.1.1. Effect of sidewall openings with closed end walls

Figure 5 (OP–CH–800–C) versus Fig. 7 (OP–CH–1100–C) reveals that for $\theta = 90°$, the windward sidewall shows slightly higher pressures with the 1100 mm opening versus the 800 mm opening. However, the suction over the leeward sidewall is consistently greater for the 1100 mm opening. Although notincluded, the same increase in suction on the leeward sidewall has been noticed in other tests with 150 mm and 400 mm ridges [3]. The end wall and the chimney pressure distributions were not affected by the increase of the sidewall opening area [3].

The data for $\theta = 60°$ and 45° showed different pressure distributions over the windward sidewall surface. Higher pressures were recorded with the 800 mm opening as compared to the 1100 mm opening at the upwind corner of the

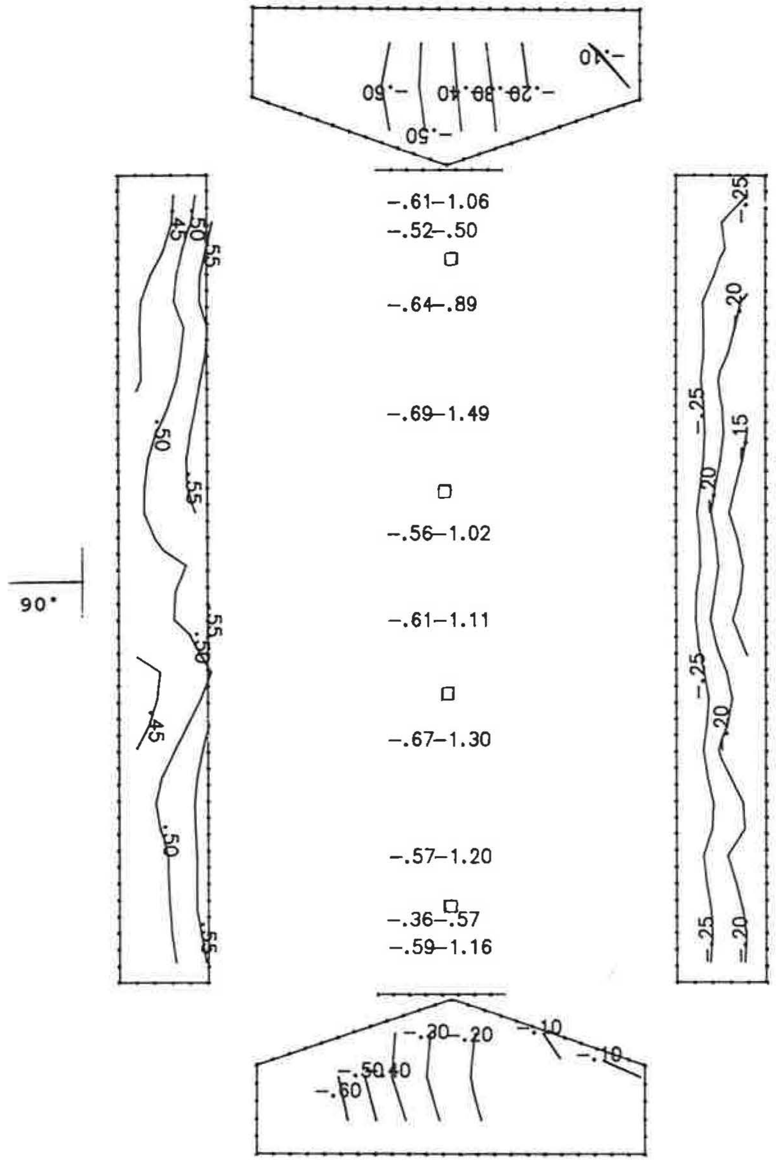

Fig. 5. C_p contour lines: open model, chimney, simulated 800 mm sidewall openings, closed end walls, wind angle of 90°.

sidewall. The larger sidewall opening area (1100 mm) may allow air to go through the opening area, reducing the blockage or the turbulent upwind effect at the corner. On the other hand, the increase in outflow through the leeward sidewall seems to create slightly higher suction.

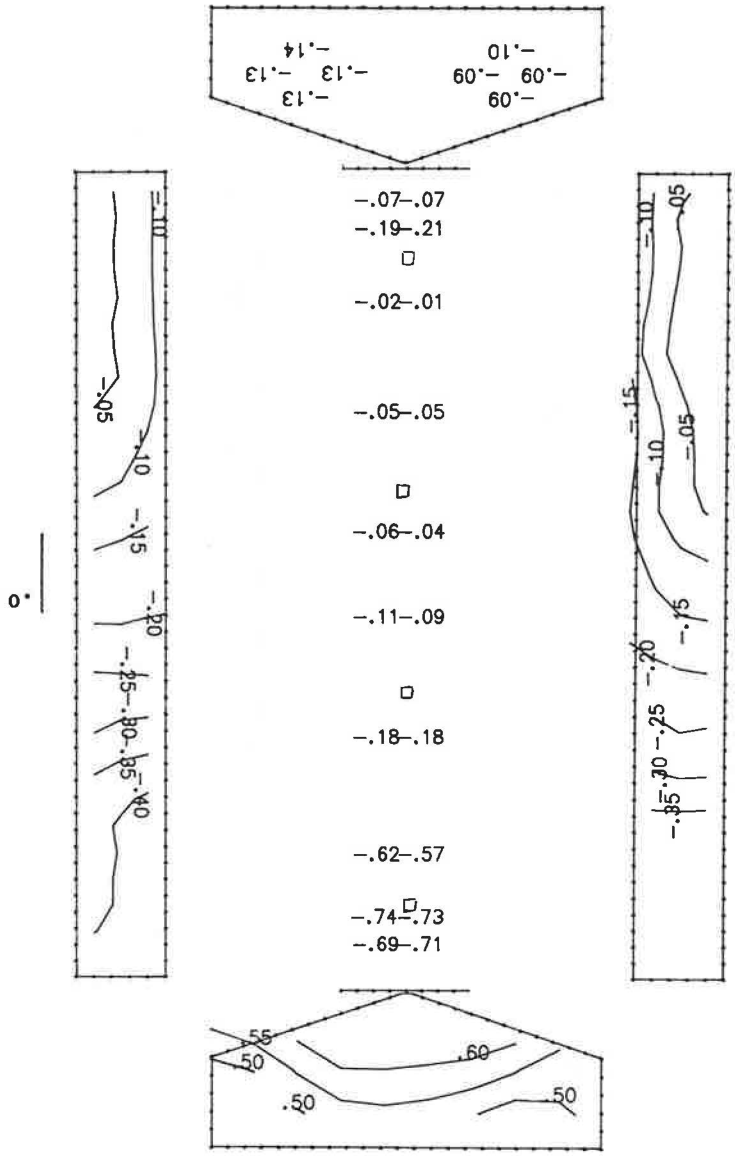

Fig. 6. C_p contour lines: open model, chimney, simulated 800 mm sidewall openings, closed end walls, wind angle of 0°.

At $\theta=30°$, 20°, and 10°, the 1100 mm sidewall opening induced greater suction at the upwind corner of the windward wall while the pressures over both end walls, leeward sidewall and chimneys remained unchanged. For $\theta=0°$, the size of the opening area had no effect on the pressure distribution elsewhere on the

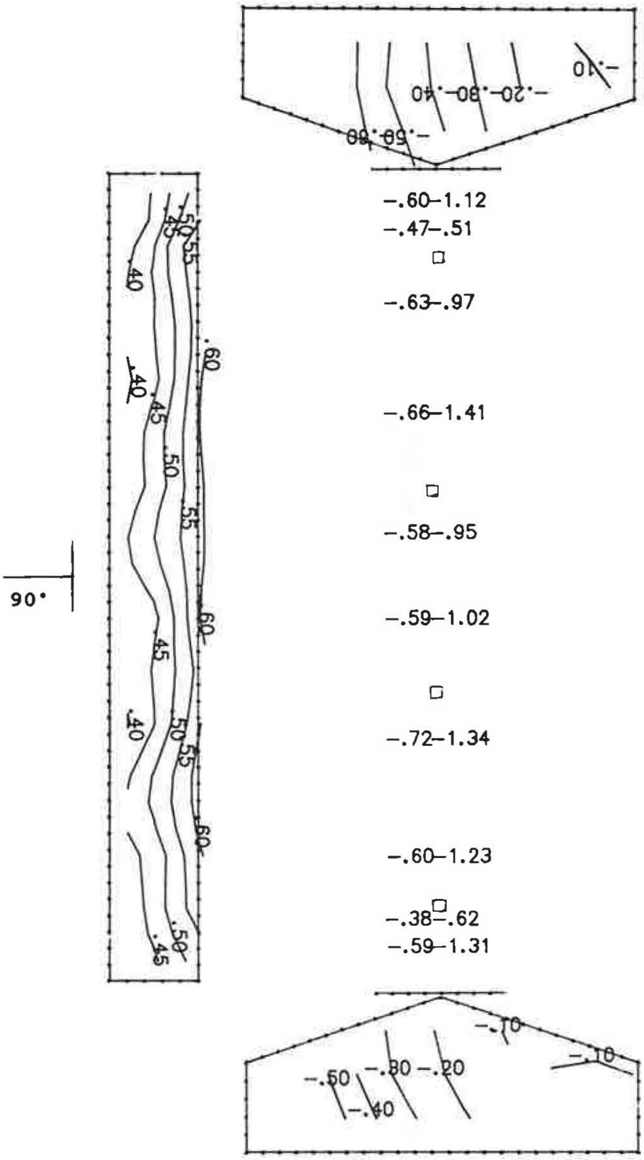

Fig. 7. C_p contour lines: open model, chimney, simulated 1100 mm sidewall openings, closed end walls, wind angle of 90°.

wall surfaces. Comparing data for continuous ridge openings of 150 mm versus 400 mm [3] shows similar effects of the sidewall opening areas on the pressure distribution. The increase in the ridge opening accentuates the difference in suction on the leeward sidewall at $\theta=90°$, 60°, 45° and shows very similar results for the upwind windward corner at $\theta=30°$, 20°, 10° and 0° [1,3].

Based on all the tests, it can be concluded that increasing the sidewall opening size from 800 to 1100 mm, with closed end walls, results in the following:
(1) higher pressure over the windward corner at $\theta=45°$ and 60°.
(2) higher suction over the windward corner for the 1100 mm case at $\theta=10°$, 20° and 30°,
(3) higher suction over the leeward wall for the 1100 mm case for $\theta=60°$ and 90°, and
(4) negligible effect at $\theta=0°$.
Similar behaviour was observed with ridge openings of both 150 mm or 400 mm.

3.1.2. Effect of end wall openings

By comparing Figs. 6 (OP–CH–800–C) and 8 (OP–CH–800–O) at $\theta=0°$, both the sidewall and chimney pressure distributions show no difference with either closed or open end walls. Major changes in pressure distribution occur, however, over the upwind end wall when end wall windows are open. With open end walls, there is a gradual decrease in pressure over the end walls from the center to the ridge and sides, while with closed end walls (Fig. 6) pressures are generally lower at the center and increase towards the sides. Also, the largest difference in pressure between open and closed end walls occurs at the window location showing the large effect of the inflow through the window. Suction was slightly higher on the down wind sidewall when the end wall was open.

Other data for $\theta=10°$ to 90° [3] shows only minor changes in the pressure distribution over both upwind and down wind sidewalls. Also, no significant change was noted in the pressure distributions at chimney level. With the larger sidewall opening area of 1100 mm, similar effects on the C_p distribution are noticed as compared to the 800 mm sidewall opening.

With both the 150 mm and the 400 mm ridges, there was a general tendency to have slightly lower suction at ridge level, with open end walls and with wind angles between 60° and 0°.

Based on the pressure distributions noted for all tests, it appears that open as compared to closed end walls, result in the following:
(1) a very small effect on the pressure distribution at both sidewalls and a negligible effect on the chimney around the scale model,
(2) major changes in the pressure distribution over the windward end wall, and
(3) slightly reduced suction at the ridge level for both 150 mm and 400 mm ridge openings, for $\theta=60°$ to 0°.

3.1.3. Effect of ridge openings

Figures 5 (OP–CH–800–C), 9 (OP–150–800–C) and 10 (OP–400–800–C) are used to compare the effect of the ridge opening on the pressure distributions. At $\theta=90°$, the pressures on the windward sidewall are not affected by ridge opening type, but the suction on leeward sidewall, for both the 150 mm and 400 mm ridges increased from about -0.1 to -0.2 as compared to with the

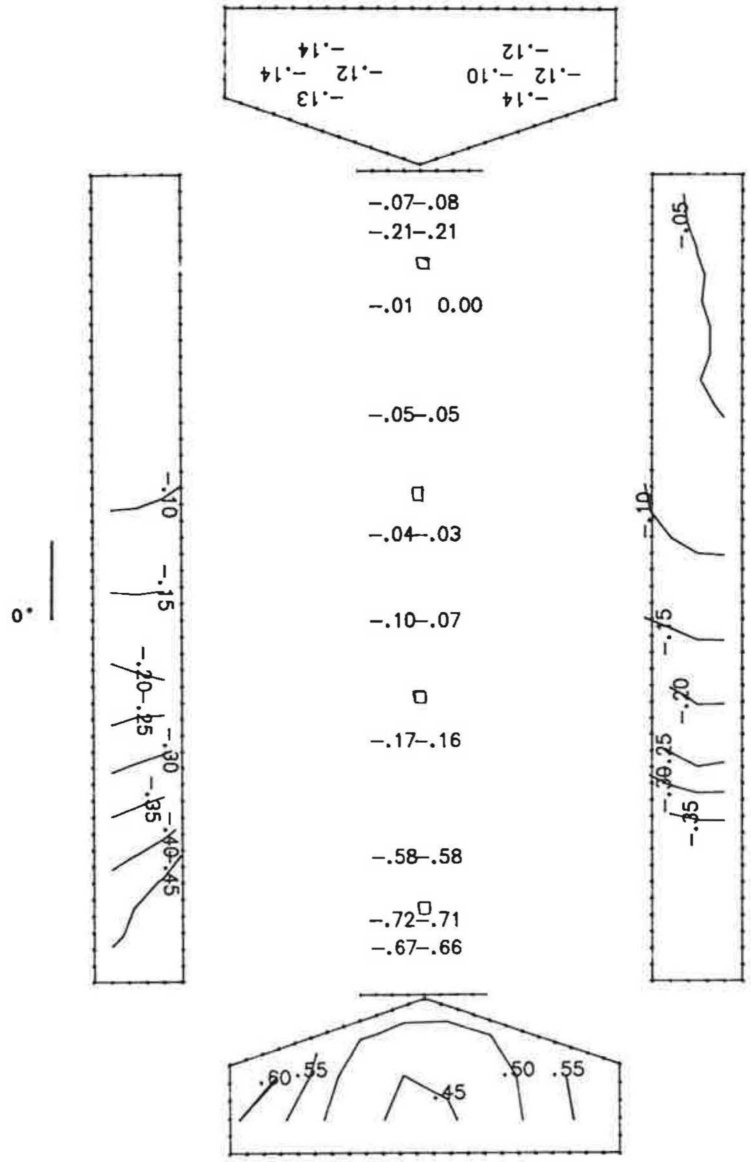

Fig. 8. C_p contour lines: open model, chimney, simulated 800 mm sidewall openings, open end walls, wind angle of 0°.

chimney. Also, the average suctions along the ridge with the chimneys are about 4 times higher than those to with the 150 mm or 400 mm ridge openings. The higher suctions along the ridge with the chimneys accompanied with lower leeward sidewall suctions may be explained by considering flow over the

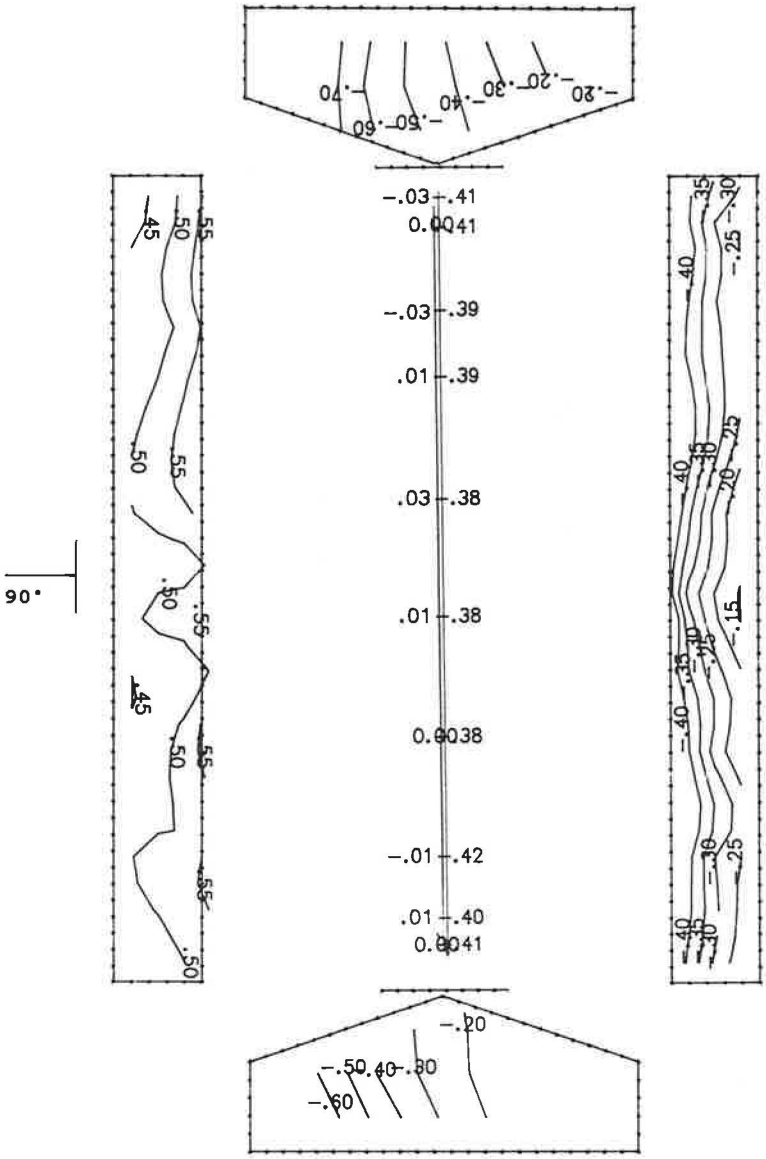

Fig. 9. C_p contour lines: open model, simulated 150 mm ridge and 800 mm sidewall openings, closed end walls, wind angle of 90°.

building. Based on full scale observations, it has been reported that outflow through the continuous ridge opening has a large effect on the pressure distribution [19,20]. The outflow disturbed the typical flow separation pattern at the ridge line. Also, from Figs. 9 (OP–150–800–C) and 10 (OP–400–800–C), it

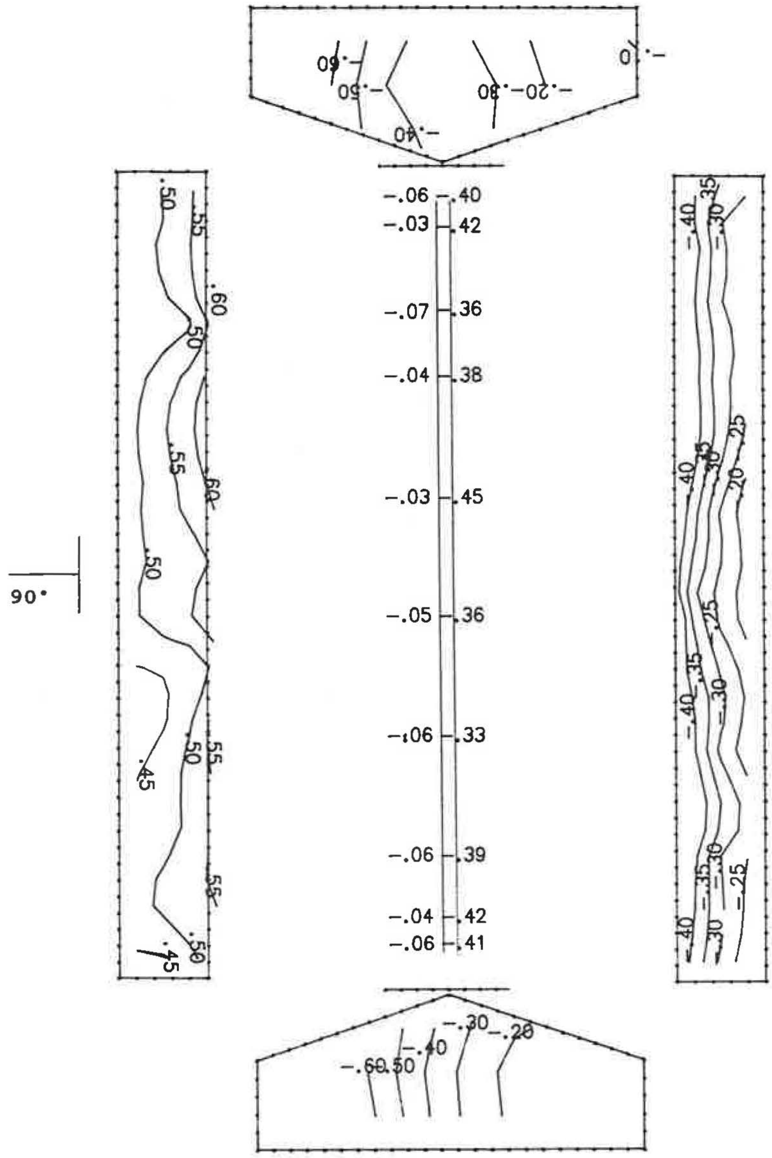

Fig. 10. C_p contour lines: open model, simulated 400 mm ridge and 800 mm sidewall openings, closed end walls, wind angle of 90°.

appears that the larger outflow exhausted by the 400 mm ridge generates slightly higher suction at the ridge.

At $\theta = 60°$, the pressure contour lines over the windward sidewall were quite similar regardless of the ridge type [3]. The suction on the leeward sidewall was lowest with the chimneys and highest with the 400 mm ridge. The pressure over the windward end wall did not change with ridge opening type, but the leeward end wall experienced lower suctions with the larger ridge opening. The chimney suctions were consistently higher (about twice more negative) than the 150 mm and 400 mm ridges, and the suction for the 400 mm ridge are slightly higher than the 150 mm ridge.

Ridge opening type had little effect on pressure distribution for $\theta=30°$. The 400 mm ridge opening induced slightly higher suctions as compared to the 150 mm ridge opening.

Finally, at $\theta=0°$, flow disturbances induced by the chimney vertical members and flat roof caused some local pressure variations. However, in general, pressure distributions were broadly similar for all three types of ridge openings. The ridge opening type induces the following general effects:

(1) the chimney suction is higher than 150 mm and 400 mm ridge openings for $\theta=45°$, 60° and 90°,
(2) for $\theta=90°$, the 400 mm ridge opening induces slightly higher suctions at the ridge compared to the 150 mm ridge opening (no difference was noticed for the other angles),
(3) the larger ridge opening gives slightly higher suctions over the leeward sidewall for $\theta=45°$, 60° and 90°, and
(4) suction along the ridge was not greatly affected by size of sidewall opening.

3.2. Sealed model results

The measured pressure distributions around the sealed model with various configurations are presented in Figs. 11 (SE–CH), 12 (SE–150) and 13 (SE–400). The type of ridge opening has an effect on the pressure distributions. At $\theta=90°$, the positive pressure over the windward sidewall increases slightly as the ridge opening width changes from 400 mm to 150 mm, and finally they are the highest with the chimneys. For the leeward sidewall, the 400 mm opening shows the smallest suctions with a gradual increase with the 150 mm and the highest suctions are noticed with the chimneys. The reverse situation occurs with the ridge opening types. The lowest suctions are noticed with the chimneys and the suction rapidly increases through 150 mm to reach their peaks with the 400 mm ridge. Based on other data [3], at $\theta=0°$, the ridge opening type has little effect on the pressure distribution on the sidewalls and end walls. Based on the results of the sealed model, the following are noted:

(1) at $\theta=90°$, all three ridge opening types have different effects on the pressure magnitudes over the windward and leeward sidewalls,
(2) at $\theta=90°$, the 400 mm ridge induces higher suction along the ridge as compared to the 150 mm ridge or chimneys, and
(3) at $\theta=0°$, no difference in pressure distribution is noticed over the ridge, sidewalls and end walls.

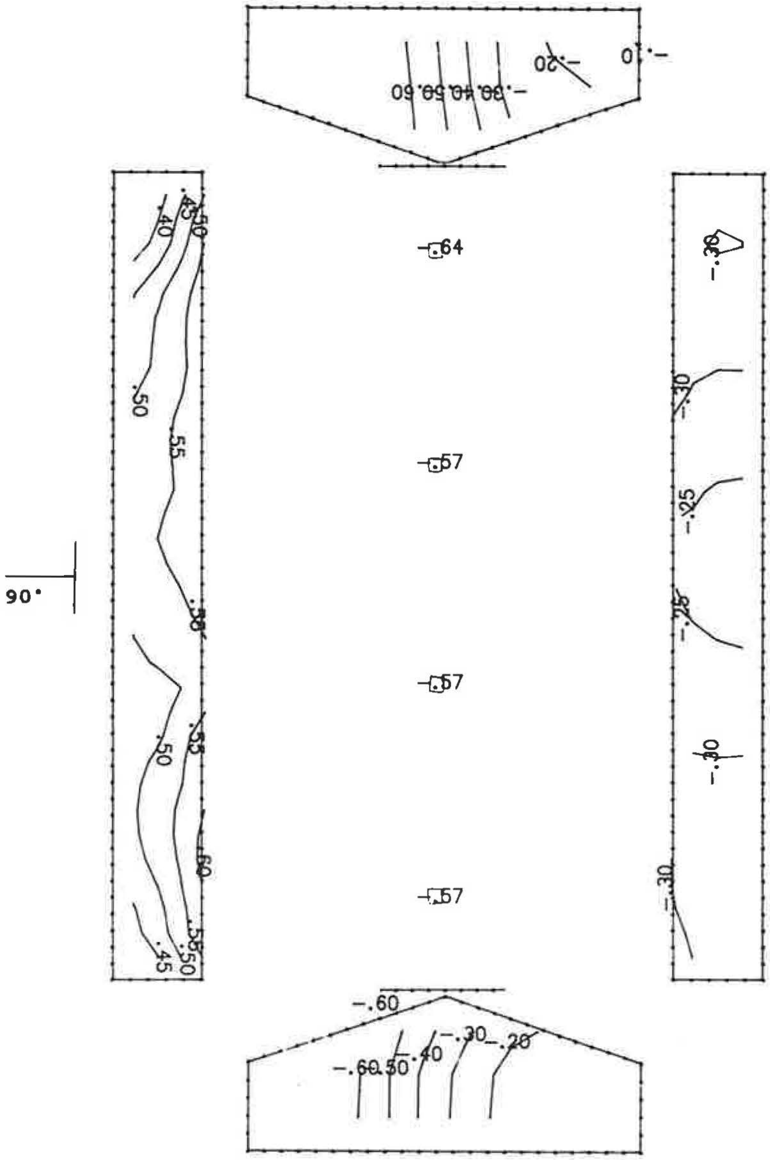

Fig. 11. C_p contour lines: sealed model with chimney, wind angle of 90°.

3.3. Sealed versus open models

3.3.1. Tests with chimneys

The comparisons of Fig. 5 (OP–CH–800–C) with Fig. 11 (SE–CH) reveals large differences in the pressure distribution caused by the opening of the model. For the case of the open model with a wind normal to the building

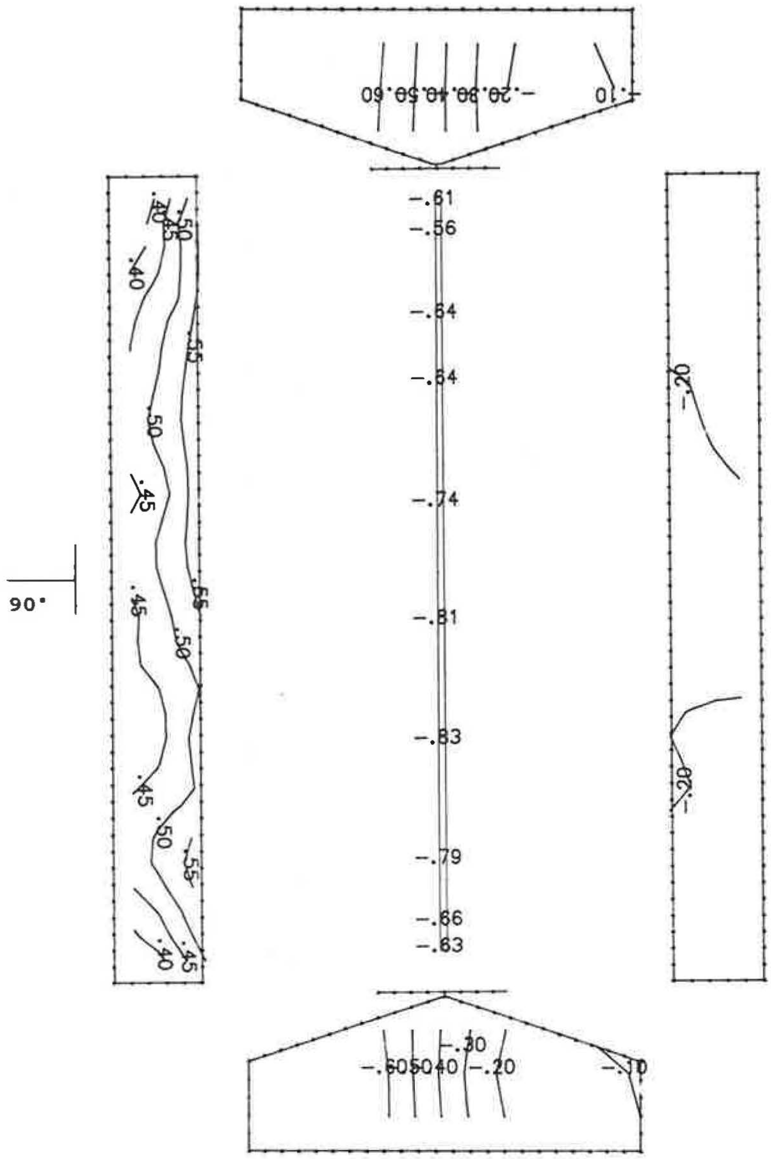

Fig. 12. C_p contour lines: sealed model with simulated 150 mm ridge, wind angle of 90°.

length (90°), for example, the pressure distribution on each sidewall is more or less uniform whereas with the sealed model there are higher pressures at the centre of the windward wall and a reduction of suction at the centre of the leeward wall. Similar tendencies on sealed models have been reported elsewhere [2–6,8]. The porosity due to the openings allows air to go through the

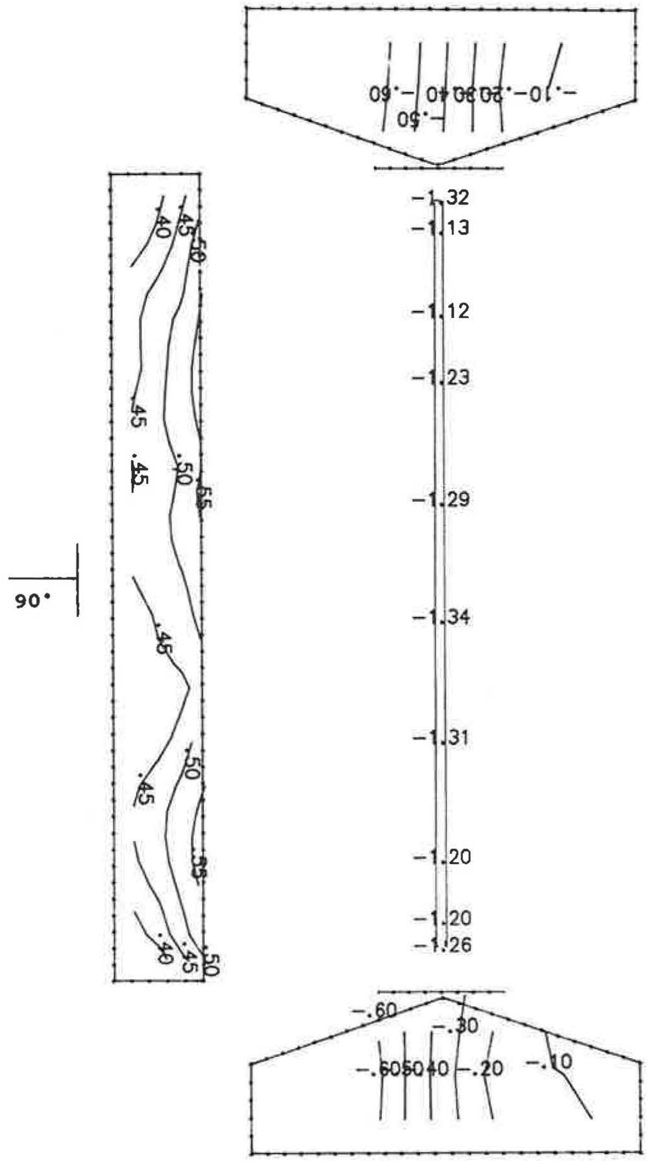

Fig. 13. C_p contour lines: sealed model with simulated 400 mm ridge, wind angle of 90°.

model resulting in more uniform pressure over the walls. The suctions along the ridge are considerably higher for the sealed model than for the open model.

For the other wind angles from 0° to 45°, the windward and leeward sidewalls have different pressure distributions [3]. A larger gradient of pressure occurs with the sealed model from the upwind to the downwind end of the building. Also, the suction over the chimneys are higher with the sealed model.

The enlargement of the sidewall opening from 800 mm to 1100 mm increases the differences in pressures between the sealed and open models. When end wall openings are used, large differences are noticed at both end walls and the C_p distributions and magnitudes are completely different for the open versus the sealed model. Generally, the comparison between sealed and open models with the chimneys show that:

(1) with the sealed model, chimney suctions are always higher as compared to the open model,
(2) the pressure distributions over the sidewalls are considerably different for all wind angles except 60°,
(3) with the larger sidewall opening of 1100 mm the difference of the pressure distributions between sealed and open model results is accentuated, and
(4) when the end wall openings are made, pressures on open model end walls are completely different as compared to the sealed model.

3.3.2. Tests with 150 mm and 400 mm ridges

The comparisons between Figs. 9 (OP–150–800–C) and 12 (SE–150), as well as between Figs. 10 (OP–400–800–C) and 13 (SE–400) tend to show that the larger the opening areas are, the larger the differences in pressures and pressure distributions between the open and sealed models. For all wind angles with the sealed model, very high suctions along the ridge level are noted while suctions over the leeward sidewall are smaller. From the results of the sealed versus open models, with 150 mm and 400 mm ridge, the following points can be made:

(1) the suctions along the ridge are considerably higher with the sealed model,
(2) the suctions over the leeward walls are higher with the open models,
(3) with the end walls open, the pressure distributions over both end walls are completely different for the sealed models versus the open models, and
(4) when the sidewall opening areas in the open model are increased from 800 mm and 1100 mm, larger differences in pressures and pressure distributions occur.

3.4. Methodology for C_p measurements over ridge openings

Comparing Fig. 5 (OP–CH–800–C), Fig. 7 (OP–CH–1100–C), and Fig. 11 (SE–CH), a difference of pressure distribution is observed between the open and sealed models with chimneys. With the open model, the measurements were made on the edge of the ridge line (Fig. 4) while they were measured inside the chimney with the sealed model (Fig. 3).

The method used for estimating the pressure coefficient for the chimney in the open model requires further investigation. With the present method, it is assumed that the effective pressure applied to the chimney is the average of the four nearest pressure tap readings. This assumption means that the pressure coefficients generated by the ridge line apply directly to the chimney without any extra air outflow effects. It has been demonstrated that the presence of vertical sides of the chimney above the ridge line may create even higher suctions [21–23].

However, with continuous ridge openings the pressures along the ridge are completely different for the open model as compared to the sealed model. This fact would confirm the presumption concerning the effect of the outflow through the ridge altering the negative pressure distribution [8,20]. The pressure changes at the ridge are in agreement with the full scale pressure observations for open versus closed ridges for low-rise buildings [7,19,20]. For the sealed model, the comparison between the pressure measurements done on the edge of the ridge openings versus the present measurements performed inside a cavity (Fig. 3) would also require further investigations.

4. Summary and conclusion

1:20 scale models of a low-rise, naturally ventilated agricultural building were wind tunnel tested to measure the wind induced external pressure distribution. 105 test runs in total were carried out with various configurations. The structural parameters examined in this series of testing were as follows:
(1) three ridge opening configurations consisting of either intermittent chimneys, or a simulated 150 mm or 400 mm wide continuous ridge opening,
(2) simulated 800 mm or 1100 mm high continuous sidewall openings, and
(3) the use of two end wall openings.

Each building configuration was tested for seven wind directions; 0°, 10°, 20°, 30°, 45°, 60°, and 90°. The general observations regarding the measured pressures are as follows:

4.1. With the open model

(1) The highest suction at the ridge were recorded with the chimneys rather than with continuous open ridges.
(2) The 800 mm or 1100 mm sidewall opening does not create large changes in the pressure distributions, except at $\theta = 60°$ and 90°, where the 1100 mm opening generates higher pressure differences across the building.
(3) The end walls openings of the open model completely change the pressure distribution over the closed end walls.

4.2. With the sealed model

(1) The suction along the ridge are increased considerably when 400 mm ridge is employed as compared to chimneys.
(2) The type of ridge opening used has a great effect on the leeward sidewall pressure distribution.

4.3. Open versus sealed model

(1) The suction along the ridge are considerably greater with the sealed model.
(2) The suction over the leeward sidewall are significantly higher with the open model especially when the 400 mm wide continuous ridge is installed.

(3) With the open end walls, the pressure distribution over both end walls are totally reversed from one side to the other side for the sealed versus open models.

Generally, the more opening areas the building has, the larger the discrepancy in pressure distribution was between the open and sealed models.

Acknowledgements

The authors gratefully acknowledge G. Garland, P. Eng. and V. Spencer, P. Eng., Resources Management Branch, Guelph, Ontario, K. Boyd, Education and Research Funds, Ontario Ministry of Agriculture and Food, Guelph, Ontario; C. Weil, P. Eng., Research and Technology and M. Paulhus, Principal Alfred College of Agriculture and Food Technology, Alfred, Ontario for their support and funding. Special thanks are addressed to the research officers of the Institute for Aerospace Research, National Research Council Canada for the extensive and helpful contribution during this study. The financial support provided by the Ontario Ministry of Agriculture and Food, Agriculture Canada, Ontario Hydro Technical Services and Development for Agriculture, the Canadian Electrical Association, the Ontario Pork Producers' Marketing Board, Sun-North Systems Ltd., Faromor Inc. and NRCC IRAP is greatly appreciated.

References

[1] Y. Choinière, H. Tanaka, J.A. Munroe and A.S.-Tremblay, Pressure distribution around sealed versus open low-rise buildings for naturally ventilated livestock housing, Part II: Comparison to previous work, J. Wind Eng. Ind. Aerodyn., submitted (1992).
[2] R.M. Aynsley, W. Melbourne and B.J. Vickery, Architectural Aerodynamics, Applied Science Publishers Ltd., London, 1977.
[3] Y. Choinière, Wind induced natural ventilation of low-rise building for livestock housing by the pressure difference method and concentration decay method, M.Sc Thesis, University of Ottawa, Canada, 1991.
[4] A.G. Davenport, D. Surry and T. Stathopoulos, Wind loads on low-rise buildings: Final report of phases I and II, text and figures, BLWT-SS8-1977, BLWT/UWO, London, Ont., Canada, 1977.
[5] A.G. Davenport, D. Surry and T. Stathopoulos, Wind loads on low-rise buildings: Final report of phase III, Part I, Text and Figures, BLWT-SS4-1978, BLWT/UWO, London, Ont., Canada, 1978.
[6] J.D. Holmes, Wind loads on low-rise buildings: A review, Commonwealth Scientific and Industrial Research Organization, Division of Building Research, Australia, 1983.
[7] G. Shrestha, C. Cramer and B.J. Holmes, Wind induced natural ventilation of an enclosed building, Am. Soc. of Agric. Engng., Paper No. 90-4001, 1990.
[8] B.J. Vickery, R.E. Baddour and C. Karakatsanis, A study of external wind pressure distributions and induced internal ventilation flow in low-rise industrial and domestic structure, BLWT-SS2-1983, BLWT/UWO, London, Ont., Canada, 1983.
[9] R.W. Bottcher, D.H. Willits and G.R. Baughman, Experimental analysis of wind ventilation of poultry buildings, Trans. ASAE, 29(2) (1986) 571–578.

[10] K.G. Boyd, Experimental analysis of ventilation due to wind in models of a modified open front (MOF) swine finishing barn, M.Sc. Thesis, University of Guelph, Canada, 1985.

[11] J.M. Bruce, Wind tunnel study: Suckler cow building, Farm Building Progress (1974) 15–17.

[12] J.E. Cermak, M. Doreb, J.A. Peterka and S.S. Ayad, Wind tunnel investigations of natural ventilation, J. Trans. Eng., 110(1) (1984) 67–79.

[13] Y. Choinière, F. Blais and J.A. Munroe, Wind tunnel study of airflow patterns in a naturally ventilated building, Can. Agric. Eng., 30(2) (1988) 293–297.

[14] Y. Choinière and J.A. Munroe, A model study of wind direction effects on airflow patterns in naturally ventilated swine buildings under isothermal conditions, Can. Agric. Eng. (submitted 1993).

[15] Y. Choinière and J.A. Munroe, Minimum ridge opening widths of an automatically controlled naturally ventilated swine barn for a moderate to cold climate, Can. Agric. Eng. (In press, 1993).

[16] Y. Choinière, J.A. Munroe, G. Desmarais, H. Dubois and Y. Renson, Effect of different ridge opening widths on the thermal performance and ventilation rate of a naturally ventilated swine building during warm summer conditions, Can. Agric. Eng. (In press, 1993).

[17] S. Tremblay, A microcomputer software package to design agricultural drainage plans, M.Sc. Thesis, McGill University (Macdonald College), Québec, Canada, 1987.

[18] R.P. Hoxey, Design wind loads for closed farm buildings, J. Agric. Eng. Res., 29 (1984) 305–311.

[19] G.M. Richardson, A.P. Robertson, R.P. Hoxey and D. Surry, Full scale and model investigation of pressures on an industrial/agricultural building, J. Wind Eng. Ind. Aerodyn., 36 (1990) 1053–1062.

[20] G.M. Richardson, Full-scale wind load measurements on a single span film plastic clad livestock building: Investigating the effect of a ridge ventilation slot, Div. Note DN 1592, AFRC, Engineering Research, Silsoe, UK, 1991.

[21] F.S Bauman, D.R. Ernest and E.A. Arens, Asean natural ventilation study: Wind pressure distributions on long building rows in Urban surroundings, CEDR, University of California, Berkeley, CA 94720, 1988.

[22] D.P. Froehlich, M.A. Hellickson and H.G. Young, Ridge ventilation effects on model ventilation characteristics, Am. Soc. of Agric. Eng., Paper No. 74-4055, 1974.

[23] J. Blessman and N.I.B. Soilveira, Wind pressures on roofs with closed ventilators, J. Wind Eng. Ind. Aerodyn., 37 (1991) 285–298.