WIND TUNNEL TESTS ON SCALE MODEL BUILDINGS AS A MEANS FOR STUDYING VENTILATION AND ALLIED PROBLEMS*

By J. J. WANNENBURG† and J. F. VAN STRAATEN.‡

SYNOPSIS.

Wind tunnel tests conducted on a scale model of a classroom show that, provided the test air speed is kept in excess of about 3 m.p.h., it is feasible to use models for predicting, with good accuracy, the air-flow conditions in and around full-scale buildings.

In the case of low-pitch roofs the height of the stagnant zone set up as a result of flow separation occurring at the windward eaves of a building is influenced by wall height rather than by roof pitch.

As a result of the absence of directed flow, roof ventilators and other ventilation openings situated within the stagnant zone will cause extraction of air from the building not by direct action of the wind but by the differential pressures acting across them.

INTRODUCTION.

WITH the more realistic trend modern architectural design is taking at present increased attention is being given to the functional requirements of the structure, and therefore also to the climatic factors involved. The reason for this is perhaps that "in modern society no shelter is regarded as adequate unless the indoor conditions are conducive to the health and comfort of the occupants".[1]

The functional requirements to which are referred include such factors as ventilation, lighting, thermal insulation and resistance of the building elements to rain penetration, but in this Paper only ventilation will be considered. The importance of ventilation in the South African climate has already been stressed elsewhere,[2] and it has been shown that since satisfactory ventilation should also provide a healthy and comfortable atmosphere it connotes something more than merely the replacement of stale air by fresh air.

In the case where limited resources prohibit the installation of costly forced-ventilation and temperature-control systems attention must be given to the most suitable and efficient way in which natural ventilation can be employed. For this purpose, and in order to provide a rational basis for design, more information regarding the effects of structural features, such as building shape and fenestration, on the natural ventilation conditions indoors would have to be obtained and made available to architects and designers of buildings. The only way of obtaining this information is through experimental investigation, and in this connection quite comprehensive tests have been conducted on full-scale buildings by overseas investigators.[3, 4] Unfortunately, however, the results of these investigations are in many cases of limited application in South Africa, where totally different climatic conditions are encountered. Tests on natural ventilation[5, 6, 7] have been conducted on full-scale buildings locally, but in view of the inherent disadvantages attached to full-scale

* Manuscript received July 2nd, 1956.

† Research Officer, Fluid Mechanics Division, National Mechanical Engineering Research Institute (South Africa).

‡ Senior Research Officer, Functional Efficiency Division, National Building Research Institute (South Africa).

Discussion invited.

[illegible] the difficulty of controlling the test conditions and the cost involved in providing test facilities, it was considered necessary to supplement these tests by means of wind tunnel investigations on scale model buildings. In this Paper the feasibility of employing model buildings for this purpose is investigated, and attention is subsequently given to the influence of some structural components on the external flow pattern over a model classroom.

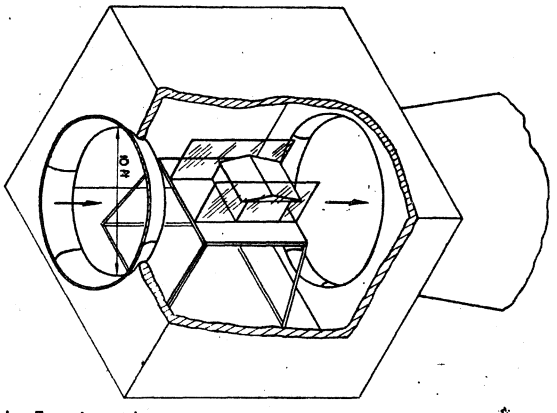

Fig. 1.—Experimental set-up in working section of 10-ft open jet wind tunnel.

TEST FACILITIES.

One of the objects of the investigation was to obtain information on school building design, and it was therefore decided to conduct the tests on a one-twelfth scale model of a typical classroom. The design provided for the alteration of such structural features as wall (or ceiling) height, roof pitch and type of window. In order to limit the number of variables involved the first series of tests was confined to two-dimensional conditions, thus simulating the flow over an infinitely long building. In practice this condition prevails more or less over the centre rooms of a long wing of classrooms. Other variables such as building orientation and aspect ratio were not considered for the present. To approach the desired two-dimensional flow conditions the model was placed on a base-plate between two Perspex side-plates in the working section of the wind tunnel, the set-up being shown diagrammatically in Fig. 1. With the object of providing sufficient illumination within the model for photographic purposes, three of the detachable roof sections, each with a different pitch, were constructed of Perspex. Static tappings for the measurement of pressure distributions were incorporated in the two roof sections having pitches of 10 deg. and 35 deg. respectively. Similar static tappings were also introduced in the windward and leeward walls of the model. For the purpose of these tests the larger roof overhang was located on the leeward side. In practice this corresponds to the corridor side of the building, which normally faces either north or east.

The tests were conducted in the 10-ft open jet wind tunnel of the National Mechanical Engineering Research Institute. The wind speed in the tunnel can be controlled within the range between about 5 ft/sec (3·4 m.p.h.) to 30 ft/sec (20·5 m.p.h.). As can be seen from Fig. 1, the model was mounted centrally in the jet of the tunnel.

INSTRUMENTATION.

Air speeds were measured by means of pitot-static tubes, the tube used for measuring the free-stream wind speed being located some distance in front of the model at a height of 20·in above the base-plate. Directions of flow were traced with a yawmeter, and all pressures were observed on Betz projection manometers.

DISCUSSION OF TEST RESULTS.

1. Scale effect.

Before embarking on the study of the external air-flow pattern it was necessary to investigate, firstly, whether it would be feasible to employ the results obtained from model tests for predicting conditions in full-scale buildings, the difficulty usually encountered in this connection being the change in flow pattern incurred by a change in the Reynolds number

$$R = \frac{lv}{\mu}$$

where l = a characteristic length,
v = free-stream air velocity,
and μ = the kinematic viscosity of the air.

A model may be said to be subjected to scale effect if a change in the Reynolds number results in a change in the various non-dimensional flow parameters. Thus if, for instance, the pressure, measured at a certain point on the model and expressed non-dimensionally in terms of the wind velocity head, is found to be constant over a range of varying Reynolds number, the model might be considered as being free from scale effect over that particular range of Reynolds number. A suitable pressure parameter to use in this connection is

$$\frac{P}{\frac{1}{2}\rho v^2}$$

where P = static pressure, in lb/sq ft, at a certain point on the model,
and ρ = air density in slugs/cu ft.

The constancy of this parameter would indicate the absence of scale effect only if all other effects such as temperature forces (convection currents) are either absent or uniform for both model and full-scale building. In this connection experience and measurements[6, 7] on full-scale, unheated single-storey buildings, having relatively large ventilation openings, have shown the effect of thermal forces on flow for buildings of this type to be small in comparison with that of the aeromotive forces, if the wind speed is in excess of 2–3 m.p.h. Thermal forces may therefore usually be neglected in model studies of this nature. However, in certain industrial and multi-storey buildings thermal effects may be important and should be reproduced or corrected for if identical flow patterns are to be obtained for both model and full-scale building.

In general, since a model building constitutes a bluff body, it might be expected to be free from scale effect at relatively low Reynolds numbers. This has been confirmed by various investigators; in particular by the results of Irminger and Nøkkentveld[8] and of Bailey and Vincent[9] (see ref. 3).

Smith,[10] using as a criterion of the flow pattern the distance to which the wake extended downstream from a model, found that scale effect was absent in models for values of E between 2000 and 125 000, E being defined by

$$E = \frac{2A}{P}v$$

where A = projected area of model normal to air flow,
and P = perimeter past which air flows.

Based on the assumption that the viscosity of the air remains constant, this factor E is proportional to the Reynolds number. Applying the above equation to the model classroom yields, for a projected area of 1220 sq in and a perimeter of 100 in, a range of air speeds from 2·7 ft/sec to 171 ft/sec for which scale effect would be negligible. Smith further noted that there was no indication that scale effect would be introduced for values of E in excess of 125 000, a value which was obtained rather by the limitations of the experiment. Hence, and since it is consistent with experience that once the flow becomes completely turbulent a further increase in Reynolds number would not reintroduce any scale effect, it could be assumed that the results obtained from these model classroom tests would be applicable to full-scale buildings, provided the test air speed is kept above about 3 ft/sec.

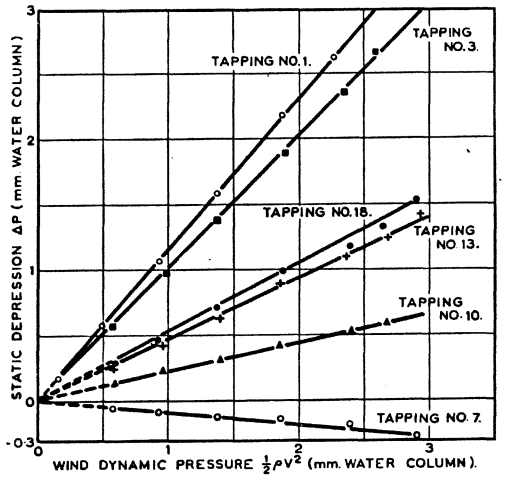

Fig. 2.—Static depression over roof of 35 deg. pitch (all windows closed).

To verify experimentally the absence of scale effect for the case of the model classroom, the constancy of the pressure parameter $\Delta P/\frac{1}{2}\rho v^2$ was investigated. For this purpose the static depression ΔP at various points over both the 10-deg. and 35-deg. pitch roof was measured in conjunction with the wind dynamic pressure $\frac{1}{2}\rho v^2$, as observed in millimetres water column by means of a pitot-static tube and Betz projection manometer. The positions at which the static pressures were measured are shown in Figs. 3 and 4. Typical results are plotted in Fig. 2, and it was clear that a linear relationship existed between ΔP and $\frac{1}{2}\rho v^2$. Since this applied to all

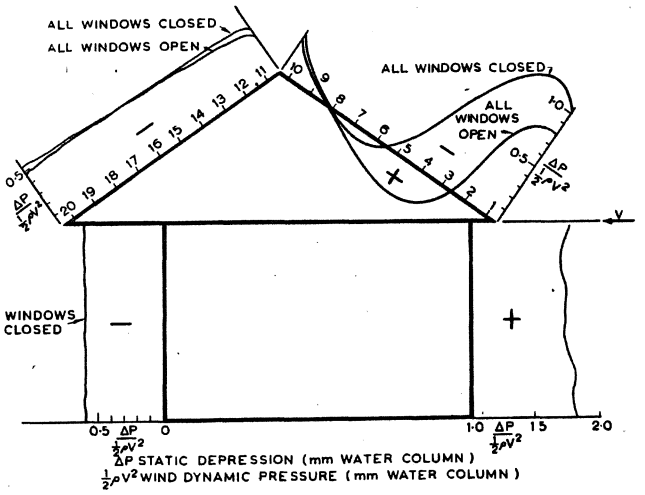

Fig. 3.—Static pressure distribution over model having a roof pitch of 35 deg. and a wall height of 15 in. (Negative sign denotes depression.)

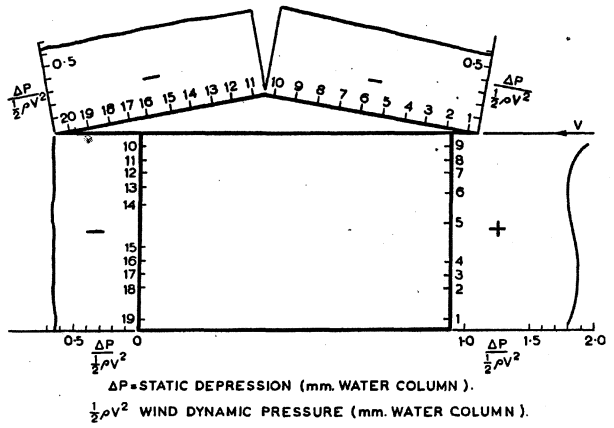

Fig. 4.—Static pressure distribution over model having a roof pitch of 10 deg. and a wall height of 15 in (all windows closed). (Negative sign denotes depression.)

measuring points it follows that the factor $\Delta P/\frac{1}{2}\rho v^2$, which represents the slope of the straight lines, remained constant over the relevant wind speed range, thus indicating the absence of scale effect. As a further verification the tests were repeated with the windows of the model fully opened and, in the same way as before, the results indicated no scale effect.

The lowest wind speed that could conveniently be obtained during these investigations was 6 ft/sec, but there is no reason why the lower limit for the absence of scale effect should not be reduced to the order of 3 ft/sec.

Finally, it may be mentioned that one of the major disadvantages of using scale models for ventilation studies concerns the difficulty of testing models under the same degree of turbulence as that existing under full-scale conditions.[11] Despite this, model studies offer many advantages over full-scale tests, and can be used with convenience to predict ventilation conditions, including air-change rates, in proposed new buildings. For instance, experiments conducted by Dick[3] showed that the rate of air flow through such openings as ventilators and cracks is approximately proportional to the square root of the pressure difference acting across the openings, thus making it possible to calculate flow rates if the pressure differences are known and if a coefficient of discharge is assumed. To illustrate the magnitude of the pressure differences that can be expected static pressure distributions were measured over the model.

2. Static pressure distribution.

As mentioned before, static tappings were provided in the walls of the model as well as in two different roofs for the purpose of measuring static pressures. Because of the constancy of the pressure parameter $\frac{\Delta P}{\frac{1}{2}\rho v^2}$, readings were required to be taken at one value of the wind speed only. The pressure distributions obtained in this way are plotted in Figs. 3 and 4 for the 35-deg. and 10-deg. pitch roofs respectively, the distribution over the roof having a pitch of 35 deg. also being given in Fig. 3 for the case where all windows in the model were opened. The effect of the two side-plates on the static pressure distribution was further investigated by removing these plates, thus changing the flow conditions from a two-dimensional to a three-dimensional pattern.

The following are the more important findings obtained from these tests:

(*i*) In the case of the 35-deg. pitch roof the largest negative pressure was measured in the vicinity of the windward eave, the absolute value of this pressure decreasing rapidly towards the ridge up to a point about midway along the slope of the roof, where the pressure assumed a positive value for some distance before again becoming negative. The pressure over the entire leeward side of the roof as well as over the leeward wall retained more or less a constant negative value. Over the windward wall the pressure was found to be positive and practically constant for the whole wall height. It appears further that the overall pressure difference across the model amounted to about 2·2 to 2·3 times the wind dynamic pressure.

For the roof with a 10-deg. pitch no change in the static pressure over the windward side of the roof could be detected, as it remained constant and negative over the entire roof as well as over the leeward wall. Similarly, the pressure on the windward side of the model remained at a constant positive value. It will further be observed that the pressure difference acting across the model was now about 2·4 to 2·5 times the wind dynamic pressure, which is slightly larger than was found for the steeper roof. This means that in practice slightly better ventilating conditions can be expected in buildings having low-pitched roofs, provided, of course, that the area of the ventilation openings remains unaltered.

Another important conclusion that can be drawn from these results is that since low-pitched roofs are more or less always under suction such roofs are more suitable for a natural ventilation scheme in which the building is ventilated through suitable ceiling and roof openings.[6]

The constancy of the static depression over the roof and leeward wall in the case where the model was fitted with the 10-deg. roof suggested the existence of a stagnant zone enveloping the entire roof and leeward side of the model, the zone constituting the wake of the windward wall and eave. For the 35-deg. roof pitch this stagnant zone existed only downstream from the ridge and resulted from the wake formed by the windward wall and the windward slope of the roof. The large negative pressure observed with the 35-deg. pitch roof was probably due to the presence of a vortex round the windward eaves. Such a vortex would direct the flow back in the direction of the roof and would therefore account for the positive pressure measured midway up the windward slope of the roof.

(*ii*) Opening the windows produced no significant change in the pressure over the leeward side of the roof, but markedly decreased the absolute value of the depression on the windward side, the pressure reaching a positive value sooner and remaining positive over a larger portion of the roof.

(*iii*) Changing the flow pattern from a two-dimensional to a three-dimensional one by removing the side-plates decreased the positive pressure on the windward wall by about 49 per cent. and the depression on the leeward wall by about 8 per cent. The pressure difference across the model was thus decreased by about 57 per cent., which illustrates the spanwise variations in ventilation conditions that may be expected in a long wing of classrooms. All other constructional details being the same, the rooms towards the centre will be slightly better ventilated than the end classrooms.

3. Stagnant zone.

In a previous paragraph reference was made to the existence of a stagnant zone above both roofs tested. The presence of this zone was confirmed by qualitative observations which were made by introducing titanium tetrachloride smoke at a point upstream of the model and photographing the traces. These photographs, specimens of which are reproduced in Figs. 5 and 6 for the 12½-deg. and 35-deg. pitch roofs respectively, indicate that the flow separated, in the case of the 12½-deg. roof at the windward eave and in the case of a 35-deg. roof at the ridge. Furthermore, the point where the air impinged on the 35-deg. roof after separating temporarily at the windward eave may be seen in Fig. 6. This point corresponds more or less to that point where the static pressure changes from a negative to a positive value.

The extent of each stagnant zone was further quantitatively obtained by making vertical pitot traverses at various positions over the 10-deg. and 35-deg. roofs, the position in each traverse where the pitot-tube reading became zero being noted. In this way the results given in Figs. 7 and 8 were obtained, these confirming the photographic results. In the case of the roof with a pitch of 10 deg. the height of the stagnant zone at the ridge amounted to about 6 in, which corresponds to a height of about 6 ft under full-scale conditions.

Superimposing Figs. 7 and 8 showed that the form of the "zero stream-

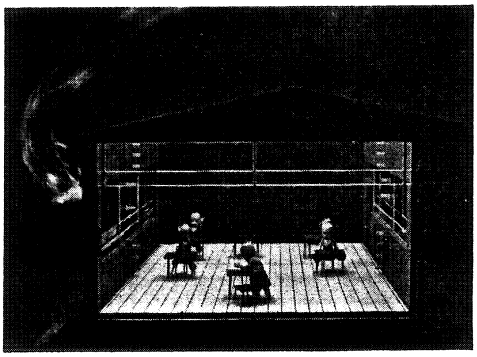

Fig. 5 Stagnant zone over roof of 12½ deg. pitch (wall height 15 in).

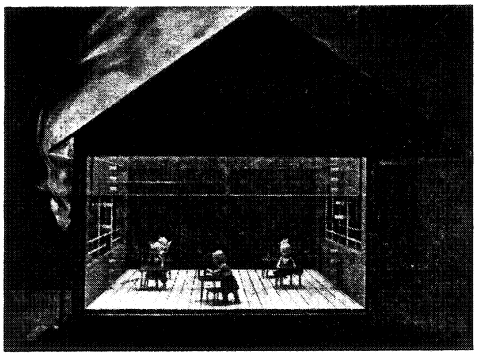

Fig. 6.—Smoke traces over roof of 35 deg. pitch (wall height 15 in).

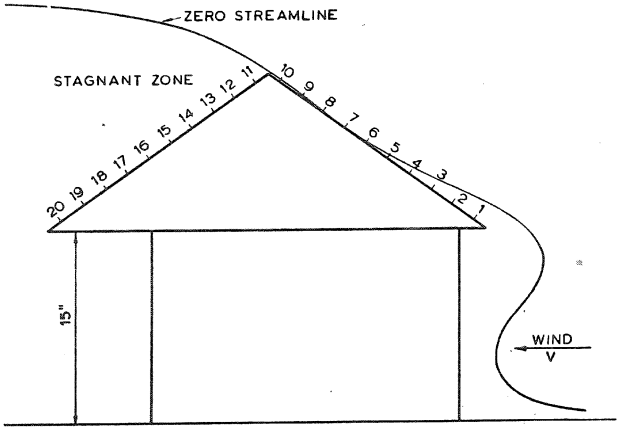

Fig. 7.—Stagnant zone over model having a 35-deg. roof pitch and a 15-in wall height.

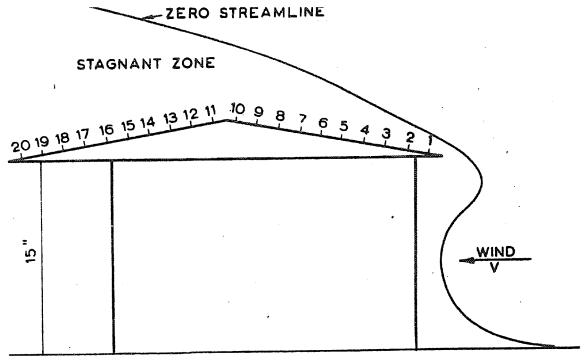

Fig. 8.—Stagnant zone over model having a 10-deg. roof pitch and a 15-in wall height.

line" (i.e. the line demarcating the region between the flow region and the stagnant zone) for both roofs had more or less the same shape and height up to a point where the flow re-attached on to the 35-deg. pitch roof, from which point it was deviated and constrained to follow the outline of the roof. This suggests that, providing the pitch of a roof is such that the roof profile nowhere touches the zero streamline as plotted in Fig. 8, the height of this streamline at the ridge would be more or less independent of the roof pitch. As will be discussed in a subsequent paragraph, the maximum pitch angle satisfying this requirement was found to be about 25 deg. for a wall height of 15 in. For roof pitches in excess of this value the flow separation point would therefore be displaced from the eaves to the ridge.

4. Relation between the Flow Parameters and the various Structural Components.

The structural features of a building which might be expected to have the largest influence on the external flow pattern are roof pitch, wall height and roof overhang. (The effects of aspect ratio and orientation with respect to the free windstream were not investigated during the present series of experiments.) With the object of investigating the effect on the flow pattern of the various structural features it was decided that instead of following the rather tedious procedure of tracing the contour of the zero streamline in each case certain parameters would be employed for characterising the flow patterns. The parameters decided upon were the direction and velocity of flow at the ridge, and the height of the stagnant zone above the ridge.

Furthermore, since it was found that the leeward portion of the model was always in the stagnant zone and that no appreciable variation in static depression was observed within this zone, it was decided to make use of this static depression as a measure of the pressure distribution. Thus the four measurements to serve as criteria of the flow were:

(*a*) Vertical distance f_0 between the ridge and the boundary* of the stagnant zone;

* This boundary, which is of a rather indefinite nature as a result of the gradual transition between the flow and the stagnant region, was taken to be defined by the positions where the pitot-static tube gave a zero reading on the Betz manometer. This means that air speeds less than about 1 ft/sec were ignored.

(*b*) the direction of flow α_3 at a point outside the stagnant zone and vertically above the ridge;
(*c*) the velocity of flow v_3 at the same point;
(*d*) the static depression ΔP at a point on the leeward side of the roof.

The independent variables consisted of:

(*i*) Roof pitch θ; roofs with pitches of 10 deg., 12½ deg., 15 deg., 20 deg. and 35 deg. being investigated;
(*ii*) wall height h; the model being constructed so as to cater for ceiling heights of 9 in and 12 in, giving total wall heights of 12½ in and 15 in respectively. (The floor of the model was raised 2½ in and the beam filling was about ½ in.)
(*iii*) the overhang d of the roof on the windward side, which was varied between 2 in and 6 in. The roof with a pitch of 12½ deg. was selected for this test.

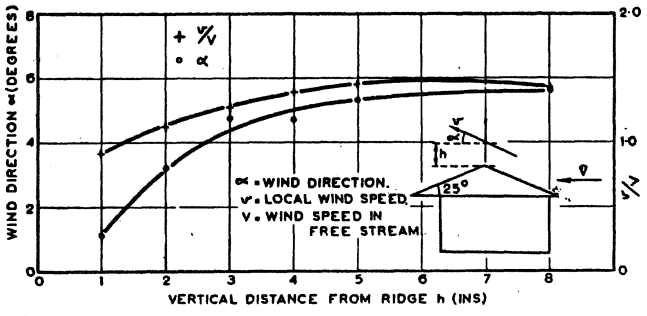

Fig. 9.—Vertical distribution of wind speed and direction at roof ridge of model having a roof pitch of 25 deg., a wall height of 15 in and a roof overhang of 2 in.

The first step was to determine the best height above the ridge for locating the measuring station, which for obvious reasons had to fall outside the stagnant zone. Since the results obtained would be useful for predicting the performance of roof ventilators, it was decided that the location of the measuring station would be such as to yield approximately average values of the wind speed and direction over the first 8 in outside the stagnant zone, the distance of 8 in being chosen (to scale) from a consideration of the usual maximum height of ventilators. Vertical traverses of α_3 and v_3 were made at the ridge of the 25-deg. pitch roof (the value of f_0 for this roof pitch having been found to be zero), and the results of this test as plotted in Fig. 9 disclosed a variation in α_3 of about 4 deg. and in v_3 of 35 per cent. over a vertical distance of 8 in, the average value of α_3 and v_3 over this distance being obtained at a height of about 3 in above the zero streamline (or roof ridge). Hence it was concluded that by locating the measuring station vertically above the ridge at a distance of 3 in outside the stagnant zone in all tests results would be obtained giving a reasonable average of α_3 and v_3 over the first 8 in inside the flow region.

Having obtained the most suitable position of the measuring station above the ridge, the influence of the structural features on the flow pattern could be investigated.

(*a*) *Effect of roof pitch, wall height and roof overhang on height* f_0 *of stagnant zone above roof ridge.*

The height of the stagnant zone above the ridges of the different roofs was in each case determined by means of a vertical pitot traverse. Two wall heights, namely 12 in and 15 in, corresponding to ceiling heights above floor level of the model of 9 in and 12 in respectively, were considered.

The graph representing the variation of f, the total height of the zero streamline above the base of the model, with roof pitch and wall height, is given in Fig. 10, whilst that representing the variation of f_0 is given in Fig. 11. From Fig. 10 it appears that, up to a point where the windward

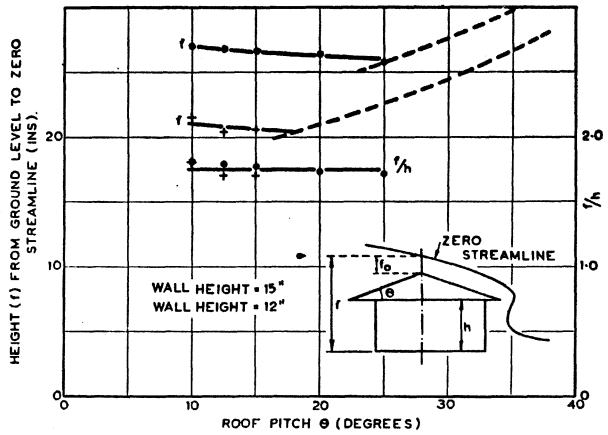

Fig. 10.—Height of "zero streamline" above ground level.

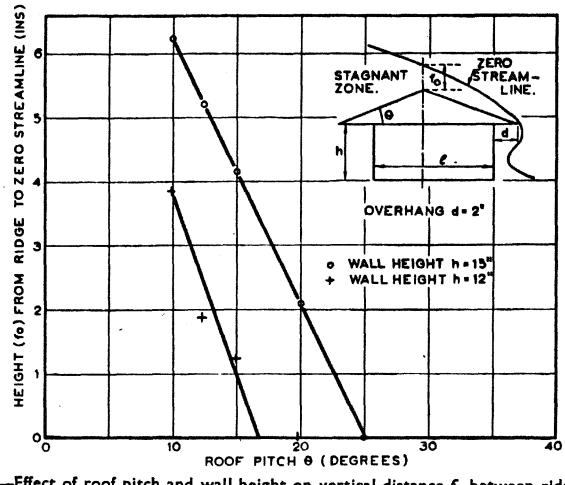

Fig. 11.—Effect of roof pitch and wall height on vertical distance f_0 between ridge and "zero streamline".

slope of the roof started interfering with the zero streamline, i.e. when f_0 became zero, a change in roof pitch had very little effect on the total height f. However, an increase in wall height from 12 in to 15 in resulted in an average increase in f of about 29 per cent. It thus appears as if wall height rather than roof pitch is the factor governing the height of the stagnant zone. The dotted lines in Fig. 10 represent the variation of f with θ for values of θ in excess of that value at which f_0 becomes zero, in which case f depends entirely upon the geometry of the model, the flow being constrained to follow the windward slope of the roof. The points where the solid and dotted portions meet give the angles below which the separation points were displaced from the ridge to the eave, and amounted to approximately 18 deg. and 25 deg. for wall heights of 12 in and 15 in respectively.

By plotting the non-dimensional ratio f/h for the two values of h in Fig. 10 it is seen that, provided separation takes place at the windward eave, not only is f/h independent of roof pitch θ but it is the same for both values of h. This ratio therefore seems to be a useful parameter in investigating the influence of the structural features on the height of the stagnant zone. However, further work in this direction involving a greater range of wall heights is required if conclusive evidence is to be obtained on the constancy of the ratio f/h.

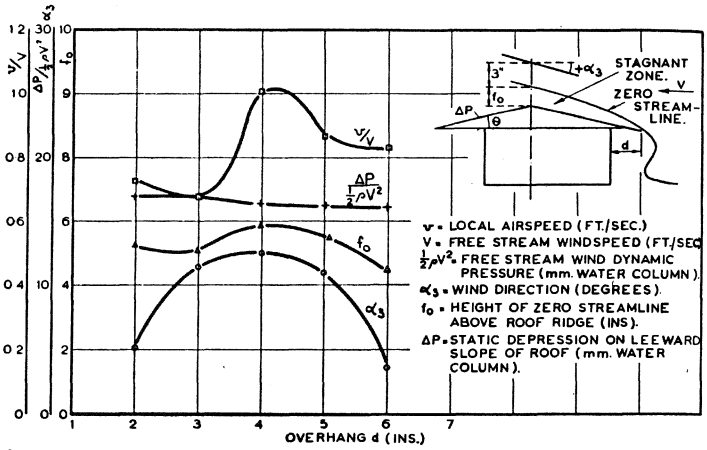

Fig. 12—Effect of roof overhang for a model having a 12½-deg. roof pitch and a 15-in wall height.

The variation of f_0 with roof overhang is shown in Fig. 12, whilst the variation of the ratio f/h with roof overhang is plotted in Fig. 13. It will be observed that f/h reaches a maximum value with a roof overhang of approximately 4 in, in which case the height of the stagnant zone above the ridge is about 6 in for the 12½-deg. pitch roof. However, the effect of roof overhang on the height of the stagnant zone is small, the variation in height being only about an inch for a change in roof overhang from 2 in to over 5 in.

As already referred to, a practical application of these results is found in the positioning and design of roof ventilators and even chimneys on roofs. For instance, if the roof ventilator is located within the stagnant zone no special design precautions regarding the shape of the ventilator need be taken, as air extraction from the building will be caused entirely by the differential pressures acting between the inlet to the ventilator and the outlet opening. A simple rainproof ventilation opening having a small resistance to air flow may under these circumstances be more effective than a roof ventilator of special design.

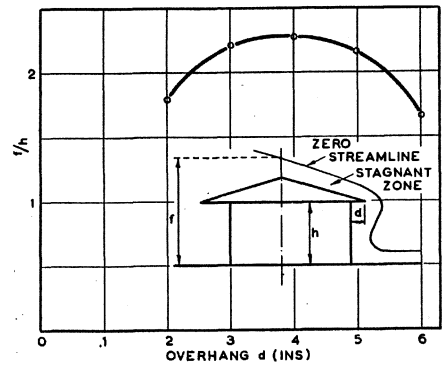

Fig. 13.—Variation of f/h with roof overhang.

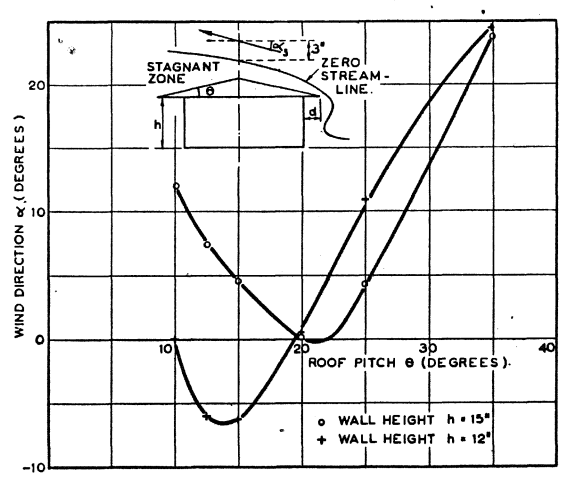

Fig. 14.—Effect of roof pitch and wall height on wind direction at roof ridge of model having a 2-in roof overhang.

(*b*) *Effect of roof pitch, wall height and roof overhang on the direction of flow α_3 outside the stagnant zone.*

The effect of these structural features on the direction of flow is illustrated

in Figs. 12 and 14. In general it appeared that the magnitude of a_3 was very sensitive to changes in roof pitch, reaching a minimum value at a pitch of about 14 deg. for $h = 12$ in and at 21 deg. for $h = 15$ in. Furthermore, a_3 was negative in the case of a 12-in wall height for values of θ between 10 deg. and 20 deg.

The effect of roof overhang was to increase a_3 as the overhang became larger up to a maximum of 4 in, above which a further increase in overhang again reduced a_3. As the aspiration action of roof ventilators depends generally to a large extent on the wind incidence, findings of this nature might prove useful in predicting their performance.

(*c*) *Effect of roof pitch, wall height and roof overhang on the velocity* v_3, *3 in above the zero streamline.*

The results of this investigation are reproduced in Figs. 12 and 15, from which it is evident that by keeping h and d constant the velocity v_3 reached a minimum at a roof pitch of about 15 deg., and apparently tended to reach a constant value for very steep roofs, i.e. roofs having pitches of the order of 40 deg. or more. Increasing the wall height produced an increase in v_3, this effect being most marked at the lower values of roof pitch.

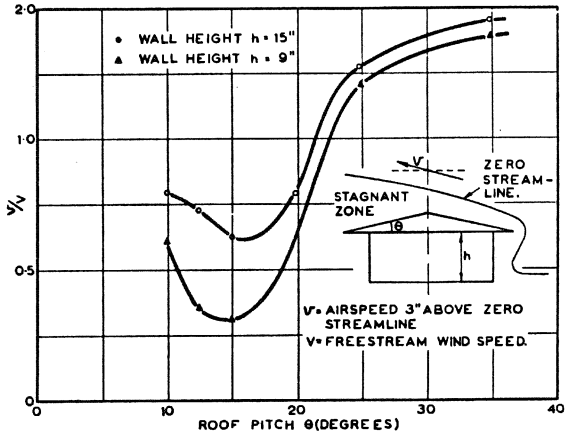

Fig. 15.—Effect of roof pitch and wall height on wind velocity at roof ridge of model having a 2-in roof overhang.

For a wall height of 12 in and a roof pitch of 12½ deg. the roof overhang had the greatest effect on the velocity for values of d between 3 in and 5 in, the maximum velocity being reached with an overhang of about 4 in. A change in eave width from 2 in to 4 in, for instance, produced an increase in velocity of 37 per cent., whilst a further increase in overhang from 4 in to 6 in decreased the maximum velocity by about 17 per cent.

(*d*) *Effect of roof pitch, wall height and roof overhang on the static depression* ΔP *in the stagnant zone.*

The results depicted in Figs. 12 and 16 reveal that the static depression had the largest values at the smaller roof pitches, reaching a minimum at $\theta = 22$ deg. for $h = 12$ in and at $\theta = 28$ deg. for $h = 15$ in. Thus, increasing the wall height increased the value of θ where the depression was a minimum. In general, an increase in wall height produced an increase in the static depression. As mentioned in a previous paragraph, these are important results not only as far as the design of a roof is concerned but also in relation to a building that is to be ventilated through roof openings. As compared with high-pitched roofs, the larger static depression over low-pitched roofs would render the use of roof openings more effective.

A change in roof overhang seemed to have little effect on the static depression, the ratio of the static depression on the leeward side of the roof to the wind dynamic pressure in the wind tunnel remaining practically constant for all the roof overhangs tested.

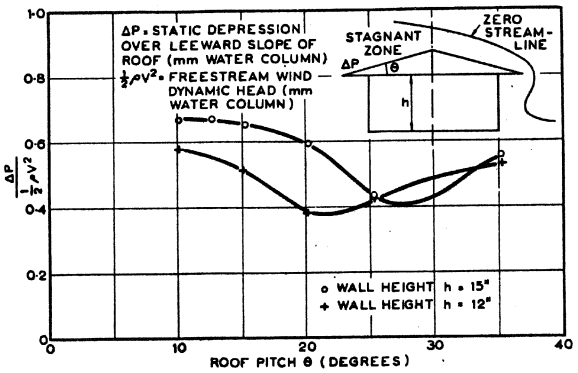

Fig. 16.—Effect of roof pitch and wall height on static depression over leeward slope of roof having a 2-in overhang.

CONCLUSIONS.

Despite the limited extent of the investigations the following conclusions seem to have been fairly well established:

(*i*) For the range of wind speeds usually encountered in practice the results obtained from model tests will provide sufficiently accurate estimates of the flow and ventilation conditions in full-scale buildings, provided the tests are performed at values of E^* greater than about 2000.

(*ii*) In the case of low-pitched roofs a stagnant zone usually exists over a building due to flow separation occurring, in the case of low-pitched roofs, at the windward eaves. The height to which this zone extends above ground level depends primarily on the wall height and is only influenced by the roof pitch when this becomes large enough to cause the roof to extend into the flow region. Due to the fact that no directed flow takes place within the stagnant zone there is practically no variation in static depression from point to point within this zone. However, this depression increases with an increase in wall height or with a decrease in roof pitch and is very little influenced by roof overhang. Roof overhang has, however, a marked effect on the velocity and

* E being defined, as before, as $2Av/P$ where A = projected area of model normal to air flow; P = perimeter past which air flows and v = free-stream air speed.

direction of the air flow over the ridge and on the height of the stagnant zone above the ridge.

Roof ventilators and chimneys or other ventilation openings situated within the stagnant zone will cause extraction of air from the building, not due to the direct action of the wind on the ventilator or chimney but as a result of the static depression existing within this zone.

(*iii*) The opening of windows has little effect on the pressure within the stagnant zone, but decreases the absolute value of the depression over the roof upstream of the point of separation.

(*iv*) Changing the flow conditions over a model from two-dimensional to three-dimensional flow markedly decreases the differential pressure across the building.

During the tests described in this Paper no attention was given to the simulation of ground boundary layer conditions as occurring in practice. Under normal conditions a boundary layer may exist which extends to a vertical height of some 30 ft above ground level and which is characterised by a wind velocity gradient in which the velocity varies gradually from zero at ground level to the free-stream value outside the boundary layer. It is obvious that such a velocity gradient would result in a flow pattern differing to some extent from that observed for a model under wind tunnel conditions, and the results given in this report must therefore be interpreted with this limitation in view.

ACKNOWLEDGMENT.

Permission granted by the South African Council for Scientific and Industrial Research to publish this Paper is gratefully acknowledged by the authors.

REFERENCES.

[1] ROUX, A. J. A.: "Protection from heat and cold in dwellings." Proceedings—Technical Papers, Vol. 1, Section III, Regional Conference on Housing Research in Africa South of the Sahara, Pretoria, November, 1952.

[2] VAN STRAATEN, J. F.: "Ventilation research in South Africa." To be published.

[3] DICK, J. B.: "Experimental studies in natural ventilation." *J.I.H.V.E.*, **17**, 420.

[4] BEDFORD, WARNER and CHRENKO: "Observations on the natural ventilation of dwellings." *J.R.I.B.A.*, November, 1943.

[5] ROUX, A. J. A., and VAN STRAATEN, J. F.: "Some practical aspects of the thermal and ventilating conditions in dwellings." Series D.S. 10. National Building Research Institute, South African Council for Scientific and Industrial Research, October, 1950.

[6] VAN STRAATEN, J. F., ROUX, A. J. A., and RICHARDS, S. J.: "Comparison of the thermal and ventilation conditions in similar houses employing different ventilation schemes." Bulletin No. 13, National Building Research Institute, South African Council for Scientific and Industrial Research, March, 1955.

[7] VAN STRAATEN, J. F.: "Permanent ventilation in urban Bantu houses of the type NE51/9." Bulletin No. 11, National Building Research Institute, South African Council for Scientific and Industrial Research, December, 1953.

[8] IRMINGER, J. O. V., and NØKKENTVELD: "Wind pressure on buildings: Experimental researches (second series)." *Ingeniørvidenskabelige Skrifter*, A. No. 42. Copenhagen, 1956.

[9] BAILEY, A., and VINCENT, N. D. G.: "Wind pressure on buildings including effects of adjacent buildings." *J.I.C.E.*, **20**, No. 8, 1943.

[10] SMITH, ELMER G.: "The feasibility of using models for predetermining natural ventilation." Research Report No. 26, 1951. Texas Engineering Experiment Station, Texas.

[11] VAN DER HELD, E. F. M.: "Der Einfluss der Turbulenz auf die Lüftung." *Gesundheits-Ingenieur*. **74**. 1953.